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Study on the Potential for Reducing Emissions of Volatile Organic Compounds (VOC) Due To The Use Of Decorative Paints and Varnishes for Professional and Non-professional Use

FINAL REPORT

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Foreword

Prior to undertaking this mission, the Study Team was aware that it would be a daunting task. This it has turned out to be in good measure, and more. Over the past fourteen months we have consulted, surveyed, visited, measured, considered and debated to such an extent it seemed that meeting our deadline would be impossible. Up to the last moment we were still dealing with written and electronic communications, and requests for further meetings. To those who could not be accommodated we offer our sincere apologies, and trust that their views are nevertheless reflected in our report. To those who have interacted with us in any way, we extend our thanks, and our assurance that we have listened to what you had to say.

This level of interest is a good indication of the importance of Decorative Paints and Varnishes in the lives of people. At a professional level, tens of thousands of Europeans are involved in the supply side of the industry, not forgetting those involved in researching and delivering the raw materials on which everything depends. On the user side, there are in excess of 1.5 million professional painters and decorators who use these products on a daily basis, and tens of millions of us indulge in DIY on a regular basis. Add to these the cultural preferences, climatic differences and service life expectations which exist throughout Europe, together with the myriad of problems which paints are expected to solve, and it will be clear that regulation in this field is not a trivial matter. However, in order to protect the environment (i.e. prevent VOC emissions which contribute to tropospheric ozone formation) as well as the health of professional painters (i.e. prevent the *Organic Psycho Syndrome*) regulation is clearly necessary.

For a project such as this, a clear understanding of the mission and its deliverables is an essential prerequisite, as is ongoing contact with the client. Our task has been immeasurably lightened by the valuable assistance we have received from the responsible Commission officials. Herbert Aichinger (Head of Unit at DG XI) has made himself available to us on an ongoing basis and attended important meetings. Dominique Klein gave us our initial all important briefing which has guided us throughout. To both of them we extend our sincere thanks.

The team wishes to express their thanks to Den Hartog Consultancy for contributions made to this study.

In some cultures, watching paint dry is considered to be the ultimate in boring experiences. Those of us who have laboured in the field for many years contend that nothing about paint is remotely boring, and the general interest in this project supports that view. No doubt over the coming months, and perhaps even years, this report will be the subject of much scrutiny, and not everyone will agree with all of its contents. The Study Team has aimed at all times to be accurate, fair, responsible and objective. In pursuit of these standards we have sought opinion and data from a number of sources. Inevitably from time to time these conflict, and we have used our best judgement. If we have made a wrong call on any occasion, or misinterpreted opinion, we apologise and accept full responsibility.

Amsterdam, Dublin.

June 2000

Executive summary

This study investigates the potential for a product based approach to reducing emissions of volatile organic compounds (VOCs) due to the professional and non-professional use of decorative paints and varnishes. Limiting the adverse environmental and human health effects associated with the formation of tropospheric ozone and direct exposure to VOCs forms the background to the study.

Literature study, meetings and interviews with trade associations and individual companies and the distribution of questionnaires among suppliers and users within the sector and the associations representing them were the main ways of collecting information. In addition, the composition of a large number of current decorative paints has been analysed in the laboratory. Major issues have been discussed with stakeholders in the sector on several occasions.

For the purposes of this study, decorative paints and varnishes have been defined as products that are applied to buildings, their trim and fittings, for decorative and protective purposes. They are applied in situ by professional or private users. While their main function is decorative in nature, they also have a protective role.

Various ways of defining "VOC" have been assessed. Definitions based on Vapour Pressure (> 10 Pa at 20°C), Boiling Point (< 250°C or 280°C) or photochemical oxidant creation potential all have their own merits and supporters within the sector. A boiling point limit of 250°C excludes important coalescing solvents which have boiling points of > 250°C. The study team has chosen the following definition to cover all volatile organic compounds that are used in decorative paints:

"VOC are all organic compounds used in paint or associated with the application of paints that have an initial boiling point of lower than 280°C".

The European decorative coatings market

Despite the recent trend of concentration, there are almost 1300 significant paint manufacturers – and over 3200 when very small localised family businesses are included - in the European Union and six major 'accession countries'. These employ about 122,000 workers. However, the 10 largest paint manufacturers account for almost 50% of total production. The southern European markets tend to be less concentrated than the northern European markets.

The total annual production of decorative coatings in the EU member states was about 3344 kilotonnes in 1997. The total production value was at least 5.2 billion EUROs, while the retail value was considerably higher. When six major accession countries are included, the production is about 3800 kilotonnes.

More than 150,000 retail outlets for decorative coatings exist in the EU. Professional painters may purchase directly from the manufacturer, at wholesalers, or in producer-owned specialised retail stores. In the Do-It-Yourself (DIY) sector, the market share of DIY superstores is rising. The number of known DIY superstores in major chains is about 8000. Currently, the top 15 DIY chains own over 40% of all stores.

Well over 200 raw material suppliers serve the European paint industry. Multinational chemical companies dominate the binder, pigment and solvent markets. In addition, it has been suggested that many very small alkyd resin suppliers exist.

At the other end of the market, over 165,000 professional painting companies exist in the EU, which according to UNIEP employ about 1.65 million painters. The split between professional and DIY-paint consumption ranges from ~30% DIY in Greece to around 70% DIY in Sweden and Finland. Labour costs of professional painters and the increasing DIY-trend are major determining factors in this.

The overall market share of waterbased paints across the EU is about 70%. Highest penetrations can be found in the Scandinavian countries, Germany, Austria, Portugal and Spain; lowest penetrations in France, Italy and Hungary. Waterbased coatings have high penetrations (up to 100% in some countries) in wall paints, and considerably lower penetrations (5-40%) in trim paints and varnishes. In most countries, the market share of waterbased paints is lower among professional painters than in the DIY-sector. However, in some countries occupational health regulations have resulted in the opposite trend.

Major trends in the decorative coatings sector include concentration, specialisation into core business, internationalisation and increased competition. Competition in the decorative paints sector is not a technology contest, but a race for market coverage. Environmental regulation as well as increased customer demands have resulted in an acceleration of innovation.

Competition among painting contractors is intense in most countries. The increased DIY-trend, as well as the increasing availability of cheap, non-qualified painters are seen as a threat to their business as are restrictions on the use of high VOC products by professionals. Among DIY-retailers, price competition is common, although local differences exist. ‘Own label’ brands are used for price competition, while prices of well-known brands are maintained.

VOC emissions

The VOC-emissions due to the use of decorative paints and varnishes in the EU-member states and six major accession countries have been estimated at ~ 580 kilotonne annually. When the solvents used for cleaning and thinning are included, the ‘reasonable worst case’ estimate of the total VOC-emission connected to the use of decorative coatings is 720-830 kilotonnes annually. Emissions of ‘natural’ VOC account for ~ 20% of the total VOC emissions in the EU.

The contribution of the decorative paints sector to total man-made VOC-emissions in the EU is currently about 4-5%, thinning and cleaning included. After implementation of the Solvents Emissions Directive (SED), which aims at a 50% VOC-reduction, the relative contribution of the decorative paints sector may rise to about 10%.

Existing measures

In four EU-member states legal measures to reduce VOC-emissions due to the use of decorative coatings already exist. In many other member states as well as accession countries, non-legal measures such as ecolabelling schemes, voluntary agreements and information campaigns have been implemented.

It has been concluded from consultation with industry representatives, that the Solvents Emissions Directive (SED) will not significantly contribute to directly reducing VOC-emissions from decorative coatings. On this basis, the need for a separate Product Directive is justified. The Ecolabel has so far not resulted in a significant market shift, although product development towards lower-VOC (high solids) products may have been enhanced. The proposed National Emission Ceilings Directive provides a framework, and creates the need, for a Product Directive for decorative coatings.

Most representatives from the authorities in the Member States, as well as the industry representatives, except most solvent manufacturers and certain resin manufacturers, welcome the initiative of a product directive limiting the VOC-content of decorative coatings. Representatives from painting contractors also welcome the initiative, but requested a generous time path for implementation, in order to enable the sector to make the technological and cultural switch. The representatives have been consulted about which types of measures would be most effective. In order to level the playing field, legal limits to the VOC-content of decorative coatings are generally preferred over financial measures, ecolabels or other labels, information campaigns or voluntary agreements. However, some of the non-legal measures may enhance implementation of the legal measures.

Review of developments in decorative coatings technology

Review of available literature reveals that the following VOC contents are associated with the most commonly employed technologies for the manufacture of decorative paints and varnishes.

Conventional alkyds	350 g/l
High solids alkyds	250g/L
Alkyd emulsions	10-20g/L (estimate)
Acrylic latex(wall)	30 g/L
Acrylic latex(wood)	190g/L (excluding water)
Styrene acrylic solution (exterior wall)	450g/l

Alkyd emulsions have been highlighted as offering significant potential for VOC reduction. Seven to eight years exposure performance has been reported. However, uptake in the market has been slow and serious drawbacks still exist inhibiting the penetration of the technology into the marketplace. The expectation is that with further development, they will gain a significant market share.

High solids alkyds, in common with all alkyds, may suffer from yellowing and full hardness properties take longer to develop, with surface drying times being reported as being up to 5 hours. Product gate cost (cost of manufacturing up to dispatch) is higher than that of conventional alkyd products. However, it is believed that high solids products have a role to play, are being used in the marketplace and can work well where performance expectations are demanding. The one-coat application has proven beneficial for professional painters as a result of labour cost savings. Application and service lifetime attributes, especially under adverse conditions, places this technology in an important position in the event of the absence of conventional solventborne alkyd coatings from the marketplace.

Typical values of VOC content for conventional alkyd, acrylic dispersion, high solids alkyd and alkyd emulsion(excluding water) are reported as being 350, 190, 250 and 42g/L respectively. This agrees well with the findings of the study team.

Ambient temperature, cross-linking latex has been reported and it appears that this can be facilitated by an oxidatively cured cross-linking additive. Curing at temperatures of 1°C have been reported, however, the manufacturers do not recommend application below 5°C.

Research activity into dendrimer polymers has been marked with a leading raw material supplier actively licensing this technology. Although market impact has not been evident to date, it is expected that these materials will find application, albeit in the industrial coatings sector initially.

Research has highlighted the demands placed upon any wood coating for exterior use reporting that from 200 products, few were in good condition after two years. However, two products, which did perform well in particular were a polyurethane and an acrylic. This is expected as the acrylic would maintain flexibility as it is UV resilient and the urethane would have very stable cross-linking chemistry. A waterborne latex system over a solventborne, barrier type primer, offers the potential for VOC reduction along with the potential for increased service lifetimes.

Characterisation and comparison of conventional and low-VOC products

The review of decorative paints and varnish formulation technology compared conventional formulations with low VOC options. In addition, the formulation characteristics of decorative coatings were outlined in the context of the particular function and application circumstances in each case. Particular emphasis was placed on the VOC content, performance expectations, technical requirements, ease of use, application and cleaning operations, as well as professional versus DIY considerations associated with each product category.

Waterborne latex formulations have dominated the interior and exterior wall sector for several decades and only small technological changes are evident. These changes have been primarily associated with control over viscosity for application, enhancing durability in terms of scrub resistance and dirt pick-up, and the formulation of very low VOC ambient cure latices. The latter development is more recent and therefore has not had significant impact on market characteristics. In some instances, there has been continued use of solventborne technology for walls. One case is that of the application of exterior wall paint where conditions are adverse and good bridging properties are required. There are many instances, supported by comments from the questionnaires (chapter 9 section 9.9), where waterborne latex is vulnerable due to either low temperature or sporadic rainfall.

Waterborne latex has not had the same impact in many markets on trim/cladding paint and varnish applications as for walls, although there are exceptions such as the Danish market. Significant technical activity has occurred in this area, in order to improve the appearance and protective characteristics of these latex films for wood applications. The technical difficulties which affect flow, lack of separation of a clear unpigmented layer and the short open film times, all detract from the application of waterborne latex to trim. Application during humid or low temperature conditions is problematic, however, some professional painters have resorted to heated enclosures, to facilitate exterior painting during winter months. Latex paints and varnishes do have significant advantages. They offer low VOC alternatives to conventional solventbore equivalents, they may maintain gloss outside, do not yellow and remain thermoplastic which means that they are less prone to cracking, although thermoplasticity can lead to dirt pick-up. There is widely accepted opinion that waterborne trim coatings have established a performance track record and experiences in Denmark have been positive, although not without reservations. Spanish professional painters have endorsed the idea of the use of waterborne paints. It has been concluded that wood rot in Scandinavian countries, associated with the use of waterborne latex, could have been avoided if a solventborne primer had been applied to the substrate as soon as the substrate had been exposed. Other findings from the study highlighted the detrimental effect of exposing unprotected wood prior to coating for prolonged periods, the influence of a reduction in the quality of wood and changes in architectural design.

The main advantages of solventborne coatings have been, cheap raw material supplies, good appearance characteristics and good application characteristics for professional users. An important advantage has been the ability to use these products at lower temperatures and in between rainfall episodes. The conventional solventborne systems however, have serious drawbacks. Conventional alkyds may suffer from yellowing indoors, necessitating their overcoating even when other functional characteristics are maintained. Outdoors, continued oxidative cross-linking may lead to embrittlement and eventual cracking especially with varnishes. Odour and clean-up have always been a problem, although low odour alternatives are now available. The interior gloss advantage is lost for exteriors, as these materials quickly loose gloss outside.

Although waterborne technology can perform many functions to satisfaction, there is still concern over the application of these products during adverse conditions. Additionally, the impact of the solvent directive (1999/13/EC could place the performance capabilities of factory treated and coated joinery, under duress. It is expected that many joinery manufacturers will move to waterborne alternatives for joinery preservation and priming due to the solvent directive. The efficacy of the priming and treatment of joinery, as well as the system’s barrier properties, stimulated by these transitions, have yet to be proven in the field, and is a matter of serious concern for this sensitive market.

High solids trim coatings have evolved significantly over the last 15 years and offer a route to VOC reduction, offer good barrier properties and a product that could be crucial for professional painters during winter painting seasons. There are drawbacks such as cost and time to achieve full hardness properties. High solids have been compared to conventional in terms of VOC emission per square metre painted. The comparison between high solids, conventional and even waterborne, presents high solids VOC emissions in a good light when expressed in g/m^2 of surface painted, especially when two coats of conventional or waterborne might be needed to achieve the appropriate film thickness. However, the resultant film thickness for high solids tends to be significantly higher and compared on that basis no longer appear attractive when thinner films are sufficient.

There have been instances where blistering has occurred when waterborne was used to coat interior joinery and a conventional solventborne system was used on the exterior joinery. The blistering occurred due to egress of water from humid quarters within the building. The availability of a solventborne wood primer for this reason, as well as others, necessitates their inclusion in the market for the future.

VOC-reduction proposals

The concern over this risk and the changes in the joinery industry due to impending directives, has led to the proposal of two approaches. These proposals are presented in Table 1 below. Option 2 is developed to protect the health of painters when painting indoors by eliminating solvents exposure from the most frequently used products (groups 1 – 5). The principle difference between the two options is the differentiation of paints for interior and exterior use on trim. One approach includes high solids solventborne for interior and exterior use, while the other eliminates high solids for interiors. Other differences between the two proposals are the identification of products for adverse conditions, the elimination of solventborne woodstains and the early elimination of interior solventborne wall paint. The identification of a product for use under adverse conditions generates perceptions of superior performance and may increase its consumption. Elimination of interior solventborne wall coatings from the outset would have serious impact on certain markets that have retained these products for cultural reasons. The need for solventborne woodstains has been reiterated in the questionnaire responses and the performance and application capabilities of waterborne have been questioned. The penetration limitations of waterborne latex systems has also limited their use in the priming, sealing and stain blocking sector and currently, solventborne products offer better flexibility and capability.

Table 1. VOC-reduction scheme - OPTION 1 and 2 products based on VOC g/L ready to use including tinters.

Category	Type	Option 1 Phase 1	Option 1 Phase 2	Option 2 Phase 1	Option 2 Phase 2
1.1 Interior matt walls and ceilings gloss levels <25 @ 60°	W/B	55	30	55	30
1.2 Interior matt walls and ceilings gloss levels <25 @ 60°	S/B	**350**	**NLA**	**NLA**	**NLA**
2.1 Interior glossy walls and ceilings gloss levels >25 @ 60°	W/B	150	100	150	100
2.2 Interior glossy walls and ceilings gloss levels >25 @ 60°	S/B	**350**	**NLA**	**NLA**	**NLA**
3.1 Exterior masonry walls	W/B	60	40	60	40
3.2 Exterior masonry walls **3.2 Exterior masonry walls for adverse conditions-*option 2***	S/B	450	430	450	430
4.1 Interior trim and cladding paint, varnish and lasures for wood and metal.	W/B	130	130	130	130
4.2 Interior trim and cladding paint, varnish and lasures for wood and metal	S/B	**250**	**250**	**NLA**	**NLA**
4.3 Exterior trim and cladding paint, varnish and lasures for wood and metal	W/B	130	130	130	130
4.4 Exterior trim and cladding paint, varnish and lasures for wood and metal	S/B	250	250	250	250
5.1 Interior/exterior trim woodstains	W/B	140	100	140	100
5.2 Interior/exterior trim woodstains	S/B	**500**	**500**	**500**	**NLA**
6.1 Primer/sealer for wood and stain block for walls and ceilings	W/B	50	30	50	30
6.2 Primer/sealer for wood and stain block for walls and ceilings	S/B	450	350	450	350
7.1 One pack speciality coatings	W/B	140	140	140	140
7.2 One pack speciality coatings	S/B	600	500	600	500
8.1 Binding primers to stabilise loose substrate particles and to impart hydrophobic properties.	W/B	50	30	50	30
8.2 Binding primers to stabilise loose substrate particles and impart hydrophobic properties.	S/B	750	750	750	750
9.1Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	W/B	140	140	140	140
9.2 Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	S/B	550	500	550	500
10 One pack reactive coatings for specific end use such as floors e.g moisture curing polyisocyanate.	S/B	600	600	600	600

NLA = no longer available

VOC = any organic compound that has a boiling point of up to 280°C. This proposal includes all VOC's that have been identified for use in decorative coatings. The contents are quoted as those being the content ready to use. This includes added tinters which can add up to 35g/L VOC to the product, and the addition of thinners.

Table 1 is an ammalgamation of Tables 9.9 and 9.10 derived and discussed in the body of the report and is presented here in this form to highlight the differences between the two proposals.
It is the view of the study team that g/L alone is not an effective means for limiting VOC in decorative coatings. A VOC limitation proposal, based on coverage is presented in Tables 9.13 and 9.14.

The study has focused on the most significant categories of decorative coatings (1-5 in option 1 and 1-6 in option 2) from the point of view of a proposal for potential VOC reduction. These categories are,

Interior wall and ceiling paints for plaster etc.
Exterior wall paints for masonry, brick etc.
Interior and exterior wood/metal primers, undercoats and finish paints.
Interior and exterior stains and varnishes for wood.

The remaining classes have been described and characterised in terms of VOC content. It is proposed that current levels of VOC content, be maintained in this sector which is negligible in terms of VOC contribution. These categories could be revisited at some future date.

Aerosols have not been dealt with in detail in the study as they constitute only a minor part of the market. All aerosol paints accounted for 5 Ktonnes of the demand for paint in Europe in 1996. This accounts for less than 0.15% of the overall production of decorative paints in Europe in 1997. It is considered, however, that aerosols may be significant as a source of high VOC emissions.

The study team challenges the use of g/L as a means of expressing VOC content, in that it does not provide an effective means of comparing the total VOC emissions during a painting operation, due to the application of similar products used for that same application. Throughout this report, the VOC content has been expressed as weight (grams) of solvent per unit volume (litres) of paint. This is satisfactory provided that one is concerned only with the VOC generation potential of each type of paint as it exists in its container. It implies however that any two paints manufactured for the same purposes, and which have the same VOC contents, are on an equal footing in terms of the quantity of VOC that they will actually generate when they are used for the purposes for which they were intended. This is not necessarily so. Taking, for example, two matt water based masonry paints, each of which contains 70 g/L of VOC, the manufacturer of one of these products specifies its maximum coverage as 10 m^2/litre, while the other specifies 16 m^2/litre. Painting a 100m^2 wall, the former therefore generates 700g of VOC while the latter only generates 437.5g. If the former product contains 50 g/L of VOC and the latter 70 g/L, the former generates 500g VOC for the same wall while the latter remains at 437.5g. Under the currently accepted format, g/L, the two products enjoy equal status in the first scenario, while the former would be favoured in the second. However, in practical use, the latter is clearly the better material from the environmental point of view. It is clear, that any directive based solely on in-can VOC content will not be effective, and will not deliver an even playing pitch for all paint manufacturers. It may even induce some manufacturers to reduce the coverage of their products for competitive reasons, giving rise to a VOC increase rather than a decrease following the introduction of the directive. In the worst case, the VOC emission could increase in a particular sector where formulations are altered to attain the VOC limit, yet provide a much reduced level of efficacy. The proposals have therefore been presented in the form of g/L for easy comparison with quoted figures in the public domain and as g/L VOC as a function of the coating volume solids in order to allow the application, VOC emission potential, comparisons.

VOC-reduction potential
Phase 2 of *option 1* of the VOC-reduction proposals will result in a VOC-reduction potential of 238 kilotonnes without thinners and cleaners, and of 365 to 493 kilotonnes when thinning and cleaning with white spirit is effectively prevented (EU-15 + six accession countries).

Phase 2 of *option 2* of the VOC-reduction proposals will result in a VOC-reduction potential of 263 kilotonnes without thinners and cleaners, and of 390 to 518 kilotonnes when thinning and cleaning with white spirit is effectively prevented (EU-15 + six accession countries). This means an additional 25 ktonnes reduction compared to option 1. In terms of health hazards for professional painters, option 2 provides an additional advantage, as for interior trim paints only waterborne products remain.

The percentage VOC-reduction potentials for the options 1 and 2, thinning and cleaning included, range from 51% to 62%. Additional action will have to be taken to reduce the use of solvents for cleaning and thinning effectively.

Economic costs and benefits

In relation to the criteria that can be formulated it seems likely that the proposed command-and-control limits will very significantly contribute to the application and diffusion of past innovations, as well as stimulate further innovations.

The first criterion formulated was that regulation should focus on outcomes, not on technology. In a sense the proposed limits do favour one technology, water-borne over another, solventborne, but not entirely so. The proposed limits do leave the option for the use of other technologies open, as long as VOC-content is significantly reduced. As such the regulation focuses on various outcomes, namely a significant reduction of VOC-emissions from nearly all different classes of different paints. As is, the regulation focuses on outcomes as much as is possible and in this respect will certainly lead to more success for low-VOC technologies.

The second criterion was that the regulation should set strict rather than lax standards. Clearly the standards set are reasonably strict, the hydrocarbon solvent emissions are likely to be reduced by over 60% and the oxygenated solvent emissions would be expected to decrease by around 15%. Consequently the limits are definitely strict enough to stimulate innovation.

The third criterion is the use of a phase-in period, which in the proposal is up to ten years. As the normal life of a paint formulation is around this time as well, the proposal creates a sufficient window for innovation and adaptation in order to eventually meet the proposed limits.

Market incentives are not proposed, but the possibility remains for the use of labelling and/or exceedance fee instruments to be used in synergy with the proposed limits. In this respect especially the paint application sector differs from other industries', as from the previous analysis it has become apparent that market incentives, as sole instruments can not lead to the desired results. However, the use of market incentives in addition to the proposed limits can increase the cost-effectiveness and efficiency of the proposed limits.

Harmonisation or convergence with regulation in associated fields, the fifth criterion, is clearly sought. Regulatory pressure on industrial VOC-emissions has mounted over the years, and occupational health regulation, at least in parts of Europe, has also focused on the reduction of especially interior VOC-emissions.

The proposed limits are ahead of the limits in most of the world. As similar regulations are likely to follow eventually throughout the world, European corporations can expect to be able to use the experience gained on the basis of the European regulation in non-European markets.

Stability and predictability of regulation is the seventh criterion. The proposed limits will stabilise the European regulatory situation. At the moment, widely diverging regulatory approaches to reducing VOC-emissions are in use in the different European countries. A Directive will harmonise and stabilise the European regulatory situation. Due to the long time horizon of the proposed limits they are very predictable. Thus the proposed limits will provide much needed clarity to industry on where regulation is going and consequently facilitate innovations in order to keep up with the regulatory requirements.

Industry participation is the eighth criterion, although it is early days yet for meeting this criterion. Industry has been extensively consulted in the pre-regulatory stage of this project, but it will be up to the regulator to facilitate industry participation in the actual formalising stage.

The ninth criterion, the need for strong technical capabilities of the regulator, is less crucial here, as the regulation proposed is relatively simple and because external expertise can and is used to assist the regulator.

The tenth and final criterion is the requirement to make the regulatory process more efficient. As a possible Decopaint Directive is still in its pre-regulatory stage, it is hard to judge to which extent this regulatory requirement will be met. However, particularly for the multinational players in the paint chain, a European standardisation of VOC-emissions from decorative paints regulation is certain to make the compliance part of the regulatory process more efficient.

The following scheme summarises the potential economic effects in the paint chain if the industry had to make an almost complete change-over to water-borne paints by 2010.

Table 1.(c) Economic effects.

paint chain	major economic effects
solvent suppliers	• revenues hydrocarbon solvents in decorative paint: minus € 65 million • revenues hydrocarbon solvents for thinning and cleaning : minus € 65 million • revenues oxygenated solvents: minus € 24-46 million or plus € 30 million (ESIG) • employment: minus 2.000 - 4.000 people (ESIG) • strong concentration • effect are modest in relation to economic strength of largest companies
resin suppliers	• additional R&D: € 45.000 per new resin • investment in new equipment • resins will become 1.3 - 2 times more expensive • revenues: up to plus € 211 million • concentration, shake out of small alkyd resin suppliers
paint manufacturers	• reformulation costs: 0,4% of sales • resins will become 1.3 - 2 times more expensive, additional resin cost up to € 211 million • stainless steel equipment: € 53 million • concentration, advantages for large companies
retail, wholesale	• no major effects
professional painters	• more expensive paint • more labour time per paint job (1% = € 600 million) • effects on quality and subsequently on demand
DIY users, consumers	• more expensive paint
waste processors	• no major effects
water treatment	• no major effects

If regulations spur innovations, it is likely that most of the above mentioned costs will get lower. Also, if the expected consolidation process occurs, the larger companies will profit from economies of scale, which will lower the cost of implementation even further. Such a concentration process will especially effect small alkyd resin and paint manufacturers and have an impact on employment. For the larger companies in the paint chain, that are often part of multinational industries, the costs will be relatively modest.

The cost effectiveness of a possible decorative paint directive seems to be better than the cost-effectiveness of the Solvents directive.

Environmental and occupational health impacts

The environmental and health impacts of the proposed VOC-reduction have been estimated by literature study and extensive consultation with experts.

The proposal may result in an overall contribution of 5-6% to further ozone reductions, although local circumstances might reduce the impact in specific cases. Benefits may be expected in reduced acute and chronic health effects due to ozone, the value of which is open to debate. Benefits may also be expected in a reduction of crop damage of over €300 million. It is not advisable to distinguish between VOC on the basis of the so-called Photochemical Oxygen Creation Potential (POCP-values), as all VOC eventually contribute to tropospheric ozone formation. The impact of ‘natural’ VOC on ozone formation is present, but very uncertain.

The practice of cleaning equipment under the tap may result in a total emission of an annual 10 kilotonnes of waterborne paints through sewage systems throughout the EU. Of this amount, 3 kilotonnes may be directly discharged to surface waters. Adverse effects to the sewage system itself are not likely to occur. The main concerns with respect to effects on wastewater treatment plants or aquatic environments concentrate on the use of certain preservatives and surfactants. However, effects in practice are hard to predict, as the emissions occur very diffusely. Nevertheless, the use of alkylphenol ethoxylates (APEOs) as surfactants and of isothiazolinone preservatives should be reduced as much as possible. APEO’s have been substituted already in most cases. Most important however is discouraging the practice of cleaning equipment under the tap.

From a life-cycle-analysis (LCA) perspective, it is complicated to produce a well-balanced environmental comparison of the various types of paint. Experts dispute many assumptions made so far in current LCA’s. Consequently, current LCA-studies do not result in any preference for a specific type of paint, although the major adverse environmental effects can be related to the manufacture of TiO_2 as a pigment and to emissions of solvents at application (traditional solvent-based paints).

As far as health impacts are concerned, due to the neurotoxic nature of most volatile organic solvents, the (interior) use of solvent-based paints has resulted in the identification of the development of an Organic Psycho Syndrome (OPS) in painters in Scandinavian countries and the Netherlands. It concerns several hundreds of patients in Scandinavia in the 80’s. Recently it was estimated, that for the Netherlands, 1,1% of the painters suffer neurasthenic symptoms (first OPS-symptoms). The number of workers in paint manufacturing suffering from these neurasthenic symptoms, is even larger at 5,3%. However, the establishment of special medical diagnostic procedures is needed to identify OPS-patients unambiguously. As a consequence OPS-patients are not identified in many EU countries. An important trigger in the development of OPS is thought to be the regularly occurring short-term high peak exposures, which are common in the painters’ practice using solvent–borne paints indoors.

A shift towards the indoor use of low-solvent-borne and especially water-borne paints seems to reduce the amount of new OPS-patients significantly. Option 2 of the VOC reduction proposals provides an advantage over option 1 in this respect, as for interior trim only waterborne products will remain.

The use of waterborne coatings provides clear improvements from an occupational health point of view. The risk of developing OPS is significantly reduced when waterbased paints are used. Residual monomers and additives are usually present in sufficiently low concentrations to prevent skin irritation or sensitisation. The most harmful cosolvents and coalescing agents (ethyleneglycolethers) are being or have been substituted by less harmful alternatives already. Further improvements can be made by carefully choosing the type and amount of biocides used.

An issue that might need attention in the future, due to potential irritative or sensitisation effects, is the use of reactive diluents in high solids paints.

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1. Introduction

Emissions to the atmosphere of Volatile Organic Compounds (VOC) contribute to the formation of photochemical oxidants - mainly ozone - at ground level in the presence of sunlight and nitrogen oxides. This so-called ‘summer smog’ gives rise to adverse human health effects and damages agricultural crops and natural vegetation.

In order to limit these effects, measures have been initiated at national as well as international levels to reduce emissions of VOC. Within the European Union, major initiatives include the Solvents Emissions Directive (1999) and the proposed National Emissions Ceilings Directive. The first includes industrial emissions only, and will have to be implemented by the year 2007, implying a 49% reduction of total man-made VOC-emissions. The latter has been drafted because additional reductions up to 60% are needed to prevent the mentioned adverse effects (EC, ’99). Emissions of VOC from non-industrial settings may be tackled within the framework of this directive. In addition, VOC-reduction targets have also been agreed within the wider framework of the United Nations Economic Committee for Europe (UN/ECE) during the Gothenburg conference in December 1999.

If the ambitious targets that have been defined are to be met, considerable efforts may be needed. The Commission has identified two sectors in which measures to reduce emissions of VOC may be cost-effective (EC, ’99): the automotive refinishing sector and the professional and non-professional use of decorative paints and varnishes. So far, the Commission has given priority to an incentive-based approach, e.g. by defining criteria for an Ecolabel for decorative coatings. In order to study the potential and cost-effectiveness of further measures in these two sectors, the Commission has commissioned two studies. The first study has resulted in a draft report (Ritchie, ’00).

This report is the draft final report for the decorative coatings study. The full title of the study contract was: “*Study on the potential for reducing emissions of volatile organic compounds (VOCs) due to the use of decorative paints and varnishes for professional and non-professional use*”. The principle objectives of this study were:

1. To present a synthesis of the relevant elements characterising the decorative paints and varnishes sector;
2. To explore at a technical level the possibilities for limiting the concentration of organic solvents in products used in this sector;
3. To analyse the environmental and economic impact of such regulatory measures.

Scope of the study
In order to define the scope of the study, the following definition of ‘decorative paints and varnishes’ has been developed by the study team:
“Decorative paints and varnishes are products that are applied to buildings, their trim and fittings, for decorative and protective purposes. They are applied in situ by professional or private users. While their main function is decorative in nature, they also have a protective role.”

Paints and varnishes used in an industrial context fall beyond the scope of this study, as they are covered by the Solvents Emission Directive. In addition, heavy-duty protective coatings such as anticorrosion products used on bridges do not belong within the scope of this study.

Geographically, the study concentrates on the 15 EU-member states. However, where available, data from a number of so-called ‘accession countries’ have been collected as well.

Health aspects related to direct exposure of professional painters or consumers to organic solvents have been taken into consideration as well as the major benefits that may be expected from VOC-reductions. Over the last decade, the disease known as Organic Psycho Syndrome (OPS) or “painters’ disease” has gained more and more attention. As the interior use of solvent-based decorative coatings is thought to be a major risk factor in this respect, these aspects have been included in the study.

Structure

This report has been structured as follows:

In *Chapter 2*, the study methods and the sources of information used in the project are described and in C*hapter 3* the definitions that have been used during the study. *Chapter 4* contains the 'synthesis of the relevant elements characterising the sector', i.e. a study of the decorative coatings market. In C*hapter 5*, the inventory of emissions of VOC due to the use of decorative paints and varnishes is presented, and in C*hapter 6* the inventory and evaluation of existing measures to reduce these emissions are presented.

Chapter 7 provides a literature review of historic, recent and expected developments in decorative paint technology, and C*hapter 8* an overview and classification of current products and low VOC alternatives.

Chapter 9 contains the comparison between conventional and low-VOC decorative paints and varnishes, and two proposals for a VOC-reduction scheme. Subsequently, *Chapter 10* estimates the corresponding VOC-reduction potential. In *Chapter 11,* an overview of the costs and benefits of the various regulatory options that are available and the assessment of the costs and benefits of the proposed VOC-reduction scheme is presented. The environmental and occupational health impacts of the proposal are dealt with in *Chapter 12.* The main conclusions have been summarised at the end of each chapter or section.

A glossary of terms used completes the main text of the report. In the Annexes, mailing lists for the questionnaires that were sent out are presented (Annex 1), as well as basic data on paint consumption and VOC-emissions (Annex 2 and 3) and a list of persons and organisations spoken to (Annex 6). In addition, written position statements of a number of industry associations are presented (Annex 4).

In order to balance these opinions, the European Environmental Bureau's (EEB) position on the Precautionary Principle has been included. One of the main conclusions from the EEB is, that asking for a "sufficient body of evidence" for damage to the environment or health caused by a certain activity, imposes the burden of proof on regulators and – by extension – on society as a whole. "*Where safer alternatives are available or may be marketed in the forthcoming future, these should be promoted as a substitute to the activity, giving rise to 'reasonable suspicion'. The substitution principle allows for technology driven changes (best environmental option) instead of waiting for the proof of harm*" (Annex 5).

Finally, annex 7 and 8 describe the decorative paint formulation data used, and discuss the CEPE-proposal for VOC-reduction, respectively, while Annex 9 presents some basic physico-chemical data on commonly used solvents in decorative coatings.

References

- EC, '99, Proposal for a Directive of the European Parliament and of the Council on National Emission Ceilings for certain atmospheric pollutants (Document 99/0067 COD), EC, Brussels.
- Ritchie, A. (Ed.), 2000, Reducing VOC-emissions from the Vehicle Refinishing sector, Entec UK Ltd., Northwich, Cheshire, UK.

2. Study methods

In addition to using the study team’s own expertise, literature and databases, questionnaires and many meetings and interviews were used as sources of information. Below a concise description of the data collection is given. An extensive survey of literature, persons met and addressees for the questionnaires has been given in the Annexes.

Literature and databases

Various types of literature and databases were used to collect market data and VOC emission data, data on paint technology, data on regulations and economic impact, data on environmental impact of VOC etc. Major sources were:

- Existing market surveys, such as the World Paint File 1998-2000 and ‘A Profile of the European Paint industry’ (IRL, ’98).
- Existing EC-studies, such as the Consultium study on decorative paints (Den Hartog & Locher, 1992), the 7th Interim Report of IIASA on Cost-effective Control of Acidification and Ground-level Ozone (Amann et al., 1999) and the Feasibility study on the Implementation of Economic Measures to reduce Emissions of Organic Solvents (Oltshoorn et al., 1994).
- Other studies, such as a case study on developments in the Dutch (and European) paint industry over the past 30 years (Mol, 1995).
- Full texts of existing and proposed Council Directives, UN Protocols and national regulations.
- Professional magazines such as SHE Alert, Coatings COMET and CORE (coatings regulations and environment) from PRA, European Coatings Journal, Surface Coatings International, periodicals of national associations of the paint industry and CEPE Newsletters.
- Annual Reports of several organisations.
- Internet sites of DGXI, UNECE, EEA, US EPA, IIASA, EMEP, AEA Technologies (CORINAIR data), CEPE, European Ecolabel, national Ministries of Environment etc.
- Database with European paint companies: Kompass Directory, Kompass International on-line.
- Starting point paint formulations from raw material suppliers and in the public domain.
- World Surface Coatings abstracts database.
- In-house product VOC data.
- IBM patents website.

Meetings, interviews and symposia

Consultation with key persons within the paint industry and among authorities constituted a crucial part of the study.

Several meetings were organised with major European *trade asso*ciations:

- CEPE’s Technical Committee Decorative Coatings (four times),
- CEFIC/ESIG (the European Solvents Industry Group - three times),
- UNIEP (the European Painting Contractor’s Association – twice)
- VVVF (the Dutch association of the paint industry - twice)
- ERMA (European Resin Manufacturers’ Association).

Also, meetings with representatives from the *Ministries* of Environment of the Netherlands, the United Kingdom, Austria and Ireland have taken place. Others have been interviewed by phone (see below).

In addition to the *industry* representatives met at the meetings with CEPE (all major multinational paint manufacturers), CEFIC (Shell, Exxon & BP) and UNIEP, a number of individual companies have been consulted. In addition, meetings were held with the raw material suppliers DSM Resins, Rohm & Haas, Goodyear and TotalFina. Many other ‘upstream’ suppliers of the paint industry have been interviewed at the European Coatings Show ’99 in Nürnberg.

Research institutes visited include the Dutch Institute for Wood Research and the Centre for Research and Technical Advice (COT) and the Austrian institute IIASA.

Furthermore, the CEN Group on Euronorms for Wood Coating Standards meeting in Dublin was attended.

Interviews - by telephone or personal - have been numerous, e.g. with paint manufacturers or suppliers of components (as a result of sending a press release), representatives from Ministries of Environment or occupational health institutes, consultants, research institutes etc. In addition, interviews have been given to a professional magazine for painters and a communication consultant who works for the paint industry.

Whenever appropriate, representatives of the study team have been present at symposia on paint topics, for example the symposium connected to the European Coatings Show in Nürnberg, a symposium on ‘Philosophy with regard to future use of VOC in paints’ in the Netherlands, and the ‘Master Painters and Decorators Centenary Meeting’ in Dublin.

A survey of meetings can be found in Annex 6.

Questionnaires

Since it was not possible to visit and interview all key organisations and all individual companies involved, the use of questionnaires was employed as a cost-effective way of obtaining information and opinions. By sending questionnaires to large numbers of target organisations, a significant effort has been put in approaching as many interest groups as possible.

By this means, information has been collected on the market and on VOC emissions, on products and low-VOC alternatives, on existing regulations and future options, on the opinions of the various key organisations with respect to a future ‘paint directive’ and so on.

The following target groups were used:

- Individual Decorative Paint Manufacturers (~700)
- National Associations of Paint Manufacturers (18)
- National Authorities: Ministries of Environment or Environmental Agencies (18)

- Individual Painting Contractors
  These have been approached through the national associations and UNIEP as well as the European Federation of Building and Wood Workers.
- Associations of Retail and Wholesale outlets and individual retailers (34)
- Individual Solvent Suppliers (~ 30)
  These have been approached through ESIG.
- Individual Resin Suppliers (~ 70)
  These have been approached directly as well as through EPDLA, ERMA and APME[1].

Most questionnaires were provided in English only. For the Individual Decorative Paint Manufacturers and the individual Painting Contractors this was not thought to be appropriate. Therefore, these questionnaires were translated into French and German. The French and German versions were distributed according to the national languages of the addressees.

The lists of addressees for the questionnaires sent during the second half year of the project are enclosed in Annex 1.

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[1] EPDLA: European Polymer and Latex Dispersion Association. ERMA: European Resin Manufacturers Association. APME: Association of Plastic Manufacturers Europe.

Response

The quantitative response to the questionnaires varied widely. Highest responses were obtained among the national associations of paint manufacturers and the national ministries of environment (82% and 76%, respectively). However, it appears that individual paint manufacturers in most cases have relied on their national associations to respond. Responses from individual companies were few, i.e. below 10%. Indeed, the study team received many messages from individual manufacturers, indicating that the national association would take care of their response.

Fifty-five responses were received from individual painting contractors. Due to the fact that these companies were directly approached by their associations, the actual response rate was not known. However, because of the wide range of countries involved in the replies, the results seemed to be quite representative for the European painting contractors.

The response from paint retailers and retailing associations appeared to be very poor (below 10%). Apparently, many retailers (in many cases: general DIY retailers) did not feel that the study would have a significant impact to their business. Besides, much of the information sought is regarded as being commercially sensitive. The response from solvent manufacturers and resin manufacturers was mainly received through the representing organisations.

Other sources of information

Sources of information also included were the Marketing Information Service at Enterprise Ireland, and Enterprise Ireland’s European Regional offices in Stockholm, Warsaw, Prague, Berlin, Brussels, Milan, Vienna, Munich, Amsterdam, Budapest, Copenhagen, Madrid, Paris and Düsseldorf.

3. Definitions

In this section, three definitions that are essential for a proper study, as well as for an unambiguous future Council Directive are set out and discussed by the study team. Subsequently, definitions will be discussed for:
Decorative paints and varnishes
Volatile Organic Compounds

3.1 Definition of Decorative Paints and Varnishes

Discussions within the study team as well as between the study team and representatives from CEPE and others have eventually resulted in the following "working definition":

"*Decorative paints and varnishes are products that are applied to buildings, their trim and fittings, for decorative and protective purposes. They are applied in situ by professional or private users. While their main function is decorative in nature, they also have a protective role.*"

Discussion

With the possible exception of artists' paints and marking materials, all paints can be regarded as having the dual functions of decoration and protection. By definition, the term "decorative paints and varnishes" places the emphasis on the decorative function, and this is valid for much of the materials covered by this study. For example, consumers of interior wall paints are mainly concerned with aesthetic characteristics such as colour and gloss, rather than protection. Indeed most repainting carried out in this context is for aesthetic reasons rather than anything concerned with loss of protection. On the other hand, exterior paints and varnishes applied to joinery, in particular softwood joinery, is required to be both decorative and protective in equal measure. In fact it can be argued that if the protective element is not present in sufficient measure, the decorative effect will be lost very quickly, together with the joinery itself. Nevertheless, these products are defined as being decorative.

It is also characteristic of decorative paints and varnishes that they are applied *in situ* to existing or new buildings, their trim and fittings. Many architectural products such as gutters, down, pipes, aluminium windows, are painted off site on factory production lines. They are not covered in this study by virtue of the fact that they are applied in factories (See Clause 5, Field of Investigation of the Technical Annex). Many radiators for example are primed in the factory before delivery to the building (not covered by the study), and have their finish coat applied following installation (covered by the study).

Heavy-duty coatings such as structural steel paints are not covered in the study because decoration is a very minor part of their function and they tend not to be applied by private users. However, some two-pack products are used by private consumers as well as professionals, and for this reason they are covered in the study.

3.2 Definition of Volatile Organic Compounds (VOC)

The term VOC is widely used in environmental and occupational health policy, but within the different policy areas the term VOC is not used unambiguously. Common descriptions refer to VOCs as being all "organic solvents" (and co-solvents), or use the term VOC to describe compounds with a specific vapour pressure, boiling point or POCP-value (Photochemical Oxidant Creation Potential). At least four different definitions are in use, which do not in every case describe the same group of chemicals. However, all of the definitions try to define the difference between volatile and non-volatile compounds.

Four common definitions in use can be *summarised* as follows:

a. VOC are all organic compounds with a vapour pressure above 10 Pa at 20°C.
b. VOC are all organic compounds with an initial boiling point under 250°C at 1 atm.
c. VOC are all organic compounds with a POCP value.
d. VOC are all organic compounds used as solvents or co-solvents.

It is generally agreed that organic compounds are all compounds containing at least the element carbon and one or more of hydrogen, halogens, oxygen, sulphur, phosphorus, silicon or nitrogen, with the exception of carbon oxides and inorganic carbonates or bicarbonates.
Some definitions limit their scope to volatile organic compounds from an anthropogenic origin, excluding methane, to distinguish the anthropogenic emissions from the natural emissions from forests, in order to enable a source-oriented policy.

Important differences arise especially in the area of low-volatility organic compounds. Using for example the vapour pressure approach (i.e. 10 Pa), certain low-volatility organic compounds are not considered to be a VOC, while the boiling point approach (250°C) in contrast may consider them as VOCs.

Nevertheless, most solvents used in decorative coatings are covered by all four definitions. Even by using the least stringent definition for future legislation, the use of at least 90% of the evaporating organic compounds in paints will be restricted.

However, driven by legislation and a growing environmental and (occupational) health awareness, the use of low-volatility organic compounds is increasing. Therefore, the simultaneous use of different definitions is confusing for paint formulators as well as for the users, and a choice for an unambiguous definition will have to be made.

All four definitions have advantages and disadvantages, which will be discussed below.

a. VOC are all organic compounds with a vapour pressure above 10 Pa at 20° C.

The vapour pressure of a compound is directly related to the maximum concentration of this compound in the air. Since concentration is the amount per unit of volume, the amount of a certain compound necessary to reach the maximum concentration increases as the volume increases. In practice, in the troposphere, having a relatively ‘infinite’ volume, the maximum concentration will never be reached. Thus, all solvents from the paint will evaporate. Indeed this is the fact during the drying of the paint[1]. For environmental protection it is therefore more important to set a limit for the *amount* of solvent than for the *volatility* of the solvent. However, taking the working environment of a painter into account, with in general only a small working area (a small “working volume”), the maximum concentration might be reached. In this case the painter might be exposed to the maximum concentration of the solvent in the air, which directly depends on the vapour pressure of the solvent. Therefore, for health protection it *is* important to limit the volatility of the solvents used. The lower the vapour pressure of the solvents used, the lower the risk of a high exposure of the painter.

The definition *“VOC’s are all organic compounds with a vapour pressure above 10 Pa at 20°C”* is used by the European Commission in order to define the scope of the Solvent Directive. This Council Directive sets limits for the VOC emissions from industrial processes and installations. The threshold value of 10 Pa was chosen arbitrarily. Initially a threshold value of 1 Pa was suggested, but on request of the chemical industry this value was increased to 10 Pa. Following the European Commission, most EU member states use this VOC definition nationally. Since the first set of requirements of the Solvent Directive has to be implemented in 2002 in all member states, all member states are forced to use this definition by then.

Consequences of using the 10 Pa-definition

Best available physical/chemical parameter. Although actually the ability of a compound to evaporate in general should be expressed, the vapour pressure at least expresses the maximum concentration in the air, which is important for local (health) effects.

Consistency in European legislation. It is preferred that in all European legislation the same VOC-definition is used. Using the 10 Pa-definition in legislation on decorative paints and coatings is consistent with the Solvent Directive. However, in the proposed National Emission Ceilings Directive a definition based on the ability to create tropospheric ozone is used (see definition 3).

Disagreement with paint industry. Although CEPE had agreed to use the 10 Pa definition when the first proposal for the paint directive was developed (Josephus Jitta,'95), the paint industry changed its opinion and are now (strongly) in favour of the 250°C definition. (see next section).

Agreement with chemical industry. The European Solvents Industry Group (ESIG) favours the 10 Pa-definition[2], as being the best available parameter to express volatility. They agree that there is an empirical relation between vapour pressure and boiling point, but that this relation is not absolute. According to ESIG a vapour pressure of 10 Pa compares to a boiling point of approximately 216°C for hydrocarbon solvents.

Some countries will be forced to use another definition than the one they are using at the moment. Some countries are using the 250°C-definition in national measures (Germany for instance). By using the 10 Pa-definition in legislation on decorative paints and coatings, they are forced to switch or to use both. However, they are forced to use the 10 Pa-definition anyway starting in the year 2002, when the implementation of the Solvent Directive has to start. Since the Solvent Directive is committed to industrial processes and installations, it still may have some impact on the paint sector.

Urgent need for a standardised method to establish vapour pressures. There are several methods for establishing the vapour pressure of a compound, all using different extrapolation equations leading to various values. Although in the Solvent Directive the vapour pressure definition is already used, there is a need for a simple and standardised method to measure the vapour pressure. This method should be available as soon as possible.

Not all volatile organic compounds used in coatings will be covered. The 10 Pa-definition does not cover all volatile organic compounds used in coatings (annex 9). Especially glycolethers, and for instance the widely used co-solvent Texanol are not covered by this definition. As a consequence, any paint directive using the 10 Pa definition will not limit the use of these volatile organic compounds. This may result in the development of paints with high levels of glycolethers or Texanol (and therefore the emissions of volatile compounds from paints will not be prevented).

Difficulty for paint industry to check chemical industry data. Paint manufacturers may wish to check whether the solvents they use are VOC or not, despite the information provided by the supplier. This may be so, because the paint manufacturer is legally responsible for the MSDSs it delivers. SME's in particular are in most cases not capable of measuring vapour pressure. Only specially equipped laboratories can measure (or extrapolate) the vapour pressure. For measuring boiling points only distillation equipment is needed. However, according to the Dutch and French paint manufacturers' associations and CEPE, the paint industry never checks volatility of solvents themselves; only incidentally they seem to have it checked by specialised laboratory.

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[2] According to ESIG, when aiming at a reduction of ozone formation, VOC should be defined by their Photochemical Ozone Creation Potential. However, when the volatility of VOC needs to be defined the vapour pressure is the best available parameter.

b. VOC are all organic compounds with an initial boiling point under 250° C at 1 atm.

Although the boiling point of a compound is neither directly related to the ability to evaporate, nor to the maximum concentration of the compound in the air, there is some kind of empirical relation between the boiling point and the vapour pressure. Because of the fact that the boiling point is a more accessible physical/chemical parameter and the boiling point is often easier to establish than the vapour pressure, the boiling point is also used to define VOC.

The definition "VOC's are all organic compounds with an initial boiling point under 250°C at 1 atm." Has been developed by a CEPE working group within the scope of the European Ecolabel for indoor paints. The German representatives wished to use this definition in particular, because it is the way VOC is commonly defined in Germany. The threshold value of 250°C was arbitrarily chosen. Since the Ecolabel is a voluntary instrument, no country will be forced to use this definition.

Consequences of using the BP 250° C-definition

- *Not the most suitable physical/chemical parameter to express volatility.*
- *No consistency in European legislation.* In the European Solvent Directive the 10 Pa-definition is used, so there will not be consistency in European legislation.
- *Agreement with the paint industry.* CEPE has reached consensus among their members about using the 250°C-definition, which will make it easier to find acceptance for the introduction of this definition in legislation on decorative paints and coatings. The paint industry is not willing to change their opinion again back to the 10 Pa definition. CEPE mainly favours the 250°C-definition because the boiling point is easier to measure and because it is an easily accessible physical/chemical property for paint producers as well as painters. Evaluation of the commonly used organic solvents for paints shows that the 250°C boiling point definition is more stringent than the 10 Pa definition (annex 9).
- *Disagreement with chemical industry.* According to ESIG, the boiling point has only an indirect relation with volatility, making the boiling point an inappropriate parameter. The reason ESIG is in favour of the vapour pressure definition may be the fact that the 250°C-definition is more stringent than the 10Pa-definition, limiting the use of more solvents as a consequence.
- *Member states are forced to use two different definitions.* All countries will be forced to use the 250°C-definition (Paint Directive) as well as the 10 Pa-definition (Solvent Directive). Since both definitions do not exactly cover the same group of organic compounds, this might be a confusing situation.
- *Relatively simple measurement.* The establishment of the initial boiling point is relatively simple and there are standardised methods available. Therefore, it is relatively simple to check the boiling point for anybody who wishes to check it.
- *Not all volatile organic compounds used in coatings will be covered.* The 250°C-definition does not cover all volatile organic compounds used in coatings (annex 9). For instance the widely used coalescing agent Texanol (that evaporates from the dying film!) is not included in this definition. Therefore, any legislation using this definition will not limit the use of Texanol.

c. VOC's are all organic compounds with a POCP value

One of the main reasons for reduction of VOC emissions is that VOC in the presence of NO_X contribute to tropospheric ozone formation. By reducing the VOC emission, ozone formation is reduced. The contribution to ozone formation varies for different VOCs. Some VOC have the potential to contribute to ozone formation to a large extent, while others have the potential for only a minor contribution. This potential to contribute is expressed by POCP values (Photochemical Ozone Creation Potential). Every volatile organic compound has its particular POCP value. One might think that, when aiming at reducing VOC emission in order to reduce ozone formation, one should focus on reduction of VOC emissions with the highest potential for ozone formation (i.e. VOC with high POCP-values). Thus, in this view, from an environmental perspective, a definition using the POCP value would be very useful. However, some of the less reactive solvents cause additional problems, e.g. they are extremely harmful to human health, difficult to handle, persistent, or they can cause other negative environmental effects. Even more importantly, the less reactive solvents (low POCP value) eventually contribute to ozone formation. While high-POCP solvents cause ozone formation close to the source of emission, due to dispersion and their lower reactivity low-POCP solvents cause ozone formation far from the source of emission (IIASA, 1999). Because most European Union member states are densely populated, both processes of ozone production are problematic.

In the case of the indoor use of decorative coatings, health effects especially need to be taken into account. The POCP value of VOC is not related to their ability to cause health problems in any way. Therefore, by defining VOC by POCP value, the possible health effects of VOC are not expressed.

In the "Protocol to the 1979 Convention on Long-range Transboundary Air Pollution concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Fluxes" the following definition is used:
"VOC are all organic compounds of anthropogenic nature, other than methane, that are capable of producing photochemical oxidants by reactions with nitrogen oxides in the presence of sunlight."
The same definition is proposed for the draft National Emission Ceilings Directive (section 7).
In the Protocol, POCP is defined as 'the change in photochemical ozone production due to a change in emission of that particular VOC'. According to the UN-protocol POCP may be determined by photochemical model calculation or by laboratory experiments.

Consequences of using the POCP-definition

- *POCP is a too specific parameter.* POCP only expresses the ability of a compound to contribute to ozone formation, while in fact contributions to other environmental and health related effects are important as well. For all effects, the volatility of a compound is of determining importance and therefore it is supposed to be a better option to use the vapour pressure or boiling point.
- *No consistency in European legislation.* In the European Solvent Directive the 10 Pa-definition is used, so there will not be consistency in European legislation. However, in the proposed National Emission Ceilings Directive the same definition as the one that is used in the Protocol is used.
- *Disagreement with paint industry.* CEPE reached consensus among their members to use the 250° C-definition, making it very difficult to get the POCP-definition accepted in legislation on decorative paints and coatings. Besides, the paint industry also has to deal with health effects, making definition by the POCP value inappropriate.
- *Partial agreement with chemical industry.* When choosing between vapour pressure and initial boiling point, ESIG strongly favours the vapour pressure. However, when possible, definition by POCP value is according to ESIG the most appropriate, since reduction of tropospheric ozone formation is the aim. Obviously, a boundary value of 0 (POCP > 0) will probably not be acceptable for the solvents industry.
- *Member states are forced to use two different definitions.* All countries would be forced to use the POCP-definition (future Paint Directive, NEC Directive) as well as the 10 Pa-definition (Solvent Directive). Since both definitions do not cover the same group of organic compounds, this is a complicated situation.
- *Urgent need for a standardised method to establish the POCP-value.* The major problem with using the POCP-values is the absence of a consistent standardised method to calculate POCP values. At the moment, POCP values are calculated as estimates, depending on the particular scenario used and on the specific feature calculated (peak ozone concentration, integrated ozone or average ozone). Clearly there are differences between the different estimates of POCP values, which in some cases can span more than a factor of four.
- *Ambiguous property.* POCP values vary in time and space. Therefore, it is very ambiguous to use POCP values to define VOC.

d. VOC's are all organic compounds used as solvents or co-solvents

This definition is often used in spoken language. For many people it seems perfectly clear what VOC are. However, although useful in daily life, this operational definition cannot be used in legislation, because it is not unambiguous.

Discussion

Both the vapour pressure (10 Pa) and the boiling point (250°C) definitions have one disadvantage in common, namely the fact that they do not cover all evaporating organic compounds used in paints. This might result in the development of paints containing (high) levels of evaporating organic compounds (e.g. Texanol) which are not covered by legislation. In order to provide this from happening, one might choose to adapt the threshold values of both definitions. The initial boiling point should in that case be increased to 280°C and the vapour pressure reduced to 1 Pa in order to cover all evaporating organic compounds. In fact 1 Pa is not really the boundary, as vapour pressures below 1Pa can not be measured.

However, by increasing the boiling point to 280°C, substances might be included, which do not function as evaporating organic compounds at all, such as some surfactants or plasticisers.

Ideally, the definition of VOC should meet the following criteria:
- *All VOC that are used should be included.* Since all volatile organic compounds that are used are supposed to evaporate out of the drying paint layer, they all end up in the troposphere. Therefore, all VOC, i.e. solvents, co-solvents, coalescent agents, monomers and other possible volatile additives, need to be included in the definition[3]. Only then is it possible to limit the use of volatile organic compounds in decorative paints and coatings. If not, future paints may contain high amounts of volatile organic compounds which are not defined as being VOC. By including all volatile organic compounds, all organic compounds with a POCP value would be included as a consequence.
- *Easy to establish whether a compound is VOC or not.* At the moment a standardised method is available to measure the initial boiling point. ESIG is working on standardisation of a method to measure vapour pressures of aliphatic organic compounds. Furthermore the department of Environmental Chemistry of the University of Amsterdam[4] have developed a simple method to establish the vapour pressure of low-volatility esters. It is not expected that the establishment of POCP values will be standardised on short notice.
- *Not only the environmental effects, but also health effects of VOC should be taken into account.* Health effects as well as environmental effects occur after evaporation of the compound. Therefore a definition based on a parameter expressing volatility might be the best option.
- *Agreement with as many organisations as possible.* Obviously, it would be best if every organisation involved agreed to use the same definition. Since every organisation seems to use its own definition, this is impossible. Therefore, distinction should be made between 'important' and 'less important' organisations.

A definition based on POCP-value meets only the first criteria, as far as the solvents used in decorative coatings are concerned. Literature shows, that in fact all solvents used in decorative coatings do have a POCP-value (Derwent et al., '96).

Definitions based on vapour pressure or initial boiling point may be appropriate. However, in order to include all VOC, the currently used threshold values would have to be changed. By changing the threshold value of any of the definitions, consistency is lost. On the other hand, health effects are included in both definitions, since all VOC can be included and consequently the most volatile and neurotoxic VOC are included. The initial boiling point is easier to measure than the vapour pressure. However, as soon as a standardised method to measure the vapour pressure becomes available, the vapour pressure will be easier to measure as well. It is expected that CEPE will relatively easily agree

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[3] Some raw material suppliers objected to this precondition (Oorschot, 1999). It was stated that for instance AMP, used as a neutraliser, should not be included in the VOC definition since this substance interacts strongly with the paint and therefore does not evaporate. One also stated that AMP (and also hardeners in 2-C systems) is used in very small amounts. However, in legislation, a limit will be set for the use of VOC, meaning that VOC may be used in paint to a certain extent. Even when AMP is defined as being VOC, it still may be used in the amount in which it is currently used. Hardeners are a more important problem, as are reactive diluents. Both of these substances may be volatile in liquid paint, but are not meant to evaporate out of the dry paint layer.

[4] Determination of Environmentally Relevant Physical-Chemical Properties of Some Fatty Acid Esters – Hildo B. Krop, 1997.

with a definition based on initial boiling point, even when the threshold value is not 250°C. The European Commission is also prepared to deviate from the existing definition in European legislation when there is a good reason to do so (Klein, '99). ESIG does not agree with a definition based on initial boiling point, because the initial boiling point is not clearly related to volatility. However, because the definition based on initial boiling point is more stringent, it will include all VOC that are defined as being VOC by a vapour pressure definition.

Conclusion
By using any of the four commonly used definitions, about 90% of the solvents used in paints can be covered by future legislation. In this respect it is a marginal discussion which definition to use. However, the use of low-volatility organic compounds is increasing. The definitions are diverging with respect to these compounds, meaning that a certain compound is a VOC according to one definition and is not according to another.

The operational definition "VOC are all organic compounds used as solvents and co-solvents" cannot be used because of its ambiguity.

All other definitions dealt with in this section have advantages as well as disadvantages. These are summarised in the table below.

Table 3.1 Advantages and disadvantages of possible VOC-definitions

	10 Pa-definition	250°C-definition	280°C definition	POCP > 0 Definition
Reflects volatility	+	-	-	-
Consistent with Solvents Directive	+	-	-	-
Consistent with NEC directive	-	-	-	+
Agreement with Paint industry	-	+	+/-	-
Agreement with Chemical industry	+	-	-	-
Standardised/ facile measurement	-	+	+	-
Easily accessible parameter	-	+	+	-
Stringent	-	+/-	+	+
Understandable for painters/ SMEs	-	+	+	-
Includes *all* volatile organic compounds	-	-	+	+

The UN/ECE definition, which is also used in the proposed NEC-Directive, seems to be an attractive option after all, because of its wide scope. The full definition is:
"VOC are all organic compounds of anthropogenic nature, other than methane, that are capable of producing photochemical oxidants by reactions with nitrogen oxides in the presence of sunlight."
In the table above, this definition is indicated as 'POCP > 0 definition', because it implies that a compound is included when the POCP-value is > 0. As mentioned before, this is the case for all solvents, co-solvents and coalescing agents used in decorative coatings. Consequently, also those solvents that for example have low POCP values but are highly neurotoxic will be included. An additional advantage is the fact that this definition is consistent with the proposed "umbrella directive" on National Emission Ceilings.

However, it should be prevented that this will give industry the opportunity to challenge the inclusion of very low-POCP solvents. The fact that all VOC contribute to ozone formation (although to a different extent) should be the leading principle. Also, the fact that very low-POCP solvents might have other adverse effects (e.g. on human health) should be born in mind. Therefore, the limit of "POCP > 0" should be maintained.

One main disadvantage associated with this definition that remains is its lack of understandability for SMEs in the paint industry. Therefore, it is proposed to implement the definition for practical use in the paint industry as follows:

"*VOC are all organic compounds used in paint or associated with the application of paints that have an initial boiling point of lower than 280°C"*.

This boiling point definition covers as many solvents as the UN/ECE and NEC-directive definition. Besides, it will constitute a 'bridge' between the in principle most appropriate definition (UN/ECE & NEC) and the more practical definition from the paint industry (CEPE). Moreover, the boundary of 280°C is used in the definition that the major UK DIY chain B&Q uses. Thus, this implementation of the definition may contribute to the acceptance of the NEC-directive definition within the industry.

References

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4. The European Decorative Paints market

In this section, the description of the elements characterising the European market for decorative paints and varnishes are presented. Existing market studies were used to provide a large part of the required data, in order to prevent duplication. These existing data was complemented by industry data provided by CEPE, national associations of the paint industry, associations of paint contractors etc. The questionnaires that have been sent out, as well as personal visits, were used for this purpose. In addition, reports on major developments in the paint industry were collected, covering issues such as competitive context, industrial strategy and degree of innovation. Please refer to Chapter 2 and the literature references for a complete survey of the information sources used. The *major* sources used in the market study include:

- Market study “A profile of the European paint market” (IRL, 1998);
- Market study “World Paint File 1998-2000” (Talmage, 1999)
- Questionnaires to national associations of the paint industry and of painting contractors.
- Annual Reports of these national associations.
- A wide variety of Internet sites, e.g. of large DIY retailers.

This chapter starts with a discussion on the reliability of the market data. Subsequently, in section 4.2 the ‘basic figures’ characterising the decorative paints sector are presented and discussed. Finally, section 4.3 provides a discussion on issues such as recent developments and trends, competitive context and industrial strategies within the decorative paints sector.

4.1 Reliability of the market data

The data that are available originate mainly from trade organisations and literature. However, literature data have also, often been published by industry experts, or originate from industry sources. Anomalies in the figures may have various causes (IRL,’98):

- *Incomplete* statistics

For example, associations of paint manufacturers generally include only data from their member-companies, i.e. the somewhat larger companies. In many cases, data from very small SME’s are not included. However, in the existing market studies estimates have been made of their contribution. In most cases this is about 10% of the national production, although this figure may in a minority of cases be much larger.

- *Inaccurate* data, i.e. a variety of mistakes, that are dependent on the persons that collected the data.

For example, understatement of production figures to reduce tax liabilities or to reduce the fee that has to be paid to the national association of the paint industry. Industry representatives have confirmed that these practices occur. On the other hand, in some cases the reported production is in fact the maximum capacity instead of real production, resulting in overstatement.

- Inclusion of *other* products (e.g. inks) in the available statistics.

This problem is of particular importance when data on *decorative* paints only are desired. In many cases, the exact definition of ‘decorative paint’ that has been used while compiling the statistics is not known. Some countries define ‘architectural paints’, and include e.g. road marking paints.

- *Unit* of measurement confusions, e.g. production versus sales figures; quantity versus value; tonnes versus litres etc.
- *Other factors*, e.g. production decline in case of political ‘unrest’, rise in production in case of starting up new plants, exports or imports etc.

In spite of the many potential anomalies, the actual production and consumption figures of decorative paints have been estimated, using different data sources. These have been presented and discussed below.

4.2 Basic data on the European Decorative Paints Market

In this section, the characteristics of the upstream decorative paint market are described (paint and raw material manufacturers) first, followed by a description of the downstream market (distribution, professional and private users). However, the two ends meet at certain points, as e.g. production of decorative paint roughly equals consumption for Europe as a whole.

4.2.1 upstream decorative paint market

Upstream industrial sectors – raw material suppliers

Most data in this section originate from [IRL, '98], unless otherwise indicated.

It is estimated that well over 200 significant raw material suppliers serve the European paint industry. Four different types of raw material suppliers maybe distinguished:

- *Multinational diversified chemical groups*, either downwards integrated (e.g. BASF, Hoechst, Akzo Nobel, Total-Fina), or not downwards integrated (e.g. DSM, Shell Chemicals, Ciba, Rhodia/Rhone Poulenc, Dow, Du Pont, Union Carbide).
- *International specialised manufacturers*, e.g. Cray Valley (Total-Fina), Zeneca Resins and Vinamul (ICI).
- *International and national paint manufacturers* who produce raw materials only for in-house use (e.g. Becker).
- *Specialised national producers* who mainly serve their national market (e.g. Ernst Jaeger in Germany).

Table 4.2.1(a) The overall raw material usage and value breakdown for the European paint industry (both industrial and decorative; data 1996):

	Quantity (ktonnes)	**% Tonnage**	**% Value**
Solvents	1420	24,2	12,0
Coloured pigments	225	3,8	15,1
White pigments	880	15,0	34,0
Resins	1775	30,2	34,3
Extenders	750	12,8	3,3
Water	735	12,5	-
Additives	90	1,5	1,3
TOTAL	5875	100,0	100,0

Increasing prices of raw materials currently cause concern among paint manufacturers. This is even more problematic because increasing competition may mean that the increasing costs cannot be passed-on to the customer.

<u>Resin manufacturers</u>

The estimated number of resin manufacturers is *over 100*, among which 40-50 are 'significant'. However, not all of these have interests in the paint industry. For each resin type there are three or four suppliers that dominate the market. Below, the market positions for major resin types on the West European market are given. Insufficient information is available on the East European market.

Overall, the major resin manufacturers include DSM Resins, BASF, Bayer, Hoechst and Rohm & Haas. Three of these are German. Two associations representing the European resin manufacturers are the European Polymer Dispersion and Latex Association (EPDLA) and the Association of Plastics Manufacturers in Europe (APME). The EPDLA represents 24 member companies and the APME has 45 member companies (CEFIC website). The APME members together have a turnover of more than 29 billion EURO and employ over 70,000 people. However, only a small part of this is connected to the production of coating resins. Of the total European plastics consumption of approximately 33,366 kilotonnes (APME website), only 1775 kilotonnes are coating resins (see the table above), being *5.3%*

(in turnover: 1.5 billion EUROs). A third association in this sector is the European Resin Manufacturers Association (ERMA). This association represents some 30 member companies across the EU (Hemmings, ’00). There is possibly an overlap between the three associations mentioned.

A breakdown of the consumption of some major coating resins over 1996 is given below (both industrial and decorative paints; ktonnes):

- Alkyds	450
- Vinyls	365
- Acrylics	195
- Polyurethanes	160

In addition to the large players, it is thought that many very small suppliers of especially alkyd resins do exist.

Because of the diversified nature of the chemical companies that produce resins for coatings, it’s not possible to estimate the number of workers involved in the production of these resins only.

Table 4.2.1(b) Market positions of manufacturers of major resins in West Europe (IRL, ’98)

Alkyds:		Acrylic emulsions:		Polyvinylacetate emulsions:	
DSM	30%	Rohm & Haas	20%	Hoechst	25%
Bayer	20%	Hoechst	17%	Vinamul	15%
Cray Valley	10%	BASF	15%	Enichem	12%
Hoechst	8%	Zeneca	13%	Wacker	10%
Others	32%	Rohm	12%	Atochem	8%
		Vinamul	12%	Others	30%
		Others	11%		
Solvent-borne acrylics:		Solvent-borne vinyl-dispersions:		Styrene-acrylic emulsions:	
BASF	12%				
Rohm & Haas	10%	Wacker	25%	BASF	50%
Hoechst	8%	BASF	22%	Hoechst	15%
Zeneca	7%	Huls	15%	Rohm & Haas	15%
Rohm	5%	Others	38%	Others	20%
Cray Valley	4%				
Goodyear	?				
Others	54%				

Solvent manufacturers and suppliers

The exact number of solvent suppliers is not known, but is “probably in excess of *50*”(IRL, ’98). However, the majority of these are traders only. The number of manufacturers is dominated by a few large petrochemical companies (BP, Total-Fina, Shell, Exxon) and some multinational chemical groups (BASF, Hoechst). However, the European Solvents Industry Group (ESIG), part of CEFIC and representing the solvents manufacturers, has 31 member companies.

Across Europe, 10,000 people are directly employed in the production of solvents (ESIG website). The industry has a turnover of € 2.1 billion. Data from one major solvent supplier shows, that approximately 25-30% of the solvents produced is destined for coatings, thus representing a turnover of €500 – 600 million (Kirby, ’99). Data from ESIG indicate that about 18-20% of the total production of *hydrocarbon* solvents is destined for *decorative* coatings, thinning and cleaning included (ESIG, ’00).

Traditional solvent borne paint largely employs white spirit as a solvent. A total of about 640 kilotonnes is consumed annually *in paints in Europe.* Approximately 50% of the total sales of white spirit is sold as a constituent of decorative and industrial paints; the other 50% is sold as pure white spirit, and is used as thinner or cleaner for brushes. Typical prices for white spirit are 300 – 500 €/tonne (ECJ, Dec. ’99).

Waterborne paints use oxygenated solvents instead, such as glycols and alcohols. Glycols and alcohols together account for an annual consumption of about 505 kilotonnes. Typical prices for these solvents range from 780 to 1300 EUROs/tonne, i.e. a factor 2 to 3 more than the prices for white spirit.

Pigment and additive suppliers

There are more than *50* suppliers of inorganic pigments, less than *20* suppliers of organic pigments and *over 200* suppliers of the various additives for paints in Europe.

Among the inorganic pigments, the white pigment titanium dioxide is by far the most important, with 780 kilotonnes of the total of 880 kilotonnes of white pigments. There are five significant producers, together supplying 90% of the demand:

- Dupont (USA)	35%
- Kronos (USA)	18%
- Millennium (UK)	18%
- Kerr McGee-Bayer (USA/D)	12%
- Kemira (Fi)	7%

The four largest suppliers of *organic* pigments cover over two thirds of the demand. Major suppliers are BASF, Ciba, Bayer, Hoechst and Zeneca.

Most additive suppliers specialise into a few particular compounds. There are no significant dominances in this market. Altogether, about 90 kilotonnes of additives are consumed annually, representing a turnover of €320 million.

Petrochemical versus ‘renewable’ raw materials

The use of renewable raw materials in coatings is for the moment confined to certain resins. More specifically, in particular *alkyd* resins are partly derived from renewable materials (Nielsen, 1999). As alkyd resins may be applied in traditional solvent based alkyds as well as in high solids alkyds or waterborne alkyd emulsions, a switch towards low-VOC coatings does not necessarily mean a decrease in the use of renewable raw materials in coatings.

Numbers of paint production facilities and employees

The European paint industry can be characterised as being both concentrated and fragmented at the same time. In most countries up to 90% of the production is covered by less than 10 large, often multinational, companies. In addition, there is a large number of paint manufacturing enterprises that are very small and are operating locally (IRL, 1998). A considerable amount of these companies are not a member of their national paint manufacturers’ association. As a consequence, they may not be taken into account in published market figures.

Table 4.2.1 presents the number of paint producing companies per country, as well as the numbers and market shares of the dominating manufacturers. When available, the estimated numbers of paint producing companies including the very small, locally operating companies are also given. Estimates of these numbers have been made by the authors of [IRL, 1998] on the basis of literature and data from trade associations. If not available, the minimum amount of manufacturers is given. No reliable separate data for numbers of *decorative* paint manufacturers were available, as most companies produce decorative, industrial and heavy-duty.

Table 4.2.1(c) - Numbers of paint manufacturers & market structures (source: IRL, 1998)

	Significant producers	**All producers (including very small, locally operating family businesses)**	**Major producers**	**Total Share of major producers**
Austria	35	> 35	6	78
Belgium	54	> 54	3	76
Denmark	25	> 25	4	86
Finland	8	14 (association's estimate)	2	82
France	215	494	8	72
Germany	238	396	6	69
Greece	20	270	5	60
Ireland	10	30	3	79
Italy	144	686	7	**41**
Luxembourg	3	> 3	-	-
Netherlands	78	104	4	78
Portugal	54	150	5	64
Spain	171	273 (association's estimate)	8	63
Sweden	28	> 28	3	81
UK	113	259	6	68
Czech Republic	10	10	5	87
Hungary	12	15	4	80
Poland	33	± 190 (association's estimate)	4	68
EU-15 + 3	**1251** (1973: > 2300)	**> 3046**	**83**	**72 (av.)**
Slovenia	6	> 6	2	88
Slovakia	13	> 13	2	70
Turkey	27	217	2	60
(EU-15 + 6)	***1297***	***> 3263***	***89***	***72 (av.)***

The almost *1300* 'significant producers' in the EU member states and accession countries are those producers accounting for at least 90% of the output. When all very small, locally operating paint producers are included, the estimates reach as high as *over 3230* paint producers (IRL, '98). Among these very small companies are many family businesses with less than 10 employees. What further can be seen from table 4.2.1 is, that *less than 89* companies (because of double counting of multinationals) account for about three-quarters of the total paint production in Europe.

It is perfectly clear that Italy is by far the most fragmented market with respect to numbers of producers. The seven major producers account for only 41% of the total production. To a lesser extent, the same lack of dominance by major producers can be seen in the other southern countries Spain, Portugal, Greece and Turkey. On the other hand, the markets in the Scandinavian countries, The Netherlands and Ireland in the north appear to be the most concentrated.

Leading paint manufacturers

The nine leading paint manufacturers in Europe are presented in table 4.2.2. The market shares given reflect the situation in 1996 (IRL, '98), but the figures have been adapted to account for the recent Total-Fina merger. The data concern the production of decorative and industrial paints, but literature (e.g. IRL, '98) has shown that the given order of companies does generally reflect the situation for decorative paints very well. However, BASF has recently sold its decorative activities to Akzo Nobel (IRL, '98), making them disappear from the top-9 below. Herberts and Becker as well are strong in industrial coatings. This stresses the strong dominance of Akzo Nobel, ICI and Sigma-Kalon in the decorative paints market.

Table 4.2.2 – Leading paint manufacturers in Europe (1996)

Company (owner)	**Nationality**	**Market share**
1. Akzo Nobel	NL	17.9%
2. ICI	UK	9.2%
3. Sigma-Kalon (Total-Fina)	B/F/UK	8.0%
4. Herberts (Hoechst)	D	7.0%
5. (BASF)	D	(4.8%)
6. PPG Industries	USA	2.6%
7. Becker	Se	2.4%
8. Tikkurila	Fi	2.0%
9. Jotun	N	1.9%
Top-9 together		44.2%

The leading companies operate in international groups and have more interests than just paint, such as inks, adhesives, plastics or other chemicals. Many of the larger paint manufacturing enterprises are also involved in the production of binders, pigments and/or additives.

Employment in the European paint industry

It's difficult to get reliable estimates of the numbers of employees involved in the paint industry. For the many diversified companies operating in the field, data on the numbers of workers involved in (decorative) paint production only are often not available. Besides, the smallest companies are often not included in official statistics. The table below is compiled from literature data (IRL, '98). In addition, estimates of the numbers of workers involved in the production of *decorative* paint, made by national associations of the paint industry are indicated in Italics. The average number of workers per company is indicated as well. When available, average numbers of workers per company, including *very small* companies have been presented between brackets.

Table 4.2.3(a) – Employment in the paint industry (1996; from IRL, '98). Association's estimates of workers involved in decorative paint production in Italics

	Number of employees	**Average number of employees per company (including small)**
Austria	2,350 (-)	67
Belgium	3,000 *(800)*	56
Denmark	2,400 *(2400)*	96
Finland	1,431 *(500)*	179
France	19,500 *(3700)*	91 (39)
Germany	23,000 *(10,000)*	97 (58)
Greece	2,325 *(2300)*	116 (9)
Ireland	650 *(800)*	65
Italy	10,460 *(7000)*	73 (15)
Luxembourg	75	25
Netherlands	6,001 *('98) (-)*	76 (57)
Portugal	3,150	58 (21)
Spain	7,599 *(490)*	44 (33)
Sweden	2,425 *(2000)*	87
UK	18,000 (*6500)*	162 (70)
Czech Republic	1,707	171
Hungary	1,250 *(700)*	104
Poland	6,250	189
Slovenia	1,150	-
Slovakia	1,500	-
Turkey	7,600	-
Total	**122,073**	

It has been estimated, that the true numbers of workers in France and Italy together might be as high as 150,000 instead of the 30,000 that appear from official figures (IRL, '98). This is due to the many very small companies that are not covered by these figures. However, these high estimates could not be confirmed through other sources. The estimates of the numbers of workers involved in the production of *decorative* paints only, from associations of the paint industry, seem in some cases (e.g. France) much too low. In other cases, e.g. Germany, they seem to be more realistic.

Not surprisingly, the lowest average numbers of workers, very small factories included, occur in Greece, Italy and Portugal. Large companies seem from the available data to be most common in the UK, The Netherlands and Germany.

Distribution of functions

The average distribution of the functions within paint producing companies is found to be as follows

Table 4.2.3(b) Distribution of functions within paint producing companies (IRL, '98).

Production and maintenance	36.5 %
Warehouse and distribution	17.5 %
Laboratory and technical	12.0 %
Marketing and selling	22.5 %
Administration and management	11.5 %

Production and consumption of decorative paints

In Annex 2, data from five different sources for production and consumption of decorative paints are presented:

- Information Research Limited, 1998 (market study): consumption data of 1996 – 20 countries.
- CEPE, 1997 (inventory among members): production data of 1997 – only the classes 1 to 6 of the CEPE-scheme, covering approximately 90% of the market – 9 countries.
- IIASA, 1998 (RAINS-database): consumption data of 1990 – 17 countries.
- Den Hartog & Locher, 1992 (EC-study): production data of 1990 (from CEPE) – 12 countries.
- Questionnaires national paint manufacturers' associations, 1999: production data of 1997 or 1998.
- World Paint File 1998-2000 (market study): production data of 1997 for 'architectural paints' – 8 countries (more paint types included than in the other data sources).

Compiling a common picture from the available statistics is not easy, as not all statistics cover the same data. The most obvious problems are the differences in *base year* to which the data refer. Also, *production* as well as *consumption* data are given. While for Europe as a whole, production and consumption roughly are equal (as exports and imports of decorative paint beyond Europe are rare) this is not necessarily the case for all individual countries. However, it is stated that the majority of the imports and exports concern *industrial* paints (IRL, '98). Therefore, production and consumption in fact do roughly equal each other.

Regarding the CEPE-data on 1997 it must be pointed out that these cover only the *first four clas*ses of the CEPE classification scheme of decorative paints (see Chapter 9 and Annex 8). It's estimated by CEPE that these four classes cover 90% of the decorative paint market.

Finally, the production statistics from most associations of the paint industry do not cover the production of the *very small companies*. It is estimated that these very small companies together cover about 10% of the decorative paint market (IRL, '98).

In a number of cases, the estimates of [IRL '98] are too low, compared to the estimates from the other sources. Therefore, for the compiled data summarised in table 4.2.4 the following approach was adopted:

- The most recent production data from the questionnaires among national associations of the paint industry have been taken as a starting point in most cases.

- In those cases where these estimates seem too low, compared to the other sources, or where no data were available, the estimates from [IRL '98] or from CEPE have been used. More or less a *'worst-case'* estimate is obtained, because the estimates that were clearly lower than estimates from other sources have not been used.
- The correction for the contribution of very small companies has not been carried out, because in most cases the highest estimate available has already been chosen.

Additionally, in table 4.2.4 the import and export volumes of *all paints* have been presented. Data originate from the market study [IRL, '98]. Potential future EU Member States that have not been included, because of being very small, are Cyprus, Malta, Estonia, Latvia and Lithuania. No data were available on Bulgaria and Romania.

Table 4.2.4 – Decorative paint production/consumption, and imports and exports of all paints. Most data concern 1997 **(data in *Italics* have been taken from literature)**

	National production/ consumption decorative paint (ktonne) **(rounded figures)**	**Imports *all paints* (ktonne) (IRL, '98)**	**Exports *all paints* (ktonne) (IRL, '98)**
Austria	65	48.5	29.7
Belgium	*79*	94.3	94.2
Denmark	52	24.9	59.4
Finland	32	24.0	29.3
France	432	112.2	123.5
Germany	860	121.2	297
Greece	90	23.2	9.7
Ireland	25	22.6	4.0
Italy	408	60.8	156.0
Luxembourg	3		
Netherlands	179 *('98)*	76.7	95.6
Portugal	87	28.4	11.1
Spain	489	55.9	47.6
Sweden	*95*	38.4	71.7
UK	448[**]	82.0	199.0
Subtotal EU-15	*3344*		
Czech Republic	*51*	46.3	25.1
Hungary	60	12.0	3.5
Poland	*172*	45.8	10.3
Slovenia	*15*	8.0	29.9
Slovakia	*27*	15.3	14.1
Bulgaria	-	-	-
Romania	-	-	-
Turkey	*179*	22.8	19.9
TOTAL	**3848**		

[**] Calculated from BCF estimate in million litres, using a factor of 1.3 kg/litre.

Table 4.2.5 presents the data on production levels of decorative paints for a number of countries. These are based on the answers given by the national associations of the paint industry in the questionnaires. Data from 13 countries have been included in table 4.2.5.

Table 4.2.5 - Decorative paint sales in EUROs according to national associations

	Million EUROs (1997)
Austria	-
Belgium	109
Denmark	177
Finland	81
France	1049
Germany	1300
Greece	16
Ireland	89
Italy	570
Luxembourg	-
Netherlands	381
Portugal	222
Spain	673
Sweden	71
UK	401
Hungary	70
Total	***5209***

As can be seen in table 4.2.5., the total production value of decorative paints in the EU member states may be estimated *at least* 5.2 billion EUROs. Obviously, the retail value is considerably higher than the sales value earned by the manufacturer.

International paint trade

As stated earlier, the major part of international paint trade of European paint manufacturers concerns *industrial* paints (IRL '98). According to CEPE-representatives, "decorative paint does not cross borders". A main reason for this is the distribution costs. This is why many multinational paint manufacturers prefer establishing production sites close to the market instead of transportation of decorative paint across borders. Another reason is the national differences in cultural habits, e.g. with respect to colours (personal communications CEPE, 1999).

As can be seen in table 4.2.4, one can distinguish some major net exporters of paint: Germany, Italy, The Netherlands, the UK and Denmark. On the other hand, some major net importers are Poland and the Czech Republic, and to a lesser extent Portugal, Spain and Ireland. In some rare cases decorative paints make up a considerable part of paint exports or imports. This is the case for Ireland, which receives large imports form the UK.

4.2.2 Downstream decorative paint market

Decorative paint consumption - general

In table 4.2.6, the 'per capita' decorative paint consumption has been indicated, as well as the share of decorative paint within the total paint markets and Gross Domestic Product (GDP).

Table 4.2.6 – Per-capita decorative paint consumption, GDP per capita and relative share of decorative paints in total national paint consumption.

	Per capita consumption (kg)	**GDP per capita '97** ***(dollar/head)*** **(IRL '98)**	**Decorative paint share (%)**
Austria	8.0	25.5	44
Belgium	7.8	23.6	57
Denmark	10.0	30.7	61
Finland	6.2	22.9	55
France	7.4	23.7	53
Germany	10.5	28.9	49
Greece	8.5	11.2	72
Ireland	6.6	18.6	58
Italy	7.1	19.7	59
Luxembourg	-	-	-
Netherlands	11.3	23.2	55
Portugal	8.8	12.4	64
Spain	12.3	13.2	53
Sweden	10.8	26.0	58
UK	7.6	19.7	59
Czech Republic	5.0	4.8	59
Hungary	6.0	7.3	55
Poland	4.4	6.4	60
Slovenia	7.8	9.4	42
Slovakia	5.1	10.7	66
Turkey	2.9	2.9	69
Average	**7.4**		**57**

As can be seen from table 4.2.6, per capita decorative paint consumption may vary considerably from country to country. A number of explanations may be distinguished:

- Characteristics of the national construction sector
  E.g. the proportion of building in wood (high in Scandinavia), or the habits to paint exterior walls which is common in Germany and less common in the Netherlands where one can find many brick-faced walls.
- Yearly variations in building activity
  Generally, the building activity is strongly dependent on the general state of the economy in a country (Talmage, '99).
- The prosperity of a country
  Expressed in table 4.2.6 as the GDP per capita.
- Cultural habits with respect to painting
  E.g. the fast growing DIY fashion in for example the UK and the Netherlands, with the tendency to repaint rooms more frequently, as opposed to the almost complete absence of DIY painting in Greece.

Indeed, table 4.2.6 shows that generally, a high GDP and a high per capita consumption of decorative paint go hand in hand. However, some inexplicable figures do occur. For example the high per capita consumption in Portugal and Spain seems to be in conflict with the low per capita GDP. However, this may be explained by the fact that in Portugal and Spain high quantities of low-cost, low-quality *distempers* are used on interior and exterior walls (IRL, '98).

Decorative and industrial paint shares

Table 4.2.6 presents the relative shares of decorative paint consumption as a fraction of total paint consumption per country (IRL, '98). Variations in these fractions probably reflect variations in the degree of industrial development in the country involved: the more industrial activity there is, the higher is the use of industrial paints.

Indeed it appears that the least industrialised countries, such as Greece, Turkey and Portugal, are on the upper end with respect to the relative share of decorative paints. On the other hand, countries with e.g. a significant automobile industry, such as Germany and France, are at the lower end. No obvious explanation can be found for the low shares for decorative paint in Austria and Slovenia. However, a detailed study of the industrial structures of these countries falls beyond the scope of this study.

Decorative Paint consumption – Paint types

The most detailed data on the use of paint types according to substrate and according to being solvent borne or waterborne, originates from the inventory that CEPE has made among their members (CEPE, 1999). Also, the questionnaires returned from national associations of the paint industry have provided useful information, although only on the breakdown of waterborne versus solvent borne.

This description starts with some data from existing market studies. Table 4.2.7 shows the relative share of waterborne decorative paints for a number of countries. The order of the countries is generally as expected, although some national experts from Denmark claim a much higher share for that country: 90% (Pade, 1999), while literature data state a lower percentage of 68% (IRL, '98). Also, the shares for Spain and Portugal might seem unexpectedly high. However, as indicated earlier, the use of low-quality waterborne distempers on exterior and interior walls is widespread in these countries. The Spanish association indicates a waterborne share of even 84% (questionnaire). Data from the CEPE-inventory confirm this observation (see later on in this section). In the case of Sweden and Finland, the data from the national associations are different from the literature data also (for Sweden, the association estimates a much lower share for waterborne paint, for Finland a higher share). In Sweden, especially the use of waterborne exterior wall paints is low (table 4.2.9).

For the countries in East Europe, one assumes that the share of traditional alkyd gloss paints is higher than in most West European countries. The relative shares of waterborne decorative paints may in those countries be in the same order of magnitude as those of France (IRL, '98). As confirmed by almost all experts spoken to in the course of the study, the use of traditional solvent borne alkyds is relatively high in France, due to the (unique) use of these paints on interior walls. In any case, the use of solvent borne exterior wall paints is in France relatively high also. By contrast, in Germany, Austria and Denmark the use of waterborne paints is very widespread already, as a result of legislation (Austria and Denmark, see chapter 6) or environmental awareness (Germany).

Table 4.2.7 Relative share of waterborne decorative paints in 1996 (IRL, '98)

Germany	82%
Austria	81%
Portugal	80% *incl. distempers*
Denmark	79% (data national association. 68% according to IRL, '98)
Spain	74% *incl. distempers*
Netherlands	69%
Sweden	68% (**50%** according to national association)
UK/Ireland	67% (Ireland)
Norway	66%
Belgium	66%
Finland	61% (**74%** according to national association)
Greece	61% (data from national association)
Switzerland	61%
Italy	58% (**72%** according to national association, but these don't include many small companies)
France	57%
Hungary	50% (data from national association)

Table 4.2.8 shows the breakdown of some decorative paint types for Western Europe as a whole. In addition, the situation among professional painters and private painters (DIY- Do-It-Yourself) is distinguished.

Table 4.2.8 - Usage of decorative paint types in Western Europe in 1996 (IRL, '98):

	Professional (%)	**DIY (%)**
Interior emulsions	30,6	54,0
Interior glosses	20,0	14,8
Exterior paints	10,3	7,4
Undercoats & primers	12,9	8,2
Wood care products	11,8	8,9
Masonry paints	8,9	4,2
All other	5,5	2,6
	100	100

Although the waterborne versus solvent borne split is not made unambiguously in table 4.2.8, it is clear that the use of waterborne interior wall paints ('interior emulsions') is much more common among DIY painters than among professional painters. This has been confirmed by experts from e.g. UNIEP and CEPE ('99), who explained that professional painters in particular like to demonstrate their skills in handling traditional alkyd paints.

A second observation that may be made is, that professional painters are more involved in wood care ('interior gloss' as well as 'woodcare products') and exterior painting than DIY painters.

<u>Data from CEPE and national paint manufacturer's associations</u>

An inventory provided by CEPE (CEPE, '99) as well as statistics from national associations of paint manufacturers and questionnaires from those organisations, have delivered detailed data on the use of the various decorative paint types. Table 4.2.9 presents data from CEPE on the relative share of waterborne coatings within the first six classes of the CEPE-classification scheme, for 10 European countries. As mentioned earlier, these classes cover approximately 90% of the total market.

Table 4.2.9 – Relative share of waterborne paints within four major market segments in 1997 (CEPE '99)

	Interior walls & ceilings (%)	**Exterior walls (%)**	**Pigmented trim – wood & metal (%)**	**Clear coatings, stains, varnishes (%)**
Belgium	96	99.5	21	18
Finland	85	73	-	40
France	52	81	6	15
Germany	100	98	30	40
Italy	85	90	20	5
Netherlands	*85**	*85**	*24***	*24***
Norway	97	15	-	18
Spain	95	87	5	10
Sweden	98	2	38	45
UK	93	87	23	68

* Interior and exterior together

** Pigmented, clear coatings, varnishes and stains together

The data in table 4.2.9 have been used for checking the data on VOC-emissions from decorative paints (see chapter 5). In this section, striking data from table 4.2.9 is highlighted.

What can be clearly seen, is that for *interior wall and ceilings*, waterborne paints dominate almost everywhere. As stated above, in France the unique situation exists, where solvent borne alkyd paints are applied to interior walls.

For *exterior walls*, waterborne paints appear to dominate practically everywhere as well, even in France. However, the low shares of waterborne paints in Sweden and Norway are striking, for this purpose. This may in part be due to high levels of wooden facades in those countries, and some bad experiences with waterbased paints in the past.

In the share of waterbased *pigmented trim paints*, generally, a north-south division can be seen. As a result of legislation and environmental awareness, especially in Sweden, Germany and Denmark, waterbased trim paints have gained a considerable market share already. On the other hand, in France and Spain this is not the case at all. For the relatively high share of waterbased trim paints in Italy, compared to France and Spain, there is no obvious explanation.

For *clear coatings, varnishes and stains* it appears that the share of waterborne products is in this case higher in France than in Italy. Also, the share of waterborne products in the UK is remarkably high. Variations in the extent to which some products, e.g. woodstains, are used may have some influence here as well.

Finally, table 4.2.10 presents the CEPE-estimates of the total consumption for the ten countries presented in table 4.2.9 together, broken down in water borne and solvent borne, for the first six classes of the CEPE-classification.

It appears that CEPE estimates the total consumption of decorative paints for these countries at **2771** ktonnes, of which **70%** is waterborne. Interior wall paints, with more than 1700 ktonnes, account for more than 60% of the total consumption of decorative paints. This explains the relatively high share of waterborne paints already.

Table 4.2.10 CEPE-estimates of the total consumption for the ten countries presented in table 4.2.9 together, for the first six classes of the CEPE-classification (CEPE, '99)

Market segment	**Water borne**		**Solvent borne**		***Total (ktonne)***
	Volume (ktonne)	**%**	**Volume (ktonne)**	**%**	
Interior walls & ceilings	1 406 561	50.7	157 187	5.7	*1 563 747*
Exterior walls	419 108	15.1	91 131	3.3	*510 239*
Pigmented trim – wood & metal	63 263	2.3	246 370	8.9	*309 633*
Clear coatings, stains, varnishes	54 589	2.0	90 347	3.3	*144 936*
*Subtotal (6 classes)**	*1 943 520*	*70.1*	*585 035*	*21.1*	*2 528 555 (91.2%)*
Total market (10 countries)					**2 771 614**

* The data provided have been broken down into four paint types, but cover the fist 6 classes of the CEPE-scheme.

Decorative paint consumption – Professional versus Do-It-Yourself

The relative share of DIY decorative paint versus decorative paint applied by professional painters has grown over the past decade, especially in *northern* Europe (IRL, '98). The overall result is a *15% decrease* of professional sales over the past decade. Table 4.2.11 shows the relative share of DIY outlets in decorative paint sales in 1997, from two sources.

Table 4.2.11 - Relative share of DIY outlets in decorative paint sales in 1997 (tonnage basis)

	IRL, '98	**Associations (questionnaires)**
Austria	40%	-
Belgium	38%	52%
Denmark	39%	50%
Finland	-	75%
France	44%	44%
Germany	41%	40%
Greece	-	30%
Ireland	-	39%
Italy	29%	-
Netherlands	35%	47%
Portugal	-	-
Spain	24%	40%
Sweden	42%	68%
UK	48%	56%

In some cases, especially for the bigger countries such as Germany and France, the estimates are quite similar. However, in most cases the data from [IRL, '98] seem to be clearly too low. For Finland, only data from the national association were known. The DIY-share they give is remarkably high, without an obvious explanation being available.

The relative share of DIY paint sales will partly reflect the share of private house ownership, as private owners will less frequently use professional painters than are used for public buildings. At the same time, in countries where DIY painting is fashionable (UK, Netherlands), this will obviously increase DIY sales, as stated before. In most northwest European countries, DIY painting has increased at the expense of professional painting over the last few years. Apart from the growing DIY-trend as such, this is to a large extent caused by increased labour costs, as about 80% of the total costs of a paint job are labour costs (IRL, '98). It is expected that in southern and eastern European countries this development will occur as well in the future.

In table 4.2.12 below, the markets for professional and DIY decorative paints are estimated. The data from questionnaires from the national paint manufacturers' associations were used for this table. However, in some cases the estimates of the total decorative paint consumption by associations seem to be clearly too low (e.g. Belgium, Sweden) and therefore are not similar to the figures in table 4.2.9. Table 4.2.12 should only be used to get an idea of the split between professional and non-professional use.

Table 4.2.12 Data from associations of paintmakers on the consumption of decorative paint by professional and DIY painters in 1996/1997

	Professional consumption (ktonne*)*	**DIY consumption (ktonne)**
Austria	-	-
Belgium	17	18
Denmark	26	26
Finland	8	24
France	243	189
Germany	515	345
Greece	63	27
Ireland	15	10
Italy	-*	-
Luxembourg	-	-
Netherlands	96	83
Portugal	84	3
Spain	293	196
Sweden	21	44.5
UK	195	253
Czech Rep.	-	-
Hungary	- *	-
Poland	-	-

* No data known by the association on the split DIY-professional

Professional painters

There are no reliable data for the numbers of painting contractors and numbers of painters as far as their geographical distribution is concerned. UNIEP, the European association of painting contractors, claims to represent about **165,000** painting contractors in 17 countries, involving ~ **1.6 million** painters. Apart from that, it is known that in the Netherlands there are about 5,000 painting companies (Mol, '95) and 50,000 painters (SZW, '99), that in Germany about 40,000 painting *companies* exist (CEPE, 2000), and in the UK about 200,000 professional *painters* are evident(BCF, '99). In Denmark, 10,600 painters are member of the Danish Painters Trade Union (Pedersen, '99).

Paint consumption and types of products used by professional painters

Unfortunately, CEPE does not distinguish between the professional and DIY markets for decorative paints. However, there are some data available from the questionnaires among national paint manufacturers' associations. These however only concern the breakdown of waterbased versus solvent based paints. In table 4.2.13, the relative shares of waterbased decorative paints used by professional and DIY painters, as provided by the national associations, are presented.

Table 4.2.13 Relative shares of waterbased decorative paints, applied by professional painters and DIY painters (questionnaires associations, ’99)

Country	**% Waterbased**	
	Professional	**DIY**
Austria	-	-
Belgium	59	61
Denmark	~95	~50
Finland	70	71
France	56	61
Germany	74	88
Greece	61	61
Ireland	~70[*]	~ 70[*]
Italy	-[**]	-
Luxembourg	-	-
Netherlands	84	81
Portugal	~80	~ 80
Spain	71	100 (?)
Sweden	48	52
UK	68	72
Czech Rep. Hungary Poland	-[**]	-

[*] Only percentage based on *sales value* available. However, the Irish and UK markets are highly similar.

[**] No data known by the association

In most countries, professional painters seem to use waterbased paints less often than DIY painters. This may be due to the fact that DIY painters use more waterbased wall paints, which are relatively easy to apply. Maintenance work on trim may be left to professional painters, who use traditional solvent borne alkyds for this purpose. According to the associations of professional painters, these painters like to show the skill with respect to working with traditional alkyds they have developed. Professional painters wish to deliver high quality (in many cases: “high gloss”) results, and are relatively reluctant to use new technologies. Also, it is stated by the industry in Germany for instance, that customers of professional painters are very demanding. Professional painters therefore will often not be willing to take the risk and thus are reluctant to use waterbased paints in a number of cases (Bartholemy, 1999; CEPE, 2000).

The opposite situation is found in Denmark and the Netherlands. In Denmark, legislation on substitution, based on the MAL-code system, has almost put an end to the use of solvent based paints by professional painters. It is possible that, the recent substitution regulations with respect to indoor professional painting in the Netherlands have had some effects before the date of coming into effect.

Non-professional (DIY) painting:

In principle, all adult inhabitants of a country are potential do-it-yourself painters, i.e. millions of painters. However, the extent of DIY painting varies from country to country. The level of prosperity, the extent of private house ownership, labour costs of professional painting and cultural and historic reasons determine the number of DIY painters in a particular country.

The level of DIY painting is also reflected in the number of retail outlets for DIY paints. These data are presented in the next section on distribution of decorative paint.

Distribution of decorative paint

Three basic modes of distribution of decorative paints can be distinguished (IRL, ’98):

- Direct sales from manufacturer to consumer
- Sales via independent wholesalers or retailers
- Sales through ‘captive outlets’ (retailers or wholesalers owned by manufacturers).

Below, direct sales, sales through wholesalers and sales through retailers will be dealt with.

Direct sales

Direct sales of decorative paint occur mainly from manufacturer to some (very) large painting contractors, to the public sector and to large retailing groups. The latter may sell a considerable proportion of decorative paint as so-called ‘own-label’ brands. In recent years, this has increased in northern Europe in particular (IRL, ’98). In France, direct sales to large painting contractors account for 15% of the total amount of decorative trade paint sold (UNIEP, ’99).

Paint wholesalers

Sales through paint wholesalers is the traditional way of distribution for decorative paints, mainly used by *professional* painting contractors (IRL, ’98). The relative significance of paint wholesalers is known for only some countries (the data include both decorative and industrial paints):

-	Belgium	60%
-	UK	60%
-	France	45%
-	Netherlands	40%
-	Germany	10%

In Germany in particular, there are many local depots that are exploited by the manufacturers themselves, explaining the limited role of wholesalers in that country (IRL, ’98). The Dutch painters’ association states that in the Netherlands, 90% of the trade decorative paint is bought at specialised retailers, owned by the manufacturer (meeting with UNIEP, ’99). This would imply a much lower share for wholesalers than indicated above.

Retail outlets

Retail outlets mainly serve the DIY sector, although specialised paint shops and builders’ merchants also serve the trade market. The relative importance of the various types of retail outlets is presented in table 4.2.14.

Table 4.2.14 Relative importance of types of retail outlets for decorative paints in 1997 (IRL, ’98)

	% of paint sold							
	D, Au	**F**	**UK**	**It**	**B**	**NL**	**Sp, Pt**	**N,Se,DK**
DIY superstores	42	45	50	18	65	75	3	)
General supermarkets	18	25	21	10	20	10	18	)
Specialist paint shops	14	18	19	15	)	7	6	) 73
‘Traditional hardware stores’	6	5	)	43	) 13	)	57	12
Builders’ merchants	10	)	) 5	10	)	)	8	10
Small DIY shops & other	10	) 7	5	4	) 3	) 8	3	5
TOTAL	100	100	100	100	100	100	100	100

It can be seen that the market share of DIY superstores is very high in the Netherlands and Belgium, while in the UK and France general supermarkets have a high market share as well. From the data in table 4.2.14, it seems that the markets in Italy, Spain and Portugal are the most traditional, and probably reflect a relatively low level of DIY painting. In the other countries mentioned, the combined share of DIY superstores and supermarkets probably reflect a high level of DIY painting.

In recent years, many small independent retailers have been absorbed by bigger groups. The market share of the chains of large DIY superstores has grown over the last years. Reasons for this are convenience for the public and the ability to offer paint for *lower prices*, compared to those at small, specialised paint shops (IRL, ’98).

Numbers of retail outlets

There are no accurate data on the *number* of retail outlets for paints in Europe. The number “is believed to be” between **150,000** and **200,000** businesses (IRL, ’98).

On estimate, there are almost **10,000** DIY superstores in western and central Europe at the moment. Table 4.2.15 shows the geographical distribution of these superstores.

Table 4.2.15(a) – Number of known DIY superstores in major chains in 1996 (IRL, '98)

Austria	236
Belgium	270
Denmark	249
Finland	348
France	1636
Germany	1834
Greece	8
Ireland	~ 30
Italy	154
Luxembourg	5
Netherlands	855
Norway	508
Portugal	10
Spain	40
Sweden	328
U.K.	1399
Czech Republic	16
Hungary	25
Poland	30
Slovenia	3
Slovakia	6
Turkey	7
TOTAL	**7988**

Again, the number of DIY superstores may be a measure of the DIY-painting activities in a certain country. These seem to be the highest in the UK, Germany, France, the Netherlands and Norway. In the central European and south European countries the number of DIY superstores is still small. However, it is expected that these numbers will start growing rapidly in the near future (IRL, '98).

Main DIY chains

The top-15 of the DIY chains in Europe own over 40% of all DIY superstores (IRL, '98). The current top in Europe according to numbers of stores is roughly as follows (BHB, '99):

- Castorama group (F/ UK)	> 500
- OBI (D)	394
- Homebase (UK)	298
- Praktiker (D)	298
- Hagabau (D)	288

A recent merger of French Castorama group and the UK groups Kingfisher and B&Q (December '98) has delivered Europe's largest DIY retailer, which operates under the name Castorama Group. The group owns over 500 stores in more than 9 countries (B&Q, '99). The group includes Castorama, Brico Depot and Dubois Materiaux in France, B&Q and Kingfisher in the UK and NOMI in Poland.

The total European DIY market is estimated at *€90 billion*. The German market alone accounts for almost 50% of the total DIY sales in Europe (Hollinger, 1999). The German, UK and French DIY markets together account for 80% of the total European DIY market. The share of decorative paint in total DIY sales range from 25% in the UK and Germany to 10% in France. Thus, for all Europe the total sales of decorative paint may be estimated at *€9 billion* to *€22 billion.*

Distribution and sales costs

Distribution costs for paint manufacturers depend on the following factors:

- The location of the production plants;
- The locations of the various types of customers and their relative importance

- The ordering habits of the customer and the level of service provided by the manufacturer (delivery versus trade-counter sale).

Manufacturers try to keep distribution costs low by production on demand (no stocks needed) and by production on location. However, on the other hand production plants are concentrated in order to increase efficiency.

4.3 Industrial strategies, competition, recent developments and trends

Types of companies in the sector

Paint manufacturing companies may vary in size, in degree of vertical integration, in degree of specialisation and in being national or multinational. These factors in turn determine the industrial (competitive) strategies followed, the level of innovation etc. In fact, the same holds true for raw material suppliers.

Table 4.2.15(b) Major paint manufacturing companies that are upwards integrated "to a notable extent" are given (IRL, '98):

	Resins	**Pigments**	**Solvents**
Akzo Nobel*	X		
BASF	X	X	
Dupont		X	X
Hoechst	X	X	
Sigma (through FINA)			X
Tikkurila (Kemira)		X	
Total	X		X
ICI (through Zeneca)	X		

***** Most resin activities passed to DSM in 1993.

Not surprisingly, among the significantly integrated companies are the top three decorative paint manufacturers of Europe, i.e. Akzo Nobel, Sigma Kalon and ICI. All three are multinationals as well. Paint manufacturers that co-operate with resin manufacturers (i.e.: are vertically integrated) may be years ahead of their competitors that do not, as paint formulation and testing generally takes years (Mol, '95).

As shown in table 4.2.1, there are about 1300 'significant' paint manufacturers in Europe and an additional 2000 small and very small manufacturers. Differences in strategies between the two types are described below.

Major recent developments and trends

In the paint industry, as well as among raw material suppliers, major recent developments and ongoing trends are the following (IRL, '98; CEPE Newsletters '98):

- Concentration/ rationalisation
- Specialisation into core business
- Widening geographical markets/ internationalisation
- Intensifying competition
- Accelerating technological changes & modernisation of plants.

Concentration

Concentration through acquisitions and mergers has been *the* major trend in the paint industry over the past decade. This development has reduced the number of 'significant' paint manufacturers considerably, from over 2000 to about 1300 in 1999. The market share of the top-10 European paint manufacturers has increased from 30% to 50% over this period. This development is expected to continue.

Between 1982 to 1998, **435** acquisitions and mergers have taken place in the European paint industry (IRL, '98). Major recent acquisitions include those of Courtaulds and BASF Deco by Akzo Nobel in

1998, and the merger of Sigma and Kalon (in fact the mother companies Total and Fina) in 1999. As a consequence, Akzo Nobel and Sigma Kalon are the numbers one and three, respectively, in the European decorative paint market. In addition to these 'horizontal' acquisitions, downward integration of raw material suppliers increases as well. The paint companies involved welcome this, because it strengthens their basis.
Below, the major expected 'company predators' are given:

Table 4.2.15(c) Leading paint manufacturers (IRL, '98).

European	***Non-European***
Akzo-Nobel - NL	Dexter - USA
BASF – D	DuPont – USA
Becker – Se	Ferro – USA
Herberts (Hoechst) – D	HB Fuller – USA
ICI – UK	Kansai Paint – Japan
Jotun – N	Lilly – USA
Lafarge – F	Nippon Paint – Japan
Sigma/Total/Kalon – B/F/UK	PPG Industries – USA
(Total-Fina)	Sherwin Williams – USA
Tikkurila (Kemira) – SF	Valspar – USA

Probable target companies for acquisitions are:

- Large companies with a significant *market share* in a certain area or in certain product groups (these are expensive, but the predator quickly obtains a company presence in new markets);
- Medium companies with *specialised technology* in specific markets
- Small companies, with an *established niche* in particular markets (specific products, local etc.)

(if not profitable enough because of being too small, or family businesses without a successor).

Because specialised or niche products are of less importance for decorative coatings, the main objective that large decorative paint manufacturers have for acquisitions is to gain a significant market share in a certain geographical area or in certain product groups.

Despite the process of concentration, there are still large numbers of very small, locally operating companies. These are tolerated by the large competitors because they are no threat. In other words, "*SME's fill up the corners and gaps multinationals cannot reach*"(Mol, '95). Medium sized companies are much more vulnerable for take-over (IRL, '98). The result is a *polarisation* of the paint industry into the large multinationals and a large number of small companies serving local or niche markets.

Among the *resin* suppliers, practically *all* of the small companies have disappeared as a result of the large R&D efforts and costs needed in the sector (Mol, '95).

Specialisation into core business

Only in the last few years, large paint manufacturers have chosen to try and become dominant in a few paint sectors, instead of covering the whole spectrum. This is achieved in two ways:

- Acquisitions of core business (e.g. acquisition of BASF Deco by Akzo Nobel);
- Divestment (sale) of non-core business (e.g. sale of BASF Deco by BASF).

Main reason for concentrating on core business was the need for cutting down costs because of the relatively weak economic position of the paint industry (Mol, '95). Research and development demands and costs for example have increased to such an extent, that maintaining many different product types is not possible anymore (IRL, '98).

Major paint companies for which decorative paint is core business include ICI, Akzo Nobel, Sigma Kalon and Jotun. The Kalon-part of Sigma Kalon is Europe's largest supplier of *private label* decorative paints, supplying many DIY stores and supermarkets (Talmage, '99).

As the large companies concentrate on their core businesses, this gives small companies an opportunity to survive, by serving niche markets or local markets. Product specialisation is a major market strategy for small paint companies, although this is stronger in the field of industrial paint..

Widening geographical markets/ internationalisation

The leading European paint manufacturers attempt to increase sales by acquiring market shares in areas outside the area that is currently covered by them. Acquisitions are the easiest way to achieve this aim. The central and eastern European countries have recently been main target areas for the expansion of market leaders such as ICI and Akzo Nobel. Many of the leading European paint manufacturers also have distribution channels, agents or subsidiaries outside Europe. However, it is questionable whether decorative paints are involved in this to a large extent.

Increased competition

Literature (IRL, ’98) and industry representatives state that competition in the paint industry is increasing. As a result, companies can not pass on increased costs to the customer. Also, increased competition results in growing numbers of new products introduced to the market each year. Competition will be treated more in detail in a separate section below.

Accelerating technological changes and modernisation of plants

Environmental demands as well as increased customer demands result in an acceleration of technological developments (IRL, ’98). This development increases the R & D efforts needed. Research and innovation will be treated in a separate section below.

Another result, also driven by the increased competition, is the expansion and modernisation of production plants, and the closure of many old units. Closure of old plants and concentration of the production in a few larger plants are needed for the improvement of efficiency. Environmental legislation and the increased complexity of paints stimulate the development.

The extent of concentration of production into a few large plants is limited by the increase in the costs of distribution which results. Companies will have to find a balance between the two.

Competition and marketing

Competition in the decorative paint market is “not a technology contest, but a race for *market coverage*” (Mattsson, ’99). Questions such as how strong the *distribution channels* are, how a company’s network functions and how the customer is reached are crucial (Mattsson, ’99). This implies that size is important, which explains the large acquisition activities leading to concentration of the industry.

The observation by the paint industry that increased costs cannot be passed-on to the customer because of increased competition implies that competition on *price* occurs. However, this may not be the case for decorative paints. For professional painting contractors the price of the paint is not decisive, as labour costs are much more important. For the general public (DIY paint) there seems to be only a small group that makes purchasing decisions mainly on the basis of price (Van Raaij, ’92). The majority makes the decision on the basis of the availability of colours, the image of the brand in question etc.

Product *quality* is important in competition, but it may have various meanings. For the professional painter, technical performance characteristics such as exterior durability, adhesions etc. will be major issues. However, the painter cannot compare every product himself. Therefore, the *image* of the manufacturer is important. Well-known manufacturers with a long-standing image of reliability will have a competitive advantage over new companies. For DIY paint, quality may mean such things as the available *colour* range or other ways of putting ‘*added value*’ to a product. For example, in the UK and the Netherlands major manufacturers have developed ‘colour lines’ that are linked to specific brand names (e.g. ‘Colour Locale’: colours linked to various countries or regions). Co-operation with DIY-magazines or television programs has started in some countries. More generally, many consumers prefer the well-known brands of the large manufacturers, although some consumers choose the somewhat cheaper private label paints of DIY stores.

As mentioned before, small companies can compete by specialisation into *niche* markets. In the case of decorative paints, the niche will in most cases not be a 'technological' niche, but a 'local market' niche.

In a few cases, competition on *environmental* or *health* issues occurs. In Denmark, the MAL-code system on health hazards of paints (see chapter 6 as well) has forced the manufacturers to increase product development. Professional painters, for whom the code system is meant, preferably choose products with the lowest code number possible, i.e. the lowest health hazard. In Germany, paints with the eco-label 'Blaue Engel' have reached a 30% market share, driven by the environmental awareness of the German public (Hirsch, '99). In other countries however, eco-labels have failed to have a significant impact (see chapter 6). And even in Germany itself, some industrial representatives question the success story (Olinger, '00).

With respect to marketing of decorative paints, various methods are used:

- Direct impersonal marketing, such as point-of-sale displays and direct mail. This strategy is of significance for both the DIY and the professional sector.
- Personalised marketing, such as visits to customers by representatives or industry shows. These strategies are used for the professional painting sector only.
- Media coverage in trade and popular press (both DIY and professionals). With regard to the DIY sector, new ways of promotion have been introduced, such as sponsored DIY-magazines. In France and Belgium, collective promotion campaigns have been carried out to boost paint consumption, which are claimed to be successful (IRL, '98). Television commercials used to be of minor importance, but this is changing. In northwest Europe, especially in the UK, the Netherlands, France and Germany, paint manufacturers have started sponsoring television programmes dedicated to DIY activities.

It is believed that in many countries outside northwest Europe, per capita decorative paint consumption can still be increased. In most countries, advertising is concentrated in spring and early summer, because the highest painting activity takes place during this time. The UK paint industry is reported to have the largest advertising budgets: about €50 million, of which 80-90% is spent on television commercials or sponsoring. In Germany, the budget is estimated at €20 million, of which only 25% is spent on advertising on television. In France and the Benelux, the promotion budgets are well below these figures (IRL, '98). The total promotional budget spent by the European paint industry is estimated at €500 million.

Recent developments in marketing mean that the response to consumer needs is improved, e.g. with respect to colour-availability, advice and ease of application. In the near future, decoration of paint cans will become more important in retail, as already can be seen in e.g. the Netherlands. In the trade sector, this is of minor importance. The increasing significance of fashions in a number of countries, mainly with respect to colours, has resulted in the development of in-store colour tinting machines by the paint industry. This enables the manufacturers (and distributors) to respond to fast-changing colour-trends without the need for large stocks.

Research & Development/ Degree of Innovation

Environmental demands as well as increased customer demands have resulted in an acceleration of technological developments (IRL, '98). This development increases the R & D efforts needed, after a long period (roughly from the '50's until the '80's) of relative stagnation during which standard traditional formulations were predominant.

The amount of money currently spent on R&D by the European paint industry is about €250 – 300 million annually. However, this budget covers research on both industrial and decorative paints. All large paint companies and many middle-sized concerns carry out their own R&D in their laboratories and pilot plants (IRL, ’98). In addition, most paint producers, except the very small companies, have technical service teams to support customers.

As a result of the increasing environmental demands, the number of researchers at major paint manufacturers in the Netherlands increased by 60%, over the period 1985-1990 (Mol, ’95). One large paint manufacturer has indicated that about 80% of the research budget is dedicated to environmental issues (Mol, ’95).

Very small paint companies without a significant own R&D capacity either rely on traditional standard recipes (i.e. in many cases solvent-based alkyds) or ‘buy’ research. In practice, this means that these companies buy resins and starting point formulations from a resin supplier. Although this may be a sufficient survival strategy for many smaller companies, one should avoid relying on one single resin supplier. This could easily lead to too great a dependency on this single supplier, resulting in a ‘captive situation’ in which the resin supplier can increase prices again and again (Widdop, ’00). Among leading paint manufacturers, different strategies can be seen with respect to R&D. For example, of two of the three leading decorative paint producers in Europe, the first one has aimed at developing waterbased coatings, while the other has aimed at developing high solids solventborne coatings. Also, some paint manufacturers rely on maintaining a solvent based paint and claim to cover a specific niche application (e.g. ‘exterior masonry painting in adverse weather conditions’).

Although many paint manufacturers perform in-house research, the raw material suppliers perform most of the research (IRL, ’98 & many interviews). Resin suppliers have by far the largest role in research and development. In particular the resin types and the design of the resins have to change when the solvent content is reduced, when other types of solvents are going to be used or when waterbased coatings are to be used. Interviews with a number of major resin supplier have established that a very large part of the R&D activities is dedicated to the improvement of various performance characteristics of low-VOC paints, in order to try and match the performance of traditional solvent based alkyds. Again, different strategies can be seen among the various resin suppliers. Some of them dedicate their R&D efforts completely to developing emulsions for waterbased coatings, while others attempt to and improve the characteristics of high solids systems. Formulation expertise tends to belong to the paint manufacturers who have gained this expertise through trial and error experience. The raw material suppliers do not have this type of expertise and it may take some time before these new materials can be used in the market, if at all.

In many countries in Europe independent *research institutes* exist, which support the paint industry, e.g. PRA (UK), CORI (B), TNO & COT (NL), INETI (Pt) and CATAS (It). In some countries, governmental research stimulation programmes exist, which are specifically aimed at the paint industry. For example in the Netherlands, the ‘IOP Verf’ (Interdisciplinary Research Programme Paint) has stimulated fundamental research on paint performance and characteristics for a number of years.

Additionally, in many countries a *technical press* of the paint industry exists, in which technical as well as economic and regulatory developments are treated. In Europe, a total of over 30 journals support the paint and raw material manufacturers (IRL, ’98).

As far as it is known, *patents* do not (yet) play a large role in protecting R&D results, despite the large research efforts in many companies. On the other hand, companies do try to register *trade names* wherever possible, as this is very effective in protecting brands (IRL, ’98). It is assumed that both patents and trademarks will gain more importance in the future.

There are a number of factors *inhibiting* innovation in the paint industry. A major factor is the need for long-lasting durability tests for proving the performance of new paint types. At least, many customers ask for these test results as they are not willing to take any risk (Jacobs et al., ’96). Another major factor is the existence (and the impact) of detailed *specifications* in many countries. Many times, new paint types can only be used as soon as the certifying institutes have approved them.

Compliance to regulations

Although the issue of environmental and health regulations, and industry's attitude towards them, is dealt with extensively in Chapter 6 of this report, a short note is presented here in connection with 'strategies' followed by the industry.

Large paint manufacturers as well as their national and European associations spoken to, indicate that low-VOC alternatives for the traditional coatings are available in most cases already. However, manufacturers maintain the production and distribution of traditional solvent based products, because a clear consumer demand for low-VOC alternatives is lacking, and because in most countries there are no regulations demanding the use of low-VOC alternatives. Paint manufacturers argue that they would loose considerable market share to competitors if they just stopped selling high-VOC paints. Therefore, CEPE and a number of national paintmakers' associations in fact have requested (legal) regulations on the VOC-content of decorative paints. The advantage is, that unfair competition among their members is prevented. Besides, a uniform European regulation would diminish the need for maintaining large product portfolio, which increases efficiency and saves costs.

At the same time however, certain niche-players in the market maintain the solvent-rich products they produce, and claim that these fulfil an indispensable role in certain applications. In a limited number of cases, such niche players might not survive strict regulations on VOC (see also chapter 11).

Anticipating expected VOC regulations, *CEPE* has developed the VOC-reduction scheme that is dealt with in Chapter 9 and Annex 8. By stressing the fact that this scheme has been agreed upon already in the entire European paint industry, one attempts to pre-empt the authorities from developing their own, possibly stricter, regulations. In addition, by proposing a time-path for the implementation, the industry would be allowed to adapt at a pace they choose themselves (Mol ,'95). It is stated that 'starting all over again' would greatly reduce the opportunity of acceptance by the industry and thus the chances of a successful implementation.

At the same time however, in a number of countries the industry already has made voluntary agreements on limiting VOC content with the authorities (e.g. in France, Germany and the Netherlands) or already have to comply with strict regulations with respect to substitution of solvent rich by low-VOC paints (e.g. in Austria, Denmark, Sweden and the Netherlands, see chapter 6). In Germany, the effects of the eco-label Blaue Engel are significant. In all these cases, industry has co-operated with the authorities, and has provided the technologies necessary to comply with the regulations. However, it has become clear that some (legal) pressure is in many cases necessary.

In the Netherlands, the paint industry has been actively co-operating with the authorities in the VOC-reduction scheme KWS2000. Strategic reasons for this have been, the opportunity to *influence* the nature of the measures and the conditions for implementation that industry obtained, the generous 'time-path' for implementation and the fact that by co-operating, government policies on VOC would have no surprises until the year 2000 (Mol, '95). The same process could be seen during the development of the legal substitution of VOC-rich paints for interior professional painting (see Chapter 6). One of the reasons why the industry gained influence on policy making was the fact that the paint industry had almost a monopoly with respect to information on the latest technological developments (Mol, '95). An important decision made by the Dutch paint manufacturers' association in this process was, that they would not try to protect all small, 'backward' companies from regulations that these companies would not be able to comply with. In other words: the developments should not be slowed down because a small part of the market was not able to comply. In fact, this meant that one accepted that some very small companies might not survive (Mol, '95). One of the reasons for this was the observation that "*companies neglecting [environmental demands] can cause negative publicity and damage the [economic] interests of the sector*" (VVVF '89, in: Mol, '95).

An important final observation is the fact that, as a result of strict environmental regulations, paint manufacturers will *not* move their activities to countries without such regulations. The reasons are, that if they do their image would be damaged, that ‘loose’ regulations will always be temporary and that the infrastructure in countries with loose environmental regulations is in many cases inferior (Mol, ’95). Besides, the regulations apply where the products are *used*.

Success-criteria for future success of the paint sector

In order to survive in the future, it has been stated (IRL, ’98) that paintmakers will have to aim at:

- Economies of scale
- Development of new products: decorative paint suppliers should ‘broaden their product range on the basis of their marketing and distribution skills' (e.g. anticipate on home decoration trends).
- Improved cost effectiveness of distribution systems: decorative paint suppliers should take full advantage of developments in retailing, such as in-store tinting systems.
- Education of users on new technologies.

In general, companies should be able to adapt to changing market conditions.

Competition strategies of painting contractors

Competition in the professional painting trade is strong in most countries, resulting in low profits (UNIEP, ’99). Competition on price and on the quality of the work occur (together). Competition is even stronger as a result of the activities of a so-called ‘grey circuit’ or black economy, of non-qualified painters working under the market prices or working without paying taxes. The official trade organisations try to combat these ‘cowboys’ in the market by stressing the quality of work they deliver.

At the same time, painting contractors have to compete with DIY-painting. In some cases, e.g. in France, professional painters therefore persist in using high-VOC alkyd paints on interior walls. These paints require more professional skills than the standard waterborne (latex) wall paints and at the same time provide the high gloss and scrub resistance French customers desire. The so-called Unified Technical Directives that have been used for decades already, and which seem to block innovations are also playing a role. Thus, French professional painters can stress the added value of hiring a professional painter, compared to DIY-painting. In most northwest European countries however, DIY painting has increased at the expense of professional painting. Apart from the growing DIY-trend as such, this is to a large extent caused by increased labour costs, as about 80% of the total costs of a paint job are labour costs (IRL, ’98). It is expected that in southern and eastern European countries this development will also take place in the future.

Price competition among professional painters and the competition from DIY-professional painting results in a demand for *faster* working methods. For example, when only one coat is needed instead of two, this will largely reduce labour costs.

Both the German and Belgian painting contractors stress that the customers in those countries are relatively demanding with respect to the quality of the work (UNIEP/ CEPE ’98). Customers are very keen in detecting failures in the paint job, and can claim financial compensation or switch to competitors very easily. Therefore, the painters in those (and other) countries would like to maintain a broad range of paint products – including solvent based – to cover all possible application circumstances. For the same reason, painting contractors claim that the same regulations should apply to professional and DIY painters, to prevent any advantages for DIY painting to occur. At the same time however, Danish painters are very keen on using the products with the lowest possible ‘MAL-codes’, i.e. the lowest health risks.

As a result of the strong competition, and the fear for failures in paint jobs, it has been observed that in many countries the associations of painting contractors are somewhat more conservative regarding environmental policies than the paint manufacturing industry (Mol, ’95).

Strategies of distributors

In *DIY* retailing, price competition is common and strong (Hollinger, ’99). Although decorative paints are only one of the many products sold, DIY chains use private label decorative paints for price ‘stunts’, in order to attract customers (personal communications retailer, ’99). Private label sales already account for over 25% of total decorative paint sales in many countries (IRL, ’98). At the same time however, DIY chains sell well-known brands at higher prices, to serve the ‘quality-sensitive’ customer. Recent developments show an increasing importance of large DIY stores, at the expense of small, specialised paint shops. Usually, the latter cannot offer the same low prices as the large DIY chains. Therefore, the small paint shops advertise with the higher quality of expert advice they can offer.

Generally, margins for coloured paints are more stable than those for white paints (IRL, ’98). This makes them more interesting for retailers. Colour tinting machines are installed in more and more DIY shops and specialised paint retailers. These allow greater flexibility in the response to consumer needs with respect to colour trends, and allow reduced stocks.

Internationalisation of DIY retailing has started only recently, (Hollinger, ’99). The merger of the French Castorama and the British B&Q/Kingfisher is the most apparent example, resulting in the number-one DIY retailing chain in Europe.

Another development is the introduction of environmental policies by major DIY retailers, with B&Q as the most well known example. These, retailers have taken over the initiative from the paint industry in this field, in order to satisfy perceived consumer needs in Britain.

In the future, it is expected that an increase in the sales of decorative paints through non-specialised outlets, i.e. supermarkets will occur(IRL, ’98).

In *trade* sales, price competition seems to be less important. Trade paints are sold through wholesalers, directly by the manufacturer or in manufacturer-owned specialised paint shops. The standing of the manufacturer and the level of service, seem to be more important than the prices in this case. In a number of countries, the significance of wholesalers is declining. As a reaction, wholesalers are forming groups, which have a stronger buying position and consequently can offer lower prices. This occurs for example in Norway, Sweden, Denmark, Germany and France. Some of these groups offer private label paints already (IRL, ’98).

The future of the decorative paints sector

Predicted growth rates for the (decorative) paint industry are not very high (1 – 2% annually) and are mainly linked to general economic and population growth rates. The market share of ‘decorative painting’ is under pressure as a result of the following developments:

- A trend away from wooden window frames towards aluminium or PVC, which do not need to be coated.

In Germany and France, the current market shares are ± 30% wood and 70% for aluminium and PVC. The public regards these materials as more durable and less demanding with respect to maintenance. Painting contractors fear that the introduction of limits to the VOC content of decorative coatings could further stimulate this development (UNIEP, ’99). Strikingly, in the Netherlands the opposite development can be seen, i.e. *towards* wood. The reason for this is mainly an aesthetic one.

- Escalating labour costs for professional painters further increases the interest in durable materials that require less frequent painting.

Despite these developments, some ‘forward-looking’ paint manufacturers are optimistic and believe they can increase turnover in the near future (IRL, ’98). This will be achieved by a continuation of *innovation*. Major developments in the decorative coatings sector will include:

- An increase in waterborne paints
- Standardised procedures for surface preparation
- All purpose one-coat sealer primers

- Improved weathering resistance for exterior paints, especially *waterbased high gloss* for application under *all conditions*
- Improved solid emulsion systems
- White paint that can be tinted after application
- Clear exterior varnishes and stains for 'natural effects' on wood.
- Special purpose masonry coatings (e.g. graffiti resistant)
- Multi colour paint systems.

Most of the large manufacturers are involved in the more significant of the new developments. They tend to widen their product ranges into some specialised application fields, e.g. woodstains, masonry coatings, 'solid emulsions', coatings for plastics, water repellent finishes (IRL, '98).

Finally, some factors affecting *future decorative paint demand* are mentioned (IRL, '98):

- Consumer 'spending power'.
- Changes in the rate of taxation.
- Growth in the building industry.
  (reductions in mortgage borrowing rates could increase building).
- Public spending policy.
- Development of more durable finishes that require less repainting.
- Increased use of materials that don't need coatings (PVC window frames, tiles).

Main conclusions

- A number of factors limit the reliability of the available market data, e.g. incomplete statistics, a lack of accuracy, confusion about units of measurements. An 'educated best guess' has been compiled.
- Well over 200 raw material suppliers serve the paint industry. Multinational chemical companies play a big role.
- For each type of paint resin, only a few large players dominate the market. In total, over 100 resin manufacturers are active in Europe, among which 40-50 significant ones.
- About *5%* of all polymers produced are used as coating resins (both industrial and decorative).
- More than 50 solvent suppliers serve the paint industry.
- About *20%* of all *hydrocarbon* solvents produced are used in decorative coatings, thinning included.
- There are almost 1300 'significant' paint producers in the EU member states and accession countries. When very small, locally operating (family) businesses are included, this number increases to over 3200.
- No *reliable* data on the number of companies producing decorative coatings *only* are available.
- The top-10 of European decorative paint manufacturers account for almost 50% of the total production.
- Italy has by far the most fragmented market, with many SME's. To a much lesser extent, this holds true for Spain, Portugal and Turkey as well. The markets in the Scandinavian countries, the Netherlands and Ireland appear to be the most concentrated.
- About 122,000 workers are employed in the paint industry in the EU and accession countries. No reliable data were available on the number of workers involved in the production of *decorative* paint only.
- The total production/consumption of decorative coatings in the EU-15 countries was *3344* ktonnes in 1997; when six accession countries are included this figure was ***3804* ktonnes**.
- Due to the insignificance of decorative paint exports outside Europe, production will equal consumption for the EU as a whole. For individual countries, small differences may occur.
- The total production value of decorative paints in the EU may be estimated at *at least* 5.2 billion EUROs. The retail value will be considerably higher (*€9 billion* to *€22 billion).*
- The relative share of waterborne paint used is about *70%* on average.
- Highest penetration of waterbased paints can be found in Germany, Scandinavia and Austria, but also in Portugal and Spain.

- Lowest penetration of waterbased paints can be found in Hungary, France and Italy.
- Waterbased paints have a high penetration (up to 100% in some countries) in wall paints, and a considerably lower penetration (5-40%) in trim paints and varnishes.
- The split between professional and private (DIY) paint sales range from only 30% DIY in Greece to percentages around 70% DIY in Sweden and Finland. Labour costs of professional painters and cultural reasons (‘DIY-trends’) are major factors determining the split.
- There are about 150,000 painting contractors active in the EU, employing about 1.5 million painters.
- In most countries, professional painters use less waterbased paints than consumers do. In some countries (e.g. Denmark, the Netherlands), occupational health regulations have resulted in the opposite trend.
- Professional painters purchase their products directly from the manufacturer, at wholesalers or at specialised retail outlets owned by a manufacturer (‘captive outlets’).
- Among consumers, the market share of DIY superstores or ‘hypermarkets’ is rising rapidly.
- The number of known DIY superstores in major chains in Europe is about 8000.
- The total number of retail outlets for decorative coatings in Europe is estimated at 150,000 to 200,000.
- The top-15 of DIY chains in Europe own over 40% of all DIY superstores.
- Major trends in the decorative coatings sector include concentration, specialisation into core business, internationalisation and increased competition.
- Competition in the decorative paint market is not a technology contest, but a race for market coverage.
- Environmental demands as well as increased customer demands have resulted in an acceleration of innovation.
- The paint-producing sector has developed its own VOC-reduction scheme in anticipation to coming regulations.
- Paint manufacturers’ associations seem not to be willing to tolerate small, ‘backward’ companies that may slow down the regulatory process, because companies neglecting environmental demands might cause negative publicity and damage the interests of the whole sector.
- Competition among painting contractors is very fierce. The increased DIY trend as well as a ‘grey circuit’ of cheap, non-qualified painters threaten painting contractors. As a result, the painting contractors in some countries are relatively conservative with respect to using low-VOC paints.
- Among DIY retailers, price competition is common. The ‘own label’ paints are especially used for this, while the prices of the ‘A-brands’ are maintained.
- Internationalisation among DIY retailers has started only recently.

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5. VOC-emissions from decorative paints

On a European level, two major projects have been identified in which data on VOC emissions were collected and/or estimated: the CORINAIR project, co-ordinated by the European Environmental Agency, and the inventories made by IIASA within the framework of developing the RAINS model. In the Interim Report of the Decopaint project, a rather wide scope was presented, involving six ‘levels’ of refinement:

- Total emissions of VOC including natural emissions;
- Man-made emissions of VOC
- Man-made VOC-emissions, excluding traffic emissions;
- VOC-emissions from ‘solvent and other product use’
- VOC-emissions from paint only (industrial and decorative)
- VOC-emissions from *decorative* paint only.

In this final report, we will confine our emphasis to the emissions from decorative coatings only, as the issue of VOC emissions in general is dealt with within the framework of other initiatives of the Commission already, such as the development of the National Emissions Ceilings Directive.

In this chapter, data on VOC emissions from the following major sources have been combined to arrive at a consolidated picture:

- The inventories made by IIASA within the framework of developing the RAINS model, based on the CORINAIR inventory (website IIASA,; Klimont, ’99);
- Questionnaires among national Ministries of Environment and Environmental Protection Agencies;
- Data on the consumption of decorative paint types provided by CEPE, combined with assumed VOC-contents of the various paint types (CEPE, ’99);
- Estimates provided by the solvents industry (Solvents Industry, ’00).
- Data from the Consultium-study of 1992 (Den Hartog & Locher, 1992).

These major sources have been complemented by literature data and data from various national inventories, e.g. the Dutch VOC-reduction programme KWS2000.

In Annex 2, a survey is given of the various estimates that were available from the above-mentioned sources. The IIASA estimates and the Consultium data represent the years 1989 and 1990, respectively. Besides, the data provided through the questionnaires among the national ministries of environment proved to be very inaccurate. Therefore, for most countries, the *CEPE-data* and the estimates from the *solvents industry* have been taken for the compiled survey below (table 5.1). Generally, the highest estimate of the two has been taken, to arrive at a ‘reasonable worst case’ estimate.

The IIASA estimates only, have been used for the Czech Republic and Poland, as no other data were available. For Hungary, Slovenia, Slovakia, no IIASA-estimates, but only the rough CORINAIR-data over 1990 were available. The most detailed indication obtained in this way is VOC-emissions from “solvent and other product use”. Therefore, a very rough estimation of VOC-emissions in these countries, as well as Turkey, has been made by taking the decorative paint consumption (table 4.2.4), and assuming an average VOC-content of *20%*.

Table 5.1 Compiled estimate of VOC-emissions from decorative coatings in Europe in (ktonne)

	VOC from decorative paints (ktonne)
Austria	12
Belgium	16
Denmark	8
Finland	4.5
France	95
Germany	90
Greece	12
Ireland	4.5
Italy	71
Luxembourg	0.5
Netherlands	27
Portugal	18
Spain	44
Sweden	18
UK	55
Subtotal	*475.5*
Czech Rep.	23
Hungary	6
Poland	32
Subtotal	*536.5*
Slovakia	5.5
Slovenia	3
Turkey	36
Total	***581***

Mainly due to the increased number of countries that are included in this study, the estimated VOC-emission from the use of decorative coatings in Europe is considerably higher than earlier estimates have shown (Den Hartog & Locher, ’92). Also, the above estimate is higher than those suggested by the European solvents industry (ESIG). ESIG suggested 380 ktonnes of *hydrocarbon* VOC were used in decorative paints for the EU-15 countries (ESIG, ’00). As oxygenated solvents, used in waterborne coatings, have to be added to this figure, this estimate may be well in line with the above-mentioned estimates. Indeed, ESIG’s estimate of 60 ktonnes of oxygenated solvents used in decorative coatings each year (ESIG, ’00) results in a total figure of 440 ktonnes for the EU-15 countries, which is quite close to the 475 ktonnes mentioned above.

Additional VOC from thinners and cleaning agents

Most of the estimates in table 5.1 do not include the use of solvents used for cleaning and thinning activities. Some of them might, but it’s not in all cases clear whether this is the case. Therefore, an estimate of the additional use of solvents due to these activities is needed.

It has been estimated, that for solvent-borne paints, the amount of thinners and cleaning agents (mainly white spirit) used - and consequently emitted - may be as high as the amount of solvents emitted through the use of these paints (Kirby, ’99). Thus, as approximately 80% of the total VOC-emissions from decorative paints originate from solvent-borne paints, an extra emission of *about 465 ktonne* might occur. This would bring total VOC-emissions connected to the use of decorative paints in the above-mentioned countries at *1046 ktonne*.

However, other sources indicate that this estimate is too high. CEPE-representatives suggest an additional VOC-emission of 100 to 200 ktonne due to the use of thinners and cleaning agents (Leggetter, ’00). The European association of painting contractors UNIEP suggests that for professional painters an additional emission of only 10% may be expected (UNIEP, ’00). Assuming

that 50% of the VOC-emissions originate from professional painting, this would mean an additional emission of:
465/2 x 10% = *23* ktonne.

For DIY painting, the estimates given by representatives spoken to vary to a larger extent. Some agreed that an additional emission of similar magnitude as those from the paint itself might occur, i.e. *230* ktonne. This estimate was based on an assessment of common habits of brush cleaning among consumers, involving immersion of brushes into relatively high amounts of white spirit. However, others indicated that the additional VOC-emission would rather be close to 50% of the emission from the paint itself, i.e. 115 ktonne.

Consequently, the emissions connected to the use of decorative paints and varnishes in the 21 above-mentioned countries, thinning and cleaning included, are estimated at somewhere in the range of **720** to **834 ktonne** (rounded figures; see table 5.2). The latter has to be considered a 'worst case' estimate.

Table 5.2 - Total VOC-emissions due to the use of decorative coatings in 21 European countries (EU member states and accession countries) – worst case estimate

Activity	**VOC-emission (ktonne)**
• Use of decorative paints and varnishes	580 (rounded figure)
• Thinning & cleaning – professionals (10% of VOC from solvent based products)	23
• Thinning & cleaning – consumers (50 to 100% of VOC from solvent based products)	115 – 230
Total	**720 – 830 (rounded figure)**

Relative significance of VOC from decorative paints
Total man-made emissions of VOC in the 15 countries involved in the Solvents Directive were 14,000 kilotonnes in 1990 (Amann et al., '99). At that time, VOC-emissions from decorative coatings in these 15 countries were 590.6 kilotonnes (IIASA, '99), i.e. **4.2%** of total VOC-emissions.

Total VOC emissions in these 15 countries is expected to be 7,000 kilotonnes after full implementation of the Solvents Directive (EC, '99) by 2010. As the Solvents Directive (see chapter 6) does not affect VOC-emissions from decorative paints, an equal 50% reduction in VOC-emissions is not obvious. Therefore, the relative significance of VOC-emissions from decorative paints may increase if no additional policies are formulated. In fact, two opposing developments can be seen:

- *Decreasing* average *VOC-contents* of decorative paints, as a result of the increased use of low-VOC paints through national legislation and information campaigns, and product development;
- *Increasing consumption* of decorative paints, which has offset the effects of decreasing average VOC-contents in some countries in the past (chapter 6).

Whether further 'autonomous' VOC-reductions will occur in the years to come, is highly speculative.
Thus, when we assume the VOC-emissions from decorative paints to be stable over the coming 10 years, the relative share of these emissions in the total VOC emissions in the EU-15 countries may be **6.8%** in 2010 (475.5/7000). When cleaning and thinning are included, the contribution may be as high as **9.8%**[5] (684.5 ktonne).

The significance of 'natural' or 'biogenic' VOC
Several times during this study, the question has been raised whether 'natural' VOC contributed significantly to the problem of VOC-emissions, and consequently to the problem of ground-level

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[5] VOC from solvent based paint = 80% x 475.5 kton = 380 kton. Thinning/ cleaning professionals: 380 /2 x 10% = 19 kton. Thinning/ cleaning consumers: 380/2 = 190 kton. Total: 209 kton.

ozone (e.g. ESIG, '99; ESIG, '00). In this section, we will briefly address the magnitude of these emissions. In chapter 12.1, on environmental impact, the impact of 'natural VOC' on ozone formation is discussed.

Biogenic VOC-emissions mainly originate from forests, and mainly at high temperatures of about 30°C and higher (Simpson et al., '95a). The most common compounds emitted are isoprene and monoterpenes. In many studies the focus is put on isoprene, as this compound is by far the most reactive with respect to ozone formation. In certain areas in the USA, isoprene is thought to play a significant role in ozone formation (see further section 12.1 on ozone modelling).

Isoprene emissions from forests are estimated on the basis of mathematical formulae, using temperature, sunlight and vegetation coverage as inputs. For a number of forest species, the VOC-emission for a given combination of temperature, sunlight and coverage has been determined by measurement. Also, the outcome of the mathematical emission estimates has been validated through measurements (Simpson et al., 1995a).

It has appeared, that studies from the USA cannot be extrapolated to the whole of Europe (Simpson et al., '95a), as different plant species are involved, and more important, as most of them deal with biogenic VOC-emissions at high temperatures (> 30°C). In many parts of Europe, these high temperatures rarely occur.

Also, a Danish study that was referred to (ESIG, '99), indicating that natural VOC account for 80% of total VOC-emissions, cannot be considered reliable. The study involved measurements of VOC-emissions from *one* (garden of) orange tree(s), in one region of Spain, during *one week* in the growing season, i.e. the blossoming period (Amann, '99). Therefore, the result was not representative for natural VOC-emissions in general at all.

Natural VOC emission data

Data from the CORINAIR '94 emission inventory show, that for the current 15 EU member states, the VOC-emissions from natural vegetation and forestry were estimated at 3689 ktonne for the year 1994 (AEA Technologies, '99). This equals *21%* of the total VOC-emissions.

Calculations made within the EMEP project show, that emissions of the most active natural VOC-species isoprene in the 15 EU member states were 1144 ktonne in 1989, i.e. *8%* of the total VOC-emissions (Simpson, '95a).

When *all* natural VOC are considered, the emissions in the 15 EU member states were 2885 ktonne in 1989, i.e. *18.6%* of the total VOC emissions (Simpson, '95a). More recent modelling work would indicate higher estimates for natural VOC, ranging between 4000 and 5000 ktonne (Simpson et al.,'99). However, an overall uncertainty factor of *at least 5* was established for these estimates (Simpson et al., '99). This hardly compares to uncertainty factors that are assumed for man-made emissions, which are thought to be quite close to 1.

In summary: as the data estimated under the EMEP project are the most recent and involve the most sophisticated models as well as the people with the expertise, these have to be considered as the most reliable. However, many uncertainties still accompany the data. As a general assumption, natural VOC emissions may be estimated at **about 20%** of total VOC. The impact of these emissions on ozone formation is discussed in section 12.1.

Main conclusions:

- The VOC emissions due to the use of decorative paints and varnishes in the EU-15 countries and 6 accession countries have been estimated at ~ 580 ktonne annually.
- When solvents used for cleaning and thinning are included, the estimate of total VOC emissions connected to the use of decorative coatings in these 21 countries is 720 - 830 ktonne. The latter figure is to be considered a ‘worst-case’ estimate.
- After full implementation of the Solvents Directive, the contribution of VOC emissions due to the use of decorative coatings (thinning and cleaning included) may be about 10% of total (man-made) VOC emissions.
- Emissions of ‘natural’ VOC account for ~ 20% of total VOC emissions in the EU.

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6. Measures to reduce VOC emissions from decorative paints

6.1 Introduction

During the project, an inventory has been made of existing measures, as well as measures in preparation, aimed at reducing VOC emissions from decorative paints and varnishes. The inventory has focused on the European Union Member States, the ‘first round’ accession countries (Poland, Hungary, Czech Republic) and a few other potentially relevant states (Switzerland, United States). In addition, a number of relevant supra-national agreements and regulations have been identified and described, among which some EU Directives as well as initiatives from the United Nations Economic Council for Europe.

The following sources of data are used:

- Literature: articles in professional magazines with a connection to the paint industry or to environment or occupational health, and existing reports such as the Consultium Study (Den Hartog and Locher, 1992) and [Olsthoorn et al., 1994].
- Interviews with representatives from national Ministries of Environment of Austria, Belgium, France, Greece, Ireland, The Netherlands and The United Kingdom,.
- Meetings or interviews with representatives from a number of other organisations, such as CEPE, CEFIC, VVVF (the Dutch paint manufacturers’ association), Berufsgenossenschaften Baugewerbes (Germany), Dutch Ministry of Social Affairs (occupational health) and the CEN Committee on Standards for Wood Coatings.
- Internet pages of EU DGXI, UNECE, EEA, European Ecolabel and national ministries (texts of Directives, national regulations and Protocols).
- Questionnaires among national Ministries of Environment and national associations of the paint industry. The response from the Ministries was 76%; from the associations 82%.

Particular attention is paid to collecting information on the *results* obtained so far with the existing measures. However, exact data on this issue is not readily available.

In section 6.2, a number of supra-national measures and agreements are described. Subsequently, in section 6.3 the existing national measures are described and valued. In section 6.4, general conclusions and remarks are made on the effectiveness of the various types of measures. Finally, the main conclusions are summarised.

6.2 Supra-national measures and agreements

On a supra-national level, four types of measures are identified: legislation, binding agreements, voluntary labelling systems and voluntary agreements.

Legislation

1. Solvents Directive (European Commission)

The Solvents Directive, which came into force during 1999, is not treated extensively in this section. Only the potential impact of the Solvents Directive on VOC emissions from decorative paints is briefly dealt with below.

The Solvents Directive aims at “Limiting emissions of Volatile Organic Compounds due to the use of Organic Solvents in Certain Industrial Activities”. A number of specific VOC-emitting sectors to which the Solvents Directive applies are defined, involving such diverging activities and sectors as the distribution of fuels, the printing industry and the chemical industry. The directive requires the sectors involved to develop Solvent Management Plans, monitor solvent emissions and actually reduce these emissions. The first set of requirements from the Solvents directive will have to be implemented by 2002, while the deadline of full implementation of the Directive has been set at 2007. Full implementation of the Solvents Directive, together with existing national policies, is expected to result in an emission reduction of 7000 kilotonnes/year (a 49% reduction compared to 1990 levels – EC ‘99).

Effects

As is clear from the full title, the Solvents Directive aims at reducing VOC emissions from static installations in particular. Thus, industrial painting like furniture coating or automotive refinishing is included, while 'on-site' painting with *decorative* coatings is *not.*

However, the following side effects of the Solvents Directive may affect the development of VOC emissions from decorative coatings as well:

- Emission reduction targets imposed on paint manufacturers might convince them to produce paints with a lower VOC content. Another possibility however, is that paint manufacturers install end-of-pipe technology, or implement 'good housekeeping' as a measure.
- Research dedicated to the application of low-VOC paints in industrial settings might speed-up developments of low-VOC decorative paints as well as a result of technology diffusion.
- The increase in awareness of VOC-related problems triggered by the Solvents Directive might result in an increased demand for low-VOC products in the decorative sector too.

The magnitude of these effects is hard to estimate. However, the national associations of the paint industry questioned, were unanimous in the opinion that legislation on VOC-emissions during the production of decorative paints will have **no** direct effect on VOC-emissions from decorative paints in general. One reason given was the fact that in many countries measures such as proposed in the Solvents directive are already in place for paint manufacturers. So far, these do not seem to have resulted in significant effects on the use patterns of high-VOC paints. Representatives from CEPE indicated that "decorative coatings manufacturers will not have to change the VOC content of their products in order to comply with the Solvents Directive, either in manufacture or in use" (Witte, '00).

Indirect effects of the Solvents Directive, connected to the increased use of waterborne primers and preservatives in the joinery industry, may have adverse impact on the performance of low-VOC waterborne coatings. These effects are dealt with in chapter 9.

The national Ministries of Environment questioned appeared to have quite a different opinion to industry. The majority stated that legislation on VOC emissions during manufacture **is** effective in cutting down VOC emissions. However, most representatives might have meant that only the emissions during manufacture of paint have been reduced, and not those during the *use* of decorative paints.

2. Proposed National Emission Ceilings Directive (European Commission – 99/0067 COD)

On June 9, 1999, a proposal for a Council Directive setting National Emission Ceilings (NEC's) for four major pollutants (NO_X, SO_2, NH_3 and VOC) was issued. This Directive was developed in line with the Air Quality Framework Directive, and is meant to integrate policies on reducing the three major environmental problems, acidification, eutrophication and tropospheric ozone. Regarding tropospheric ozone, both emissions of VOC and NO_x play a significant role, and interact with each other. The NEC Directive will be *complementary* to the Solvents Directive as far as VOC emissions are concerned. The Directive sets longer-term objectives for further emission reductions, to be met by 2010. It is estimated that full implementation of the Solvents Directive, national policies and the proposed NEC-Directive together will decrease VOC emissions by 60%, compared to 1990 levels. The remaining emissions would be 5580 kilotonnes/year (EC, '99).

In the proposed NEC-Directive, VOC are defined as "*all organic compounds of anthropogenic nature, other than methane, that are capable of producing photochemical oxidants by reactions with nitrogen oxides in the presence of sunlight*" (EC, '99).

The NEC-Directive asks for different efforts from different countries, based on cost-effectiveness of emission abatement measures (as calculated with the help of the RAINS model). According to the accompanying paper to the proposed directive, most member states support the ambitious targets of the Directive, but question the feasibility of achieving their own national ceilings. For example, the Dutch employers' organisation VNO-NCW has sent a letter to the Dutch Ministry of Environment, stating that the proposed Dutch NEC for VOC should be increased from 156 kilotonnes to 190 kilotonnes.

Effects

A study on additional measures, contributing to the implementation of the NEC-Directive, revealed (according to the same paper) the potential cost-effectiveness of a Directive on VOC-content of paints and varnishes. This resulted in the current project (Decopaint), which might lead to the development of a Council Directive on limiting VOC emissions from decorative paints and varnishes, through a reduction of the VOC-content of these products.
Thus, as a potential future "Decorative Paints Directive" is meant to be an *implementation* of the NEC-Directive, both Directives will not interfere.

3. Biocides Directive

In discussions with the paint industry (CEPE TC Deco, '00), the question was raised whether the proposed Council Directive concerning "the placing of biocidal products on the market" (or: 'Biocides Directive'; EC, '98) might interfere with a future directive on decorative coatings. The background of this question was that as a result of future limits to the VOC-content of decorative coatings, waterbased products might be the only alternative for a number of applications. At the same time it is generally recognised that waterbased coatings need small amounts of biocidal agents, either for in-can preservation, for film-conservation or both. Therefore, if the Biocides Directive would limit the use of biocidal agents used in waterborne coatings, it might interfere with putting limits to the VOC-content of decorative coatings.

After studying the text of the proposed Biocides Directive (EC, '98) it is concluded by the study team that this interference is *not* likely to occur. The Biocides Directive itself does not limit the use of any specific biocidal agent. Instead, it provides a *framework* for the *evaluation* of the effectivity, the health hazards and the adverse environmental effects of biocidal products. The Member States will carry out this evaluation. The following main rules can be distilled from the draft text of the Biocides Directive:

- Biocidal products should *not* be placed on the market unless a common *core data sheet* is submitted, and unless the substance is – after evaluation- placed on a '*positive list*' of approved substances.
- An active substance may be removed or refused from the 'positive list' when less hazardous alternatives are available.

After the Directive has entered into force, the Commission will commence a 10-year programme of evaluating the current products, with a view to placing them on the positive list or not. During this period, products which have not (yet) been placed on the positive list may still be used. However, this is only true for products that are already on the market at the moment of entering into force. In addition, a four-year transition period follows every decision to remove a certain substance from the positive list.

As far as waterbased coatings are concerned, it is obvious that the Biocides Directive will not prevent the use of any biocidal agent at the time of implementation. However, it might turn out that certain specific agents would be rejected over the 10-year evaluation period that will follow. This will probably only be the case when alternative agents are available, which are less hazardous, but perform as well as the rejected agents. Therefore, a negative impact on the potential of using of waterbased coatings instead of solvent based coatings is *not* expected.

Binding agreements

Convention on Long-range Transboundary Air Pollution (United Nations Economic Council for Europe)

The Convention on Long-range Transboundary Air Pollution aims at providing a legally binding framework for the development of policies dealing with air pollution problems which cannot be tackled nationally. It was drafted after scientists demonstrated the transboundary nature of some

specific environmental problems such as acidification and tropospheric ozone generation. The Convention involves all 35 ECE countries. It was signed in 1979 and entered into force in 1983.
In November 1991, the *Protocol* (to the Convention) *concerning the Control of Emissions of Volatile Organic Compounds or their Transboundary Fluxes* was adopted. It entered into force in September 1997. The main target for most countries participating in this binding agreement, was a *30% reduction* of VOC-emissions by the year 2000, compared to the level of 1988. For a limited number of countries with relatively low VOC emissions[6], stabilisation at 1988 levels were allowed. The Protocol uses the same definition for VOCs as the proposed NEC-Directive.

The Protocol defined a few measures that participating countries might take to implement the Protocol, among which are: labelling of the VOC-content of products, ecolabels and taxation of products containing VOC. Thus, the Protocol can be seen as a framework for the development of policies at a European and national level.

In December 1999, an updated version of the Protocol was agreed during a session of the Executive Body at ministerial level in Gothenburg. The target was set at a *40%* reduction of VOC-emissions compared to their *1990* levels. During the session, *25* European countries (13 EU member states), as well as Canada and the United States, signed the Protocol.

Effects

The UN/ECE website presents some data on the status of *implementation* of the Protocol too. It appears from these data, that 7 participating countries have already achieved the 30% reduction or more in 1996, among which three EU member states: Germany, Austria and Denmark. No data are given for The Netherlands, but it's known from other data that The Netherlands will at least approach this target as well (Infomil, '00). Another four countries seem to be on course to achieve the 30% reduction by the year 2000, among which three EU member states: Finland, Sweden and the United Kingdom. In two EU member states – Italy and Spain - the VOC emissions have *risen*, as well as in Norway. A future directive on decorative paints might be one way of implementing the UN/ECE protocol. In fact, the German Federal Environmental Agency has advocated the elaboration and incorporation of Technical Annex to the Protocol on VOC-containing products (FEA, '99). As far as it is known, this has not been brought into practice during the session in Gothenburg.

Voluntary labelling systems:

European Ecolabel for decorative indoor paints and varnishes

In order to decrease confusion among consumers about the environmental performance of products, the concept of eco-labelling was devised to provide consumers with an independent, authoritative 'seal of approval'. An eco-label is awarded to those products that are judged to have a reduced impact upon the environment compared to equivalent alternative products, whilst ensuring that they are fit for their purpose when in use (Jackson, 1999). In March 1992 the European Commission adopted an eco-labelling scheme for the European Union, while in January 1996 eco-label criteria for *decorative indoor paints and varnishes* were first published. In December 1998, the criteria were revised (decision 1999/10/EC). These revised criteria will be valid until January 2002. Floor coatings and wood stains are excluded from the Ecolabel scheme. The main criteria as far as maximum VOC-content is concerned are the following:

* Low-gloss paint (interior walls)	30 g/L (water excluded)
* High-gloss paint (interior trim)	200 g/L
* High-gloss paint with extra hiding capacity:	250 g/L (hiding at least 15 m^2/litre).

Furthermore, it should be stated on the can that the product is meant for indoor use.

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[6] Total emissions < 500 kilotons/year *and* < 20 kg/inhabitant *and* < 5 tons/km^2

Effects

By April 1999, 20 companies took part in the Ecolabeling scheme, involving 9 countries. In total, 107 products with the European Ecolabel existed at that moment (source: website Ecolabel):

Table 6.1(a) Countries participating in the Ecolabel scheme.

Country	**Number of companies participating**	**Total number of labelled products**
Sweden	5	59
United Kingdom	3	7
Portugal	2	16
Denmark	2	10
Finland	2	9
Greece	2	2
Spain	2	2
France	1	1
Ireland	1	1

Of a total of *at least* 1300 significant companies producing decorative coatings in the European Union, the participation of ~1,6 % of the companies seems a slow start. Moreover, in most cases the companies select only one or a few products for the Ecolabel scheme[7]. Discussions with industry representatives suggested that some companies used these few products to test the concept of the Ecolabel, the procedures and consumer reaction to the Ecolabel. Thus far, there are no reliable data on the effect of the Ecolabel on *sales* of the paints concerned. However, according to some industry sources, such market tests have shown that sales *decrease* as soon as the product involved has an Ecolabel. Indeed, a number of key persons interviewed (Winkelaar & Terpstra, ’99; Vriens et al. ’99) were of the opinion that an ‘environmental’ image is not necessarily favourable for a high-performance product such as paint. Consumers would in the first place choose a high-*quality* paint, and feel that environmentally sound paints may be of an inferior quality.

In some cases, in fact the German case in particular, the existence of a national eco-label for paints (the Blaue Engel) may have negatively affected the participation in the European Ecolabel.

Despite the low participation rate of industry, there are indications that ecolabel criteria have had a guiding role in paint development: companies adapted their products (towards the 250 g/l VOC-criteria) without actually applying for an ecolabel. This development was stimulated by the expectation that the Ecolabel would be important. In this way, the Ecolabel in fact *may have* an effect in reducing negative environmental impacts of decorative paints.

The issue of the merits of eco-labels is further discussed in section 6.3 on national measures.

Voluntary agreements

CEPE-scheme on reducing VOC content of decorative paints

The members of the European Association of the paint industry CEPE have agreed on a voluntary scheme for the reduction of the VOC-content of decorative paints and varnishes. This scheme is extensively dealt with in the section on a Classification System for decorative paints and varnishes (section 9). We will not repeat this description, but only make a few remarks.

The ‘CEPE-scheme’ defines a ‘current typical VOC-content’ for 12 main classes of decorative paints (subdivided into solvent-borne and water-borne), and distinguishes two phases of VOC-reduction. In the first phase, the VOC-content should be indicated on the can, and reduced to relatively loose target values. In the second phase, the VOC-content should be reduced to more stringent target values. The first phase should be implemented three years after final adoption of the scheme, the second phase six years after adoption.

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[7] Only in Sweden, 1 company has 23 products with an Ecolabel

Effects

No ‘absolute’ time frames have been given in the CEPE-scheme. It has been suggested that the major aim of the CEPE VOC-reduction scheme is to anticipate future EU-legislation. By agreeing on the industries’ target values, the Commission is discouraged from developing its own (possibly more stringent) target values (see also section 4.3). Currently, CEPE promotes the scheme among its members and among other key organisations in the market. As far as it is known to date, only in the UK has the paint industry already implemented the first phase of the CEPE-scheme (Leggetter, ’99). The Dutch industry has developed a ‘state-of-the-art document’ based on the CEPE-scheme, and will use this document in coming negotiations with authorities and trade unions, on ‘Occupational Health Covenants’ (Winkelaar, ’99/’00).

6.3 National measures and agreements

In this survey of existing measures, the following measures have been identified:

- Legislation
- Financial: product taxation or tax reduction
- Other financial instruments (e.g. subsidies)
- National ecolabels
- Other labelling instruments
- Voluntary agreements
- Information campaigns.
- Other

The survey below is presented country-by-country. If nothing is said on a certain type of measure, these do not exist in the country involved.

Austria

Legislation:

In Austria, legal restrictions to the VOC-content of decorative coatings exist. The legal ban is stricter for *consumers’* paints than for professional paints. The regulations are part of the ‘Solvents Ordinance’ or ‘Lösungsmittelverordnung’ of 1995 (BMU, ’95), which is an updated version of the Solvents Ordinance of 1990.

The maximum VOC-content of decorative paints for consumers is 10%, which is defined as a percentage of the total product, including water. Austria defines VOC as being organic compounds with a boiling point < 200°C. Ethanol and isopropanol are exempted. For metal and plastic coatings, a limit of 15% has been set. The regulation means, that consumer (DIY) paints can only be waterborne. The regulation is enforced by maintaining separate departments for professional and consumer (DIY) users, in DIY stores that sell decorative paints. In the DIY-part, no paints with a VOC-content of more than 10% are allowed. The Chemicals Inspectorate checks twice a year whether retailers fulfil these requirements (Krajnik, ’99).

Professional painters still can use decorative paints with a higher VOC-content. However, there are certain restrictions. Products with a VOC-content of more than 10% may only be used in case of ‘adverse weather conditions’. In the regulation, these conditions are not further specified, although an information leaflet of the ministry gives an indication: temperatures below 10°C and a relative humidity of more than 80% (BMU, not dated). It is not clear in which way the restrictions for professional painters are enforced.

Results

The results that are claimed from the Solvents Ordinances from 1990 and 1995, is a *40%* reduction of the VOC emissions from decorative paint, over the period 1990-1996 (Krajnik, ’99). It is not likely that, the entire reduction has resulted from the Solvents Ordinance. Part of it will be due to (market-) developments that were taking place already.

National ecolabels:

A national ecolabel – Umweltzeichen – exists for ‘lacquers and lazurs’ for wooden floors. In order to obtain the Umweltzeichen, the products in this product group should be water based.

Effects

At the moment, four companies participate in this Umweltzeichen, with in total 10 products. According to the ministry, this means that most products sold in this market segment do carry the ecolabel. However, because of the small share of the total market that this application covers, the impact of the ecolabel is limited.

Other labelling instruments

A number of paint manufacturers *voluntarily* present the VOC-content of their products on a label on the can, for advertisement purposes. Although no detailed information is known on the effects, the fact that manufacturers do this indicates that at least they expect a positive effect on sales.

Information campaigns

The Austrian ministry of environment has issued a brochure, describing the ozone problem, the measures in the Solvents Ordinance, the consequences for paint application, the advantages and disadvantages of low-VOC paints etc (BMU, not dated). The brochure has been developed in co-operation with the paint industry.

The union of paint retailers organises an annual meeting for professional painters, at which information is exchanged on new products and how to apply these. About 150 painters take part in these annual meetings.

Exemplary role of the government

At the Austrian ministry of environment, the assumption is that it is “standard” to use low-VOC paints in public works (Krajnik, ’99). However, no exact data were known.

Belgium

According to a contact person at the national ministry of environment, there are *no* measures devoted to the reduction of VOC-emissions from decorative paints and varnishes in Belgium at the moment (Woestyn, ’99). However, the Belgian ministry is very interested in the developments, favoured the development of an EU regulation and would like to be kept informed. It was indicated, that for the near future, also national initiatives were being considered.

Information campaigns

The association of paint manufacturers has carried out information campaigns for consumers, and various paint manufacturers have organised training sessions for professional painters. According to the national association (IVP), this has ‘changed the behaviour’ of consumers and painters (De Brue, ’99).

The Belgian Committee for the European Ecolabel has organised information sessions for different key groups (industry, public, NGO's, ...) with the aim to promote the label for paints and varnishes. More actions are prepared for the promotion of those labelled products in the future (Woestyn, ’00).

Czech Republic

Financial instrument: Tax reduction

In the Czech Republic a measure exists that involves a reduction of VAT for low-VOC paints. The VAT-rate for high-VOC paints is 22%, while the VAT-rate for low-VOC paints is only 5% (Rychlikova, ’99). No data is available on the *results* of this measure.

National ecolabels

A Czech national ecolabel for decorative paints has been established. According to 'Directive no. 4-98' an ecolabel can be awarded to waterbased coatings only. Various types of coatings carry the Czech ecolabel: interior and exterior wall coatings, interior and exterior trim coatings for wood, radiator coatings, lacquers etc.

Results

In 1999, there were in total 31 decorative paint products carrying the Czech ecolabel, from seven different companies (Rychlikova, '99). It's not known which market share these products together constitute, or whether the ecolabels have resulted in increased sales.

Other labelling instruments

A legal obligation to express the VOC-content of coatings on a label is in *preparation.* It is one of the activities that are carried out under the 'National programme on VOC-abatement' (Rychlikova, '99) The label "Not suitable for indoor use" is already in use for some products.

Information campaigns

Manufacturers and importers of low-VOC paints are organising instruction sessions for users of these products. In addition, the State research Centre of Material Protection has held about 20 of such sessions over the last seven years (Rychlikova, '99).

Denmark

Legislation & Labelling (obligatory)

In Denmark, the use of high-VOC decorative paints has been drastically decreased by the legally required substitution, based on the "MAL-code" labelling system. The MAL-code system was first introduced in 1972 already (Pade, '99). The MAL-code label is obligatory for paints that are used by *professional* painters (National Labour Inspection, 1982). The MAL-code consists of two numbers, the first number of which reflects the paint's VOC-content and the health hazards linked to those substances. The second number reflects the health hazards of other components. The background to the development of the code-system is the protection of painter's health. The system was developed in co-operation with the authorities, painters, painting contractors and paint manufacturers.

The "Executive Order on Work with Code-numbered Products" (National Labour Inspection, 1982) states that substitution with a paint that has a 'lower' MAL-code is obligatory when technically feasible. In addition, each specific MAL-code is linked to a required level of ventilation. In general, professional painters are obliged to choose the product with the lowest MAL-code possible (i.e. roughly the lowest VOC-content) under any circumstances. The measures are enforced through the Labour Inspection.

There is no legislation on VOC-content of consumer paints yet, but this is in preparation at the moment (Pade, '99; Petersen, '99). This regulation will forbid the indoor use of products with first code numbers 3 or higher by consumers, thus limiting the VOC-content of indoor paints used by consumers.

Finally, a ban on alkylphenolethoxylates (APEO's) as a surfactant in waterborne paints came into force at the end of 1999. This measure may affect some manufacturers of waterborne paints, although many manufacturers have refrained from using APEO's already.

Results

With respect to the *results*, it was noticed in 1992 already that the MAL-code system "has provided systematic substitution of high-VOC paints by paints with a lower VOC-content (Den Hartog & Locher, 1992). More recent data from the Danish national association of painting contractors and the Occupational Health Service shows that indeed drastic effects have occurred. When the first version of the MAL-code was introduced in 1972, about 50% of interior professional decorative paint were water based. The introduction of the substitution principle in 1982 has speeded up the developments considerably. In 1999, it was estimated that about 98% of the interior professional decorative paints used were waterbased. When interior and exterior professional paints are taken together, about *90%* would be waterbased (Pade, ’99).

Up till now, the developments among consumers have been less pronounced. However, the new regulation mentioned above is expected to have its effect in the near future.

Financial instrument: tax on designated solvents

By order nr. 568 of 1998, a tax has been imposed on certain chlorinated solvents. Most of these solvents have no significance for decorative paints. However, one solvents, methylene chloride, is used as a paint stripper. No data are known on the effects of this tax.

Financial instruments – subsidies

The authorities support several research projects on cleaner products.

National ecolabels

Denmark takes part in the ‘Nordic Swan’ ecolabel system. At the moment however, there is no labelling scheme for paints and varnishes yet.

Voluntary agreements

In 1989, the paint industry and the authorities have agreed on some ‘guidelines’ with respect to paint use by consumers. The main guidelines with respect to this study are:

- VOC based paints should not be sold by retailers for walls and ceilings
- Consumers should be advised on how to use waterborne paints
- Waterbased products should be used outside as well, when technically possible.

These guidelines are not binding, but have the status of recommendations.

Results

According to the Danish Environmental Protection Agency (EPA) the use of high-VOC products by consumers has decreased considerably (Petersen, ’99). However, no figures are known.

Information campaigns

An information campaign for consumers is part of the above-described voluntary agreement.
Both the association of the paint industry and the Danish EPA have developed information brochures that describe the hazards of the various paint types and gives recommendations for their use. In addition, the paint sector organises training courses for professional painters (Plambeck, ’99).

Finland

National ecolabels

Finland takes part in the ‘Nordic Swan’ ecolabel system. At the moment however, there is no labelling scheme for paints and varnishes yet.

Voluntary agreements

In Finland, a ‘tripartite’ agreement on restriction in the use of solvent-based products in indoor painting has been made between paint manufacturers, painting contractors and professional painters. In addition, the paint industry itself has made an agreement on decreasing the VOC-content of paints.

Results

According to the national association of the paint industry, a *35%* reduction of the average VOC-content of products has been achieved over the period 1988-1996 (Kastinen, ’99). It is not exactly clear whether this concerns decorative coatings only or also industrial coatings.

Information campaigns

Paint manufacturers carry out retraining courses for professional painters.

France

National ecolabels

The French ecolabel 'NF Environnement' has been established for paints and varnishes. The following limits with respect to the VOC-content have been set for the ecolabel;

- Low-gloss (wall) paints: 125 gr/l, water excluded.
- High-gloss (wall or trim) paints: 250 gr/l, water excluded.

The ecolabel criteria have first been adopted in 1992, and have been revised in 1995.

Results

In January 2000, in total 85 different products carried the NF Environnement for paints and varnishes, among which 12 'own label' products from DIY retailers (AFNOR, '00). In total, 13 paint manufacturers were involved, including some major companies such as Akzo Nobel and ICI. In addition, four DIY retailers participated, including Europe's largest DIY chain Castorama (AFNOR, '00). No data was available on the market share that the labelled products have.

Voluntary agreements

In 1986, an agreement was made between the paint industry and the authorities on the VOC content of paints. Not only decorative, but all types of paint are involved. The target was a reduction of the average VOC-content of paints by 25%, based on 1986 levels. The reduction had to be achieved in 1991. The results were a 16.5 % reduction of the average VOC-content of decorative and industrial paints (Bouton, '99). However, paint consumption rose by 20% over the same period.

Information campaigns

An information campaign was part of the voluntary agreement. The paint industry committed itself to encourage the use of waterbased paints by conducting advertisement campaigns.

Germany

Legislation

At the moment there is no legislation with respect to VOC emissions from decorative paints yet, but it is being considered.

Financial instruments – Taxation

Taxation of high-VOC paints has been considered, but has not been implemented because objection from the European Commission was expected, with respect to the single EU-market.

Financial instruments – subsidies

The authorities support several research projects on cleaner products.

National ecolabels

A national ecolabel – Blaue Engel or Blue Angel – for paints exists. Waterbased wall paints can not get a Blue Angel, because these are practically the only wall paints used in Germany already. One of the main criteria for the Blue Angel for (trim) paints is that the paint should have a VOC content of less than 15%.

According to some industry sources and literature, the Blue Angel for paints is a success in Germany: "Everybody wants it". The Blaue Engel is well known among consumers, and many of them buy labelled products (Hirsch, '99). According to the same sources, the sales of low-VOC trim paints have risen from 1% in 1980 to 30% in 1992. Within the product sector the Blaue Engel is meant for (consumer DIY paints, excluding wall paints), the current market share of labelled paints is estimated at 70% (Hirsch, '99). This is in contrast to the earlier described market studies by some large paint suppliers (see section 6.2 – European Ecolabel). National culture, i.e. a high environmental awareness among the German public, might play a significant role here. However, according to the German association of painting contractors, the success of the Blaue Engel has ebbed, and sales of labelled paints have dropped (Olinger, ’00). The reason would be disappointments about technical performance (see chapter 11 as well).

Voluntary agreements
In 1984, an agreement between the authority and the paint industry was arrived at, to reduce the VOC-*emissions* from (all types of) paints with 25%, by 1991. This target was not met, as a result of an increase in paint consumption. A reduction of 7% was reached (Hirsch, ’99). However, the average VOC-content of paints did decrease faster.

Information campaigns
The Berufsgenossenschaften des Baugewerbes, an occupational health authority, publishes a CD-ROM with health and safety information on building materials. Decorative paints are subdivided into classes, based on their VOC content. The appropriate safety information is linked to each class (Kersting, ’99).

The German Federal Environment Agency (UBA) carries out information campaigns for the general public as well (Hirsch, ’99). A brochure on the use of low-VOC paints was developed.

Exemplary role of the government
The German authorities generally use low-VOC paints in public works (Hirsch, ’99).

Greece

In Greece, no specific regulations, agreements etc. with respect to decorative paints exist at the moment (Gryllia, ’99). Some manufacturers voluntarily present the VOC-content on the can (Mihail, ’99).

Financial instruments – Subsidies
A financial stimulation programme for ‘ecological products’ – the PAVE-programme – exists (Mihail, ’99).

Hungary

Financial instruments - Taxation
The introduction of a “general solvent tax” is being considered. The tax would be imposed on products such as paints and varnishes as well, depending on their VOC-content. The tax might be introduced in the year 2001, but the decision depends on the results of some environmental and financial impact assessments that are yet to be completed (Lotz, ’99; Pataky, ‘00).

Another option that is considered is the introduction of a tax or a fee on the basis of the amount of VOC emitted by a company (Lotz, ’00). This may affect professional painting companies as well, but obviously not the consumer.

Financial instruments – subsidies
Applications for subsidies can be submitted at the Central Environmental Protection fund (Lotz, ’99).

Information campaigns
The authorities have the intention to start information campaigns for consumers by video-film promotion, in order to convince them to use waterbased paints (Lotz, ’99).

Ireland

Prior to the imposition of the Solvent Directive there have been a number of measures introduced into Irish legislation to limit the amount of solvent emitted to the atmosphere. Up untill the Environmental Protection Agency Act, of 1992, there was no statutory body responsible for licensing certain manufacturing activities.The local authorities were able to control to some extent the activities of certain industries by attaching conditions under the various planning and development acts. With the introduction of the Environmental Protection Agency Act, enacted on the 23rd of April 1992, a new framework was introduced for the control of environmental pollution in Ireland. The Environmental Protection Agency is responsible for the licensing and regulation of industrial and other processes, with significant polluting potential, by means of Integrated Pollution Control (IPC). In conjunction with the introduction of IPC licensing, BATNEEC was introduced with the publication of a number of BATNEEC guidance notes issued by the Environmental Protection Agency to cover all the sectors contained in the First Schedule of the Environmental Protection Act, 1992. Under the Environmental Protection Agency (Licensing) Regulations, the licensing function commenced on the 16th of May 1994 and will be expanded on a phased basis. The emission limits stipulated in the sectoral guidance notes are mainly derived from the TA Luft (1986).

Italy

Currently, no specific measures exist in Italy (Surdi, ’99). However, the expectation of some Italian manufacturers of binders is, that within two or three years regulations will be introduced (Aramini, ’99).

Luxembourg

Financial instruments – subsidies
The Luxembourg authorities have granted a subsidy for the development of a waterbased paint.

Information campaigns
According to literature, information campaigns to encourage consumers to use low-VOC paints do exist (Den Hartog, ’92).

Netherlands

Legislation
On 1/1/2000, a legal ban on high-VOC paint for interior use by *professional* painters has come into force (SZW, 99). Occupational health concerns form the background to this measure. Therefore, consumers remain unaffected, as well as exterior use of solvent-based paint. The maximum VOC-content for interior paints applied by professional painters is as follows:

• Wall paints:	75 gr./litre (water included)
• Other paints (trim, metal):	125 gr./litre (water included)

On 1/1/2002, these limits will be decreased to 60 gr./litre and 100 gr./litre, respectively.

The regulation is indicated as “Substitution obligation”, because high-VOC paints should be substituted by low-VOC paints. A few exceptions will be allowed, e.g. sealing of very powdery walls, and hiding of nicotine stains. The Substitution obligation is enforced by the Labour Inspection.

Results
Because of the recent nature of the regulation, the effects are not yet known. However, it may be estimated that the direct effects of the regulation on the VOC-emissions will be limited for the following reasons:

- Exterior painting is not affected
- DIY painting is not affected (47% of the market)
- More than 90% of the interior wall paints that are currently used are waterborne

The market segment that *is* affected (professional interior trim painting with traditional solvent-based alkyds, plus 10% of the interior wall paints) may be estimated at **10.5 ktonne.**[8] As the total use of decorative coatings in the Netherlands was 179 ktonnes in 1998 (VVVF, '99), only *5.9%* of the market is affected. However, this market segment may be responsible for a VOC-emission of roughly **5 ktonne**, being ± **19%** of the total emissions of VOC from decorative coatings in the Netherlands (see chapter 5). As waterborne trim coatings contain about 10% VOC themselves, an emission reduction of about **4 ktonne** may be achieved by full implementation of this regulation (i.e. **15%** of the total VOC-emissions from decorative coatings in the Netherlands).

Financial instruments – Taxation

Taxation of high-VOC paints was considered by the Dutch authorities, but was rejected on the basis of the outcome of a market test (Josephus Jitta, '99; Winkelaar, '99). Taxation of high-VOC paint was simulated in one Dutch town. The effect was the opposite of what was intended: sales of high-VOC paints *rose*, as a result of the association of high prices with 'high quality' by the consumers.

Financial instruments – subsidies

Widely used within the framework of the VOC reduction programme KWS2000 (see 'Voluntary agreements'). Demonstration projects as well as product development have been supported.

National ecolabels

The Dutch ecolabel foundation Stichting Milieukeur has in 1994 considered establishing an ecolabel for paints, but due to a lack of interest from industry this was cancelled. The Dutch paint industry association feels that a national ecolabel 'on top' of the European Ecolabel is not reasonable. Moreover, the results of market tests revealed that paint sales were not affected, or were even negatively affected, by ecolabels (Winkelaar, '99).

Very recently, one small Dutch manufacturer of waterbased paints has asked the Ecolabel Foundation to establish an ecolabel for paints after all. Research has been carried out on the feasibility of a national label for decorative coatings, but again was advised against, due to a lack of interest from the vast majority of the industry (Westra & le Feber, '99).

Labelling; other (voluntary)

At the end of 1999, the Dutch paint industry, the Construction Trade Union, the Environmental Movement and two Retailers' organisations have voluntarily agreed on introducing a labelling system. The labelling is based on the VOC-content and will be introduced on paints for professional and on paints for DIY-use. The recent legislation on substitution (see above) was the reason for introducing the labelling system. In turn, the labelling system will support the implementation of this regulation. In order to prevent the professional sector from being disadvantaged, the system is aimed at the DIY-sector as well. The labelling system distinguishes three classes of decorative paints:

- Wall paints with < 75 g/L and trim paints with < 125 g/L:

Label: "No or very low amount of solvent – Complies with 'ARBO' for professional use" (ARBO: occupational health regulation)

- Paints with < 300g/L:

Label: "Low-solvent – Does *not* comply with ARBO for professional use"

- Paints with > 300 g/L:

Label: "Solvent-rich – Does *not* comply with ARBO for professional use".

The labelling system will be introduced during the year 2000. The system is part of a broader agreement (see below).

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[8] Total use of trim paints by professional painters is 17 ktons in 1998 – about 50% of this is assumed to be *exterior* (VVVF, '99).

Voluntary agreements

In 1986, an agreement between industry and government on the limitation of VOC emissions from a number of sectors, including decorative paints, was made. The main target of this ‘KWS2000’ programme was an overall reduction of VOC emissions (traffic excluded) by 50%, compared to 1981 levels and to be reached by the year 2000. The main instruments used under this programme were subsidies and information campaigns.

The programme KWS2000 is “generally considered successful in accelerating innovation and bringing consumers and producers together” (Mol, 1995). The Annual Report 1996-97 states, that the market shares of low-VOC paint (defined as < 250 gr./litre) in the Do-It-Yourself sector has risen from 8% in 1990 to 25% in 1996. For professional painters, these figures are 9% and 23%, respectively. The VOC emissions from *total* paint use (not only decorative) had fallen from 90 kilotonnes in 1990 to 58 kilotonnes in 1996 (a 35% reduction). The Dutch association of the paint industry estimates the reduction in 2000 to be 45%. All in all, the average VOC-content of decorative paints has decreased significantly.

Another voluntary agreement is the “Verfovereenkomst” (Paint agreement), which was made in 1990 between paint suppliers, painting companies, an occupational health institute and the trade unions. The agreement was made from an occupational health perspective. Paints were divided into 4 classes, based on health risks. The RAQ-value (Required Air Quantity) was used for this. VOC-content is a major criterion in this value. The parties agreed that use of paints from the two most favourable classes should be stimulated. Unfortunately, this agreement has remained an agreement ‘on paper’, with little effect on daily practice.

The above-mentioned labelling system is part of two broader agreements, in which the parties agree to stimulate the use of low-VOC paints in the consumer sector too. One agreement was made between the paint manufacturers, the construction trade union and the environmental movement. The other agreement was made between the paint manufacturers and three organisations of retailers and/or wholesalers. Workplans for the implementation will be developed over the year 2000.

Information campaigns

Three information campaigns can be identified:

- Information within the framework of the KWS2000 programme. Brochures, radio and television advertisements used to inform professional sectors and consumers.
- Campaign “Duurzaam Klussen” (Sustainable DIY), supported and organised by the authorities and the DIY retailers’ sector. The campaign involves radio advertisements, brochures and information of customers in DIY retail stores.
- Information campaign for the paint industry together with DIY retail stores. Mainly through providing information in DIY stores: introduction of a voluntary label (see above).
- Re-training of professional painters through the campaign “Schilder Anders”. Professional painters were trained in using waterbased paints that they would have to use indoors at the introduction of the substitution regulations on 1/1/2000. The paint industry, together with trade unions organised this campaign.

Finally, the Stichting Arbouw, an occupational health institute for the construction sector, publishes a CD-ROM with health and safety information on building materials. Decorative paints are subdivided into classes, based on their VOC content. The appropriate safety information is linked to each class. At the moment, a revision of the classification is considered.

Results

According to a large retailer, waterborne paints have finally had a breakthrough, over the last year. One of the reasons is the media coverage of the introduction of the new ‘substitution’ legislation for professional painters, and media coverage of Organic Psycho Syndrome issues in general.

Exemplary role of the government

The authorities encourage, and sometimes prescribe, the use of low-VOC paints in public works. According to the Dutch ministry of environment, 40% of public buildings are painted with low-VOC paints (Josephus Jitta, ’99).

Poland

At the moment, no specific regulations exist on limiting VOC-emissions from decorative coatings in Poland (Fudala, ’99).

Portugal

No specific regulations or activities on limiting VOC-emissions of decorative coatings exist (Boavida, ’99). Regulation of VOC emissions during paint manufacture exists in line with the Solvents directive and indication of the VOC-content on a voluntary basis may occur (Boavida, ’99). Information campaigns are made “in particular situations” (Boavida, ’99), but not specifically aimed at substitution of high-VOC decorative paints. Two Portuguese manufacturers have products that carry the EU Ecolabel.

Spain

National ecolabels

A Spanish ecolabel for paints and varnishes, “AENOR Medio Ambiente”, has been established since 1994 (‘Pinturas y barnices, UNE 48300: 1994). Details of criteria and participation rate were not available.

Labels- VOC-content

On a voluntary basis, companies may indicate the VOC-content of their products on a label (Diez, ’99).

Sweden

Legislation

Restrictions that closely resemble the new Dutch regulations (per 1/1/2000) have been in force in Sweden already from 1/1/1987 on (Pajerson, ’99). For professional painters, only *waterborne* coatings are allowed when *indoor* painting is carried out. The only exceptions are those made for specific restorations of traditional buildings (Pajerson, ’99).

National ecolabels

Sweden takes part in the ‘Nordic Swan’ ecolabel system. At the moment however, there is no labelling scheme for paints and varnishes yet.

Labelling – other

A label exists which indicates the VOC-emission to indoor air (Pajerson, 99). Protection of indoor air quality is the background of the label.

Information campaigns

The paint manufacturers, together with professional painters’ organisations, promote the use of waterborne paints indoors (Pajerson, 99). In addition, re-training of professional painters is carried out. The Swedish occupational health authorities in particular put a lot of effort into encouraging substitution.

Exemplary role of the government

For public buildings, painted by professional painters, low-VOC paints are used.

Results

The results of the Swedish regulations and activities are, according to the national association of the paint industry, that professional painters can only use waterborne paints indoors (Pajerson, '99). However, as the production and consumption data show (see chapter 4), only about 50% of all decorative paints used is waterborne. Thus, the majority of the paints used outdoors is still solvent-borne.

Switzerland

Financial instruments – Taxation

In Switzerland, a Solvents Tax was planned for introduction at 1/1/'99, though the "VOC-Verordnung SR 814.018". However, the introduction has been postponed until 1/1/2000 (Thiess, '00). The initial tax rate is 2 Swiss Franc per kilo VOC. The taxation is put on solvent-containing products as well. It is charged either at production, when production takes place in Switzerland, or at importation. The yield of the tax will be returned to the public as a 'per capita' payment. Because of the recent nature of the tax, no information on its effects was available.

Voluntary agreements

An agreement was made between government and the paint industry, to reduce the average VOC-*content* in paints by 25%, over the period 1985-1990. The agreement involved all types of paints, not only decorative paints.
The *results* were a 12% reduction in the first 3 years (Den Hartog & Locher, '92).

United Kingdom

For the moment, the UK Ministry of Environment has decided *not* to develop national legislation, on the basis that it 'appears to be an area of EC competence'. They await the developments around the UN Protocol, the European Community's implementation of it and the National Emission Ceilings Directive (Smith, '00).

Labelling

One large DIY-retailer (B&Q), in co-operation with the British Coatings Federation (BCF), has developed a labelling scheme based on the VOC-content of decorative paints (Williams, '00, Knight, '00). Five classes are distinguished (from 'minimal' to 'very high' VOC-content). The class that a specific product belongs to is clearly presented on the can. In addition, the phrase "*VOCs (Volatile Organic Compounds) contribute to atmospheric pollution*" is added. The labelling system is part of a wider-oriented information campaign from the retailer and the BCF.

Secondly, the BCF has adopted a voluntary phrase that may be put on high-VOC products:
"*Restrict interior use to small surface areas such as doors, skirting boards and window frames. Not recommended for interior use on large surface areas such as walls, floors or ceilings, or in confined spaces*" (BCF, '00).

Voluntary agreements

Industry advised the UK Ministry that a voluntary agreement was unlikely to work in this case. Agreements between the authorities and industry are therefore unlikely to be developed.

Nevertheless, the CEPE scheme has been partially implemented already by the UK paint industry on a voluntary basis. Indication of the VOC-content on the can has been implemented by 100% of the suppliers already, according to a large British manufacturer. Complying with the first phase (soft) target levels for the VOC-content of decorative paints has been implemented for 65% of the *retail* paints. For paints that are specifically sold to professional painters, the percentage is "much lower". Also, mainly the large companies comply with these targets to date, although some SME's are also involved.

The labelling system mentioned above is part of a voluntary agreement within the British coatings industry, the “Decorative Paints and Coatings Environmental Policy” (Williams, ’00). An information campaign is also part of the agreement(see below).

Information campaigns

The ministry has issued a public information pamphlet on the use of decorative paints during ozone ‘episodes’. Furthermore, B&Q mentioned above, as well as other DIY-retailers, informs its customers through brochures, Internet websites and through point-of-sale information displays.

The paint industry (BCF) has issued its own ‘Consumer guide’ on ‘decorative coatings and the environment’ (BCF, ’97).

Finally, paint manufacturers also carry out training for professional painters (Williams, ’00).

United States of America– Federal Authorities

Legislation

The Federal Environmental Protection Agency (EPA) has developed a *proposal* for “National VOC-emission standards for architectural coatings”. This proposal sets limits to the VOC-content of 55 types of architectural coatings used by professionals as well as consumers. Using the study team’s definition of decorative paints and varnishes, about 14 paint types are involved (see table). The regulation will *not* apply to paints that are sold in containers of *less than 1 litre*. However, in the US most containers are bigger. The proposal, which was published in 1996, is still being negotiated. The current proposal defines rather soft targets, but the feasibility of adopting more stringent VOC-levels will be studied.

The EPA proposal, does not indicate a definition of VOC (EPA, 1996). However, from other sources it is known that the USA generally uses a definition similar to those used in the proposed NEC-Directive and the UN Protocol (VOC are organic compounds with a POCP-value > 0).
No time frame has been defined for the introduction of the maximum VOC-levels, i.e. they will come into effect as soon as the regulation has been adopted. Instead, an *exceedence fee* economic incentive approach is being considered for inclusion in the regulation, in order to provide manufacturers with the option of paying a fee for the time they do not (yet) have the low-VOC technology available. The initial rate of the fee has been set at $0,0028 per gram VOC in excess of the applicable maximum level. Implementation of the regulation would result in an emission reduction of 106.000 tonnes VOC annually, which is 20% of the total VOC emissions from the architectural coatings involved. The *estimated costs* involved are $260 per tonne VOC-emission reduction.

Table 6.1(b) – Proposed maximum VOC-content USA-EPA proposal 1996 (gr./litre, excluding water, unless otherwise specified)

Coating category	Maximum VOC-content (g/litre)
Flat coatings (low gloss), exterior	250
Flat coatings, interior	250
Nonflat coatings (high gloss), exterior	380
Nonflat coatings, interior	380
Nonflat primers and undercoaters	350
Lacquers (including lacquer sanding sealers)	680
Metallic pigmented coatings	500
Multi-coloured coatings	580
Quick-dry Enamels	450
Quick-dry primers, sealers and undercoats	450
Quick-dry sealers	400
Clear and semi-transparent stains	550
Opaque stains	350
Low solids stains	120 (water included)
Varnishes	450

Financial instruments

An exceedence fee is part of the above-described regulation (see above).

Labelling – other

Labelling is part of the above-described regulation. The VOC-content and *coverage* should be indicated on the can. Considered is a requirement to put a 'warning' on the can such as: "This product contains VOC which are hazardous … etc."

United States – Southern Californian authorities

Legislation

In Southern California, a regulation that sets limits to the VOC-content of architectural coatings has already been adopted. The regulation, "Rule 1113 on architectural and maintenance coatings", has been issued by the Southern California South Coast Air Quality Management District. It sets relatively stringent limits to the VOC-content of the coatings involved, which should be met by *2006*. The most relevant target values, with respect to the coatings covered by the current study are the following:

- Flat and nonflat coatings	50 g/litre (exterior as well as interior)
- Floor coatings	50 g/litre
- Quick-dry enamels	50 g/litre
- Primers, sealers and undercoaters	100 g/litre
- Quick-dry primers, sealers and undercoaters	100 g/litre

The above-described limits will mean that *only waterborne* coatings can be used. According to the paint industry in the US, SME's will not be able to comply with these targets, and large number of products would be banned. The *estimated costs* connected to reformulation of products would involve $250.000 per product.

United States – California – rest of the state

Legislation

The California Air Resources Board has published a *proposal* for a regulation that sets limits to the VOC-content of architectural coatings. Most limits are close to the Southern-California limits. However, non-flat coatings are not mentioned, which might result in an 'escape route' for gloss paints. Also, the effective dates for the VOC-limits vary:

Table 6.2 – Proposed maximum VOC-content California proposal (gr./litre, excluding water and tinting systems)

Category	**Current limit** (g/l)	**Proposed limit** (g/l) (effective date)
Flat coatings	250	100 (2001) 50 (2008)
Lacquers/ Clear wood coatings	680	550 (2001) 275 (2005)
Floor coatings	400	100 (2001) 50 (2006)
Multi-coloured coatings	420	250 (2001)
Primers, sealers, undercoats	350	200 (2002) 100 (2006)
Quick-dry enamels	400	250 (2002) 50 (2006)
Clear and semitransparant stains	350	250 (2002)
Opaque stains	350	150 (2001)
Wood waterproofing sealers	400	250 (2002)

(source.*: SHE Alert, July 1999, PRA, UK)*

6.4 General conclusions on the effectiveness of various types of measures

In this section, some general statements on the potential effectiveness of various measures that can be taken to reduce VOC-emissions from decorative paints and varnishes are discussed. Two sources of information have been used for this purpose:

- Current experiences with measures in EU-member states and non-EU member states, as described in section 6.3
- Questionnaires returned from national ministries of environment and environmental protection agencies, as well as among national associations of the paint industry. In the questionnaires, the addressees were asked to rank the (expected) effectiveness of the various measures possible on a scale from 1 ('not effective') to 5 ('very effective'). Also, their comments were solicited.

Legislation

Legislation putting limits to the VOC-content of decorative paints, or actually *restricting the use* of high-VOC paints, exists in Denmark, Sweden, the Netherlands and Austria.

In Denmark and Sweden the regulations have are primarily aimed at indoor professional painting. The result has been that professionals use practically only waterbased paints indoors. The regulation in the Netherlands is too recent to notice effects, but the effects are expected to be similar to those in Denmark and Sweden. In Denmark, for exterior painting by professionals, the use of low-VOC paints has increased as well; in Sweden this is not the case. In all these cases, the regulations are actively enforced through the Labour Inspectorates, and have been actively promoted by trade associations themselves.

The Austrian regulations are primarily aimed at DIY users, and restrict the *availability* of high-VOC paints for this target group. The Chemicals Inspectorate enforces this regulation by visiting paint retailers twice a year. The VOC emissions from decorative paints have decreased by 40% as a result of the regulation.

Generally, legal measures are considered very effective measures by both ministries and industry associations. Measures limiting the *availability* of high-VOC products for *anyone* are considered easier to enforce than measures only limiting the *use* of high-VOC paints to certain applications. However, in Denmark and Sweden it is the restrictions on professional painters use of high-VOC paints that has resulted in a limited availability of high-VOC paints in the trade distribution channels. Paint manufacturers started competing in the supply of low-VOC paints. The same development may be expected for the Netherlands. In addition, the Dutch regulations for professional painters are supported by information campaigns that address the DIY-sector. The raising of awareness caused by the rules for professional painters is expected to affect the DIY-sector also. Besides, when consumers see that professionals use only waterbased paints indoor, this may convince them that waterbased paints are of sufficient quality (Ducque, '99).

A remark which came from industry was, that *thinning* before use should *not* be allowed anymore. This might mean introducing a prohibition on selling white spirit or other thinners as such.

Legislation on VOC-emissions during the manufacturing phase of decorative paints (as defined in the Solvents Directive) was *not* thought to have a significant effect on VOC-emissions during the use of decorative paints, as manufacture is driven by end user's requirements.

Financial measures

Financial measures other than subsidies for product development have only been implemented in the Czech Republic and Switzerland. In the Czech Republic, a decreased VAT-rate exists for low-VOC paints, while in Switzerland a solvent tax has been introduced. In both cases, no data on the effectiveness were known (in the Swiss case because of the recent nature of the measure).

Many representatives from national ministries and the industry question the effectiveness of fiscal measures. In Hungary, tax measures are still considered. In Germany and the Netherlands, tax measures have been considered and rejected by the authorities. In Germany, the main reason was the expected opposition from the European Commission, because of ‘internal market’-reasons. In the Netherlands however, a study on consumer behaviour suggested the lack of effectiveness of fiscal measures (Van Raaij, ’92).

In general, the following two reasons for the expected lack of effectiveness of fiscal measures were given:

- For professional painting contractors, the price of the paint has only a limited impact on total costs, as labour costs make up about 80% of the total costs;
- For many consumers, price is not a decisive factor. Purchasing decisions are made on factors such as colour(-availability), quality(perception) and brand-names of the paint. Besides, consumers are expected to associate a high price with a ‘high quality’.

Although many industry and government representatives agreed on these two factors, the growth of relatively cheap ‘private label’ paints in some countries does suggest that price has an influence after all. Besides, representatives of CEPE’s Technical Committee on Decorative Coatings *do* expect an influence on the consumers’ market. Product prices are thought to be a decisive factor for many DIY consumers. Only in a minority of cases would the awareness of specific (high-cost) brands be sufficient to justify higher prices (Witte, ’00). Painting contractors from Spain appeared to be remarkably positive towards pricing mechanisms as a way of stimulating the use of low-VOC paints (painters’ questionnaires, ’00).

In a number of countries (e.g. Germany, the Netherlands and Denmark) subsidies for environmentally oriented product development exist. However, most representatives believed that these are of little significance, as the availability of low-VOC technologies is not the main barrier to a break-through of low-VOC paints.

Ecolabels

In Germany, France, Spain, Austria and the Czech Republic, national ecolabels exist for certain types of paint (mainly low-VOC paints). In the Netherlands, initiatives for the development of a national ecolabel were cancelled because of a lack of interest among the paint industry.

In most of the countries where national ecolabels exist, the impact of the label is very low. Reasons are that the participation rate among the industry is low, the label covers only one or a few product types or the label is not known among the general public. In the German case however, it is claimed that the ecolabel has significantly increased the use of low-VOC paints. This was most likely caused by extensive information campaigns that supported the introduction of the ecolabel, and by the general environmental awareness of the German public.

In general, industry representatives do *not* think that ecolabels have any effect on the purchasing decisions of consumers. As mentioned above, other factors prevail. Moreover, some market tests would have pointed out that even negative effects might occur, as some of the consumers regard ‘environmentally friendly’ products as being of low quality. Thus, because of a lack of market demand from consumers, paint manufacturers do not see the added value of ecolabels and consequently the vast majority does not co-operate.

The representatives from national ministries of environment generally expected more effects from ecolabels. However, most of them stressed the need for supporting information campaigns or advertisements, to introduce and explain the label to the general public. This in fact is at least one of the reasons for the lack of a significant market influence of the European Ecolabel too.

However, the Ecolabel seems to *have* had an influence on *product development*, thus reducing negative environmental impacts of decorative coatings. For example, it has been observed that a number of paint manufacturers have formulated certain products according to Ecolabel criteria (e.g. the VOC-content of < 250 g/litre).

Labelling connected to VOC-content

Product labelling with the VOC-content exists at a few large retailers in the UK. In Denmark (and Norway) a very effective labelling systems that is partly based on VOC-content does exist, but this is closely connected to legal requirements with respect to substitution. In the Netherlands also, a labelling system based on the VOC-content is being developed. For professional painters, this cannot be seen apart from legal requirements as well. For consumers however, the labelling system as such (in combination with information campaigns) will have to bring about the desired changes.

Generally, most industry and government representatives are of the opinion that labelling as such will have limited impact. Moreover, presenting just the VOC-content on the can (as in the UK) would result in confusion among consumers, as they do not know the meaning of a particular VOC-content. An extensive information campaign to inform the user would be needed to achieve any success with labels.

Most of the representatives are a little more positive about labels that give statements such as “High VOC paint – not suitable for indoor use”. The advantage of such a label is that it is very clear.

Information campaigns and training

Information campaigns to inform the general public and re-training of professional painters are carried out in many countries in north-west Europe. Information campaigns for the general public are carried out by the authorities and/or the manufacturing industry and retailers. Mainly the manufacturing industry and retailers, and in some countries the trade unions, carry out re-training of professional painters.

The opinions on the effectiveness of campaigning and training vary. The overall (average) opinion is that these measures have a moderate effectiveness. While a number of representatives feel that information campaigns from the industry have the highest credibility, the same number of representatives (from industry) feel that campaigns from the authorities are more credible. The general feeling is, that information campaigns are a crucial support to other measures such as labelling or legal measures. Campaigning as such is valued as being less effective.

With respect to re-training of professional painters, in order to train them in using low-VOC paints, the opinions varied very widely. Some representatives stated that it’s crucial, and that substitution will fail without it. Others state that professional painters are well-trained, are experienced in using low-VOC paints already and thus do not need re-training.

However, although the opinions vary, manufacturers and retailers will probably continue organising (e.g.) workshops for painters, in order to present new products and maintain their market shares. Paint manufacturers invest considerable amounts of money into these activities. Therefore, they welcomed suggestions to develop and organise special (EU-funded) educational programmes for professional painters, in order to motivate and train them in using low-VOC paints (Witte, ’00).

Voluntary agreements

Voluntary agreements between authorities and the paint industry exist in Germany, France, the Netherlands and Denmark. In all of these cases, certain effects with respect to decreasing the average VOC-content of decorative coatings are claimed. The industry tends to co-operate with agreements like this, because of the possibility to influence targets and time frames for implementation.

It has been observed that cultural differences influence the estimations of the potential effectiveness of voluntary agreements. For example, in the Netherlands on the one hand, a long-standing tradition exists with respect to agreements between authorities and industry, while in Austria this tradition is absent. This difference was expressed very clearly in the opinions about the effectiveness of agreements.

Generally, among the industry representatives the fear exists that part of the industry will not comply with the targets set in voluntary agreements, and thus create a competitive advantage. It is probably for this reason that agreements with the authorities are considered a little more effective than agreements within the industry (such as the CEPE-scheme) itself. Moreover, this is the reason why the industry welcomes legal measures on a EU-level. The paint industry seems to welcome clear targets, which have to be met by the *entire* industry.

Exemplary role of the government

The strategy of authorities setting an example by using low-VOC paints only in public buildings is followed in Germany, Denmark, Sweden, the Netherlands and Austria. Again, very different opinions exist on the effectiveness of such a measure. However, it is indicated that it is obviously crucial for the credibility of the measures that the authorities comply themselves. Also, the consumer as well as professional painters might in this way be convinced of the quality of low-VOC paints. However, an information campaign telling them that low-VOC paints are used at public buildings is necessary before any effect will be seen.

Impact of international agreements and other EU-directives

Some representatives pointed to the developments around the UN/ECE Protocol on the abatement of VOC-emissions (section 6.2) and explained that these developments were awaited before taking action on decorative coatings. The same holds true for the proposed directive on National Emission Ceilings.

However, both act as a framework for the abatement of VOC-emissions and do not prescribe specific measures. Therefore, measures to reduce VOC-emissions from decorative coatings, possibly within the framework of a ‘Coatings Directive’ do not interfere with the Protocol or the NEC-directive, but may be one way of implementing these.

The (lack of) influence of the Solvents Directive has been dealt with in section 6.2 and in the section on ‘Regulations’ above.

Remarks with respect to a potential ‘Coatings Directive’

Various representatives of industry and ministries of environment have made remarks with respect to the need for and the design of a ‘Coatings directive’ aimed at decorative coatings.

Generally, the industry welcomes a directive, as described above. The directive may set clear (research-) targets and the entire industry will have to comply. Thus, ‘free-rider’ behaviour will not be possible anymore. The representatives from painting contractors in Europe expressed the same opinion (UNIEP, ’99). However, a number of remarks have been made.

The remark that was most made by the paint industry was that the VOC-reduction scheme that has been developed by *CEPE* (see section 6.2 and Annex 8) should be taken as a basis for a Coatings Directive. Within industry, consensus has already been reached on this proposal, which would greatly increase the chance of a successful and ready implementation. If the process were ‘started all over again’, implementation would be very complex, according to the national associations of the paint industry.

With respect to the VOC-limits, both the manufacturers and the professional users (UNIEP, ’99) of decorative paints suggest that these should *not be too strict* right away. It is feared, that in that case the market shares of alternatives for decorative paints such as PVC or aluminium window frames would increase at the expense of the paint sector. One of the causes for this would be the problems in achieving the desired durability of coated wood. In addition, the painting contractors indicate that sufficiently generous time frames should be set (“one generation”), in order to enable the sector to make the switch.

Some remarkable exceptions to the ‘general’ opinions among painting contractors, as expressed by the European trade association, occurred. Danish painters appeared to be very confident about the achievements made towards increasing the use of low-VOC paints in their country. They were generally positive about the results, and were very willing to transfer the experiences to other parts of the EU (Pade, '00). Besides, a large number of Spanish painting contractors expressed a very positive attitude towards a potential coatings directive in the questionnaires that they returned. They state that waterbased alternatives have been accepted for most interior and exterior uses, and that the authorities should prescribe those products.

The European solvents manufacturers, represented through ESIG, strongly oppose a potential product directive on decorative coatings. ESIG is of the opinion that the benefits in terms of ozone reduction are too insignificant to justify the large economic effects they anticipate (Sarginson, '00, see section 12 and annex 4 as well). Similar remarks have been made by a number of resin manufacturers, represented through the European Resin Manufacturers Association (ERMA) (Hemmings, '00). However, a major concern of ERMA seemed to be causing division among their member companies, as both waterbased and solvent based resin suppliers are involved. At the same time, more specific waterbased-oriented resin manufacturers, organised into EPDLA, seemed to have a more positive attitude towards a potential directive (Teheux, '00).

Finally, a remark made by the paint industry and painting contractors was that the regulation should be *simple* and easy to understand for all parties involved. Concentrating on a few major product types that constitute 90% of the decorative market was suggested. This approach is followed in the VOC-reduction scheme from CEPE. When this is done, 'niche-applications' which demand higher VOC-levels would be allowed, but would not contribute significantly to overall VOC-emissions.

The Ministries of Environment *unanimously welcome* an EU-regulation that limits the VOC-content of decorative paints and varnishes. Some countries, e.g. France, Germany and the Netherlands have proposed such a regulation before. The EU-level is generally considered the appropriate level to take action in order to prevent market distortions. Also, a product directive is assumed to be the only way of limiting VOC-emissions from product like decorative coatings.

Various representatives stress that the limits should *not* be *less strict* than the current limits or current practice in their own countries (e.g. Denmark and Austria). Other representatives agreed with this view, but recommended that the limits should not be too strict straight away. Once the sector *is used to the idea* of VOC-limits, then the limits may be gradually reduced.

A remark made several times was that a *combination* of measures will be needed to achieve the best results, e.g. legal VOC-limits, product labelling and information campaigns.

The view was expressed by ERMA that the legislators should not interfere in this sector, since experience shows that the market itself deals with the issues involved effectively.

Main conclusions

Current measures and effectiveness of types of measures

(Please refer to chapter 11 as well).

- It is likely that the Solvents Directive does not contribute significantly to reduction of VOC emissions due to the use of decorative paints and varnishes. Therefore, the development of a separate product-oriented 'Coatings Directive' is needed.
- The proposed Council Directive on National Emission Ceilings and the UNECE Protocol on limiting VOC emissions constitute a framework for a future 'Coatings Directive', and therefore are not impediments to a proposed directive.
- The European Ecolabel for indoor decorative paints has had a negligible effect on paint sales. However, it seems to *have* had an influence on *product development*, thus reducing negative environmental impacts of decorative coatings.
- Legal limits to the VOC-content, restricting the availability of high-VOC paints for *all* target groups (DIY and professional) are thought to be most effective and easiest to enforce.

- Restrictions on the use of high-VOC paints by either professional painters or consumers only have resulted in considerable reductions in VOC-emissions in some countries.
- Financial measures – product taxation, tax reduction or subsidies – have a limited impact on reducing VOC-emissions from decorative coatings.
- In general, there is a lack of interest from the paint industry, as well as the consumers, in ecolabels.
- Only when connected to intensive information campaigns, can ecolabels be a successful tool in reducing VOC-emissions from decorative coatings. The same holds for presenting the VOC-content on the can.
- Information campaigns as such are expected to have a limited impact. However, they may be a crucial support to other measures such as legal VOC-limits or (eco-) labelling.
- Voluntary agreements may contribute considerably to reducing VOC-emissions from decorative coatings when a national culture of co-operation between authorities and industry is present. However, industry prefers legal measures in order to prevent ‘free-rider’ behaviour of part of the industry.
- The solvent industry is of the view that tropospheric ozone is of a local nature and should be dealt with on that basis.

Future ‘Coatings Directive’

- Both representatives from EU member states and their national paint industries, the European paint industry and painting contractors, *welcome* the initiative of a ‘*Coatings Directive*’ on an EU-level.
- All parties agree with setting limits to the VOC-content of products as a way of limiting VOC-emissions from decorative coatings.
- The coatings directive should be as simple as possible, and according to the industry it may be most effective to concentrate on a few major paint types.
- It might be most effective to set the actual limits to the VOC-content of decorative coatings rather ‘soft’ at the start, in order to enable the market to get used to the principle. Subsequently, the limits may be tightened step-by-step.
- A number of member states are opposed to limits that are ‘softer’ than those that are currently in practise in their own countries.
- A *combination* of measures will be needed to achieve the best results, e.g. legal VOC-limits, product labelling and information campaigns.
- The European solvents industry, as well as some resin manufacturers, strongly oppose a product directive for decorative coatings, on the grounds that the environmental benefits will be minimal while the costs will be high.

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7. Review of technical developments in the decorative paints market from the early 1980's to the end 1990's

7.1 Summary

Developments in decorative coatings technology has been segmented in the literature into two primary areas of activity. The first area has been developments involving dispersions of vinyl and acrylic polymers in aqueous media, while the second area has been the development of oil/fatty acid modified polyesters or alkyds. The former has found application in wall coatings for plaster, brick and masonry. The latter has maintained dominance in wood coating such as trim, doors and cladding in many markets.

In the early eighties, a rapid increase in the use of waterborne coatings was reported. Waterborne had increased by 50% from 1975 to 1985, with predictions for further growth into the future at the expense of traditional solventborne coatings. Similar growth was expected of high solids solventborne. Concerns about health risks associated with the use of hydrocarbons were expressed. At that time the drawbacks of latex dispersions were associated with low levels of gloss, poor rheological control (flow-out, lapping etc.) and adhesion over porous surfaces. By comparison, some conventional solventborne alkyds suffered from yellowing indoors, while odour, slow drying, cracking and blistering were associated with exterior use. High solids alkyds offered lower VOC emission, however, had longer drying times and more rapid yellowing. Cost and higher build were drawbacks where thinner coats only were required. VOC comparisons in 1993 put conventional at 350g/L, high solids alkyds at 210 g/L and waterborne acrylic at 120 g/L (including water).

Goodyear adopted a stance of maintaining specialist solventborne coatings for masonry and introduced aromatic-free solventborne resins in 1986.

Traditional inorganic silicate paints were reported as having revival potential as they offered zero VOC, high adhesion, permeability and UV resistance, although the colour range would be restricted and in-store tinting is not a possibility.

The largest DIY chain in the UK initiated their own VOC reduction campaign and it was reported that the company considered the British Coating Federation (BCF) targets, based on the European association of paint manufactures (Conseil Européen de l'Industrie des Peintures-CEPE) proposals, were currently achievable. Additionally, the VOC definition of 250°C boiling point was considered too low and B&Q had chosen a boiling point of 280°C to include all solvents.

7.1.1 Alkyd technology development.

It was expected that alkyd resins would maintain a consolidated position for application over wood and the emphasis on their development was placed on VOC reduction by the increasing the solids content of the formulations.

Molecular weight was considered not to be the route to high solids and reactive diluents were employed to accelerate drying and act as a solvent, yet not being involved in liberation from the film.

Akzo in 1993 compared conventional, high solids alkyds and waterborne acrylics in terms of VOC. Conventional alkyds had a level of 350g/L, high solids 210g/L and waterborne 120 g/L. By 1994, high solids alkyds still had yellowing, hardness development and cost drawbacks. The low VOC requirement of alkyd emulsions was considered a major advantage of the technology being typically 2% compared to 4-11% for waterborne acrylics. Zero VOC formulations were envisaged. Blends of up to 40% acrylic with alkyd emulsions were suggested. In 1995, high solids alkyds with potential for 100g/L were reported. In 1995, a comparison between conventional, high solids, waterborne acrylic and waterborne alkyd formulations for wood that same year, placed typical VOC levels for each consecutively at 350g/L, 170g/L, 190g/L and 42g/L representing Akzo's leading formulations.

By 1999, Sigma described high solids alkyds with VOC levels of 250g/L, dendrimers for high molecular weight low viscosity and reactive diluents as the routes to low VOC alkyds. Reactive diluents such as drying oils, low molecular weight alkyds and methacrylate esters were reported as beneficial for formulating high solids alkyds with low VOC and viscosity. Elsewhere, Star, hyperbranched and dendritic polymers were described as a route to high molecular weight polymers with low viscosity.

It was argued that simple VOC comparisons did not present the entire environmental impact picture. It was argued, principally by the alkyd manufacturers and solvent suppliers, that Life Cycle Analysis, placed high solids alkyds on an even footing with waterborne dispersions. It was also generally agreed that the basis for analysis, no standardised method and different sources of data, made the process somewhat subjective.

The one-coat application potential of high solids alkyds was identified as beneficial in terms of offsetting material cost against labour costs. The Eco-label was identified as a driver for alkyd high solids development.

7.1.2 Acrylic dispersion technology development.

Developments in acrylic technology in the early eighties led to the use of a new generation of polymers based on monomers such as butyl acrylate, methacrylic acid and acrylonitrile. Better gloss, hardness and durability were exhibited, however, as a consequence, the minimum film forming temperature increased from <20°C to >20°C, thereby necessitating the use of cosolvents such as propylene glycol and glycol ester coalescing agents. Additions of up to 20% solvent on latex solids were reported in 1982.

Core-shell polymerisation offered a route to facilitate film formation through lower Tg shells with harder core material to impart durability, gloss and low dirt pick-up. Softer, shell material that could film-form at lower minimum film-forming temperatures (MFFT), presented the opportunity for coalescent-free paints. Another route to VOC free emulsions was that of hydroplasticisation of vinyl acetate by water, offering self-plasticisation, incorporated with ethylene which has a Tg of –80ºC. Rohm&Haas described ambient cure latex which utilised atmospheric oxidative cure mechanisms, thereby lowering coalescent demand. Performance equaling and exceeding conventional alkyd enamels was reported. Other work described ambient cure polymers that had low MFFT's and high Tg's allowing zero-VOC formulations.

7.1.3 Wood coating developments.

Considerable concern existed over Norwegian wood cladding which had suffered wood rot and had been coated by waterborne products. A consensus of opinion suggested that weathering of timber prior to coating, can be highly detrimental to the performance of any applied coating. It was also recommended by several sources that a solventborne primer be used prior to application of a waterborne product. Many researchers reported that waterborne coatings for exterior wood protection were capable of offering good protection of wood and that in many cases, the longevity and breathability of acrylic latex imparted superior performance. A comparison of typical VOC's for wood coatings was presented for a conventional solventborne, waterborne alkyd, waterborne acrylic and cross-linked acrylic. The levels quoted were, consecutively, 400g/L, 0g/L, 0-150g/l and 90g/L.

7.2 Historical overview of VOC issues associated with decorative technology

Work reported here, serves to highlight the transitions from cost/performance activity in the early 1980's to efforts to develop and improve low VOC and VOC-free technologies from the mid 1980's up to the present time. Opinions expressed here are those of the referenced authors and not necessarily those of the project team. The study team's position on the significant issues will be presented in the discussion of this overview.

UK Polymers Paint Colour Journal (1) in 1985 described little future for hydrocarbon solvents and indicated that waterborne technology continued to replace solventborne technology. The theme of a lecture by the Chief Executive of Berger Britain supported this view with the following statistics,

- 50% increase in waterborne 1975-85.
- Waterborne constituted 60% of UK decorative sales and 70% of US sales.
- High on the list of requirements were exterior, permeable wood finishes.
- High positive slopes for growth of high solids and waterborne.
- Growth in decorative solventborne poor and estimated at 1-2%.
- Health risks also in the limelight with hydrocarbon solvents.

Cox(2) of Reliance Universal Inc., summarised innovations in waterborne coatings in 1986. Waterborne technology developed from research into synthetic rubber during World War II. Latex emulsions first used in houses in the 1950's, resulted from these efforts. Alkyd technology had been prevalent in decorative coatings technology from the beginning of the century, evolving into water dispersible variants in the 1960's. The oil crises of the 1970's, along with new requirements for low VOC, accelerated growth in the waterborne area. Cox describes the impetus in the 1980's as being driven by Government Legislation. He compares some of the key characteristics of emulsion with dispersion technology and their status at that time.

Table 7.1. Comparison of performance attributes (1986).

Characteristics	**Solutions**	**Emulsions**
Chemical resistance	Fair to good	Good
Dry rate	Usually slow	Fast
Film porosity	Low	High
Gloss	High	Low
Humidity Resistance	Excellent	Poor to fair
Hydrolytic stability	Fair to good	Very good to excellent
Molecular weight	Low to medium	Very high
Rheology	Good	Poor to fair
Thermal stability	Usually Good	Sometimes
Viscosity	High	Low

In particular, gloss and humidity resistance of dispersions were reported as being low. Surfactant free emulsions were identified as a future requirement.

Jotischy(3) of the PRA in 1985 reported on the move towards 100% acrylic formulations for masonry paints, away from traditional PVA grades. The market for masonry paints in the UK in 1983 was reported as 6.6% of the total decorative volume and amounting to 19M litres. The trade consumption was reported as being 4.2M litres compared to 6M litres for DIY, with the remaining 8.8M being for local authority, public works and industro-commercial properties. Poor growth of reinforced concrete for architectural design was expected, with coatings for this area likely to be remedial in function.

Sandford and Gindre(4) of Goodyear presented the strategy for Goodyear in 1986, by introducing aromatic-free resins in the Plioway range to produce non-aggressive, low toxicity solvents. The inability of waterborne paints to achieve the necessary adhesion, especially to porous and chalky surfaces, was highlighted. Additionally, reference was made to the contamination of waterways by waterborne paints due to the cleaning of utensils/equipment after manufacture and application. The presence of bactericides, fungicides, coalescing agents and surfactants were also described as having harmful effects on the water system. Aromatic free naphthenics and paraffins were identified as the way forward for solventborne Pliolite resins, with exposure limits (OEL-Essochem) three times higher than current white spirits and six times higher than aromatic white spirits.

Schumacher(5) of Ernst Jäger(alkyd resin manufacturer), in 1991 predicted that modified alkyds would continue to be widely used and reiterated the concerns of Sandford and Gindre(4) over the effects of waterborne paint washings on the waterways. Dwindling petrochemical stocks and increasing prices presented an advantage for alkyd resins in that up to 50% of the raw material could be based on animal or vegetable oils or fats. Schumacher described the three main areas for future development in alkyd technology as being,

Table 7.2. Future developments for alkyd technology.

High solids	Replacement of o-phthalic acid with isophthalic, adipic or dicarboxylic acids
Odour reduction	Aromatic free white spirits and low odour oils and fatty acids.
Waterborne emulsions	Not amine-neutralised

Rape and sunflower seed oil were seen as emerging materials along with the use of esterifying agents such as sugars and starch. Better solvents were predicted such as citrus terpenes, alcohols and esters for high solids development. Amine or ammonia neutralisation was not seen as the developmental route for waterborne alkyds. Self-emulsifying, shear resistant alkyd polymers were seen as the future of waterborne alkyd development.

Simms(6) of DuPont (resin manufacture), in 1993 introduced the concept of star polymers or dendrimers as a route to high molecular weight (Mw 70,000-290,000) with low viscosity's (0.27-2.55 Stoke). Star polymers are highly branched polymers with branches radiating from a central core. The result is a material which has lower viscosity than a linear polymer with similar molecular weight. Simms described a 25-30% benzyl methacrylate star polymer which gave fast drying, improved hardness/flexibility while allowing VOC contents of 3.5 lb/gallon(US) or 420g/L.

Guerink(7) of Akzo in 1993 asked if VOC was the most important issue associated with coatings and the environment. Features of high solids alkyd (HS) and waterborne (WB) acrylic were outlined in reference to conventional alkyd characteristics for trim,

Table 7.3. Comparison of performance attributes of WB acrylic and HS alkyd with respect to conventional alkyds

Property	**WB acrylic**	**HS alkyd**
VOC emission	Lower	lower
Pretreatment	Special attention	equal
Initial drying	faster	slower
Flow	less	equal
Blocking	more critical	equal
Layer thickness	less	more
Dirt-pick up	more	equal
Yellowing	less	equal

A comparison of VOC levels, representing the leading edge from Akzo's product portfolio at that time gave,

Table 7.4. Comparison of VOC's w/w%

Conventional Alkyd	**HS Alkyd**	**WB acrylic**
30	16	10

Assuming typical SG's of 1.18 for conv. alkyd, 1.32 for HS alkyds and 1.22 for acrylic the approximation in g/litre including water is,

Table 7.5 Comparison of VOC's g/L

Conventional Alkyd	**HS Alkyd**	**WB acrylic**
350	210	120

Guerink suggested that volume solids of the formulation, coverage and durability,
should have been taken into account when evaluating VOC reduction in products. Guerink also examined the life cycle analysis approach and arrived at a unit which accounted for the amount of paint necessary for the protection and maintenance of $100m^2$ of surface over a 40 year period. It was concluded that TiO_2 production had the largest environmental impact, 40% of VOC emission was associated with removal of the paint and that emission to water increased with waterborne emulsions.

Padget(8) of Zeneca Resins, presented a review of waterborne coatings in 1994 and outlined the difficulties at that time, remaining to be resolved with that technology. The use of carboxylic, sulphonic acid and tertiary amine groups were identified as the primary functional groups which were used to confer water solubility to otherwise water-insoluble polymers. The acid functionality concentration determined the extent of solubility with low concentrations capable of providing charge or stearic stabilisation to a dispersion. Difficulties associated with waterborne were outlined. These difficulties are summarised below.

Drying Latent heat of evaporation (~540 cal/g) for water is high. Therefore, difficulties are encountered at low temperature and high humidity.

Film formation Elimination of cosolvents and coalescing agents required redesign of the polymer system. Blending of low and high Tg polymers offered a route to low temperature film formation.

Wetting Surface energy of water is 72 dynes/cm^2, therefore wetting of pigments, extenders and the actual substrate required the aid of cosolvents and surfactants. Cosolvents increased the VOC level of the formulation while surfactants could have caused foaming/pinholing, necessitating the addition of defoamers.

Pigment dispersion Dispersion of pigments in emulsions was more difficult than in solventborne systems. Good colour reproduction and barrier properties depended on good dispersion. Soluble additives such as ZnO could have caused flocculation. Packing arrangements in coalescing emulsion films complicated pigment dispersion by introducing competition for free volume.

Flash rusting Presence of water and electrolyte, derived from soluble components in the formulation, produced the necessary conditions for corrosion to occur. Sodium nitrite could have been used to complex Fe^{2+} corrosion products to reduce visual effects.

Freeze thaw Additions of VOC (propylene glycol) are required to lower the freezing point of the aqueous medium. Ice crystals can rupture or destabilise the dispersion.

Bacterial growth Aqueous media as well as starch/sugar components encourage the activity of bacteria necessitating the addition of bactericide.

Padget maintained that the future requirements for latex technology from 1994 were,

- Low foaming dispersions
- Latex with good intrinsic wettability.
- Latex with improved film-forming characteristics
  (consequently low VOC requirement).

Chapman(9) of Berger paints in 1994 reported on the efficacy of waterborne media as anti-corrosive systems. Environmental legislation was viewed as the primary driving force for waterborne development within paint companies rather than "conscience pricking" motives. The global trend in VOC reduction was described as initiating in the US, followed by Europe, with much slower response from the Asia Pacific region. The 1990 world coating market was identified as being 23 million tonnes with 10% contribution from coatings to the total man-made VOC and 5% being derived from building and construction. Chapman also expressed concern over the polluting aspects of waterborne.

Pettersson(10) in 1996 reported on the new development of dendrimer or star polymers and their potential application to high solids alkyds. Hyperbranched polyesters and tall oil polyesters had been utilised to produce 75% oil-length, acid values of 10mg KOH/g and OH values of 7mg KOH/g and compared to conventional alkyds based on pentaerythritol, di-pentaerythritol, phthalic anhydride and tall oil fatty acids of similar molecular weight. The results were,

Table 7.6. Comparison of viscosity and drying times between conventional and hyperbranched

	Conventional alkyd	**Hyperbranched**
Viscosity	20,000 mPa.s @ 23ºC	8,000 mPa.s @ 23ºC
Drying times	20 hrs	4 hrs

Hazel(11) of BP chemicals in 1996 reported on life cycle analysis (LCA) for selection of optimum environmental and cost performance. Higher solids and high solids solventborne coatings, waterborne and powder were identified as the routes for coatings users to meet requirements for VOC reduction due to proposed European Legislation aimed at governing air quality. Hazel presented the argument that the company which takes on excessive pollution control, will be less economic, risks losing market share (particularly in global markets) to less environmentally active competitors thereby nullifying or even negating the original intentions. It was also pointed out that as solids content increased towards high solids, the environmental burden/differences would become less significant.

Kiechle (12) Export Market Manager of Keimfargen signalled a renaissance of mineral paints in 1995. The origins dated back to 1878 when King Ludwig I of Bavaria wished to emulate the limestone fresco's of Northern Italy in his own kingdom. Adolf Wilhelm Keim was awarded the imperial patent for the invention and manufacture of liquid potassium silicate paints with inorganic pigments. The benefits were outlined as follows,

- High adhesion.
- Water vapour breathable.
- UV stable in all respects.
- VOC free.

Kiechle believed that the emergence of large DIY supply chains placed cost pressures on the technology for the decorative market and pointed out that silicates were the predominant technology utilised in monument preservation.

Marketplace Review(13) in 1999 quotes Robert Hemmingway, Kalon's Technical Director, suggesting that the first set of VOC limits proposed by CEPE and then taken up by the BCF, were already achievable but the second set of limits would require " a lot more formulation" and alternative technologies. Akzo Nobel had to develop a new resin with Cray Valley to meet the limits for the non-drip gloss trim paints. Goodyear's Pliolite resin failed to meet exterior masonry limits. Akzo's

Weathercoat and McPhersons Powercoat, based on Goodyears Plioway resin currently fail to meet exterior masonry paint limits. Akzo were currently conducting durability trials using a different resin.

The review reported that B&Q considered the BCF targets were soft, for example, phase two target of 30g/L was already achievable and B&Q's own brand contained 3g/L currently. Also, the BCF definition of VOC being BP 250ºC while B&Q had set a boiling point limit of 280ºC making their limits more stringent. B&Q aimed for an absolute reduction, however, a 20% increase in sales, especially for special effect products, means they probably would not meet their targets. B&Q hold 40% of the UK market and therefore Akzo, ICI and Great Mills have adopted the B&Q ***Globe*** system for identifying VOC levels on the product. The BCF ***Box*** for identifying VOC levels on the product, has been adopted by ICI for other than Dulux brands, Homebase and Kalon. Akzo are not reapplying for the Ecolabel. BCF director Moira McMillan said that BCF's program goes a lot further in reducing VOC's and "the ecolabel is not going to change people's buying habits".

7.3 Developments in alkyd technology

Early work on alkyds concentrated on the manipulation of the polyol, acid anhydride and drying oil components of conventional technology. The benefits of pentaerythritol over glycerol, linseed oil over dehydrated castor oil (DCO), as a modifier and maleic anhydride over phthalic anhydride, were reported by Rao, Yaseen and Aggarwal in 1968(14).

7.3.1 Developments in alkyd technology concerning VOC

Hochberg(15) in 1982 reported that low molecular weight, as a route to higher solids alkyds, produced appearance defects. Rapid viscosity increases due to flocculation, colour control and gloss were affected.

Larson and Emmons(16) of Rohm&Haas in 1983 described dicyclopentenyloxyethyl methacrylate DPOMA as a reactive diluent to facilitate the formulation of high solids alkyds. Improved through-dry and alkali resistance, were claimed. The diluent approach was described as acting as a solvent in the high solids formulation, yet was incorporated into the final film at ambient temperatures by oxidative polymerisation.

Kangas and Jones(17) of North Dakota University also warned of the limitations of using low molecular weight characteristics alone to achieve higher solids. Levelling the molecular weight distribution by reducing the polydispersity indices (PDI's), by means of mid-temperature esterification, resulted in lower viscosities. This permitted coatings to be formulated at 2-10% higher solids, however, key properties such as impact resistance, were inferior. Kangas and Jones concluded that the route to high solids technology by means of molecular weight alterations was not feasible.

Fjëldberg of Dyno Industrier AS(18) described in 1987 how additions of between 5 and 30% alkyd resin can improve performance of acrylic dispersions. Poorer freeze-thaw and shear force stability for alkyd emulsions were reported compared to 100% acrylic dispersions. The hardness of alkyd emulsion films was found to be only half that of conventional alkyds due to the plasticisation effect of the emulsifiers. Water Vapour Permeation (WVP) was controllable through manipulation of oil length and molecular weight and was much lower than that for acrylic dispersions. Seven to eight years of exposure of alkyd emulsion formulations delivered very good performance according to Fjëldberg, and future expectations for the technology were high.

Tuckerman(19) of ICI Paints in 1989 described the use of NAD technology for architectural paints to overcome the drawbacks of both conventional alkyd and latex acrylic paints. Formulations at 60% solids were described.

Hayon(20) of DSM in 1993 presented a comparison of a range of high solids alkyds with a conventional type. The situation in 1993 was considered more favourable for high solids alkyds as drying time, through drying and gloss, major drawbacks previously, were considered acceptable. However, hardness development and yellowing resistance were viewed as inferior to conventional. It was suggested that the latter could have been due to vapour uptake and subsequent plasticisation. Hayon suggested that manipulation of molecular weight was not the route to high solids alkyds.

Hofland(21) of DSM in 1994 outlined the positioning for high solids alkyds at that time. High solids alkyds, had a favoured position alongside siliconised alkyds for extreme exterior exposure. Price, hardness development and yellowing were still considered drawbacks of high solids at that time. Alkyd emulsions were best placed in the moderate exposure category where versatility and VOC levels made them competitive. Hybrids of emulsions and high solids were suggested. Hofland cited the LCA studies on acrylic and alkyd emulsions of Guerink(7) and pointed out that many alkyd raw materials were based on renewable sources compared to dwindling petrochemical sources for acrylics. 4-11% coalescing agents for typical acrylic emulsions were compared to a maximum of 2% for alkyd emulsions. VOC-free rheology modifiers (Ser-Ad FX1100 by Servo), pigment pastes (Aquatec by Winter-Bouts) and dryers (cobalt linoleate by Vliegenthart) were reported as being available, allowing for zero VOC formulations.

Rodsrud and Sutcliffe(22) in 1995, of Dyno Industrier AS, reported comparable performance of alkyd emulsions with conventional alkyds in terms of ageing, water adsorption and penetration. The comparison with acrylics were summarised as follows,

Table 7.7. Comparison of performance attributes.

Property	**Alkyd SB**	**Alkyd WB**	**Acrylic dispersion**
Binder penetration	Good	Good	Poor
Fungicidal penetration	Acceptable	V.good	Poor
Adhesion	Good	Good	Poor
Aging	Yes	Yes	Little
Water vapour permeation	Low	Medium	High
VOC values	>30%	>2%	>2%

Blending with up to 40% acrylic was suggested. No difference in wood penetration between solventborne alkyds and waterborne alkyds of the same composition was seen.

Kuo, Chen and Nirali(23) of the Eastern Michigan University in 1994, also reported on the benefits of (meth)acrylic compounds (MA) and oils as reactive diluents in fast air-drying alkyd clear coatings and paint formulations. The unsaturated triglyceride oils underwent autoxidation with formation of hydroperoxides, which initiated rapid polymerisation of the MA, and resulted in very fast alkyd through dry. Incorporation of 20% of (1:4) trimethylolpropane trimethacrylate and linseed oil into a long oil alkyd (Reichhold Beckosol 10.060) produced a clear coating, with a viscosity of 3700 cP, a VOC level of 103g/L and a short drying time of 2 hours. Gloss, UV resistance and yellowing were similar to unmodified paints. Paints based on the same resin gave 334g/L for unmodified and 263g/L for modified.

Rees(24) of Cray Valley in 1995 described long oil alkyds and the overall environmental impact of HS alkyds from the point of view of LCA. Recent improvements in drying characteristics were presented for films of 40 and 50μm for conventional, however, surface drying times were still no better than 5 hours, with through drying times no less than 8 hours. Lithium and strontium driers in combination with cobalt and calcium reduced the surface drying time of Synolac E94155 by 50%. Synolac E94154 used with Co, Li and Ca driers produced potential formulations at 100g/L with faster drying times than those at 250g/L. Yellowing difficulties were reported as being resolved with respect to the new material using soyabean oil with an oil length of 68%.

Hofland(25) of DSM in 1995 compared conventional, acrylic dispersions, high solids and alkyd emulsions in terms of VOC. The results were as follows,

Table 7.8. Comparison of VOC levels for trim paints (g/L excluding water).

Conventional alkyd	**Acrylic dispersion**	**High solids alkyds**	**Alkyd emulsion**
350	190	170	42

(based on data from Akkerman of Akzo Coatings)

Water vapour permeability was reported as a % volume fraction of water after 500 mins. The characteristic permeabilities were,
<1 for conventional
1.5 alkyd emulsion
5 for acrylic/alkyd hybrids
>8 for acrylic dispersions

Hofland recommended HS for extreme conditions with alkyd emulsions competing well with acrylics in moderate conditions but having the advantage of low VOC.

Watson (26) of Croda Resins in 1995 reported on how LCA could show that reduced performance, through simply substituting solventborne with waterborne technology, could put solventborne technology in a more positive light. Long oil alkyds could produce VOC levels of between 350-400 g/L. High solids required 250 g/L, however, the hardness and drying times were not considered adequate. Reactive diluents were described as a means to achieving 250 g/L, while obtaining drying times of 6 hours.

In 1997, Rees(27) suggested that cost and profitability should be given the same consideration as technical performance. The Eco-label made possible the use of high solids, which drove the development for better performance. Use of experimental design and modelling tools were effective in accelerating the delivery of optimum performance with these new materials. Rees used modelling to predict the following attributes,

Table 7.9. Modelling predictions.

Speed of drying	Good predictions possible
Hardness	No success
Yellowing	Less successful (used 4 weeks in dark at 40ºC).
Solids content	Good predictions.

Rees believed that HS offered benefits of one coat application, which can offset the price. Several applications were required for lasures and stains and HS technology could have presented benefits in this area. Drawbacks identified were expensive materials and sag control. Lessons learned from polyurethane thixotropy could have been be utilised.

Viez(28) of DSM in 1998 suggested that not all paints for internal decorative application could meet EC and CEPE proposals for reduction of VOC. Latex dispersions and alkyd emulsions were seen as the routes to VOC compliance. The principal difficulties to overcome were, in terms of durability, yellowing in the dark, adhesion and penetration. Alkyd emulsions were recommended for internal use.

Beetsma, Santing, Hofland and Grootoonk(29) in 1998 described a means of obtaining fast-drying, high hardness and other key properties, that were comparable to those of conventional alkyds.

Hyperbranched molecules achieved low viscosity at high molecular weight. HS alkyds co-polymerised with silicone oligomers produced high levels of durability. Methacrylic or allylic reactive diluents were described which achieved faster drying at low paint viscosity for high solids.

Wildman and Bojarski-McEwen(30) in 1998, of Engineered Polymer Solutions compared VOC levels typical for the available alkyd technologies, identifying 250g/L VOC content for high solids alkyds.

Weijen et al(31) of Sigma coatings in 1999 described high solids alkyds with reactive diluents and dendritic polymers, as routes towards developing lower VOC alkyd paints. High solid alkyds were developed to meet 250 g/L and were a new class of coating. Dendrimers composed of unsaturated fatty acids on the peripheral surface and polyol/di-hydroxy acids on the inside, comprise spherical macromolecules of high molecular weight and low viscosity. The results of a survey of Dutch painters and housing co-operatives, were reported. Drying time for high solids was identified as a drawback by professionals, while cost was a drawback for DIY users. Reactive diluents for alkyds such as methacrylic ester dicylopentadienyloxyethyl methacrylate, drying oils such as linseed oil and low molecular weight alkyds were described.

In 1999, W Rees(32) mentioned that CEPE's upper limits on VOC would cause wholesale substitution of solvent based products. Additionally, the Consultium Consultancy had proposed adoption of mandatory limits, based on the European Ecolabel and B&Q's draft paint policy had thrown down the challenge to paint producers to lower VOC. Rees identifies high solids alkyds, latices, alkyd emulsions and conventional paints, as all being viable. Performance levels of high solids had been raised to a point where they had advantages even over conventional solventborne systems. Overall environmental impact had to be viewed using life-cycle-analysis where high solids had a more favourable comparison, and were equal to waterborne. However in the study conducted by the French Ministry of the Environment, and used to set criteria and thresholds for the European Ecolabel, Rees reported that high solids have VOC emissions between waterborne and conventional technologies. Cost penalties were associated with high solids alkyd systems, however, compared in terms of dry film per litre of paint with waterborne, the overall cost was estimated to be lower. Rees suggested that reformulation of high solids paints away from the optimum performance using modelling techniques allowed more favorable cost comparison with water based and conventional. Manipulating the PVC through particle size distribution and increasing the extender:pigment ratio was possible due to the thicker coatings applied. One coat application and resultant labour costs was a key characteristic.

Manshausen(33) of Jäger (Head of Application and Quality Labs) in 1998, described possibilities for alkyd resins. Alkyd resins could be modified by urethane or acrylics to improve drying characteristics and durability. First generation of waterborne alkyds had acid values of 30-50 mg KOH/g using maleic anhydride for example, and delivered with large quantities of cosolvent such as butyl glycol. Second generation had values of 20-30 mg KOH/g and were pre-neutralised and diluted with water. Acid values of 20 mg KOH/g were reported as current and incorporated polyglycols to achieve self-emulsification. The latest developments were core-shell technologies, which were produced with very low acid values and a surplus of OH groups and reacted with hydrophilic high acid value polyacrylates. A key parameter in emulsion polymers was viewed to be the MFFT , which could be determined by the Tg of the polymer. Monomer selection and polymerisation process controlled the resultant Tg. The principal attribute of pure acrylics was reported to be their colour and gloss stability with their thermoplastic nature being reduced by the incorporation of extremely hard monomers. Vinyl acetate emulsions were normally chosen for wall paints. For low water vapour permeability and weather resistance without chalking, styrenated acrylics were chosen. The first generation of WB polyurethane emulsions were high speed dispersed in water with suitable emulsifiers and co-solvents. Modern waterborne polyurethanes (PU), were described as having acid functional polyols incorporated and were neutralised with an organic base and were self-emulsifying. Due to their high price, they tended to be blended with pure acrylic or styrene-acrylic emulsions. Associated problems with the use of waterborne technology were described as,

- Low temp and humidity drying.
- Flash rusting.
- Wetting agents were required to reduce the surface energy.
- Neutralising amines could form complexes with driers and therefore increase drying times.
- Additives and cosolvents used in emulsions could cause loss of gloss and shelf-life when used in hybrid systems (acrylic/alkyd combinations).
- Acrylic and alkyd emulsions did not form useful millbases to achieve grind characteristics as they have limited shear stability.

Health concerns have been associated with the use of cobalt metal driers to accelerate the drying process in alkyd paints. Alternatives include the use of other metal driers such as manganese, enzymatic curing systems and organic compounds capable of decomposing hydroperoxides(84).

7.4 Developments in acrylic technology

Early work on emulsion technology for decorative paint application focused on appearance attributes and adaptation of latex technology to new roles such as corrosion protection.

Aronson(34) of Tioxide in 1974 reported on the considerations of formulators at that time. Development of opacity was reported as a key future development requirement and six routes to achieving that goal were outlined,

1) Increasing TiO_2 at the same PVC level.
2) Higher opacity grades of TiO_2.
3) Extenders upgrade.
4) Increasing total PVC.
5) Increasing emulsion particle size.
6) Thicker paint films.

(PVC = % pigment volume concentration of the dry-film volume.
CPVC = % PVC of the film at which interparticulate contact is possible)

Simpson(35) of Tioxide in 1978 expressed concerns associated with weathering effects, particularly those associated with chalking. White paints could enjoy the benefit of self-cleaning, however, for tinted systems, it was reported that an undesirable washed-out appearance resulted. It was concluded that as the CPVC was approached, chalking increased and increased further with increasing TiO_2:binder ratio. Close to the CPVC, pigment grade became less important.

Hoy(36) of Union Carbide in 1978 explored the semicontinuous nature of latex production and outlined the influence of key latex manufacturing variables on particle structure and morphology.

Bierwagen(37) in 1979 examined the physical drying processes in latex paints to provide a model by which to predict the on-set of mud-cracking.

In 1981, Burgess, Caldwell and Padget(38) of ICI Mond Division, reported comparable anti-corrosive properties using vinyl acrylic copolymer latex with an alkyd system in early attempts to exploit latex technology for steel protection. Polymerisation in the absence of colloids and in the presence of a minimum surfactant level, produced films with the required O_2 and H_2O barrier properties.

7.4.1 Developments in acrylic technology concerning VOC

Wiel and Zom(39) of Polyvinyl Chemie Holland B.V. in 1981 referred to the development of new emulsions which facilitated their application beyond internal flat walls. Insufficient wetting, flow, gloss and hardness were identified as drawbacks of the early emulsions based on monomers such as ethyl acrylate and vinyl acetate. Developments in particle size distribution, new emulsifiers and surface active agents had led to emulsions with good wetting, flow out and humidity resistance.

Polymers based on harder monomers such as methacrylic acid and acrylonitrile had produced harder films, exhibiting better gloss, pigmentation characteristics and improved resistances. However, it was recognised here that the transition from early films with MFFT's of <20ºC to >40ºC depended on the addition of well-selected aids such as glycol ethers, as volatile coalescents. High gloss, low dirt pick-up, good extension durability and low temperature cure were possible through the use of these new monomers.

Mercurio, Kronberger and Friel(40) of Rohm&Haas developed the theme in 1982 by describing a "new approach" to high gloss, quick-drying enamels using dispersion latex. This approach involved the use of a higher Tg polymer E—1630 with careful selection of cosolvents and coalescing solvents. Glycols imparted good wet-edge and freeze/thaw characteristics and were identified as good cosolvents due to their remaining in the aqueous, rather than polymeric, phases. It was suggested that a blend of efficient ester coalescents with glycol wet-edge agents was the best approach. Additions of 20% solvent on latex solids was quoted. Performance levels, in terms of flow, build and gloss, were comparable with conventional alkyds due to the higher Tg polymers and solvent additions.

Grant(41) of Eastmann in 1981 also commented on the coupling efficiency of cosolvents through understanding of miscibility diagrams of glycol ether/water containing systems. Phase separation was demonstrated to have occurred at different temperatures if the choice of cosolvent and resin was not correct.

Lee and Rudin(42) in 1992 described the kinetic and thermodynamic variables which controlled the structure of poly(methyl methacrylate)/polystyrene two-stage latices. The resultant "core-shell" latex morphology lent itself to production of latex particles with low Tg shells, surrounding higher Tg core materials. This opened the possibility for VOC reduction, as film-formation could be facilitated at temperatures as low as 1ºC, without the addition of a coalescing solvent(43).

Currie(44) of Nacan Products in 1993 described a route to solvent-free latex paints. Ethylene vinyl acetate and acrylated ethylene VA was reported as offering a route to "zero VOC". VOC in latex paint was identified as due to cosolvents (propylene glycol) and coalescing solvents such as dipropylene glycol n-butyl ether, diethylene glycol monobutyl ether acetate and 2,2,4-trimethyl pentane diol-1,3, mono isobutyrate. VOC content was described as being typically 1% coalescent and 3% cosolvent. Currie estimated that the contribution of VOC from waterborne trade paint sales may well have been in the order of 45M Kg's in north America. Polymers based on vinyl acetate, ethylene and acrylic monomers were reported. VA contributed to hydroplasticisation, using water as a coalescing solvent. Ethylene, due to its Tg being –80ºC, delivered softness without tack. Acrylic additions regulated the VA content to control hydrolysis resistance. Formulations based on Vinamul 3692 were compared in terms of scrub resistance, with conventionally plasticised vinyl acrylic. Scrubability, durability and gloss stability in a semi-gloss compared equally with conventional films. It was pointed out that that the German standard DIN 53.778 allowed 28 days drying time prior to testing compared to seven days allowed for in ASTM D2486. Currie also pointed out that VOC reduction was required in addition, for tinters, rheology modifiers such as associative thickeners and residual monomer levels remaining in resin as supplied. The influence of testing régimes was pointed out for evaluating new technology in that full properties for solvent free latices took several weeks.

Lewis(45) of the PRA in 1993 described the emergence of waterborne gloss enamels as a reemergence and compared the properties of the latest offerings with earlier generations. The performance of those waterborne glosses in the mid seventies was considered to be ineffective by the consumer and were withdrawn after a short period of time. Problems associated with flow and poor block resistance were described. Developments over the years, such as associative thickeners, greatly improved the properties of these materials. Lewis referred to a February '93 issue of Which? Consumer magazine in the UK, in which concerns were expressed over the ease-of-use and performance characteristics of waterborne indoor gloss paints.

Richey and Wood(46) of Rohm & Haas in 1994 described ambient temperature crosslinking as an approach to improve the performance of architectural latex enamels. It was recognised that conventional enamels or gloss paints had a significant share of the decorative market despite developments in enamel, latex technology. Cross-linking reactions based on atmospheric, oxidative cure mechanisms, were outlined. The rate of cure could be accelerated by a drier package consisting of a combination of low levels of cobalt drier and unsaturated fatty acids. Substantial improvements in wet and dry adhesion to alkyd substrates and relatively low coalescent demand were attributes associated with this new technology. Candidate formulations equalled or outperformed conventional alkyd enamels in terms of block resistance, resistance to household chemicals and abrasive scrub resistance.

Thames and Wang(47) of the University of Southern Mississippi developed the theme by associating ambient cure with low and zeroVOC requirements. Separating the MFFT requirement from the ultimate Tg of the film was proported to be a route to reducing the VOC requirement. This had been achieved by the workers, through the use of a stearically hindered isocyanate moiety, di-methyl meta-isopropenyl benzyl isocyanate (TMI), which had been reported in the synthesis of acrylic or styrene modified acrylic latices. Formulations of vinyl acrylic and acrylic paints were presented with the following VOC figures expressed in g/L excluding water,

Table 7.10. Formulation details

Polymer type	**20%PVC**	**60%PVC**
Vinyl acrylic	238	152
Modified vinyl acrylic	<0.2	<0.4
Acrylic	133	125
Acrylic modified	<0.2	<0.3

Separation of the Tg and the MFFT by 30ºC for the vinyls and 20ºC for the acrylics was achieved for the experimental polymers compared to a separation of less than 10ºC for the standard commercial equivalents. The scrub resistance of the vinyl latices equalled that of the commercial polymers while that of the acrylics approached ten times that of the commercial systems. The crosslinking mechanism was not effective when acid functionality was incorporated through the use of methacrylic acid.

Patel(48) of Goodyear Chemicals described the use of de-aromatised mineral spirits (1%aromatic content) such as Exxol D series from Exxon and aromatic free isoparrafins such as Isopar from Exxon and Shellsol from Shell in Goodyear Plioway resins. Excellent adhesion, chemical resistance, stain-blocking and colour retention were described. The benefits of Occupational Exposure Limits (OEL) of 300 ppm for de-aromatized mineral spirits, compared to 100ppm for standard and 50ppm for high flash solvents were outlined.

Warson(49) (Chemical and Polymer Consultant) in 1998, described developments in emulsion polymerisation since 1980. Emulsifier-free latices with polymerisable surfactants were described. The potential of core-shell polymerisation was also described. Compounds including multiple double bonds, derived from cyclopentadienyl acrylate, were described which facilitated air curing in the same manner as drying oils.

7.5 Developments in technology for coating wood

The area of greatest concern in the transition from waterborne to solvent decorative coating technology, has been the protection of exterior wood. Experiences with waterborne hybrids of acrylic/alkyd chemistry in Norway, have resulted in much concern being expressed over the viability of waterborne for exterior wood protection, Thus, a treatment of wood coating technology developments merits special mention in this review.

Derbyshire and Miller(50) of the Princes Risborough Laboratory (BRE) in 1981 reflected the developmental concerns of formulators with clear finishes for exterior wood at that time. It was reported that ultraviolet light was highly active in degrading wood, resulting in breakdown of lignin in the middle lamella. The most pronounced effect on surface integrity resulted from the depolymerisation of the cellulose constituent. It was also found that wood exposed to wavelengths greater than 400nm degraded at half the rate of wood exposed to the full solar spectrum. It was therefore concluded that visible light had a significant role to play and this posed a serious limitation in principle, on the performance of clear and semitransparent finishes.

Boxall, Hayes, Laidlaw and Miller(51) of the Princes Risborough Laboratory (BRE) in 1984, pointed out that of over 200 products reviewed in a study of commercially available products, poor performance overall was manifest, with relatively few products in good condition after two years. The use of UV absorbing extenders was explored and it was found that pulverised fuel ash (PFA) and phlogopite mica afforded improved performance for exterior exposure. Various modified alkyd, polyurethane and acrylic binders were chosen for the study and it was found that within two years, all of the coatings exhibited significant breakdown except for the polyurethane and the acrylic.

Woodridge(52) of Berger Decorative Paints outlined the role of aqueous coatings for wood finishing in 1984. The growth of aqueous coatings was presented diagrammatically in figure 7.1.

Woodridge singled out water permeability as one performance criterion for examination. It was pointed out that badly weathered wood required adequate preparation whatever system was chosen.

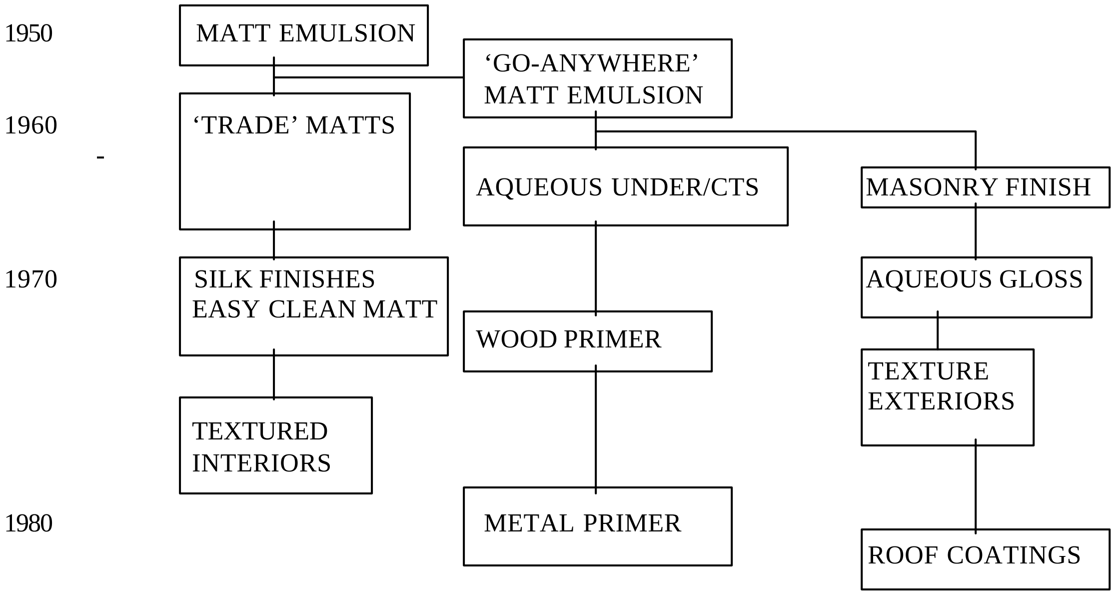


Figure 7.1. Development of Aqueous coatings

Water uptake in excess of 26% for long periods, was considered a risk in terms of wood decay. In addition, reference was made to Dooper in 1975 who maintained that permeability should be less than 50g/m^2/24hours, and Burgers in 1978 maintaining 60g/m^2/24hours for European redwood and 35g/m^2/24hours for meranti was required to prevent wood cracking. The following permeability data was presented for waterborne and conventional systems.

Table 7.11. Influence of composition on permeability.

System	**Permeability (g/m^2/24hours)**
2 cts PVA copolymer paint (at CPVC)	125-200
2 cts Acrylic gloss over 1 ct primer	50
3 cts Conventional gloss system	11

Table 7.12. Permeabilities of current paint systems for wood.

System	**Permeability (g/m^2/24hours)**
2 cts Transparent stain – low build	50-125
2 cts Transparent stain – high build	40
2 cts Opaque stain/matt	30-60
3 cts Aqueous gloss system	50
2 cts Solventborne microporous system	40

The low permeability of conventional systems, it was suggested, led to the common phenomenon of blistering and flaking. It was concluded that whatever the exposure requirement, an aqueous system was available that would have met the requirement.

Derby(53) of Air Products and Chemicals in 1995 described the use of acrylic/urethane hybrid polymers. Good film build, minimal grain rise, excellent stain and chemical resistance along with comparable gloss to conventional products were reported. In addition, good UV resistance and zero yellowing were encountered.

Aagaard, Lund, and Markussen(54) of Jotun A/S Norway in 1994 addressed the issues, which concerned serious wood rot in exterior cladding in Norway. A hybrid, waterborne system of alkyd and acrylic had been used to protect exterior wood cladding in Norway and between 1983 and 1992, 1500 damage inspections were made.
The frequency of damage was high in houses treated with waterborne opaque stain or paint. The attack took the form of the common jelly fungus *Dacrymyces Stillatus.* Some of the conclusions arrived at from the study were,

- Concerns already existed over the quality of Scandinavian spruce forests. 30% of standing trees exhibited rot blighting.
- Dense pinewood with a high proportion of heartwood had been formerly used and in recent years spruce had almost exclusively been used.
- Standards that applied to exterior wooden cladding in Norway, did not exclude "blue stain" and weathering.
- Architectural design had evolved to enhance aesthetic concepts and had compromised traditional design, which afforded better protection.
- Changes from dark to light colour schemes could have meant that the 32°C substrate temperature, lethal to *Dacrymyces Stillatus* would not have been exceeded as often as before.

The final conclusion pointed to the recommendation that cladding should have been treated as soon as possible after installation so as to avoid weathering of the timber prior to coating. Additionally, it was recommended that a hydrophobic oil primer should have been used as a first coat. The emphasis on adequate wood pretreatment prior to coating is in accordance with work carried out by the BRE(55,56).

Trotman(55) of the BRE in 1996 suggested that well formulated waterborne paints could out-perform solventborne paints. It was particularly recommended that in maintenance work that exposed wood should be sealed and consolidated with a solventborne primer before applying any waterborne product.

Loos and Thys(57) of Akzo Nobel Resins in 1996 described routes to lowering the VOC requirement of waterborne binders for wood coatings. It was stated that alkyd emulsions could be formulated at zero VOC and offered advantages as a primer over acrylic dispersions. Poor block resistance in the early stages was a draw back due to slow drying. It was suggested that structured, self cross-linking latices could provide the route to low temperature cure with the necessary flexibility. VOC figures were presented for comparison.

Table 7.13. Comparison of structured cross-linked latex with conventional technology and other emulsions.

Parameter	Solventborne	W/B alkyd primer	W/B acrylic primer	Structured Cross-link
VOC g/L	400	0	0-150	90

Tillman(58) in 1999, discussed the strategy of paint or stain on buildings and reminded contractors that September 1999 was the deadline for US EPA regulations on architectural and industrial maintenance coatings. Antonio Leandres, Technical Manager for Akzo-Nobel (Sikkens brand in the US), stated that stains would be most affected by the new VOC ruling and that a better product would be offered to the consumer at the same price. Leandres also maintained that the oil/latex split in the stain market was 50/50 and that latex had made inroads into the oil based stain market. It was suggested that the new VOC ruling would force more users to change products.

Podgorski and Roux(59) in 1999 described the outcome of investigations into the durability of coatings for wood. The increase of Tg with weathering time, as the coating continued to cross link, was outlined. It was stated that the dimensional flexibility and therefore durability was related to Tg. Best performance was associated with Tg's between 25-30ºC. Greater oil-lengths could produce Tg's of less than 25ºC. The authors investigated the treatment of wood to reduce substrate dimensional variability and found that chemical and thermal treatments lead to substrates with poorer wettability. Polyethylene glycol was identified as a useful addition to primers to stabilise the movement of the substrate and lower colour change due to UV exposure. It could only be used in waterborne media and operated as a plasticiser to lower the Tg of the primer. Plasma treatment of the substrate, normally used on plastics of low surface energy, led to ideal surface characteristics in terms of wettability, however the performance benefits were not established.

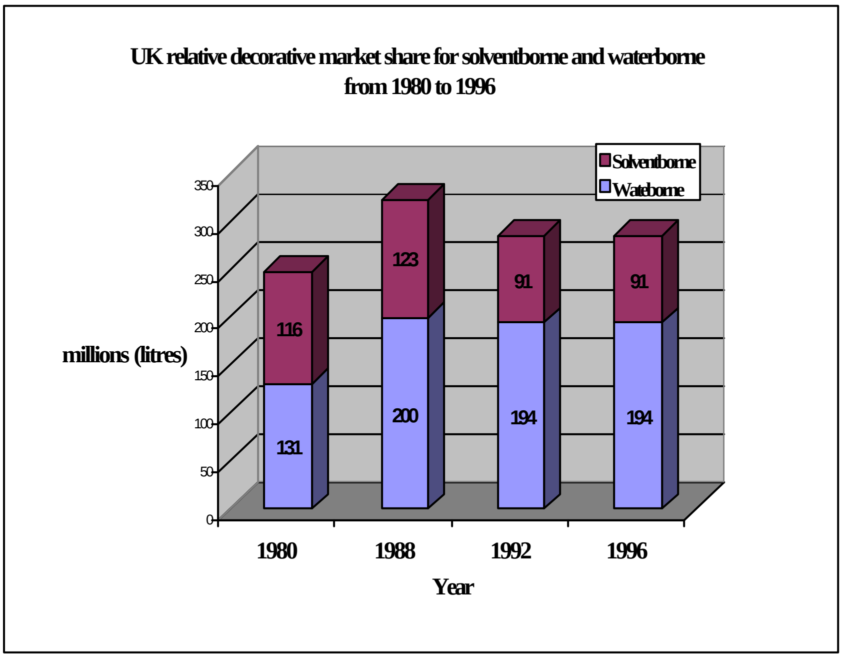
7.6 Solvent developments

Taylor(60) of Esso Chemicals Ltd., in 1985 recognised the pressure on paint producers to reduce VOC and suggested that alternative high boiling point solvents with better solvating power were required to cope with the move to increased solids. A series of high boiling aliphatic esters, hexyl-acetates and heptyl-acetates, were identified which imparted some of the benefits of aliphatic hydrocarbons while exhibiting the solvency of oxygenated materials.

Dawoodi(61) of BP chemicals in 1986, reported on the reprotoxic effects of glycol ethers as highlighted by the European Chemical Industry Ecology and Toxicology Centre (ECETOC). The effects were reported as being confined to methyl glycol ether, ethyl glycol ether and their respective acetate esters. Effects consisted of bone marrow damage, testicular atrophy and teratogenicity (damage to the foetus). Effects were observed for methyl glycol ether at concentrations as low as 10ppm. Butyl glycol ether and butyl glycol acetate were not identified as exerting bone marrow damage or reproductive effects. In addition, no TLV's had been associated with diglycol ethers and acetates. Propylene based glycol ethers and acetates had fast growing acceptance by coatings and resin manufacturers. BP offered ethoxypropyl acetate as a new glycol ether acetate to substitute the commercially important ethyl glycol acetate.

Frederix (62) of Shell Research, in 1996 reported work on compliance technologies. It was shown that for ambient temperature cure coatings, the solvent-free and high solids route led to technological drawbacks such as longer drying times, reduced long term flexibility by on-going extraction of components such as benzyl alcohol and the likelihood of internal film stresses. Where the characteristic high build of high solids may have been an advantage in industrial sectors, it was seen as a drawback in the decorative scenario. Solids could have been increased by careful manipulation of pigment packages, particle size distributions to optimise packing.

Paterson[(63)] of Exxon in 1999, stated that VOC contribution from decorative paints represented 3% from all man-made sources (R. Leggetter,Decorative Paint and the Environment, NHHWF Conference, London, 1996). The conclusions were that solventborne technology remained a mature but resilient market segment. Little development in the use of higher quality solvents in this area was reported. Low volatility, high flash point hydrocarbons were seen to be emerging as the leading diluents for solventborne paints. High solids alkyd glosses, based on selected isoparaffinic solvents, offered the optimum combination of low environmental impact, low risk to the applicator and convenience of application. The market share for decorative solventborne versus decorative waterborne was presented.



SB market stable at 32% from '92 to '96 with little market penetration due to consumer requirements for cost, performance, familiarity and ease of application.

Figure 7.2 UK relative decorative solventborne/waterborne market share 1980-1996.

7.7 Emerging technologies with low or VOC-free potential

7.7.1 Silicate based paints

Silicate barrier coatings are widely available commercially throughout the world.
References on the Internet identifies several companies across the world who are supplying the paints for decorative purposes. They appear to be aimed specifically at masonry and plaster for both large scale exterior projects e.g. the San Siro stadium in Milan, and interior applications.

The mineral components of the paints are sodium or potassium oxide and silica with various inorganic pigments. The Austrian company, Keimfarben, offers over 700 colours available in "smooth or stone" finishes. They are being sold on the basis that they are VOC free, have exceptional durability and performance characteristics. Keimfarben believe that there are limitations to the depth to which they can penetrate the market. Several reasons are listed below:

1. The materials attract considerable opposition in the marketplace from the petrochemical lobby.
2. While Keim offer a variety of colours, in-store tinting is not possible.
3. They are 20-30% more expensive than their acrylic equivalents, and 3 coats are recommended rather than two with the consequent labour costs.
4. They suffer the same common limitations as water based coatings, such as high humidity drying and rain sensitivity.

Several grades are offered by each company. These range from simple silicate paint for concrete waterproofing, to concrete floor hardening and dust-binding materials. The polymer backbone is based on inorganic materials but formulations contain organic additives depending on the application. For example, the references to the Australian water repellent grade mention siloxane additives, while the Austrian paint producer mentions styrene acrylic dispersions in its technical data. Keimfarben do not offer any hybrids and do not envisage providing the option as they suggest the result would have stability problems.

The materials are available and their use is increasing rapidly. They are sold mainly on architectural specification to contractors though they are available to the DIY market. They are not in the mass market and are not expected to become widely available in the large DIY stores. They are slightly more expensive but offer very good durability and colour retention.

It is believed that these materials should have more application than they have currently. Keimfarben appear to be careful about marketing the material through building renovators and specifically not through the DIY chains.

A preliminary search of the US patents on the Internet suggests that there is little being published on silicate paints for anything other than very specific industrial applications. Three companies are among those currently listing the materials.

1. Keim Mineral Paints Ltd	UK
2. Radcrete	Australia
3. LZ	Austria

An American company (ThermaCell), known to have developed and publicised the technology on the Internet, offers the material through their e-commerce web site (paint-n-stuff.com) but little technical data on the materials are evident. Information is available on the chemistry behind the technology (64).

Silicate paint references refer to a silicate based paint (zinc primer) and the use of a hybrid silicate/styrene acrylic hybrid as examples (65-67).

An important property requirement for silicate coatings, in order to have impact on the decorative coating markets, would be tolerance to existing organic coatings. This topic has been discussed with reference to adhesion on various substrates(68). It has been suggested that this can be done successfully.

Coatings based on this technology have been contrasted with equivalent organic coatings (69). This paper however, was published in 1985 and demonstrates the apparent lack of activity in the literature that normally accompanies an emerging technology. This activity can be contrasted with that observed relating to the use of dendritic materials.

7.7.2 Dendritic polymers and their potential for use in coatings

A dendritic polymer is formed by reacting monomers onto a central compound that has at least two functional groups. The monomers in turn branch out further as the molecular weight is increased. The most obvious use of these materials in coatings technology is the substitution of linear polyols with dendritic polyols. The compounds are more compact (lower hydrodynamic radius) than the linear materials of comparable molecular weight and consequently produce less viscous solutions than their linear equivalents. This presents obvious advantages as the amount of solvent required to solvate the polymers is significantly lowered, possibly to a point where the polymer can be formulated as a 100% solids material.

The hydrodynamic radii (calculated from intrinsic viscosity) also increases approximately linearly with the dendrimer generation. These results suggest that the density of these macromolecules decreases from the core unit. This may have implications for latex particle formation in that the outside of the particle has possibly a different characteristic to that of the core. There may even be potential for latex science in the formation of hard cores as seed for latex particles. However, no mention of their application in latex applications was found in the literature.

The majority of the references both on the Internet (IBM patent engine search of US patents) and in the World Surface Coatings Abstracts relate to industrial applications. Internet literature references are to a broad range of applications, few if any referring to coatings. Fluorinated and silylated dendrimers are mentioned most often without specific application. References are made to both coatings and surfactants.

On the WSCA database there are many references to dendritic–type polymers being used in coatings. A cursory search of the database identifies ~130 references. These are illustrated with the examples shown below.

There are many references to how dendritic polymers are formed. Many are academic with little application detail. Many others deal with the properties of the polymers(70). In this case the property dealt with is Tg, an intrinsic property of coating binders. Reference (71) gives a description of how the materials are prepared.

The coatings companies are well aware of the potential of the materials and are active in this sector as the number of references show (Courtaulds/Akzo Nobel and DSM). In many cases no specific materials are claimed but the patents convey the breath of functionalities that are available to the chemist in preparing materials(72,73).

It appears that DSM are heavily involved in the technology as they have made licence agreements with a company (Dentritech) specialising in these materials. This company was formed in the US as a subsidiary of the Michican Molecular Institute with the Dow Chemical Company. The company is examining the potential of the use of dendrimers in high performance coatings. DSM were reported in 1993 to have been approaching the market with the technology(74). They are also looking at pilot synthesis of the materials(75).

The materials have also being examined for use in waterborne inks as shown by the Xerox patent (76). As mentioned previously the main application area for the technology is in the area of high performance industrial coatings where high volumes of solvent are required to solvate the binder. The obvious and immediate application for the technology in decorative applications, lies with high solids, solvent free and water based alkyds. With lower intrinsic viscosity for a given molecular weight, coalescence should be achieved more effectively and the strength of the polymer film should be greater, all with significantly lower solvent use(77).

References refer to the materials as base polymers for a variety of coatings e.g. polyurethane polyols, but potentially the same technology can be applied to polyols used in polyesters, alkyds and epoxies (78,79).

There are many references to their use in high solids and water borne coatings. One paper makes specific reference to their use in waterborne wood stains(80). For this purpose the materials may be ideal as pore penetration, which is a major aspect of wood coating technology.

It appears that there are even references to the polymers being used with specifically low VOC coating formulations in mind, though not necessarily in decorative coatings(81).

It appears that dendritic polymers are just one of several novel technologies that are making their appearance in the literature. Developments are also taking place in catalytic chain transfer polymerisation with reviews on these technologies currently available (82,83).

The use of super-critical CO_2 as a solvent for paint has been described(85). At a temperature of 31.3°C and a pressure of 7.4 MPa(72.9 atm), CO_2 exists in a liquid state and has similar solvency to aromatic hydrocarbons. This property has been used in the US, by paint applicators and manufacturers(86) , to use atmospheric $CO_{2,}$ converted to its super-critical state, thereby eliminating the VOC requirement. DYRUP Ltd. in Europe, have embarked on the route of super-critical $CO_{2\,,}$ for use as a solvent for the impregnation of wood preservatives. This concept presents the opportunity for VOC elimination in paints. Specialized apparatus is required and therefore its impact on the decorative sector in the short-term would expected to be minimal. However, the use of spraying equipment by professionals for exterior flat walls and interior ceilings could result in new paint materials being applied in the future. The impact of the solvent directive on factory applied coatings and the efficacy of their application to joinery may have an impact on the performance of joinery in the near future where precautions are not taken. This development in the treatment of joinery could alleviate any fears associated with radical changes to this manufacturing sector.

7.8 Review of decorative paint technology patents from 1980 to the present

The decorative paint sector can be split into two areas, alkyd technology and latex technology. Originally, most decorative paints were based on solventborne alkyd technology, however concerns over the related environmental impact and health and safety issues led to the development of waterborne alternatives, the fore-runners of which were latex paints. Currently, latex paints predominate in the decorative market with regards to internal flat wall paints, while conventional alkyds remain the polymer of choice for wood coatings and certain external applications. Within the traditional solventborne sector (alkyd technology), the primary focus has been on reducing the amount of solvent required to solvate the resin with a subsequent increase in the volume solids, i.e. high solids technology. A desire to exploit the benefits of both waterborne and alkyd technology has also led to the development of alkyd emulsions. Innovations within latex technology over the past twenty years has seen the development of new polymerisation techniques which has led to the production of polymers with unusual shapes, e.g. star and telechelic and improved polymer properties.

7.8.1 Alkyd technology.

Conventional alkyd technology, in the decorative field, over the last twenty years has remained, largely static. This is reflected in the number of patents, directly attributable to the decorative sector, registered in this period (62 patents). It is important to note that there has been relatively little activity in this area by the leading decorative paint manufacturers and raw materials suppliers. Many companies are reluctant to register patents to avoid disclose of valuable information regarding areas of interest. However, it is more likely, in this case, that the low level of patent activity in the conventional alkyd sector indicates that the primary research focus is the production of low or zero solvent alternatives to the traditional, conventional alkyds, i.e. alkyd emulsion and high solids technology. Over the same period, 86 patents relating to alternative alkyd technology, for the decorative sector, were found to be registered (56 for high solids alkyds and 30 for alkyd emulsions). Analysis of the patents indicates that alkyd emulsion research was more popular in the eighties with very little activity in the nineties (there are some indications that there is renewed interest in this area). High solids research on the other hand was prevalent in both decades.

7.8.1.1 Alkyd resins.

Alkyd resins are formed by the reaction of polyhydric alcohols and polyfunctional acids and can be further modified with oils to give oil modified resins. Long oil alkyds, optionally blended with medium oil alkyds, remains the major resin used in brush-applied solvent based decorative coatings.

Phthalic anhydride has traditionally been the leading dibasic acid used in alkyd production. As with other dibasic acids such as maleic anhydride, isophthalic acid and terephthalic acid, it imparts hardness and durability to the resulting alkyd. Other acids such as straight chain dibasics, e.g. adipic and sebacic are used to produce less rigid alkyds and are more commonly used in the production of coil coatings.

Since, phthalic anhydride continues to dominate in conventional alkyd formulations due to low cost and ready availability, modification of the alkyd properties is carried out by modifying the fatty acid or fatty acid content. Alkyd resins are commonly modified by urethane or silicon cross-links to impart greatly enhanced performance. The polyols used in the production of alkyds are generally trihydric or greater. Glycerol is the traditional alcohol of choice. It is trifunctional, with two primary and one secondary hydroxyl groups. In terms of long oil alkyds, pentaerythritol is the most commonly used alcohol. It has four primary hydroxyl groups, which allows it to form more complex structures than those formed with trihydric alcohols. Alkyds produced using pentaerythritol consequently exhibit faster drying times, higher viscosities and increased water resistance.

7.8.1.2 Alkyd modifications.

Rosin modifiers

Rosin is a monobasic acid and can be used as a chain stopper; it enables the oil length to be shortened without a subsequent increase in viscosity. Rosin modified alkyds have reduced drying times and are harder than pure alkyds but have the drawback of having poor exterior durability. Other monobasic acids such as benzoic acid can also be used for much the same reasons. ***Chuvash University 1982, SU 891635, Kalinin Polytechnic 1982, SU 854944, Hoechst Ag 1981, DE 2618629***.

Phenolic resins

Modification with phenolic resins results in alkyds with increased water and alkali resistance and improved gloss and hardness. However, as the phenol content increases the colour retention of such alkyds is reduced. ***Hitachi Chem. Co. 1983, JP 58108260, Cargill Inc. 1988, US 4740567, Exxon Chem. Patents Inc 1997, US 5681906.*** Phenol formaldehyde modified alkyds are used as primers, as cheap alternatives to epoxy resins.

Vinyl monomers

Vinyl modification of alkyds using styrene, vinyl toluene and to a lesser extent methyl methacrylate results in alkyds with reduced drying times, increased hardness and greater water and alkali resistance. Vinyl modified alkyds, however, display poorer gloss retention and solvent resistance. ***Atom Chem. Paint Co. 1987, JP 62010170 , Cargill Inc. 1988, US 4720522, Kansai paints 1987, JP 62148576.*** Vinyl modified alkyds are primarily used for metal finishes.

Polyamide

Polyamide modification results in a loosely hydrogen bonded gel structure and imparts thixotropy to the final resin solution. Thixotropic paints derived from these resins are often referred to as non-drip paints. The physical properties of the resulting paints are related to the composition and processing of the alkyd and the type of polyamide used. Typical polyamides are derived from dimer fatty acids and a diamine. ***Sherwin-Williams 1997, US 5591793, Imperial Chemical Industries 1984 EP 86034.***

Urethane alkyds

Long oil urethane alkyds are used in decorative paint formulations to give subsequent reduced drying times and increased hardness. It is possible to replace the entire dibasic component of the alkyd with diisocyanate to give urethane oils. However, the normal process involves the replacement of some of the dibasic component. The isocyanate groups react with the hydroxyl groups to form urethane links. ***Kansai Paint Co. 1992, JP 4255773, PPG Ind. 1986, US 4591518, Kansai Paint Co. 1982, JP 57061049.***

7.8.1.3 Alkyd emulsions

Full gloss finishes are not easily attainable using conventional waterborne technology (acrylic/vinyl emulsions), alkyd technology is still predominantly used in the production of trim paints. In order to capitalise on the properties of alkyds and yet reduce the need for organic solvents, water-reducible alkyd resins have been developed. There are three main ways to render alkyds water-reducible:

1. Incorporation of carboxylic/amine groups which are partially neutralized.
2. External emulsification of the alkyd using surfactant.
3. Water soluble polymer can be incorporated into the alkyd. Polyethylene glycol is used in such a way to produce alkyds that are water-reducible.

Incorporation of carboxylic/amine groups.

The major route to water-reducibility is the preparation of polymers containing acid or base functional groups on the polymer backbone. These polymers are then reacted, on addition of alkali/acid to give water-soluble salts. Alkyds are generally prepared with an acid value of 40-60 using secondary alcohols or secondary ether alcohols as solvent. The acid groups are then neutralised with amine or ammonia. The resulting resin is not soluble in aqueous solutions but can be dispersed since the salt groups prevent precipitation. Resistance to hydrolysis and hence storage stability is critical with these types of resins. As hydrolysis occurs the acid group becomes detached from the polymer leading to destabilisation of the dispersion. Phthalate-based alkyds are susceptible to hydrolysis and therefore are not commonly used for water-reducible resins. Preferred resins are based on either isophthalic acid or trimelletic anhydride. ***Ashland Oil Inc. 1987, US 4659380, Daicel Ltd. 1987, JP 87003858***

Some of the earliest water-reducible resins were based on maleinised oils; i.e. maleic acid reacts across the double bonds of the oil or fatty acid and thereby increasing the acid functionality. Maleinisation, (reaction of an alkyd with maleic anhydride) to increase the number of free carboxylic groups, results in resins with better hydrolytic stability. The carboxylate salt groups are not susceptible to hydrolysis and thus the stability of the dispersion is preserved. ***Vianova 1983, GB 2100271, Coates Bros. 1982, GB 1597763, Kansai Paints Co. 1987, JP 62129366.*** Fatty acid esters of styrene-allyl alcohol can also be maleinised to give water-reducible alkyds. ***Arco Chem. Tech. LP 1996, US 5569714, Daicel 1987, JP 62174214.***

External emulsification of the alkyd using surfactant

Alkyd emulsions are dispersions of alkyd resins in water, which are stabilised by the presence of the surfactant. There are two ways in which stabilisation is achieved, charge repulsion (electrostatic) and repulsion by adsorbed layers (steric). Electrostatic repulsion using anionic surfactant was originally considered the most effective method for stabilising waterborne systems. The use of steric repulsion using nonionic polymeric surfactants is becoming more prevalent. Resin dispersions stabilised using nonionic surfactants are less sensitive to the presence of ions than those stabilised by electrostatic repulsion. Nonionic surfactants are, however, generally more expensive and are required in greater quantity to achieve maximum stability. ***Dai-Nippon Ink and Chemical Inc. 1991, JP 3021673, Hoechst Ag 1998, EP 741176.***

Incorporation of water soluble polymer:

Water-reducible resins can be prepared by reacting hydrophillic groups, such as polyethylene glycol with alkyd resins. Incorporation of water-soluble moieties into the alkyd structure renders the resin self-emulsifying. Addition of water results primarily in a water in oil emulsion that inverts to an oil in water emulsion on further addition. ***Hitachi Chem. Co. 1992, JP 4170410, Clorox Co. 1989, US 4814016, Henkel KGAA 1998, EP 507821***.

7.8.1.4 High-solids alkyds

High solids formulations have emerged as a response to the need to reduce the amount of solvent present in a paint formulation. Increasing the solids content has a consequent effect on the viscosity and thus application properties of the formulation. There are a number of ways to increase the solids content without adversely affecting the application viscosity. Primarily, the molecular weight of the resin can be reduced with the result that less solvent is required for solvation. The consequence of reducing the molecular weight, however, is that substantially larger number of functional groups need to crosslink, in order to achieve films comparable to conventional alkyds. The large number of functional groups required has the negative effect of increasing the viscosity, since they are in general polar in nature. ***Sherwin-Williams 1991, US 49997480.***

Analysis of the patents registered in this area suggests that a method for increasing the solids content is through the use of reactive diluents. Reactive diluents are unsaturated monomers that can be used in place of solvent. During film formation the unsaturated monomers react with the alkyd and copolymerise into the cured film. Allyl ether based oligomers are the most prevalent, in terms of registered patents, in particular trimethylolpropane derivatives. ***Akzo NV 1988, EP 234641, BASF 1992, EP 333723, Coates Bros. 1988, GB 2190672, Reichold Chem. Inc. 1999, EP 552641.*** Other possible reactive diluents are dicyclopentenylmethacrylate, ***Rohm & Haas 1983, US 4387190*** and vinyl monomers ***Kansai Paints Co 1981, JP 80039266.***

Decreasing molecular weight, as a means to increasing solids content, by decreasing the dibasic acid/polyol ratio and going to longer oil length has the negative effect of increasing drying time. Attempts to overcome this problem by increasing the drier concentration has led to accelerated yellowing. Reduction in the tendency for yellowing may be accomplished using aluminium complexes as driers. ***Rhone-Polenc Chem. Ltd. 1996, GB 2269169***

In an attempt to further reduce the impact of the solvent in the paint formulation, solvents that are more environmentally acceptable can be used, such as de-aromatised mineral spirits and isoparraffins. ***Akzo NV 1988, EP 234641, Coates Bros. 1988, EP 253474.***

7.8.1.5 Latex technology

During the period, 1980-1990, over 400 patents, related to latex technology, were registered in the decorative sector. The level of patenting activity waned slightly in the mid-late eighties but overall has been uniform throughout both decades. This reflects the continuing pressure to reduce the amount of organic solvents used by the decorative paint industry. At present, latex paints account for approximately 65% of the market. The remaining 35% is still based on solventborne technology and is comprised of coatings for exterior applications and wood trim. Penetration of latex/emulsion technology, into these areas, has been hampered by a number of factors, such as drying time and film formation in adverse conditions. The inability of latex paints to deliver full gloss finishes has also been perceived as a problem. The need to close the performance gap between conventional solventborne technology and latex technology is the primary focus for the activity in this area.

Latices

Latexes are dispersions of polymer particles in water. They are prepared by first dispersing a monomer, with low water solubility, (acrylic and vinyl resins are by far the most common) in an aqueous phase with the aid of surfactants. Free radical initiated polymerisation (chain growth polymerisation) of the monomers results in a relatively stable emulsion of high molecular weight in water. This type of polymerisation is referred to as emulsion polymerisation. Since latices are dispersions, the high molecular weight of the polymer does not have the effect of increasing viscosity that is manifest with solution based systems.

Associative thickeners

One of the major drawbacks associated with the use of latex paints has been their rheology profile. The viscosity of latex paints increases more dramatically than their solution based counterparts due to the rapid evaporation of the water phase. Certain application defects, such as poor levelling, have been attributed in the main to the anomalous viscosity behaviour of waterborne systems. Some of these problems have been overcome through the use of associative thickeners. Low molecular weight, water soluble polymers with at least two long chain non-polar hydrocarbon groups, such as modified polyurethanes are used to give latex paints with high viscosity at high shear rates and lower viscosity at low shear rates. ***Rheox International Inc. 1999, EP 773263, PPG 1997, EP 741764, Rohm & Haas 1986, EP 190892.***

Latices with reduced coalescing agents

Latices film form by evaporation of the water phase followed by coalescence of the polymer molecules. High molecular weight polymers are used in order to achieve films with good performance characteristics. Such polymers subsequently have high Tg's and high MFFTs. In order to reduce the working temperature of higher Tg polymers coalescing agents such as Texanol (Eastman) are used in the formulation. Latex paints, that are free from coalescing agents, have been formulated using copolymer systems based on vinyl acetate. Vinyl acetate, which is a hard polymer, can be plasticised by water, thus eliminating the need for coalescing solvent. ***Glidden Co. 1994, US 5367018, Glidden Co. 1995, US 5470906, Shell 1989, EP 295727.***

VeoVa based latexes

VeoVa monomers are extremely resistant to alkali attack and therefore find use in coatings for cement. They can also be combined with methacrylates to give flexible water-resistant coatings. ***Shell International Research Mij, 1996, EP 518406, Shell International Research Mij 1996, EP 516202.***

Core-shell technology

Core-shell polymerisation is a technique that allows the polymer morphology to be manipulated. The technique involves changing the monomer composition in a sequential manner as polymerisation progresses. This results in gradient morphology, i.e. a variation in polymer composition between the inner core and the outer shell. Core-shell technology can be used to produce hollow particles or microvoids which can then act as opacifiers. ***Rohm & Haas 1996, US 5527613, Dow Chemicals Co. 1996, US 5521253, Rohm & Haas 1986, US 4594363***.

Core-shell technology may also be used to reduce the requirement for coalescing solvents. Surrounding a hard, high T_g core by a soft, low T_g shell can reduce the MFFT of the polymer and allow it to film form at lower temperatures. Incorporation of styrene improves the gloss levels achievable with latex paints**. *Rohm GMBH 1991, EP 379892, Johnson & Son Inc. 1999, EP 853636***.

Bimodal distribution

Bimodal latex systems consist of a mixture of large and small particles that can pack more efficiently. During film formation the smaller particles fill the interstitial spaces between the larger particles, thus reducing the number of percolation pathways and increasing the integrity of the cured film***. Goodrich 1998, US 5744544, Gencorp Inc., 1998, US 5726259***

7.9 Likely developmental pathways for decorative coatings technology into the next decade

Advances within the decorative sector appear to be closely associated with the introduction of new polymers with various morphologies (star, telechelic and dendritic polymers). Despite the advent of these materials, other areas with exploitable potential do exist, based on existing technology (silicate or cement paints).

7.9.1 Group transfer polymerisation

Group transfer polymerisation involves the repeated catalysed addition of monomer to a growing polymer chain that carries a reactive silyl ketene acetal group. Group transfer polymerisation is used to produce polymers with specifically arranged functional groups. Telechelic (linear, multi-branched polymers containing terminal functional groups) and star polymers (high molecular weight multi-armed polymers containing cross-linked cores) are produced in this way***. Nippon Shokubai Co. 1992, JP 4149207, Shell 1996, US 5496898.***

7.9.2. Dendritic polymers

Other structure control techniques have resulted in the development of hyperbranched dendritic structures. These compounds are more compact than linear polymers of equal molecular size and subsequently require less solvent for solvation***. Oxazogen Inc. 1998, US 5731095, Courtaulds Coatings 1999, GB 2308363, DSM NV 1997, EP 741756***.

7.9.3. Silicate paints

Silicate paints have been used in Europe, particularly in Germany, for over 100 years and were originally based on a mixture of potassium silicate and inorganic pigments. Silicate paints are marketed as being highly durable, environment friendly paints, however they are considerably more expensive than their acrylic equivalents***. Metal Corrosion Protection 1993, SU 1756325, Belorusskii Polytechnic 1993, SU 1738781, PPG 1982, US 431267***.

7.10 Levels of innovation within the decorative sector

Whilst every effort was made to exclude patents relating to industrial applications (marine, automotive, can coatings, stoving, etc.), it should be noted that the number of patents registered are not all directly attributable to the decorative field. Despite this, the patent breakdown (see table 7.14) shows the overall trends for the industry and highlights some of the areas of interest for the individual companies. It is also felt that any gains made in industrial research may have an impact on the decorative sector also.

From the numbers in table 7.14, it can be seen that the largest research area, in terms of patent activity, is conventional latex technology (acrylic/vinyl emulsions). It would appear that the level of activity within conventional alkyd technology is also quite high. However, in some respects the figures are slightly misleading for a number of reasons. Firstly, not all of the patents are directly attributable to the decorative sector and secondly there is a proliferation of Japanese and Russian patents. Japanese companies quite often register a large number of patents pertaining to a single process or product. The level of activity within the alkyd emulsion area and the high solids alkyd appear to be approximately equal.

7.10.1 Resin manufacturers.

Due to increasing pressures related to solvent usage, the trend within the paint sector has been a move towards environmentally friendlier products with low or no solvent content. Resin suppliers can be split into two groups, those supplying solventborne polymers and those supplying waterborne polymers, although in some cases there may be an overlap between the two (for example water borne alkyds).

In terms of patent registration, all three would appear to have a low level of activity within the relevant sectors. This, however, is probably misleading. It may be that it is company policy not to register in the company name or not at all for fear of disclosing valuable market information. Also, certain companies prefer not to register patents and publish their findings in the public domain.

From the figures it can be seen that DSM and Cray Valley are both involved in alkyd technology. Cray Valley in the high solids area and DSM in both high solids and alkyd emulsions. DSM is also heavily involved in dendritic chemistry, one of the emerging areas thought to be of possible interest to the decorative sector. They have a patent registered in the area *DSM NV 1997, EP 741756* and have entered a license agreement with a company specialising in this area (Dentritech).

The patent search revealed 1216 patents for latex, 885 for conventional alkyds, 92 for high solids alkyds and 103 for alkyd emulsions. Those that could be attributed to a company are outlined in table 7.14 below.

Table 7.14 Patent breakdown 1980-1999.

Company	**Conventional alkyd**	**High Solids alkyds**	**Alkyd emulsions**	**Conventional latices**
Polymers				
Rohm & Haas	10	1	2	74
BASF	10	4	-	13
Cray Valley	-	1	-	-
DSM	-	-	2	-
Goodyear	-	-	-	19
Chemicals				
Exxon	1	-	-	5
BP	-	-	1	1
	4	-	1	59
Shell	0	-	-	13
Union Carbide	4	4	-	19
Paint				
ICI	4	1	-	19
Akzo	3	1	-	3
Sherwin Williams	2	4	-	-
PPG	-	2	1	18
Sigma	-	-	-	-
Valspar	-	1	-	-

Goodyear, on the other hand, is involved in styrenated acrylic technology, specifically the Pliolite and Plioway ranges of resins. From the number of registered patents, it would appear that Goodyear is primarily interested in water borne technology. The figures, in this respect, are misleading. Plioway, which is the new generation of styrenated acrylic terpolymers, is soluble in dearomatised mineral spirits and isoparaffins. Products based on these polymers offer low temperature cure along with the penetration characteristics of solution polymers. Goodyear continues to promote the use of solvent borne products on the premise that the level of performance obtained with water borne products is inferior. The activity within the water borne sector may indicate that Goodyear is preparing for legislation prohibiting the use of organic solvents.

The main suppliers of water borne resins are Rohm & Haas and BASF, both of whom feature quite heavily in terms of patent registration (in comparison to other resin suppliers). Rohm & Haas is prolific in patent registration and are heavily involved in all areas of acrylic latex technology, specifically associative thickeners and core shell technology.

7.10.2 Solvent suppliers

Due to the trend towards low or zero VOC products, the market for solvents has been under threat. However, most formulations still require a certain proportion of organic solvent, in order to achieve adequate performance characteristics, for example reactive diluents for high solids technology and cosolvents/coalescing solvents for water borne technology.

The popularity of waterborne technology over other low solvent alternatives is reflected in the high level of activity registered by the solvent suppliers in this area. The trend towards low or zero solvent content technology has led to a decrease in the demand for aromatic solvents. In terms of waterborne products there is an increase in the use of oxygenated solvents, in particular esters and ethers. Union Carbide (Carbitol) and Eastman Chemical (Texanol) feature very strongly in that market. Other major solvent suppliers, such as Exxon and Shell are concentrating on aromatic free solvents, such as dearomatised mineral spirits (Exxol D) and isoparaffins (Shellsol and Isopar). Such solvents find use in high solids formulations and specialist masonry products, such as the Pliolite range from Goodyear.

7.10.3 Multinational paint manufacturers.

From the patent breakdown, it would appear that the leading paint manufacturers are predominantly involved in conventional latex (acrylic/vinyl) technology and that little research is being carried out in alkyd technology. Any activity within the alkyd sector is largely restricted to high solids alkyds. Despite the predominant interest in conventional latex technology, it should be noted that almost all the leading companies have registered at least one patent in the high solids area. This may be due to some crossover from research carried out in the industrial sector and may indicate that advances within the industrial applications field can translate into advances in other sectors.

It is interesting to note that despite having interests in both latex technology and alkyd technology (to a much lesser extent), none of the major companies appear to be involved in patented work in the area of alkyd emulsions.

7.10.4 Others

From the figures, it can be seen that there is a large shortfall between the overall numbers of patents registered and those registered by the major companies within the decorative field (multinational paint manufacturers and raw material suppliers). Other raw material suppliers, specifically pigment suppliers and additive suppliers make up this shortfall along with SMEs, research institutes and private individuals.

In general, there is a large level of patenting activity originating from research institutes and individual researchers in Russia. Japanese companies are also largely responsible for the number of registered patents, which may reflect the nature of the Japanese sector, i.e. large number of patents registered pertaining to a single process or product.

7.11 Factors affecting innovation within the sector

In terms of motivation, the underlying factor, with respect to innovation, is the need to comply with environmental legislation (either now or in the future), specifically regarding solvent usage and emissions (see chapter 4 as well). This is seen clearly in the high level of activity in the conventional latex area and the relatively high level of activity in the alternative alkyd technologies.

Within these specific areas (conventional latex, high solids alkyds and alkyd emulsions), the emphasis has been on product improvement. In terms of specific claims made within individual patents, improvements are cited most often, followed by VOC reduction, with little or no reference made to cost or sustainability. One indication that cost is a major factor may be evident in the low level of activity in the alkyd emulsion area (this technology is available but is still quite costly).

7.12 Major breakthroughs in the technology leading to significant reduction in solvent content in the short to medium term

Significant activity is evident in the area of molecular weight development. Dendrimer technology has attracted the interest, and harnessed the activities of polymer suppliers and paint companies alike. This is likely to offer VOC reduction in the form of alternative high solids coatings.

Super-critical CO_2, is being utilised by major paint suppliers to achieve VOC-free application of paint. The adaptation of this approach to the decorative paints sector for in-situ application of paint presents difficulties in terms of the equipment required.

7.13 Discussions

Review of available literature reveals that the following VOC contents are associated with the most commonly employed technologies for the manufacture of decorative paints and varnishes.

Conventional alkyds	350 g/l
High solids alkyds	250g/L
Alkyd emulsions	40g/L(excluding water)
Acrylic latex(wall)	30 g/L
Acrylic latex(wood)	190g/L(excluding water)
Styrene acrylic solution (exterior wall)	450g/l

The B&Q DIY chain in the UK reported that the VOC definition of 250°C was too low, and chose a limit of 280°C for their own, VOC limits initiative. This is in agreement with the study teams findings. A limit of 250°C on the VOC definition, excludes Texanol™, an important coalescing solvent that has a boiling point of 255°C. The study team has chosen a limit of 280°C to cover most common volatile organic compounds from decorative paints.

Alkyd emulsions have been highlighted as offering significant potential for VOC reduction. Seven to eight years exposure performance have been reported(18). However, uptake in the market has been slow and serious drawbacks still exist inhibiting the penetration of the technology into the marketplace. Formulation has been reported as being difficult, with these binders being high-speed, shear sensitive. Full properties take time to achieve and drying is affected by humidity and temperature in the same way as their waterborne acrylic counterparts. Overcoating time can be long and there is a risk of water entrapment. Yellowing may still occur in common with solventborne alkyds. The current availability of VOC-free tinting pastes along with these binders, offer potential for very low VOC decorative paints with the appearance attributes of conventional products. Although these products have not had an impact currently, the expectation is that with further development, they will have gained a significant market share.

High solids alkyds suffer from yellowing, which is more rapid and full hardness properties take longer to acquire with surface drying times being reported as being up to 5 hours(24). Product gate cost, cost of manufacturing up to dispatch, is twice that of conventional alkyd products. However, it is believed that high solids products have a role to play, are being used in the marketplace and can work well where performance expectations are demanding. The one-coat application has proven beneficial for professional painters. Application and service lifetime attributes, especially under adverse conditions, places this technology in an important position.

Typical values of VOC content for conventional alkyd, acrylic dispersion, high solids alkyd and alkyd emulsion(excluding water) are reported as being 350, 190, 250 and 42g/L respectively. This agrees well with the findings of the study team.

Ambient temperature, cross-linking latex has been reported and it appears that this can be facilitated by an oxidatively cured cross-linking additive. Curing at temperatures of 1°C have been reported, however, the manufacturers do not recommend application below 5°C. The absence of cosolvent to maintain an open film at higher temperatures would create difficulties in reworking the film. Open times for existing waterborne latex paints for trim applications currently suffer from short open times, even with the addition of cosolvent such as propylene glycol. Which magazine in 1993(45) expressed concern over the user friendliness of these products.

Research at the BRE highlighted the demands placed upon any wood coating for exterior use reporting that from 200 products, few were in good condition after two years. However, two products, which did perform, well in particular were a polyurethane and an acrylic. This is expected as the acrylic would maintain flexibility as it is UV resilient and the urethane would have very stable cross-linking chemistry. The higher permeability of latex systems has been reported(52) and is in agreement with measurements taken within the study teams laboratory. Levels of permeability have been measured at levels close to that permissible before wood rot ensues. This reinforces the view that waterborne latex systems for wood should be used in conjunction with a solventborne primer. This is one of the findings reported from the investigations into wood rot beneath waterborne coatings in Scandinavia. However, high permeability has been known to cause blistering where rouge water ingress becomes trapped behind the film. A waterborne latex system over a solventborne, barrier type primer, offers the potential for VOC reduction along with the potential for increased service lifetimes. Research activity into dendrimer polymers has been marked with a leading raw material supplier actively licensing this technology. Although market impact has been non-existent, it is expected that these materials will find application, albeit in the industrial coatings sector initially.

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Chapter 8. Decorative paints and varnish formulation technology.

8.1 Introduction.

Decorative paints and varnishes are essentially blends of raw materials which are formulated for application under a wide range of uncontrolled conditions, in order to modify the characteristics of the surfaces to which they are applied. The manufacturer seeks to achieve this by skilful selection and processing of these raw materials in a cost-effective way so that a balanced range of properties is delivered to the ultimate user, with due regard to the market sector at which the product is aimed. These include:

- Ease of application / User friendliness.
- Drying rate
- Compatibility
- Appropriate decorative effects.
- Durability.
- Protection.

In recent years consumer concerns about environmental and health and safety issues have increased to such an extent that in many European markets, they are regarded as being of equal importance to some or all of these. In general, the relative importance of each of them varies according to the intended end use.

In this sector all coatings start their useful lives as liquid materials which, following application, must undergo a number of physical and chemical transformations in order to produce serviceable coatings. This implies that during the drying/curing process, some components (the volatiles), are lost from the liquid material in order to allow the dried film to develop (the solids). If solventborne technology is employed, these volatiles will be essentially VOCs. If waterborne technology is employed, they will be both water and VOCs, water being predominant. Thus, decorative coatings fall into two convenient categories depending on the carrier medium being used. Formulations are either waterborne or solventborne. Over the past two decades, the technologies employed have fallen into generic types depending on the end use with the most significant development being the growing replacement of traditional solventborne paints with waterborne equivalents. A discussion on the formulating characteristics and formulating trends in the decorative sector over the past two decades is presented here. Typical formulations for decorative application are discussed with emphasis on the formulation parameter characteristics related to the intended end-use and the subsequent impact on required levels of VOC. VOC is quoted as g/L for comparison purposes for waterborne and solventborne alike. Where possible, the nearest equivalent formulations have been sourced from raw material suppliers starting point formulations and those generally available in the public domain.

8.2 Classification of decorative coating products.

A considerable range of products are available for decorative application. Sixty types have been identified when solventborne and waterborne coatings for each application are considered. These coating types are outlined in the inventories detailed in Tables 8.1 to 8.3. Forty eight categories for the classification of products for wood alone(87), are available. The inventory of decorative paints and varnishes for the purpose of a possible Directive on VOC limits, can be reduced to a condensed classification of 11 categories. This condensed classification is presented in Tables 8.4 and 8.5, which forms the basis of the proposal of a classification of decorative paints and varnishes. Particular attention has been directed to the principal decorative applications with regard to the volumes used. These applications are as follows,

Inerior wall and ceiling paints for plaster etc.
Exterior wall paints for masonry, brick etc.
Interior/exterior wood/metal primers, undercoats and finish paints.
Interior/exterior stains and varnishes for wood.

The European production/consumption of decorative paint is estimated at 3848 kilotonnes (table 4.2.4). The applications presented in the above classes represent 90% of the total market of paint production in Europe (section 4.2.2) and therefore, the majority of decorative paint volume consumed. Therefore, particular attention is paid to these categories in terms of their functional and formulation details. The remaining categories will be treated in summary.

Table 8.1 Inventory of decorative paints for plaster, plasterboard, and masonry

Class	**Coating & Substrate**
1	**Alkali resisting primer for plaster and masonry**
2	**Full gloss finish for internal plaster plasterboard walls and ceilings**
3	**Semi-gloss finish for internal plaster plasterboard walls and ceiling**
4	**Low gloss finish for internal plaster plasterboard walls and ceilings**
5	**Full gloss finish for external masonry**
6	**Low gloss finish for external masonry**
7	**Water repellents**
8	**Stabilising solutions**
9	**Primer sealers**
10	**2-Pack primers**
11	**2-Pack finish coats**

Table 8.2 Inventory of decorative coatings for wood

Class	**Coating & Substrate**
12	**Wood primer**
13	**Wood undercoat**
14	**Wood full gloss paint**
15	**Wood full gloss varnish**
16	**Wood semi-gloss paints**
17	**Wood semi-gloss varnishes**
18	**Wood low gloss paints**
19	**Wood low gloss varnishes**
20	**Wood penetrating stains**
21	**Wood high build stains**
22	**Wood varnishes for floors. One - pack**
23	**Wood varnishes for floors. Two – pack**

Table 8.3 Inventory for decorative paints for metal or plastic

Class	**Coating & Substrate**
24	**Primers for ferrous metals**
25	**Primers for aluminium**
26	**Primers for zinc**
27	**Primers for plastics**
28	**Undercoats or primer surfacers for metals**
29	**Finish coats for metals**
30	**Finish coats for plastics**

Table 8.4 ***First proposal for classification of decorative coatings for the development of a possible VOC directive.***

Category	**Type**
1.1 Interior matt walls and ceilings*	W/B
1.2 Interior matt walls and ceilings*	S/B
2.1 Interior glossy walls and ceilings**	W/B
2.2 Interior glossy walls and ceilings**	S/B
3.1 Exterior masonry walls	W/B
3.2 Exterior masonry walls	S/B
4.1 Interior/exterior trim and cladding paint, varnish and lasures for wood and metal.	W/B
4.2 Interior/exterior trim and cladding paint, varnish and lasures for wood and metal	S/B
5.1 Interior/exterior trim woodstains	W/B
5.2 Interior/exterior trim woodstains	S/B
6.1 Primer/sealer for wood and stain block for walls and ceilings.	W/B
6.2 Primer/sealer for wood and stain block for walls and ceilings.	S/B
7.1 One pack speciality coatings	W/B
7.2 One pack speciality coatings	S/B
8.1 Binding primers to stabilise loose substrate particles and to impart hydrophobic properties.	W/B
8.2 Binding primers to stabilise loose substrate particles and impart hydrophobic properties.	S/B
9.1Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	W/B
9.2 Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	S/B
10 One pack reactive coatings for specific end use such as floors e.g moisture curing polyisocyanate.	S/B

*gloss levels <25 @ 60°
**gloss levels >25 @ 60°

Table 8.5 ***Second proposal for classification of decorative coatings for the development of a possible VOC directive.***

Category	Type
1.1 Interior matt walls and ceilings*	W/B
1.2 Interior matt walls and ceilings*	S/B
2.1 Interior glossy walls and ceilings**	W/B
2.2 Interior glossy walls and ceilings**	S/B
3.1 Exterior masonry walls	W/B
3.2 Exterior masonry walls for adverse conditions	S/B
4.1 Interior trim paint, varnish and lasures, for wood and metal	W/B
4.2 Interior trim paint, varnish and lasures, for wood and metal	S/B
5.1 Exterior trim and cladding paint, varnish and lasures for wood and metal	W/B
5.2 Exterior trim and cladding paint, varnish and lasures for wood and metal	S/B
6.1 Interior/exterior trim woodstains	W/B
6.2 Interior/exterior trim woodstains	S/B
7.1 Primer/sealer for wood and stain block for walls and ceilings	W/B
7.2 Primer/sealer for wood and stain block for walls and ceilings	S/B
8.1 One pack speciality coatings	W/B
8.2 One pack speciality coatings	S/B
9.1 Binding primers to stabilise loose substrate particles and to impart hydrophobic properties.	W/B
9.2 Binding primers to stabilise loose substrate particles and impart hydrophobic properties.	S/B
10.1Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	W/B
10.2 Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	S/B
11 One pack reactive coatings for specific end use such as floors e.g moisture curing polyisocyanate.	S/B

*gloss levels <25 @ 60°
**gloss levels >25 @ 60°

8.3 Characterisation of conventional decorative products.

The following section describes the materials employed by formulators for use in products for decorative application. Section 8.3.1 deals with the typical materials used for the formation of the decorative film, while section 8.3.2 deals with the additives, which have traditionally been used to impart the decorative, in-service and application properties to the paints.

8.3.1 Film forming materials.

The vast majority of decorative coating technology is based on solventborne alkyd and latex or waterborne emulsion technology. Alkyd resins have been used for many decades and have dominated the trim and joinery sector due to their competitive costs and superior application and appearance attributes. Wall paints have been dominated by latex paints, first finding their application in the 1950's. Polyurethane, epoxy and silicone technologies have found indisputable niche roles within decorative coating applications.

8.3.1.1 Alkyd resins.

Alkyd resins are derived from the reaction of polyhydric alcohol and polyfunctional acids. These resins have dominated the solventborne decorative coatings industry for many decades. This has been due to their being inexpensive resins that are readily modified with other materials to influence control over their durability, flexibility, chemical resistance and drying times. Being polyesters, they are susceptible to ester hydrolysis, which makes them sensitive to alkali. However, they do offer excellent gloss levels. Alkyds can be modified by many other materials. Rosin, abietic acid, which is easily involved in esterification with OH groups also contributes unsaturation and confers enhanced hardness, durability, water and solvent resistance. Vegetable oils are reacted with the polyol and subsequently esterified to produce an oil-modified alkyd. Styrene and silicon modification improves toughness and durability respectively. This constitutes the dominant quantity of the material utilised by the coatings industry. The incorporation of the oil allows considerable control of the drying by oxidative means and supports the competitive cost of these materials. Alkyds can also be modified by phenolic resins, due to the available OH groups, to increase their alkali, water and chemical resistance. Silicone resins can also be reacted across the free OH functionality to impart superior exterior durability. Typical raw materials for the manufacture of alkyd resins are,

Table 8.6 Raw materials for alkyd resin manufacture.

Acids	**Alcohol**	**Oil (fatty acid% composition) (91)**
Phthalic anhydride	Glycerol	Linseed (Linolenic 48-54, Linoleic 14-19, Oleic 20-24, saturated acids 10).
Isophthalic acid	Pentaerythritol	Dehydrated castor oil (Linoleic 48-50, Oleic 6-8, saturated acids 2-4, conjugated acids 40-42).
		Tung (Linolenic 3, Linoleic 4, Oleic 7, conjugated acids 80, saturated acids 6).

Film formation is derived from uptake of oxygen by the wet film which becomes involved in oxidation reactions leading to the formation of hydroperoxides as proposed by Farmer in 1942. The hydroperoxide formation occurs at the active methylene groups and this is followed by rearrangement of the double bond structure to achieve conjugation. The hydroperoxides are highly unstable and decompose to form free radicals that can attack the available double bonds to form OH or H_20 reaction products or more importantly, partake in crosslinking to form C-C or C-O-C bonds. The rate of this important reaction is not rapid enough to facilitate the use of these materials as paint binders, and therefore driers are used. These are usually organometallic driers such as cobalt and manganese whose action is specific, i.e. surface or through drying. Normally, a combination package is used.

Alkyd characteristics are based on the oil length used. Oil length refers to the percent of oil by weight used in the preparation. Long oil alkyds (60-75%) are soluble in aliphatic solvents and based on linseed oil and tall oil. Increasing oil length leads to increased drying times, flexibility and solubility in aliphatic hydrocarbon solvents. They possess good brushing and gloss characteristics. Linseed oil alkyds suffer from yellowing and substitution by tall oil alleviates this. Medium oil alkyds (45%) are highly versatile and are also soluble in aliphatic hydrocarbons. Linseed oil is also used here and they tend to find application in higher performing paints such as metal primers for exterior use.

8.3.1.2 Latex or emulsion polymers.

Paints based on latex binders are frequently and incorrectly referred to as emulsion paints. An emulsion is a dispersion of one immiscible liquid in another, while a latex is a dispersion of a solid (as particles of polymer) in a liquid (usually water). An important distinction between alkyd solution binders and these waterborne dispersion latex binders is the means by which they film-form. The alkyd resins dry by solvent evaporation, as they are in solution, and further properties are achieved by the oxidative curing mechanism described earlier. In contrast, latex films form by the evaporation of the water carrier-medium and subsequent close packing of the polymer spheres. The coalescing solvent concentration leads to the softening of the particle, which allows it to flow or coalesce, thereby forming a continuous film. The influence of the ambient conditions at application have immediate implications in that the water must be lost to pack the polymer spheres prior to coalescence. The softening point temperature (glass transition temperature Tg) of the polymer must be low enough to permit coalescence and loss of coalescing solvent must result in an increase in the toughness of the polymer to achieve adequate in-service performance.

There are several serious implications to this coalescent solvent use, apart from the obvious VOC considerations. For example in hard-wearing, water based wood-floor coatings, a considerable period of time is required for the film to attain its optimum properties, even after the film is touch dry. This is because even with the solvent actively plasticising the polymer particles, the achievement of the film properties (interdiffusion) is slow (of the order of days), and while the solvent is in the film, it is soft and has low resistance to mechanical, block or water damage. This is in contrast to solvent based systems where the polymer is always in an interdiffused state (a solution) and the mechanical properties are achieved as soon as the solvent evaporates (hours).

A different scenario occurs with water based alkyd emulsions when, after water evaporation, air mediated cross-linking occurs, at roughly the same rate as is observed for its solvent based equivalent. The alkyd emulsion undergoes phase inversion whereby the system inverts from an oil in water dispersion, to a water in oil dispersion. This has implications, in that the drying film at this point is then a continuous alkyd film containing droplets of water, removing the need for coalescing solvents. Latex paints are thermoplastics, so that in some cases, they are quite slow to attain their optimum hardness and may under certain conditions become quite soft, for example when exposed to strong sunshine.

While both environmentally benign, and, for most application methods adequate as the carrier, water presents some problems. As described above, the polymer in the bulk of water-based systems is carried in the form of either solid or liquid particles. This is inherently an unstable state and during manufacture of the resin itself, care has to be taken so that the polymer is not destabilised. The potential for destabilisation is a feature of most water-based resin systems that carries right through their use, transport, paint formulation and in-can storage. Destabilisation in the form of flocculation can occur for many reasons; mechanical shearing, poor interaction with additives, increase in salt concentration, shocking out during letdown, sensitivity to solvent addition, freeze-thaw cycles and changes in pH. For these reasons, a minimum level of understanding is required by the formulator, as to the sensitivity of the systems and the precautions needed in their use.

As has been presented elsewhere, typical water based formulations can contain many small quantities of additives used for specific purposes. These are added to address specific problems, for example surface defects in the dry film. All have the potential to interact with each other and the main components of the paint, and it is not uncommon to find that the addition of an additive (often at concentrations, 1.0% w/w) does not have the desired effect or causes other problems in the formulation. This results in complex formulations and it is important that the formulator be aware of the potential interactions that can occur and their likely pitfalls. Generally these materials (dispersants, stabilisers and surface wetting agents) along with other water soluble components (latex initiator salts, low molecular weight oligomers and other components) detract from the properties of the final film. Most are exuded to the surface of the film as it forms, but those retained in the body of the film offer routes for water penetration and barriers to the formation of uniform polymer films, with the consequent detraction from the film’s optimum properties. This water sensitivity is relatively permanent in the final film and is apparent after the temporary sensitivity seen during film formation has disappeared. Both phenomena are well recognised and efforts to remedy these problems has centered on speeding up the rate of film formation with the use of new materials, as well as the production of latex resins with lower serum-solubles.

Traditional water borne paints used cellulosic thickeners that were characterised by high viscosity at low shear and quite low viscosity at high shear in contrast to solvent based paint that show more Newtonian behaviour. These paints manifest low viscosity at low shear and little if any loss of viscosity at high shear(5). A lower viscosity at low shear allows the paint to flow out leading to a more uniform film. Associative thickeners (e.g. polyurethanes) overcome this problem by forming networks that are broken with shear, and reform at a rate that allows the film to flow out to an acceptable finish. The flow behaviour improves dramatically and approaches that of the traditional solvent-based materials in some cases. The newer polyurethane associative thickeners are less susceptible to bacterial growth. Emulsion polymerization requires the presence of monomers as starting blocks for polymerization, water as a reaction and carrier medium, surfactant to maintain the evolving polymer in dispersion, initiators to activate the monomer for reaction and chain stoppers to terminate the reaction and control important parameters such as molecular weight.

A wide variety of monomers are available which allow control of final film properties and polymer costs. These chemicals must possess unsaturation in order for the initiator to form a free radical, by which polymerisation can occur. Typical polymers employed by paint manufacturers for the decorative coatings industry are based on acrylic and vinyl chemistry. Acrylics became associated with Plexiglas^{TM} and Perspex^{TM} acrylic sheet and later, as strong substitution fiber for carpets and clothing. The principal building blocks for acrylic polymers are acrylic and methacrylic esters. Methacrylic esters posses a methyl group on the alpha carbon and monomers for coatings are usually based on methyl or ethyl esters, as higher alcohol ester monomers produce softer coatings. They are used to produce copolymers to achieve the desired properties. Thus the properties of the polyester polymer depend on the alcohol used to produce the monomers. Methacrylate polymers are harder and have higher tensile strengths due to the presence of the methyl group. Consequently, methyl methacrylate is considerably harder still. Ethyl and butyl methacrylate polymers are softer. The glass transition temperature of the polymer (Tg), predicts the mechanical properties of the film. Table 8.7 below shows typical values of Tg for common acrylate polymers and associated properties.

Table 8.7 Properties of acrylic polymers$^{(92)}$

Polymer	**Tg °C**	**Properties**
Polymethylacrylate	8	Tack-free, fairly soft, moderately high elongation and tensile strength, fairly high water absorption and moderately high brittle point.
Polyethylacrylate	-22	Tacky, soft and plastic, low tensile strength, very high elongation, slight water absorption and low brittle point.
Poly-n-butylacrylate	-54	Very tacky, very soft and plastic, very low tensile strength, extremely high elongation, very small water absorption, extremely low brittle point.
Polymethylmethacrylate	105	Tack-free, fairly hard, high tensile strength, low elongation, slight water absorption and moderately high brittle point
Polyethylmethacrylate	65	Decreasing hardness and increasing toughness with decreasing Tg.
Polyisobutylmethacrylate	48	
Polyn-butylmethacrylate	20	
Polystyrene	100	High hardness, high gloss and water resistance.

Surfactants create micelles in the water into which monomer is attracted. The surfactant has limited solubility in water. When the critical micelle concentration is exceeded, hydrated aggregates are created. The micelles form due to hydrophilic (or ionic) and hydrophobic (or nonionic) elements of their structure. The hydrophilic portion orients outwards while the hydrophobic component orientates inwards. Insoluble monomer migrates to the hydrophobic micelle centers where polymerization can take place. Initiator is added to provide free radicals, which are activated by heat or some other agent. Typical initiators are hydrogen peroxide or potassium persulphate. Water acts as the medium in which all of the chemical activity occurs. The initiators and monomers are dispersed in the water and therefore the quality of water is important. The presence of metal ions can have a destabilizing effect on the surfactant leading to flocculation of the polymer emulsion. Therefore, deionised water is used.

Polymerisation progresses with surfactant supply to the growing micelle surfaces being self-regulated. The polymerization continues to completion when all of the monomer has been involved in reaction and a dispersion of particles of characteristic particle size distribution is present.

Tinting systems are widely used and offer the paint user a wide selection of available colours, of the order of several thousand, from a selection of standard white paints (bases) and pigment concentrates (tinters). The paints maybe mixed in-store at the point of sale (POS) and sophisticated equipment is required to dispense accurately, the volume of tinter required to produce an accurate colour match. Additions of up to 7% can be made by means of calibrated injecting devices and carousel-type machines are commonly found that inject automatically the required volume of each tinter, predetermined by the recipe. Computer control now offers greater control, and therefore accuracy, over the process and in some cases the computer is interfaced to a spectrophotometer to identify a paint colour match to a fabric or other material. Tinters are employed in solventborne and waterborne technologies alike and therefore they have evolved into universal schemes which has led to some compromise in their flexibility. Tinters are commonly formulated into solvent/surfactant pastes. Ethylene glycol has traditionally been used along with alkylphenol ethoxylates (APE's) surfactants such as nonyl phenol ethoxylate. Toxicological concerns have arisen over the use of ethylene glycol and propylene glycol has been used as a substitute. Other toxicological concerns have arisen, in addition, over the use of APE's and currently, aided by the ever increasing market share of waterborne decorative paints, VOC and APE-free tinting systems have become available from the leading suppliers(93), based on water and alternative surfactants. There are always difficulties associated with formulation stability due to the components of the tinter, water/surfactant and glycol, and this is particularly true where they are required to be universal. Conventional tinters can add up to 35g/L of VOC to a formulation in the form of the glycol, in fact the colsolvent requirement could be fulfilled entirely by tint paste. An important distinction therefore in this study is the definition of the ready-to-use state of the paint formulation which describes all of the VOC required to apply that paint, including that added by the tint paste or by thinning.

8.3.1.3 Comparison between solventborne coatings and waterborne latex binders

Important differences exist between the two types of film, which present distinguishing advantages and disadvantages. Latex films (acrylic) offer very high molecular weight, excellent longevity in terms of UV resistance and require significantly less VOC for their film formation. However, they suffer from drawbacks associated with poor drying at low temperatures and high humidity, poor penetration on porous substrates, lower levels of gloss and poorer barrier properties. Solution films (alkyds) by comparison exhibit high levels of gloss, are based on economic raw materials, are easy to apply and offer relatively good barrier properties. Their drawbacks are also as significant, in that they progressively cure which leads to embrittlement and cracking, and some are prone to yellowing indoors. Their good barrier properties are beneficial when contrasted with those of latex systems. However, the low levels of water permeation of conventional solventborne systems has led to blistering over surfaces that contain high water contents. Wood rot has occurred where rogue water ingress, through unsealed grain ends, remained in the substrate and could not permeate through the film. Solventborne alkyds are susceptible to saponification in the presence of alkali such as cement.

8.3.1.4 Alkyd emulsions.

Water-based alkyd resins have seen renewed interest and significant improvements have been made in the technology. They hold significant potential for low, if not zero VOC formulations, while maintaining the properties associated with their solvent based equivalents. In the past, problems have centered on their production, stability, requirement for neutralisation and drying. These problems have for the most part been overcome using new preparation methods, better dispersants and less solvent and amine neutralisation agents. The new materials are currently produced under high shear conditions with non-ionic surfactants. They may contain little or no solvent and are currently commercially available. The amines were traditionally used as volatile neutralisation agents and it has been shown that their retention in the film is less of a water sensitivity issue and more importantly related to their complexation of the metal ion driers(94). Other issues that have caused problems include the sensitivity of the materials to in-can hydrolysis and the need for alternative grind materials. The first issue has been overcome using less sensitive esters derived from isophthalic acid and pentaerythritol, and the latter by utilising water-soluble unsaturated resins that are incorporated into the film as it dries. These materials are still being developed and while attention still needs to be dedicated to their formulation, they have established a market share in the decorative sector..

8.3.1.5 One and two-pack polyurethane polymers.

Polyurethane polymers have found increasing use in architectural applications where demanding performance is required. The penetration of this technology, into the architectural market, has been impeded by cost and safe handling issues associated with two-pack materials. The benefits available are, the longevity of the system, with in excess of 20 years lifetime possible, as these materials have high levels of chemical resistance, barrier properties and UV stability. The versatility of polyurethane chemistry is derived from the isocyanate group, which reacts with available active hydrogen. Therefore, the reaction possibilities are extensive in that any hydroxy functionality can be used as source for isocyanate cross-linking. This reaction also allows moisture to be used as a curing activator. An important characteristic of polyurethane coatings is the temperature of reaction can be low. Thus, these coatings can be applied and cured even at 0°C or below.

Although paint products are frequently referred to as urethanes, often the urethane element refers to the urethane links in the polymer backbone. This is the case with urethane alkyds. Alkyds can be easily modified by the adding diisocyanate at the appropriate stage. Alkyds can have some of the diacid component replaced by diisocyanate during manufacturing process to react with the remaining hydroxy functionality. The reaction can proceed at lower temperatures untill no free isocyanate is remaining and is therefore moisture stable and non-toxic. Thus no self-bodying, or viscosity increases. The resultant materials offer faster drying alkyds due to the higher molecular weights possible. Modification produces an alkyd, which is more hydrolytically stable, has better alkali and abrasion resistance. Urethane alkyds find useful application as clear varnishes for flooring and wood trim.

One-pack

Moisture cured polyurethanes rely on the reaction of the isocyanate groups with atmospheric moisture to form a true urea film. Prepolymerisation can produce faster drying times or the isocyanate can be reacted with any polyol to produce larger molecules for film formation. Toluene diisocyanate is commonly used although issues of toxicity and yellowing are associated. Carbon dioxide is a by-product and evolves slowly. In-can stability is a major concern, as moisture must be excluded to prevent in-can gelation. In-can water scavangers are used to prevent this.

Two-pack

Catalysts can be added to accelerate the drying process. The base paint is the polyol and contains the pigment. Tertiary amines added as a second component to rapidly accelerate the drying of moisture-cured urethanes where it is required and in sufficient concentration. Additions to the paint base must be moisture-free and the catalyst is kept separate and cannot be used to contain pigment.

Any polymer that can supply active hydrogen functionality can be isocyanate-crosslinked. The curing agent can be an isocyanate prepolymer based on a suitable polyol, with the paint base containing all of the paint additions, based on any polymer with the appropriate functionality.

Health concerns are associated with the application of polyurethanes. All isocyanates are known respiratory sensitisers. Therefore, spray application of two-pack materials must be approached with care. Usually, air-fed masks are worn by paint applicators, even when they are working within extraction facilities. Contamination by unreacted isocyanate can also lead to skin irritation. This exposure risk is not associated with urethane-modified alkyds as the reaction has already been driven to 100% completion during resin manufacture and no free isocyanate should be present.

8.3.1.6 Epoxy resins.

The majority of epoxy resins are produced from the reaction of epichlorohydrin with a dihydroxy compound, usually bisphenol A. The reactivity of the resins is associated with the epoxide group, which terminates the molecule. Further reaction can occur across the hydroxy functional groups along the polymer chain. The epoxy ring ressembles an ether link, however, it is highly reactive as a double bond and can therefore be opened by any active hydrogen. The final polymer molecule consists of these epoxide reactive sites at either end, and hydroxy groups, which are a by-product of other epoxy ring opening reactions during polymerization. The high degree of chemical resistance is a result of the linkages being either carbon-carbon or ether, which come about from the phenolic and epoxy reactions during polymerization. The hydroxy functionality also contributes to the polarity of the polymer and the overall polarity results in good adhesion characteristics especially over blasted steel. However, they are susceptible to UV degradation.

Although epoxy modification greatly enhances the performance characteristics of commodity resins, epoxy technology is usually utilised to produce epoxy polymers in their own right. These resins come in the form of two-pack products. The first component contains the epoxy polymer and paint additives and is a paint in its own right. The second component contains the curing agent, which is often a polyamine such as ethylene diamine. The active hydrogen is involved in the ring opening and therefore the resultant polymer is in fact an epoxy polyamine. Amine adducts are frequently employed to assist with controlling the reaction on mixing. These materials are pre-reacted diepoxides with excess amine so that there is free amino hydrogen available for cross-linking. Drying is accelerated and better control of the reaction results.

Polyamide epoxy resins can be produced by the use of dimer fatty acids. Instead of using epoxy resin to produce an adduct, the fatty acid is reacted with excess amine to provide unreacted amino groups. The carboxylate/amino reaction produces the amide group, which has poorer alkali resistant than the amine link and therefore the chemical resistance of polyamides are poorer than those of polyamines. However, they find a useful role in terms of cost where some chemical resistance, toughness and adhesion are required. Therefore, they are often used to protect concrete flooring and indoor walls where adhesion, abrasion resistance, chemical resistance and barrier properties are required. Epoxy resins alone would be highly brittle materials and amine/amide cross-linking introduces flexibility.

The VOC content can also be reduced by manipulating the molecular weight. Waterborne materials are now also available and can be produced by emulsifying the epoxy resin and the amine curing agent into water with appropriate surfactants.

Health concerns also exist with the use of epoxy materials and most polyamines and reactive diluents can act as skin sensitisers.

8.3.2 Decorative paint formulation

The following constituents are commonly found in latex paint formulations for flat walls.

Latex paints

Water	Water is the carrier medium in which the polymer, pigment, extender and other additions are dispersed or dissolved. In order to maintain a stable dispersion, deionised water can be used. The rate at which water evaporates from drying films must be controlled in the interests of good film formation. If it evaporates too quickly application properties will be adversely affected. If it evaporates too slowly, coalescing solvent may be lost before the dispersed particles contact each other, resulting in poor film formation.
Rheology modifiers (thickener)	The viscosity of water alone does not lend itself to paint application and storage. The dispersion requires thickening or a degree of "body" to maintain the various additions in dispersion while in storage e.g. prevent in-can settling. Good control over rheology is required to prevent sagging, settling, yet promote levelling. The thickener must also control the rate of penetration into porous surfaces so that penetration is not rapid resulting in poor levelling.
Thixotrope	The film needs to be able to flow when sheared (brush-applied) while subsequently maintaining hold-up when that shear has been removed. Activated clays can be used to introduce a shear-thinning element to the rheology of the paint. Pigment settlement is also prevented. This is employed for thixotropic paints where a minimum degree of spatter is required, e.g. ceiling paints.
Dispersant	Facilitates the effective dispersion of the additions especially the effective distribution of pigmentation.
Fungicide /Biocide	Prevents growth of bacteria/fungus, which can occur due to the presence of materials such as cellulose, on which these organisms can thrive. Fungicides are needed to control mildew growth on decorative paint films in damp conditions. Biocides are required to prevent in-can degradation of the product. An example is Kathon LXE™ which is based on 5-chloro-2-methyl-4-isothiazolin-3-one and 2-methyl-4-isothiazolin-3-one. ZnO and Cu_2O are common fungicides although ZnO is used in decorative formulations. Care is required as the metal cation can become involved in chemical interactions, which can destabilise the formulation. Skane M-8, 2-n-octyl-4-isothiazolin-3-one, is a common fungicide for masonry coatings.
Surfactant	The surface energy of water is 72 dynes/cm^2. Therefore, surfactants are required to facilitate the wetting of the substrate. This can be achieved by nonionic surfactants. Additionally, surfactants are used to stabilise the pigment dispersion while not interfering with the stability of the latex dispersion itself. Anionic and cationic surfactants are used for this purpose.
Defoamer	The addition of surfactants to facilitate wetting with waterborne media can cause foaming particularly during manufacture. Defoamer additives minimise this artifact.
Cosolvent	The carrier medium, being water, can freeze with the resultant destabilisation of the dispersion. The cosolvent is usually a glycol and functions by lowering the freezing point of the medium. In addition, the rapid drying characteristics of latex paints can be slowed by the cosolvent to maintain a workable consistency for the film to allow reworking for the desired level of finish and overlapping by subsequent coats. Partially dried latex forms an incomplete film and reworking would break up the film into fine particles. This application requirement is referred to as wet-edge time.
Coalescing Solvent	In order to obtain the required durability, polymers with high softening points or glass transition temperatures (Tg's) are chosen. In order to facilitate the flow of the polymer under ambient conditions, the Tg must be lowered for application. This is achieved by the addition of coalescing solvent, which partitions between the water medium and the polymer particle thereby lowering the Tg. This liquid is eventually lost from the film thereby raising the Tg of the film to meet its fitness for purpose

	expectations. A typical coalescing solvent is Texanol™ which is the monoisobutyrate ester of 2,2,4-trimethylpentane-1,3-diol. These solvents have characteristically high boiling points and in the case of Texanol, the B.P. is about 255°C.
Pigments (colouring)	The hiding power of the product and the coloured appearance of the film is supplied by the pigments. Typically, white pigment is TiO_2. Colouring pigments function by virtue of having a different refractive index (n) from the film forming medium and other additions e.g. TiO_2 n = 2.76, water n = 1.33, extender n = 1.6, polymer n = 1.5. The refractive index difference leads to light scattering and therefore hiding.
Pigments (extender)	Extender pigments are inert, non-colouring pigments that can contribute to film properties such as hardness, permeability, but are usually added for cost considerations. A common example is calcium carbonate or chalk, however most are clays such as aluminium silicate. A fine particle size grade facilitates the effective distribution of the TiO_2 additions.
Latex Polymer (binder)	The polymer is typically derived from vinyl and acrylic monomers and takes the form of polymer particles dispersed in water. On application, the water commences evaporation and the particles pack closely, come under significant capillary and surface tension forces and eventually coalesce. The particles flow together, to form the continuous film. The ability of the film to coalesce is controlled by the choice of monomers used to manufacture the polymer and the coalescing solvent, which lowers the operating Tg of the polymer. Monomers are also chosen depending on the properties required. Polymers derived from polymethylmethacrylate have high degrees of hardness but may be inflexible, while those based on butylacrylate are soft and prone to dirt pick-up at ambient temperature. Therefore, a choice of monomers are selected to achieve the balance of properties at the required cost.
Opacifiers	Polymeric particles, which do not deform are added as opacifying agents, which contribute to the overall hiding power of the formulation by increasing light scattering.
Ammonium hydroxide	pH control of the final paint is required to maintain the stability of the anionic dispersing agents. Additionally, if the pH is kept high, then steel exposed through breaks or defects in the can lining will be passivated and cannot rust. Wetting ability is improved through control of the pH.

Many of the pigments and extenders common to latex paints are also formulated into solventborne products, albeit at different levels due to the nature of the polymer itself and the nature of its interaction with the carrier medium, i.e. solventborne polymers are solutions rather than dispersions. Elements characteristic of solventborne paint in addition to the common additives above are,

Solventborne paints

Polymer (binder)	The non-volatile portion of the liquid vehicle of the coating which is film-forming. It also carries the other components in the coating. Many paints are described according to the name of the binder, e.g. alkyds, acrylics, epoxies etc. In solvent borne coatings the binder is soluble in some or all of the solvents used. Solventborne paints are traditionally based on alkyd systems.
Drier	These systems harden by oxidative cure and this could require 4 to 5 days for cure if left unaided. Thus, organometallic driers are utilised to catalyse the free radical formation from oxidatively generated hydroperoxides. These free radicals then become involved in the cross linking reaction by which oxidatively-cured oils and alkyds harden. This process leads to useful drying times for paint systems. Excess use of driers leads to skinning. The use of lead driers has been discontinued for health and safety reasons. Cobalt driers, which are important for through-drying of the film, are currently giving rise to concern for similar reasons. Therefore efforts have been made to reduce rather than replace them. Driers are not used in most waterborne decorative paints, with the exception of alkyd emulsions where they have the same role as in their solventborne equivalents.

Anti-skinning agents	Due to the addition of the metal driers, the surface of the resin is much more reactive than that of the unmodified resin. This leads to skinning in the can where a head-space of air supplies O_2. This is counteracted by the addition of antioxidants or anti skinning agents. They fall into two groups mainly, phenols and oximes. Oximes are most commonly used by the paint industry. They function by complexing the metal driers in the wet paint and subsequently evaporating from the film on exposure thereby allowing the drier to function. Additionally, the high solvency of oximes, retard the formation of a surface skin. Care needs to be taken with the addition of the anti-skinning agent in that a colour change can occur.
Solvents	Dissolve or disperse the film forming constituents, control the viscosity and regulate the drying properties of the coating. They evaporate from the coating during and following application. They are selected according to their solvent power, boiling point, vapour pressure, flash point etc, and are often used as blends. The most common solvent used in traditional solventborne paint systems is white spirits, which is a blend of aliphatic hydrocarbons with some aromatic hydrocarbon content. Although the level of aromaticity is often 15-20%(29,63), low aromatic white spirits (~1%)(48) are available. White spirits is an economic solvent for use in traditional solventborne paints and exhibits a boiling point of between 150°C to 210°C.
Additives	Small additions of a range of materials to improve the characteristics of products. Some may be used to produce transient effects only, such as improved application characteristics, while others may have more permanent effects such as improved hardness or flexibility in the case of plasticisers.

The following section discusses typical formulating parameters,

Density (specific gravity) = Mass per unit volume of paint (kg/L). This allows conversion of weight % additions to volume %. SG is commonly used as a QC measurement to ensure that all of the formulation additions have been made.Paint is manufactured by weight and sold by volume.

Mass solids% = % weight of the non-volatiles or solids. This parameter describes by weight, the solid component of the formulation and suggests the weight% of dry film that will remain on the substrate. It is also used as a QC measurement for batch control.

Volume solids% = % volume of the non-volatiles or solids. The volume solids, is an important parameter for determining the efficacy of coverage of the formulation.

PVC% (pigment-volume-concentration) = % pigment volume of the dry-film volume. A route to cost saving is the utilisation of solid particles or extenders to fill out the film. Extenders are significantly cheaper than the resin and the colouring pigment and therefore the aim is to maximise the level of these solids, PVC, in the film.

CPVC (critical-pigment-volume-concentration) = The level of pigment in the film at which interparticulate contact is possible, is called the CPVC level. Important film properties such as gloss, water permeability and scrub resistance are radically altered, mostly to their detriment, when this point has been exceeded.

VOC content = Quantity of VOC in a unit of paint. The units chosen for most of the formulation discussions are grams per litre of paint (g/L), for ease of comparison with other quoted VOC figures in the public domain. However, other methods of describing VOC emission in terms of unit area covered by the dry film are more effective and this will be discussed later.

Viscosity = A measure of the resistance to shear of the final paint. This usually measured by a Stormer Viscometer for latex paints and equilibrated values refer to thixotropic paints that have been allowed to restructure after shear. High shear viscosity properties are the principal means of controlling film thickness with latex paints. The viscosity of solventborne paints can be measured by cone and plate viscometers and flow cups.

A typical manufacturing procedure might involve the first phase (concentrated pigment/binder-millbase) being passed through a bead/ball mill or high speed dispersed to achieve an optimum dispersion. The mill would be washed out with the second phase solution and the third phase used to let down the millbase to make up the final formulation. Some mineral solvent or water might be held back to adjust for the final viscosity. In the first phase, a bead or ball mill would be used to achieve accurate control over pigment grind where this is crucial for appearance, while high-speed dispersion would be used where this control is not required. Beadmilling is more laborious, time consuming and therefore costly.

8.3.3 Application methods

The application of decorative paint must facilitate the efficient transfer of paint to the substrate while maintaining the decorative and in some cases protective, integrity of the film. Decorative products have been traditionally applied by brush and cloth, yet the earliest cave paintings of the Pêche-Merle in the Dordogne manifest the use of paint applied by blowing through a straw some 19,000 to 30,000 years ago. Perhaps the earliest application by spraying? Whatever method is chosen, the appearance characteristics must not be detracted from and in more recent times, attention has been paid to the transfer efficiencies of the different methods. Universally, brushes and rollers are the most common ways of applying decorative paints, however, professional painters use spraying techniques where appropriate. This is especially the case where large areas need covering and when new buildings are being decorated. Commonly, the painter will spray apply all of the ceilings first before any other paint is applied. Spraying by the DIY user is uncommon although portable, simple electric applicators are now being used, especially for exterior applications such as garden fencing and sheds.

8.3.3.1 Brushes.

A wide variety of materials are available for the manufacture of brushes. The bristle material varies in capability and cost from polyester and nylon fibers to hog and animal-hair. The brush must be able to pick-up enough paint for each application and remain stable in the solvents found in the formulation. Bristles must stay attached to the stock and the decorative finish of the brush itself must be solvent resistant. The bristles function is to collect enough paint for each application and spread enough to apply the appropriate wet film without introducing defects. Characteristic lines are always produced in the film and the professional painter in particular receives significant training in the skill of working the wet film to remove these surface imperfections while maintaining control over the area of application. Alkyd air-drying coatings lend themselves well to brush application and solvents such as white spirits are chosen as they have a boiling point in the range 150°C-210°C. These slower evaporating materials allow the film to stay fluid so that this re-working operation can occur. By contrast, waterborne latex paints dry rapidly as the water evaporates and the viscosity of the paint approaches the viscosity of the polymer, which is normally of very high molecular weight. This necessitates the use of high boiling alcohols such as propylene glycol, which maintain an open film for the painter to rework the film. This is not entirely successful and is a drawback for the use of latex paints where there are high gloss requirements. Professional painters claim that high degree of skill is required for the application of these paints and that the necessary brush design is not readily available across Europe to facilitate the achievement of high levels of finish. Specially tailored bristles(95) allow the application of a straight edges with rapidly drying latex gloss paints.

Applying decorative paint by brush allows versatility, offers control to the painter, involves little wastage of the paint and the majority of the paint is applied where it is required. The principle disadvantage of brush application is that of productivity and most professionals will tend to rely on brushes for the application of trim paint only, using other means such as rollers or spraying equipment for other applications. Brushes can be cleaned by soaking in white spirits, immersion in water to maintain a fluid paint or cleaned by proprietary brush cleaners. In the case of waterborne latex paints, this cleaning operation is done using running water and detergent. Strong hot-water/detergent solutions may also be used to clean implements used to apply some solventborne alkyds.

8.3.3.2 Rollers.

The productivity drawbacks of brush application has led to the common use of rollers for the application of paint on large areas such as walls. Rollers can be made of many materials such as polyurethane fibres or synthetic sponge. The viscosity requirements of the paint are the same. The roller introduces cavitations into the film due to the applied pressure and as these bubbles are elongated as the roller moves past, they break and flow across the immediate area. A particular phenomenon associated with latex paints is that of spatter due to this mechanism and this can be alleviated by the use of thixotropic paints particularly for ceiling applications. The paint exhibits a high degree of shear thinning during application and very rapidly recovers a high level of viscosity on removal of the applied shear. Some paints appear almost solid in the container and this type of product has been marketed as “solid emulsion” sold in tray containers for ease of use. Similar to brushes, rollers offer high degrees of transfer efficiency at high rates of productivity and many adaptations such as paint lines and reservoirs have been developed to enhance this attribute. Cleaning operations are similar to those used for brushes.

8.3.3.3 Conventional spraying.

Conventional spraying equipment was first used to apply lacquer to furniture and then to cars and was designed to provide the finish qualities expected of that type of product. Conventional spraying equipment involves the application of paint by the use of air and paint mixtures under pressure 240-480 kPa (~35-70 psi), through a hand-held gun. The paint reservoir can deliver the paint by means of suction as the pressurised air is passed over the opening, or by means of gravity from an overhead cup and also by the application of pressure to paint itself. The paint spray is directed at the object to be painted by the application of further streams of forced air. The paint is highly atomised and therefore, due to the immense surface area presented by the paint in this form, considerable solvent is lost before the paint meets the substrate. Particles must flow on hitting the substrate and enough solvent must remain to allow this to occur. Consequently, high levels of VOC are required for this application method and due to the pressures involved, considerable amounts of the paint are lost by overspray or bounce-back. Table 8.8 shows the transfer efficiencies of typical spraying techniques. Cleaning operations can involve significant levels of solvent as paint residues can produce defects in the final film. This cleaning operation must occur immediately after the gun has been used for 2-pack paints. Most paints applied by conventional spray equipment require thinning, up to 10w% wt., to achieve the necessary spraying viscosities.

Table 8.8 Typical baseline transfer efficiencies (85) .

Type of Spray gun	Transfer efficiency (%)
Compressed air	25
Airless	40
Air-assisted airless	50
HVLP*	65

* high volume low pressure.

8.3.3.4 Airless spraying.

Airless spraying involves the application of high pressure onto the paint itself and to use that pressure to deliver the paint through an orifice in a hand-held gun. The pressures involved are much higher than those encountered with conventional spraying techniques, being of the order of 10-60MPa (~1,500 up to 10,000 psi). The gun is much less complicated than that used for conventional spraying and as no air is intentionally mixed with the paint, little overspray or bounce-back occurs. This is reflected in the higher transfer efficiencies in Table 8.8. Airless spraying is an important application technique for professional painters as very high productivity, with much reduced paint wastage is enjoyed. Paint can be applied in difficult areas and extension lances are available to allow the painter better access. Higher film builds are usually applied with airless spraying equipment due to the rate of delivery of the paint. Cleaning operations follow the same procedures as conventional spraying equipment excepting one significant advantage. Due to the simplicity of the gun, the tip can be removed during operations when a blockage is encountered, and reversed so that paint can be forced through to remove the restriction. Paints applied by airless spraying, due to the size of the apertures chosen, 0.18 to 1.8mm, and the high pressures applied, do not always require thinning and most can be applied as supplied in the can.

8.3.3.5 Paint formulation aspects.

Paints applied by airless spray suffer less solvent or carrier medium loss that those applied by conventional spraying. Therefore no reformulation work on decorative paint products is required for that application technique. Latex paints lend themselves to airless application in that their shear-thinning characteristics allow the application of high pressure with subsequent rapid recovery of sufficient viscosity to maintain hold-up on the substrate. Solventborne paints and varnishes applied by conventional spraying, due to the high degree of atomisation require high levels of VOC to allow for the losses and to force the paint through the tip. Transfer efficiencies can be low at ~25% and therefore paint consumption is much higher.

8.3.4 Cleaning operations.

Apart from the use of decorative paints and varnishes, cleaning of equipment is an activity that may have significant environmental impacts, if not carried out properly. For solvent borne products, this may involve the use of white spirit as a brush cleaner, giving rise to VOC-emissions. Alternatively, proprietary brush cleaners are available. For waterborne products, this might involve cleaning of brushes and rollers under the tap, giving rise to water pollution. In both cases, alternative methods are available.

8.3.4.1 Cleaning alternatives for equipment used for solvent borne coatings

Normally, decorative solventborne paints are cleaned from brushes by means of white spirits. Several alternatives for using white spirit to clean brushes or other materials have been identified. Some professional painters already use these alternatives, while some DIY consumers still use white spirit. Alternative possibilities are,

1. Storage under water
Brushes or rollers that contain solvent-based paint can be stored in water overnight or even longer. The solvent will not evaporate, and the brush may be used again the next day or later. Painting contractors' associations say that among professional painters this is common practice. However, it's not clear whether this practise is common across the EU and water particles trapped may give rise to further problems in the dry film.

2. Storage in an airtight bag or in the paint can
Another possibility is, to store the brush or roller in an airtight plastic bag, in order to prevent evaporation of the solvent, and thus drying of the paint. However, airtight storage is less easy to ensure than storage under water. In some countries, special brush storage equipment is on the market for professional as well as DIY painters. Brushes can be stored in the paint-can, using a seal that contains a cut-away (notch) for the brush.

3. Disposal of brushes or rollers
Many professional painters do not clean their brushes, but let them dry-out and throw them away at the end of the day. As the price of brushes is not significant for professional painters, this is a convenient way of dealing with the problem. However, from a viewpoint of waste generation, the previously-mentioned two options have to be preferred. DIY consumers do not tend to dispose of brushes after a paint job, as they are more aware of the price.

4. Non-volatile cleaners
Non-volatile cleaning agents that may clean brushes and rollers are on the market. These include the fatty acid esters derived from vegetable oils. A problem with this option is, that it's not clear what should be done with the contaminated cleaning agent. One application for non-volatile cleaning agents is cleaning of the *hands*. Cleaning of the skin with white spirit is has potential health risks (dermatitis). Specific alternative hand cleaners are on the market.

8.3.4.2 Cleaning alternatives for equipment used for waterborne coatings

For waterborne coatings, the same cleaning alternatives can be used as those described for solvent borne coatings.

1. Cleaning in water and settlement of paint
Brushes and rollers can be cleaned in a container or with water. The paint components will settle, as the stability of the emulsion or dispersion is broken. Special settling agents are on the market, which may accelerate the process. Subsequently, the water may be discharged to the sewage system. The settled paint components may be disposed of with normal household waste provided that they have dried out completely. If not, they should be treated like hazardous waste.

2. *Drying out and disposal*
Other equipment that has been contaminated with waterbased paints (trays etc. used for wall-painting with rollers) may be left to dry. The dried-out paint may be removed (scraped out or pulled out), and disposed of through the normal household waste. Hands contaminated with waterbased paint can be cleaned under the tap, with normal soap and/or a brush. However, this is not easy after the paint has fully coalesced. The greatest source of VOC involved in the cleaning operations is associated with the use of white spirits for the cleaning of alkyd paints from brushes and spills. Professional painters are more likely to either store their equipment carefully for re-use or discard the contaminated materials after drying-off. DIY users are more likely to immerse their brushes in excess amounts of white spirits, possibly equaling or exceeding the quantity of paint used, to recover them for reuse after painting has ceased. Therefore, an effective means to limiting this uncontrolled emission would be to discourage the excessive use of white spirits sold separately as cleaning or thinning products. This could be achieved by means of heavy taxation with respect to the quantity used, e.g. containers less than 10 litres.

8.4 Interior matt and semi-gloss wall and ceiling paints for plaster etc.

Latex paints have largely replaced their solventborne counterparts for interior use over the last two decades. Use of solventborne paint for walls and ceilings indoors has become uncommon with a wide range of emulsion technologies available, although French painters still prefer to use solventborne paints for flat walls and ceilings. Latex paints dry rapidly, have lower odour compared to alkyd products, lower VOC per unit volume of product and are easily cleaned in the case of spillages. Waterborne paints used in this area are based on vinyl acetate, acrylic, styrene-acrylic, PVA-homopolymer, PVA-acrylic, and PVA VeoVa emulsions.

Emulsion paints have moved to higher PVC's over the last two decades to achieve more cost effective hiding. Considerable development has occurred over the last two decades in the area of pigment surface treatment and development. Opacifiers such as Ropaque™ from Rohm&Haas and Spindrift™ technology from ICI and general TiO_2 surface treatment/encapsulation, has facilitated the formulating of higher PVC wall coatings and reduced the overall formulating requirement for TiO_2, an expensive component of all colouring films. Water-soluble thickeners are used to control viscosity of the final paint. Thickeners have been used to control spatter, which is prevalent with roller applications. This has led to a generation of thixotropic paints, which have found particular application where reduced dripping is important.

A characteristic of latex paints is their ability to cover or bridge porous surfaces. The continuous phase is quickly absorbed into the substrate resulting in a rapid viscosity increase in the film. This results in a film, which lays on the surface providing cover. However, this phenomenon has a significant drawback in that where binder penetration is needed on loose or friable surfaces, the polymer does not bind the material effectively resulting in spalling. This is a common defect attributed to latex paint. Solventborne paints offer better penetration of porous substrates in that the polymer is dissolved in the carrier solvent and absorption of the solvent into the substrate carries the polymer into the substrate. Therefore, waterborne latex products do not offer the same priming or sealing capability of traditional solventborne products. Latex used over water-soluble materials such as those from pluming leaks, tends to result in the stain being carried into the water based medium and subsequently leading to bleed-through of the stain into the final film. Certain cement-based substrates can present these alkaline conditions, to which alkyd paints are vulnerable. In those instances, latex media are unaffected.

8.4.1 Formulations for interior matt and semi-gloss paints.

Typical formulations for matt (flat) and silk (semi-gloss) interior paints from leading raw material suppliers are presented below. Although particular resin supplier formulations are presented here, this is not to suggest that these represent benchmark, leading edge commercial products but typical conventional starting-point formulations from which paint manufacturing companies might begin to formulate their products. Considerable in-house proprietary formulation expertise exists in paint manufacturing companies. While the VOC contents represented below might be possible according to the raw material suppliers, currently the formulator in the paint manufacturing company will concentrate on optimising final film properties such as scrub resistance and achieve a resultant VOC content rather than concentrate on reducing VOC levels. Current formulations are compared with formulations for the same application from the early eighties (92).

Table 8.9 Solventborne interior matt wall paint formulation

Raw material	**Kilogram's**	**Function.**
Uralac AF283 V 60	156.00	*Alkyd binder*
Serad FA 601	7.00	*Wetting agent/surfactant*
Tioxide TR 92	250.00	*Pigment*
Omyalite BLP 3	480.00	*Extender*
Durham Co6	0.80	*Metal drier*
Durham Zr12	3.80	*Metal drier*
Exkin 2	2.00	*Anti-skinning agent*
White spirit (5%Aromatic)	98.40	*Solvent*
	1000	

Formulating parameters.

Density	1.805Kg/L	PVC	72.2%
Mass solids	82.7%	Volume solids	60.4%
VOC content	312g/L		

Table 8.10 Conventional waterborne interior matt wall paint formulation

Raw material	**Kilograms**	**Function.**
Water	352.80	*Carrier medium*
Oraton 1124	9.64	*Dispersant*
Kathon-LXE	0.70	*Biocide*
Nopco NXZ	2.82	*Defoamer*
Ethylene glycol	14.17	*Freeze-thaw/wet edge*
Water	35.28	*Carrier medium*
Acrysol TT-935	9.88	*Rheology modifier*
Aqueous ammonia	0.77	*pH control*
Tioxide TR-92	129.82	*Pigment*
Polestar 200P	149.22	*Extender*
Durcal 5	202.74	$CaCO_3$ *extender*
Nopco NXZ	1.27	*Defoamer*
Texanol	6.69	*Coalescing solvent*
ROVACE 9100	121.66	*Polymer*
Ropaque OP-62LOE	76.62	*Opaque polymer*
Aqueous ammonia 28%	2.00	*pH control*
Acrysol TT-935	13.33	*Thickener*
Water	208.00	*Carrier medium*
	1330	

Formulating parameters.

Density	1.34	PVC	78.15%
Mass solids	46.75%	Volume solids	25.56%
VOC content	21 g/L		

The solventborne formulation in Table 8.9, is based on an alkyd resin formulated to high volume solids and with VOC content of 312g/L. Typical conventional products have been measured at 43% volume solids, with a resultant VOC of 346 g/L. By comparison, a latex matt wall paint, Table 8.10, can achieve a possible 21 g/L from SP formulations, with the PVC of 78%. The addition of tinters adds up to 35g/L to the VOC content. Current VOC levels for this type product have been measured at 100g/L in practice. The low volume solids of 25% reflects the limitations on volume solids for latex at high PVC levels.

Early formulations from the 1980's, Table 8.11, show that higher volume solids are possible if the PVC is lower and the lower VOC content of 11g/L reflect that current latex paints employ tougher films to achieve better dirt-pickup resistance and scrub resistance. In order to increase the level of gloss the PVC has to drop below the CPVC and this is reflected in the formulations below, Tables 8.12 and 8.13, where ~30% is typical. The reduction in solid pigment or extender would be expected to result in an increase in the level of VOC and this is reflected in the higher VOC values of around 45g/L for both the current, Table 8.12, and older formulation, Table 8.13. In practice however, the VOC values are significantly higher, with 100 g/L, being common. The higher gloss formulations for interior walls also include those formulations where better scrub and burnish resistance would be required such as in bathrooms and kitchens, which would require better water resistance and more frequent cleaning. In those formulations VOC content would be expected to be higher. Levels of 120g/L have been measured. The current and older formulations for interior matt and interior semi-gloss show that latex technology has been dominant in this sector for some time and that formulation strategy has largely remained unchanged.

Table 8.11 Waterborne matt wall paint from early '80's .

Raw material	**Kilograms**
Water	280.00
Cellulose thickener	1.50
Anionic dispersant	3.00
Wetting agent	2.50
Antifoam	1.00
Ammonia solution	1.50
Preservative	0.50
Talc	200.00
Diatomaceous silica	75.00
Rutile TiO_2	300.00
Coalescing agent	10.00
PVA acrylic emulsion 55%	308.00
Antifoam	1.50
Ammonia solution	1.50
Cellulose thickener 3%NV	150.00
Cellulose thickener or water	83.00
	1419.00

Formulating parameters.

Density	1.492	PVC	57%
Mass solids	52.5%	Volume solids	32.8%
VOC content	11 g/L		

Table 8.12 Conventional interior semi gloss wall paint formulation

Raw material	**Kilograms**	**Function**
Water	258.77	*Carrier medium*
Oraton 1124	5.29	*Dispersant*
Kathon-LX 1.5	2.55	*Biocide*
Nopco NXZ	2.55	*Defoamer*
Propylene glycol	19.12	*Freeze thaw/wet edge*
Acrysol SCT-275	20.40	*Rheology modifier*
Tioxide TR-92	201.96	*Pigment*
Durcal 5	62.31	$CaCO_3$ *extender*
Nopco NXZ	1.27	*Defoamer*
Texanol	27.18	*Coalescing solvent*
ROVACE 9100	494.22	*Acrylic polymer*
Ropaque OP-62LOE	51.16	*Opaque polymer*
Tilcom AT-23	2.55	*Rheology modifier*
Water	89.68	*Carrier medium*
	1239	

Formulating parameters.

Density	1.239	PVC	30.3%
Mass solids	47.4%	Volume solids	32.5%
VOC content	46.3 g/L		

Table 8.13 Waterborne semi-gloss interior wall paint from early '80's .

Raw material	**Kilograms**
Rutile TiO_2	350.00
Calcium carbonate	100.00
Anionic dispersant	4.00
Non-ionic wetting agent	3.00
Polyphosphate dispersant	2.00
Antifoam/defoamer	1.00
Preservative/fungicide	0.40
Ammonia solution	1.00
Water	100.00
PVA acrylic emulsion 55%	550.00
Propylene glycol	30.00
Coalescing agent	*15.00*
Antifoam/defoamer	2.00
Cellulosic thickener	102.00
PVA acrylic emulsion 55%	35.20
(or Flattening paste)	21.50
Cellulose thickener or water	98.96
Ammonia solution	1.00
	1395.56

Formulating parameters.

Density	1.395	PVC	32.2%
Mass solids	55.3%	Volume solids	38.7%
VOC content	45g/L		

8.5 Exterior wall paint for masonry, brick and stucco.

Exterior wall paint formulations are often based on acrylic latex polymers. 100% acrylic latex formulations are be chosen for exterior use due to their superior durability, as they remain thermoplastic and have good UV resistance. Acrylic lattices are linear thermoplastic polymers and are not susceptible to breakdown in the presence of alkali. Additionally, they do not progressively cross-link with time and therefore maintain flexibility. Acrylics remain flexible and are transparent to the effects of UV and therefore do not suffer from chalking on exterior exposure. Chalking may only be a localized effect, however, although surface specific, loss of gloss occurs. Thus, although acrylic latices have lower levels of gloss from the outset, that gloss level is maintained and in a short space of time exceeds that of the traditional oil-based films.

Latex is more permeable than a solventborne polymer, due to the coalescing nature of film formation, which will always result in a percolation pathway to some degree, and the Tg of the film remains stable due to the thermoplastic nature of the film. A serious drawback of latex systems for exterior use is that of the medium in which the polymer is dispersed. If the application temperature is +5°C or lower, then the evaporation rate of the water is slow. This results in lack of film coalescence and the drying time becomes too long. In the event of high humidity levels or rain, the film is in danger of being washed off the substrate. High humidity can even result in the loss of solvent, which is unperturbed by the water vapour present, while the water remains in the film. This results in an uncoalesced film with the subsequent loss in properties. The lack of substrate penetration by the latex particles can also be a drawback for porous or friable substrates, as the film tends to sit on the surface and does not bind or stabilize the loose material. Adhesion can be poor and this can lead to spalling of the coatings. This is where solventborne styrenated acrylic coatings offer an advantage in that, penetration of the substrate by the solvent is also accompanied by the binder.

The thermoplastic nature of a latex coating can also mean that the coating becomes soft during summer months and therefore dirt pickup can be a problem. This was a problem for exterior latex paints formerly, however, harder monomers such as methyl methacrylate, copolymerised with butyl acrylate to balance the toughness properties, overcame these difficulties. However, higher levels of VOC in the form of coalescing solvents were required to compensate for the higher Tg. These coalescing solvents are also affected by low temperatures and they are lost slowly at low temperatures thereby maintaining a soft film with depressed Tg. Freeze-thaw cycles can also affect the system if the correct cosolvent is not chosen and at the correct level. Apart from the polymer, the principal difference between interior and exterior wall paints is the PVC is lower. Barrier properties are needed for exterior exposure and in addition, freeze-thaw conditions would lead to spalling if significant porosity were present. Exterior formulations can suffer from chalking, breakdown of resin/pigment interface, and formulating above the critical PVC would exacerbate this phenomenon. Fungicidal additions may necessitate the use of materials such as 2-n-octyl-4-isothiazolin-3-one.

8.5.1 Conventional exterior wall paint for masonry, brick and stucco.

Tables 8.14 and 8.15 represent typical formulations for exterior walls over the last two decades. Table 8.14 represents a typical formulation for wall paints for exterior use based on latex formulations. Primal AC 532K is 100% acrylic latex for exterior application. The PVC does not exceed the CPVC as the durability would be reduced and chalking would occur. The main solvent used is Texanol, which works as a coalescing solvent. Propylene glycol is commonly used in addition, operating as a freeze-thaw additive and open-time agent. VOC levels are higher than those for interior matt wall formulations to reflect the harder monomers chosen to produce polymers for this application and to compensate for faster drying conditions. Viscosity is controlled by the hydroxyethylcellulose (HEC) additive and TiO_2 is the principal colouring pigment used. Additionally, chalk is used as an extender to make the formulation cost effective and to impart durability. Mica and talc can be used instead of chalk, however, increased chalking has been found with these extenders. Mica being platelet like imparts toughness through interlocking. The VOC level of 35g/L reflects the lower VOC requirement of latex systems in general compared to solventborne equivalents. Adding tinter could increase this content 70g/L.Current VOC levels have been measured at 60g/L for actual products. Comparison with older formulations, Table 8.15, shows that similar to interior applications, the formulating strategy has not altered radically.

Solventborne products are used where low temperature, high humidity or particularly difficult substrates are encountered. Table 8.16 represents a typical formulation for this application. The binder is based on a styrenated solution acrylic, which imparts durability to the system, although chalking can occur. Waterborne or solventborne acrylics exhibit high levels of durability in terms of their flexibility and UV transparency. Solventborne exterior wall paints fulfill a niche requirement where waterborne paints cannot offer satisfactory performance. The benefits of a solution acrylic over a waterborne latex are,

- Low temperature/high humidity application.
- Good adhesion over difficult substrates due to the penetration nature of the binder.
- Rainfall resistance.
- Good biocidal/fungicidal resistance.
- Extended lifetime.
- Crack bridging characteristics.

Waterborne latex paint is susceptible to being washed from the substrate if rainfall occurs during application prior to coalescence. It is inadvisable to use latex paint outdoors where the temperature is below 4-5°C due to the slow evaporation of the water. Latices cannot penetrate as significantly as a solution polymer due to the particle size of the polymer particles. Standard solvents for solventborne such as white spirits are used although the trend has been for a move towards aromatic-free solvents based on aliphatic hydrocarbons.
Volume solids and PVC are similar to the conventional latex system, however the VOC demand of these solventborne systems, is at 450g/L with 480g/L being measured on a current product.

Table 8.14 Conventional waterborne exterior masonry paint formulation

Raw material	**Kilograms**	**Function.**
Water	109.60	*Carrier medium*
Natrosol 250 MBR	2.60	*HEC rheology modifier*
Aqueous ammonia	2.00	*pH control*
Dowicil 75	1.60	*Preservative*
Nopco NXZ	5.90	*Defoamer*
Orotan731K	15.00	*Dispersant*
Sudranol 340	11.20	*Wax*
Triton CF10	2.00	*Surfactant*
Ropaque OP-62LOE	90.90	*Opaque polymer/extender*
Primal AC-532K	310.60	*Polymer*
Tioxide TR-92	111.00	*Pigment*
Durcal 5	116.90	*$CaCO_3$ extender*
Mikal 00160	49.80	*Extender*
Mikal 00180	144.20	*Extender*
Texanol	24.40	*Coalescing solvent*
Ammonia or water	2.10	*pH control*
	10000	

Formulating parameters.

Density	1.43	PVC	60%
Mass solids	61.4%	Volume solids	45%
VOC content	35 g/L		

Table 8.15 Conventional waterborne exterior flat wall paint from early '80's.

Raw material	**Kilograms**
Water	130.0
Anionic dispersant	4.0
Non-ionic wetting agent	3.0
Polyphosphate dispersant	2.5
Preservative/fungicide	0.6
Antifoam/defoamer	1.0
Ammonia solution	1.0
Calcium carbonate	50.0
Mica	40.0
Rutile TiO_2	350.0
Acrylic emulsion 46%	583.0
Antifoam/defoamer	1.0
Propylene glycol	30.0
Coalescing agent	*15.0*
Cellulose thickener	100.0
Cellulose thickener or water	45.4
Ammonia solution	1.0
	1357.5

Formulating parameters.

Density	1.357Kg/L	PVC	33.7%
Mass solids	52.2%	Volume solids	35.7%
VOC content	45g/L		

Table 8.16 Conventional solventborne exterior masonry paint formulation

Raw material	**Kilograms**	**Function.**
Pliolite AC80	46.30	*Styrene acrylic polymer*
Pliolite AC4	2.49	*Styrene acrylic polymer*
Cereclor 54DP(85%)	5.62	*Plasticiser*
Soya lecithin	0.24	*Dispersant*
Tioxide TR92	17.95	*Pigment*
Omya BLP3	7.69	*Extender*
Calibrite SL	28.51	*Extender*
Celite 281	4.10	*Flattening agent*
White Spirit 17	23.02	*Hydrocarbon solvent*
Solvesso 100	5.75	*Hydrocarbon solvent*
	100	

Formulating parameter.

Density	N/A Kg/L	PVC	64.4%
Mass solids	N/A %	Volume solids	44.9%
VOC content	450g/L		

8.5.2 Exterior and interior wall formulation comparison.

The characteristic type of formulation for wall paint has not changed significantly over the last decade in that the binder is still latex, based on vinyl or acrylic monomer or blends for most uses. The PVC of the current matt paints has increased beyond the CPVC while the VOC level of 21g/L reflects the use of higher Tg polymers for interior and exterior durability (scrub resistance and dirt pickup respectively). Current products have been measured at between 60g/L and 150g/L for interior and exterior walls. Styrenated solution acrylics are still used as they fulfill a niche requirement and can be formulated around 450g/L. These products have been developed to provide aromatic free variants based on solvents with less impact on the operators health and low odour.

8.6 Decorative paints for Wood.

Wood coatings have particular demands placed upon them, which are not shared by other substrates. Wood is organic in nature and made up of fibrous cells which originally contained up to 200% water before felling. The type of wood has significant bearing. Heartwood is durable and less permeable to water but may contain natural oils, which can stain, while sapwood is newer wood which has larger cells capable of absorbing greater amounts of water rapidly. Additionally, sapwood is less durable and dimensionally stable than heartwood. The method of preparing the wood has some degree of influence over the coating. Tangential cuts across the grain leaves many exposed channels for the ingress of water and therefore places heavier demands on the barrier properties of the coating. Moisture, sunlight and organisms all have detrimental effects on the surface of wood, which requires coating. Moisture affects the dimensional stability of the structure, which is important if that structure is load bearing such as joinery. Shrinkage of timber occurs when felled, however several percent dimensional movement can occur due to alterations in ambient conditions. Biodegradation has received significant attention in recent times due to the effect of *Dacrymyces Stillatus*(54) on Scandinavian architectural timber. In the same instance, the effects of exposure of untreated timber to sunlight and moisture, on the performance of applied coatings were drawn sharply into focus. Although the paint company involved in that particular litigation case was exonerated, the impact of the event has been felt and many negative perceptions and concerns still exist. Wood used indoors also requires protection but from different impact events. Trim indoors, has traditionally been fabricated from wood and coatings for those applications are required to resist impact damage, regular cleaning, remain attractive in appearance and maintain appearance expectations on application. Very high expectations of performance of coatings for wooden floors exist where durability and appearance go hand in hand.

In order to beautify and protect wood against the above, a range of product types exist aimed at fulfilling a discrete functions. Typical products for application over wood are,

Wood paint - Opaque film. Usually alkyd based binder with high levels of opacity and high levels of gloss. High degrees of gloss and low cost have ensured that these paints have maintained a dominant position in this sector. Yellowing and embrittlement have been serious drawbacks, which have been tolerated. Additionally, high levels of impermeability have lead to blistering where indigenous or exogenous moisture transport is impeded.

Wood varnish - Transparent coating with a binder system similar to the above but with the additional requirement for UV protection which is provided for in the paint by the pigment and extender. The same advantages and drawbacks apply as with paint.

Wood stain - Colouring, semi-transparent film with no film build. Often required to provide preservative as well as beautification to the timber. Permeability to moisture is high.

Wood primer - Alkyd binder with low solids designed to penetrate wood cell structure and provide barrier properties in addition to providing good adhesion for the topcoats applied.

8.6.1 Conventional decorative paint for interior and exterior wood.

The purpose of the final finish coat is to provide good surface appearance with good wear/scrub resistance, especially for high traffic areas. Interior paints need to have minimal yellowing. The barrier properties for exterior use are key. As a result, the PVC is maintained low as presented in Table 8.17 (15%) and efforts are made to optimise the efficacy of the TiO_2 white colouring pigment to maintain good hiding and colour at effective cost. The conventional system relies on the properties of the alkyd medium to achieve good gloss and this is achieved by the separation of a clear layer of resin at the surface and by the good levelling properties of solvent borne resin. It is postulated (85) that the initial striping of the coating sets up differential surface tension effects due to different levels of solvent in the peaks and troughs. The troughs have higher surface tension compared to the peaks and therefore the surface self-levels. Probably the most important influence is the prolonged presence of the solvent, usually white spirits, which maintains flow. Careful control is maintained over the viscosity of the paint to minimise sag, by means of anti-sag gel, at the application wet film thickness. Alkyd resins unaided would require several days to dry therefore, metal driers are added to reduce this to hours. A combination is normally used as each have a specific role. Cobalt offers surface drying and manganese a balance of surface and bulk drying. Calcium is used in combination with lead and is effective at low temperatures. TiO_2 is used as the colouring pigment in the case of white paints. The resultant VOC of 359g/L for the conventional formulation, Table 8.18, and 375 g/L for the early 1980's formulation, Table 8.17, is typical and levels of 350g/L to 400g/L have been routinely measured for currently available products. Little difference is evident between the early and current formulation and this reflects the degree of establishment of this technology for wood finishes.

Table 8.17 Conventional high gloss finish for wood from early 1980's

Raw material	**Kilograms**
Rutile TiO_2	350.00
Anti-sag gel 8%	35.00
Lecithin solution 50%	4.00
Long oil alkyd resin 70%	75.00
White spirit	62.70
Long oil alkyd resin 70%	620.00
Cobalt drier 6%Co	2.50
Lead drier 24%Pb	14.00
Calcium drier 6%Mn	6.00
Anti-skin solution 25%	5.00
White spirits	30.40
	1204.60

Formulating parameters.

Density	1.26 Kg/L	PVC	15.6%
Mass solids	70.2%	Volume solids	55.9%
VOC content	375 g/L		

Table 8.18 Current conventional alkyd high gloss finish for wood

Raw material	**Kilograms**	**Function**
Uralac AD44 W-70	132.0	*Alkyd resin*
White spirit	10.2	*Hydrocarbon Solvent*
Serad FA 601	2.8	*Wetting agent*
Tioxide TR 92	284.4	*Pigment*
Uralac AD44 W-70	436.7	*Resin*
Durham VX 71	22.3	*Drier*
Exkin 2	3.0	*Anti-skinning*
White spirit	108.5	*Hydrocarbon solvent*
	1000	

Formulating parameter.

Density	1.176 Kg/L	PVC	15.8%
Mass solids	69.5%	Volume solids	54.1%
VOC content	359 g/L		

Semi-gloss finishes are usually based on full gloss formulations but with flattening agents and at a higher PVC, 29.8%, Table 8.19, to disturb surface appearance. Gloss levels can be 25-50 at 60º. In some cases, additions of diatomaceous silica are used to break the surface. Correct choice and use of flattening paste is important, otherwise the result can be patchy in appearance. The principal difference between the recent and early formulations is the absence of lead in the recent formulations which has come under scrutiny due to health concerns. Otherwise the constituents remain the same. White spirit is still the principle solvent employed and the VOC level of 426g/L remains characteristic. Levels of about 360g/L have been measured for this class of product. Wood undercoats are used to provide cost efficient hiding with good surfacing so that the final finish coat can be formulated with primary emphasis on appearance attributes such as gloss. This is achieved with high PVC of 51.8%, Table 8.21. In addition, they need to be quick drying with low odour. Normally, no differentiation is made between indoor and outdoor formulations where consideration would have to be given to the different drying conditions, and therefore solvent blends, inside and out. A traditional undercoat only is presented here. These products are particular to some markets and are less common elsewhere. VOC levels are similar to full gloss at 352g/L and levels of 380g/L have been measured on current products.

Table 8.19 Satin finish for wood early 1980's

Raw material	**Kilograms**
Rutile TiO_2	400.00
Calcium carbonate	350.00
Thixotropic alkyd 42%	75.00
Long oil alkyd resin 70%	230.00
Lecithin solution 50%	20.00
White spirit	46.10
White spirit	23.70
Medium oil alkyd 50%	252.00
Cobalt drier 6%Co	2.60
Lead drier 24%Pb	14.00
Calcium drier 6%Mn	5.60
Long oil alkyd resin	32.60
Or Flattening paste	37.60
White spirit	9.10
Anti-skin solution	7.00
	1467

Formulating parameters.

Density	1.47 Kg/L	PVC	29.8%
Mass solids	75.3%	Volume solids	53.8%
VOC content	363 g/L		

Table 8.20 Current satin gloss for wood

Raw material	**Kilograms**	**Function**
Uralac AF294 V-55	110.00	*Resin*
Urathix AT 413 V-55	225.00	*Resin*
Kronos 2190	240.00	*Pigment*
Millicarb	50.00	*Extender*
Syloid ED 5	25.00	*Extender*
White spirit	80.00	*Hydrocarbon solvent*
Uralac AF294 V-55	230.00	*Resin*
Durham Co 10	2.00	*Drier*
Durham Zr 12	9.00	*Drier*
Durham Ca 10	7.00	*Drier*
Exkin 2	3.00	*Anti-skin*
White spirit	19.00	*Solvent*
	1000	

Formulating parameters.

Density	1.166 Kg/L	PVC	22.8%
Mass solids	63.5%	Volume solids	45.5%
VOC content	426 g/L		

Table 8.21 Undercoat for wood from early 1980's

Raw material	**Kilograms**
Thixotropic alkyd	80.00
Long oil soya alkyd resin	150.00
Lecithin solution	8.00
Anti-sag gel 8%	40.00
Clay	100.00
Calcium carbonate	400.00
Rutile TiO_2	380.00
Mineral turpentine	140.00
Long oil alkyd resin 70%	200.00
Cobalt drier 6%Co	2.50
Lead drier 24%Pb	12.00
Calcium drier 6%Mn	5.50
Anti-skin solution 25%	8.00
White spirits	3.90
	1529.9

Formulating parameters.

Density	1.530 Kg/L	PVC	51.8%
Mass solids	77%	Volume solids	56.3%
VOC content	352 g/L		

8.6.2 Conventional decorative varnish for interior and exterior wood.

Interior wood varnish has traditionally been based on alkyd, tung and urethane modified oils and two-pack urethanes. Urethane oils are more suitable than unmodified alkyds in high traffic areas such as floors and stairs. Ultimate performance for conventional exterior varnishes is achieved with the use of tung and linseed modified resins. The main differences between interior and exterior stain and varnish formulations are due to the requirement for protection from the effects of sunlight on the film and the substrate. Degradation by UV of the substrate at the substrate/coating interface leads to coating failure and degradation of the binder at the surface leads to loss of gloss and colour. In addition, protection of the substrate from moisture and dimensional stability are key issues concerning exposure of exterior wood and therefore, good flexibility is required. As a consequence, formulations for exterior use contain UV absorbers at low levels. Tung modified resins are considered to be superior due to the UV stability. UV absorbers have been known to deactivate driers and therefore care must be taken when selecting these materials. Varnishes based on oxidatively cured resins suffer from continuing embrittlement and varnishes are susceptible to cracking and flaking on exterior use. Solventborne alkyd binders have maintained a dominant position in the varnish sector due to their good application properties and high gloss. An early formulation for exterior varnish and stain is presented here for comparison with interior formulations in terms of VOC. These formulations are less complex than paints for wood in that there are less additives competing in the same volume. No extenders, pigments are present to a large extent and subsequently there is no need for dispersing agents. Colouring can be provided in the form of very fine particle size red or yellow iron oxide, which also act as UV absorbers. Solvents are still based on white spirits and higher levels of VOC, 439-485g/L, reflect that the volume solids of 40% in Table 8.22 and 46% in Table 8.23, have no associated PVC. Thus, compared to paint at the same volume solids, there is significantly more volume of resin requiring solvent. Levels of between 500g/L and 600g/L have been measured in current products.

Table 8.22 Clear varnish for interior wood from early 1980's

Raw material	**Kilograms**
Urethane modified oil 60%	660.00
White spirit	102.00
Cobalt drier 6%Co	2.00
Lead drier 24%Pb	3.10
Anti-skin solution 25%	10.00
White spirit	104.00
	881

Formulating parameters.

Density	0.881Kg/L
Mass solids	44.9%
Volume solids	39.6%
VOC content	485g/L

Table 8.23 Clear varnish for exterior wood from early 1980's

Raw material	**Kilograms**	**Litres**
Long oil linseed alkyd resin	664.80	707.20
UV absorber	17.30	13.90
White spirit	163.20	208.20
White spirit	15.20	19.40
Cobalt drier 6%Co	4.00	4.20
Lead drier 24%Pb	16.00	13.60
Calcium drier 6%	5.00	5.50
Anti-skin solution 25%	5.50	6.50
White spirit	16.80	21.50
	907.9	1000

Formulating parameters.

Density	0.908 Kg/L
Mass solids	51.7%
Volume solids	46.4%
VOC content	439 g/L

8.6.3 Conventional decorative woodstains for interior and exterior use.

Woodstains have found increasing use in recent years and consist of very low volume solids solutions, usually based on alkyds. They are formulated at low volume solids ~15% (Table 8.24) and 28% (Table 8.25), in order to reveal the grain and texture of the timber yet imparting some UV resistance through the addition of very fine pigments such as iron oxide. Sufficient binder is used to stabilise the pigment in the wood and no significant film is obtained. Little water repellency, is afforded by these products. In addition, they offer no real benefit in terms of substrate preservation and should be applied to previously treated wood. Some surface preservation is afforded which maintains appearance The addition of the colouring pigments give these materials better UV stability than clear varnishes so that appearance is maintained over longer time periods. Brush application alone over fresh timber does not achieve the penetration required for long-term preservation. Fungicides are included for exterior use with typical metal soaps such as copper and zinc being used.

Due to the penetration requirements, the volume solids are very low with the remainder of the volume being taken up with solvent. Therefore, these materials are very high VOC emitters, with contents of between 600g/L and 700g/L presented here. These levels are still representative with levels of 750g/L being measured on current products.

Table 8.24 Semi-transparent woodstain for interior wood from early 1980's

Raw material	**Kilograms**
Synthetic yellow iron oxide	38.00
Natural red iron oxide	24.00
Anti-settling agent	12.00
Lecithin solution 50%	1.00
Long oil alkyd 70%NV	115.00
Zirconium drier 6%	1.00
Mineral turpentine	120.00
Mineral turpentine	20.00
Mineral turpentine	20.00
Alkyd resin non-yellowing	110.00
Mineral turpentine	300.00
Cobalt drier 6%Co	1.00
Manganese drier 6%	1.00
Anti-skin solution 25%	5.00
Mineral turpentine	144.20
	912.2

Formulating parameters.

Density	0.913	PVC	9.7%
Mass solids	22.2%	Volume solids	15.2%
VOC content	710g		

Table 8.25 Exterior woodstain from early 1980's

Raw material	**Kilograms**
Vegetable black	20.00
Lecithin solution 50%	2.00
Long oil linseed alkyd 70%	50.00
Anti-sag gel	50.00
Mineral turpentine	30.00
Boiled linseed oil	160.00
Medium oil alkyd 60%	100.00
Fungicide	4.50
Cobalt drier 6%Co	4.00
Lead drier 24%Pb	16.00
Anti-skin solution 25%	6.00
Mineral turpentine	234.00
Mineral turpentine	185.12
	907.9

Formulating parameters.

Density	0.862	PVC	3.3%
Mass solids	30.8%	Volume solids	28.5%
VOC content	596 g/L		

8.6.4 Conventional primers and sealers for wood.

Primers are required to provide adhesion to the substrate, as well as intercoat adhesion to subsequent undercoats and finish coats. Flexibility is an important characteristic to maintain adhesion and in the case of wood, significant movement has to be tolerated. Primers for wood are required to impede the passage of water, from inside and from outside the building, of water. This is of particular importance for wood where water transport can greatly influence the dimensional stability and longevity of the substrate. Decay in wood is prevented by maintaining the level of moisture in the wood below 22% (91). Dimensional stability in joinery must be maintained where significant movement is possible. Primers are particularly important for sealing end-grains, in order to prevent wood rot due to their exposure. Most joinery is pre-primed by the manufacturer in the factory before delivery to the user. A common scenario has been for joinery to arrive for installation pre-primed, which is trimmed on-site, thereby exposing the end grain and by-passing the protective barrier film provided by the paint elsewhere. The situation is exacerbated where highly impermeable paint systems are used. Traditional wood primers were formulated with white and red lead and linseed oil, which offered good protection in the form of barrier systems due to the lead soap formation between the pigment and the oil component. The associated toxicity effects of lead have resulted in the removal of lead from these primers. However, wood primers may still be formulated to a pink colour due to the association of performance with colour.

Wood primers are also formulated with aluminium flake to provide barrier properties against resin exudation and water transport. Leafing aluminium provides tortuous paths for water to permeate through. Formulating with aluminium can lead to problems associated with out-gassing where water contamination is present. Leafing aluminium can migrate and align at the surface resulting in overcoating difficulties in the form of adhesion loss.

The conventional alkyd/oil primer, Table 8.26, has a high PVC at 68% which can aid intercoat adhesion. Volume solids are low at 32% to aid penetration of the substrate by binder and due to this, the subsequent VOC is therefore about 500g/L. Wood primers have been measured at between 250g/L and 400g/L in current products. A blend of natural drying oils (linseed oil in this case) with a medium oil-length alkyd is used to facilitate speed of drying, consistency of performance and cost. An advantage of traditional solution binders, as primers, is the penetration capability of the binder, which penetrates the wood with the solvent. High water barrier properties are enjoyed with alkyd paints, however, this can lead to blistering as water leaving the substrate cannot pass through the film fast enough to prevent build-up of water and adhesion loss due to osmotic forces.

Table 8.26 Conventional wood primer from early 1980's.

Raw Material	**Kilograms**
Rutile titanium dioxide	100.00
Calcium carbonate	700.00
Lecitchin solution 50%	16.00
Anti-settling agent	3.00
Methylated spirits	1.00
Raw linseed oil	150.00
Thixotropic alkyd 40%	150.00
Mineral turpentine	40.00
Raw linseed oil	65.00
Mineral turpentine	24.00
Medium oil alkyd 55%	150.00
Cobalt drier 6%Co	4.00
Manganese drier 6%Mn	2.00
Lead drier 24%Pb	17.00
Red oxide tinter	20.00
Anti-skin solution 25%	6.00
Mineral turpentine	14.70
	1462.7

Formulating parameters.

Density	1.463Kg/L	PVC	68.7%
Mass solids	64.4%	Volume solids	31.5%
VOC content	512g/L		

There are many substrate imperfections, which can be presented to the painter, such as stains, which may be transported by means of solution. They can be soluble in the paints by which they must be overcoated. This is particularly true of water-soluble stains such as those introduced from plumbing leaks, to which waterborne products are particularly vulnerable. Nicotine stains have always presented problems for the painter and this has resulted in specialty products know as stain blockers. Waterborne acrylic latex, employing a wide particle size distribution to achieve better packing at coalescence, is used effectively on many common stains encountered. Latex film formation does not provide the degree of homogeneity of a solution derived film and permeation values, due to percolation pathways, are always higher. Solventborne products still dominate as they provide the best blocking for most stains. Typical VOC values are presented in Table 8.27,

Table 8.27 Stain block.

Product	**VOC content**
Styrenated solution acrylic	450g/L

8.7 Conventional primers, sealers, stabilizing solutions and other applications.

Many specialist products are designed with a particular niche function in mind. All of the products involve consolidation of the surface to prepare it for further application of other products or to prevent ingress or egress of stains, oils, salts or moisture to and from the substrate.

8.7.1 Water repellants.

The primary function of these materials is to control water transport, usually into masonry. The majority of products are now based on solventborne silicone resin technology due to the hydrophobic properties of the resin, although acrylic resin solutions and epoxy resin solutions can also be used. These products all tend to have low volume solids contents and they aim to penetrate the substrate deeply. Adhesion can be a problem with overcoating where weathering has not occurred. Typical VOC values associated with these products are as follows,

Table 8.28 Water repellants.

Product	VOC content
Silicone	750 g/L
Acrylic solution (high build)	327 g/L

8.7.2 Stabilisers.

Special care is required when painting over surfaces which have friable or loose material. Thus a penetrating and consolidating product is needed. Similar to water repellants, deep penetration is required, although a higher level of volume solids is characteristic in order to provide a binding layer. Solventborne and waterborne variants exist, although waterborne latex does not lend itself to this application due to the particulate nature of the binding medium. Solventborne technology can be any solution resin although care should be taken when employing alkyd or saponifiable materials over alkaline surfaces. Latex materials use very fine particle size polymer spheres to aid penetration. Typical VOC values are as follows,

Table 8.29 Stabilisers.

Product	VOC content
Solventborne alkyd or acrylic	350-750g/L

8.7.3 One-pack specialty products.

A requirement exists for general-purpose specialty products that provide decoration and protection to certain substrates such as floors and metal work. These products must offer a degree of durability not afforded by other typical products for decorative use and this must be supplied at reasonable cost. The variety of substrates encountered in the architectural environment means that a wide variety of products exist and many small specialist companies exist to supply them as well as the large companies. Typical applications belonging in this class are,

- Primer and finish coat for plastic.
- Primer coat for ferrous substrates.
- Primer coat for reactive metals such as zinc and aluminium.
- Anticorrosion finishes.
- Floor coatings, including wood and cement.

Cost effective modified alkyd technology dominates the anticorrosion sector where rather benign conditions prevail, however, where retention of appearance is crucial and the substrate can be highly alkaline, acrylic solution films have a particular role to play. It is important to understand that the protective requirements may not be high and typically these products could not be described as heavy-duty, for which very different and much more costly technology is employed. Some of these generic types are described in the two-pack classes that follow, which inevitably can be used in architectural applications and may be associated with some heavy-duty applications. In order to provide corrosion protection, formulations must provide an optimum level of adhesion, particularly wet adhesion, act as a barrier to the ingress of aggressive ions such as Cl^- and SO_4^-, as well impede the permeation of oxygen and water. The aim is to prevent electrochemical activity at the substrate. Barrier properties are also imparted by the addition of lamellar pigments, which provide an extended pathway to the permeating species. In some cases, anti-corrosive pigments such as $ZnPO_4^-$ and sacrificial pigments are added to provide additional protection.

Typical values of VOC for these anticorrosion products are,

Table 8.30 Coatings for metal

Product	VOC content
Metal primer coat	400-500g/L
Metal finish coat	400-500g/L

Table 8.31 High gloss urethane modified alkyd.

Raw Material	Kilograms	Function
Rutile TiO_2	28.70	*Pigment*
Zinc oxide	1.50	*Fungicide*
Polyurethane 2388 50%	65.50	*Binder*
Cargill N lecithin	0.30	*Dispersant*
Antioxidant	0.10	*In-can stabiliser*
Cobalt octoate 6%Co	0.10	*Drier*
Calcium octoate 5% Ca	0.30	*Drier*
Zirconium complex 6% Zr	0.30	*Drier*
White spirits	3.20	*Hydrocarbon Solvent*
	100	

VOC g/L ~ 36wt.%
(equates to 485g/L if typical SG is 1.35Kg/L)

In the case of flooring, durability is particularly required and the resin is chosen specifically with this attribute in mind. Hardness, chemical resistance, speed of drying, toughness and moisture resistance can be imparted to standard alkyds by means of urethane linkages. This is achieved by means of reaction of a drying oil with a suitable polyhydric alcohol such as glycerol to produce a mixture of mono- and diglycerides. Instead of employing ester linkages by reaction with an acid, as is the case with conventional alkyds, an isocyanate cross-linker such as toluene diisocyanate (TDI) can be used, to react across the OH groups. Therefore, these materials are neither true alkyds nor true urethane but offer some of the benefits of both. No ester linkages are present, thus the film is not water sensitive and excellent toughness and chemical resistance is available, at competitive cost. Typical VOC figures associated with these one pack floor coatings are as follows,

Table 8.32 Floor varnish.

Product	VOC content
One-pack floor paint/varnish	400g/L

Flooring protection and decoration is also provided by two-pack products.

8.7.4 One and two-pack reactive coatings.

Certain applications demand performance approaching heavy-duty levels particularly those applications encountered by professionals. These materials are usually based on the polyurethane, epoxy polyamine/amide and acid catalysed phenolic resin chemistry outlined earlier. Thermosetting or reactive coatings are not susceptible to hydrolysis or saponification. The carbon-carbon ether links of the epoxy polymers and the urethane links used in polyurethanes or urethane modified resins are highly resistant to alkali and hydrolysis. Additionally, the cross-linking mechanism involved with both systems means that toughness and good barrier properties are provided. Epoxy materials, due to the high levels of polarity in the molecule offer excellent adhesion, although they are sensitive to UV exposure. Urethanes offer excellent chemical resistance and are UV stable. Therefore they are used where a combination of chemical resistance, colour and gloss retention are essential. However, the two pack products require care in application as airborne isocyanate groups are a health hazard. These products therefore, find application on floors (cement and wood) and walls where barrier and abrasion properties are essential. The one-pack moisture curing systems find application on floors where the urethane hardness is required without the difficulty of handling and applying two-pack products. Typical products based on these specialist materials are presented below.

Table 8.33 High impact resistant concrete coating.

Pack 1 -Base pack.

Raw Material	**Kilogram's**	**Function**
Rutile TiO_2	26.28	*Pigment*
Anti Terra U	0.26	*Surfactant*
EPON Resin 1001-CX-75	28.29	*Epoxy*
Beetle 216-8	1.13	*Dispersant*
Xylene	15.72	*Solvent*
Butyl Oxitol glycol ether	2.49	*Solvent*
	74.17	

Pack 2 -Curing agent

EPI-CURE 3164	204.1
2-Propoxyethanol	50.2
Xylene	108.4
GE SIR-882M	28.3
	390.58

Part A	74.17
Part B	25.83
	100

VOC = 479 g/L quoted.

Table 8.34 Moisture-cured polyurethane floor varnish.

Raw Material	**Kilogram's**	**Function**
Polyurethane 3651	66.4	*Binder(60% solids)*
Xylene	33.2	*Solvent*
Dimethylethanolamine	0.4	*Catalyst*
	100	

VOC ~ 59.76wt.%

(equates to 597.6 g/L if typical SG is 1.00 Kg/L)

Table 8.35. Summary of VOC levels of conventional waterborne decorative paints and varnishes.

VOC g/L*	**Class Description**
21	Interior matt walls and ceilings
46	Interior glossy walls and ceilings
35	Exterior walls
*	Interior and exterior trim and cladding paint
*	Interior and exterior trim varnish and lacquers
*	Interior/exterior trim woodstains and lasures
*	Primer/sealer and stain block for walls, ceilings and wood.
*	One pack coating for radiators, floors, metal and plastic.
*	Binding primers to stabilise loose substrate particles and to impart hydrophobic properties.
*	Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.

***** These products are treated in the low-VOC section

Table 8.36 VOC levels for conventional solventborne decorative paints and varnishes.

VOC g/L*	**Class Description**
312	Interior matt walls and ceilings
312	Interior glossy walls and ceilings
450	Exterior walls
359	Interior and exterior trim and cladding paint
439	Interior and exterior trim varnish and lacquers
596	Interior/exterior trim woodstains and lasures
512	Primer/sealer and stain block for walls, ceilings and wood.
400-500	One pack coating for radiators, floors, metal and plastic, including physically drying solvent based coatings and oxidative drying coatings.
750	Binding primers to stabilise loose substrate particles and impart hydrophobic properties.
479	Two-pack reactive coatings for specific end-use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.
597	One pack reactive coatings for specific end use such as floors e.g. moisture-curing polyisocyanate.

*Value are not including tinting pastes. The addition of tinting pastes could add up to 35g/L to the VOC content.

8.8 Low VOC options for categories of decorative paints and varnishes.

The following section describes the low VOC or VOC free options that are available at the present time. Low VOC substitutions are provided for those categories that represent a non-negligible share of the solvent based decorative paints and varnishes sector. Water based paints contain solvent so the exercise involves all decorative paints and varnishes of non-negligible or significant market share. These categories have been presented in section 8.2 and include,

Interior matt and semi-gloss paints.
Exterior wall paint.
Full and semi-gloss finishes for wood.
Interior and exterior varnish and stains for wood.
Primers and sealers (especially for wood).

8.9 Low VOC formulations for interior matt and semi-gloss paints.

Latex emulsion paints have dominated this sector for several decades, therefore the low VOC options can be represented by one of the lowest VOC formulations available from these current formulations. Tables 8.37 and 8.38 represent available starting point formulations for interior matt wall applications. The first formulation can also be described as conventional for this category with a VOC content of 21g/L. Accounting for tinters this value could be 56g/L. However, values of 100g/L have been measured on current products.

The second formulation in Table 8.38 represents a formulation which is currently available and that has no solvent or coalescing solvent identified. The mass solids and volume solids are significantly higher than those of conventional formulations, being 63% and 39% respectively.

Table 8.37 Low VOC waterborne interior matt wall paint formulation

Raw material	**Kilograms**	**Litres**	**Function.**
Water	352.80	352.80	*Carrier medium*
Oraton 1124	9.64	8.16	*Dispersant*
Kathon-LXE	0.70	0.68	*Biocide*
Nopco NXZ	2.82	3.13	*Defoamer*
Ethylene glycol	14.17	12.69	*Freeze-thaw/wet edge*
Water	35.28	35.28	*Carrier medium*
Acrysol TT-935	9.88	9.34	*Rheology modifier*
Aqueous ammonia	0.77	0.83	*pH control*
Tioxide TR-92	129.82	31.05	*Pigment*
Polestar 200P	149.22	55.27	*Extender*
Durcal 5	202.74	73.67	$CaCO_3$ *extender*
Nopco NXZ	1.27	1.41	*Defoamer*
Texanol	6.69	7.04	*Coalescing solvent*
ROVACE 9100	121.66	110.60	*Latex polymer*
Ropaque OP-62LOE	76.62	74.20	*Opaque polymer*
Aqueous ammonia 28%	2.00	2.17	*pH control*
Acrysol TT-935	13.33	12.60	*Thickener*
Water	208.00	208.30	*Carrier medium*
	1337	999	

Formulating parameters.

Density	1.34	PVC	78.15%
Mass solids	46.75%	Volume solids	25.56%
VOC content	21 g/L		

Table 8.38 Low VOC waterborne interior matt wall paint formulation

Raw material	**Kilograms**	**Function.**
Water	157.02	*Carrier medium*
Oraton 731K(25%)	40.32	*Dispersant*
Natrosol 250 MHR(2.5%)	179.75	*Thickener*
Kathon-LXE	1.00	*Biocide*
Clerol LSB-908	3.99	*Defoamer*
KOH (1N)	3.0	*pH control*
Triton CF-10	2.0	*Dispersant*
Tioxide TR-92	197.46	*Pigment*
Talc AT-1	79.18	*Extender*
Aluminium silicate P-820	40.95	*Extender*
Durcal 10	327.16	*Extender*
Primal SF-015	241.52	*Latex polymer*
Ropaque OP-96	154.09	*Opaque polymer/extender*
Acrysol RM 2020(20%)	23.06	*Thickener*
Acrysol TT-615	1.5	*Thickener*
	1452	

Formulating parameters.

Density	1.452	PVC	74.4%
Mass solids	63%	Volume solids	39%
VOC content	0 g/L		

Semi gloss formulations are also available, Table 8.39, formulated to high mass solids of 63%, and relatively high volume solids of 43%. Alkyd emulsions are also available, Table 8.40, which offer zero VOC formulations for ceiling applications. The alkyd emulsions are uncommon and these formulations are offered as an alternative to glossy, solventborne wall coatings.

Table 8.39 Low VOC interior semi-gloss solvent-free wall paint formulation.

Raw material	**Kilograms**	**Function**
Water	4.44	*Carrier medium*
Oraton 1124	9.93	*Dispersant*
Natrosol 250 HBR(2.5%)	184.66	*Thickener*
Kathon-LXE	1.30	*Biocide*
Clerol LSB-908	4.00	*Defoamer*
NaOH (30%)	0.9	*pH control*
Triton CF-10	2.0	*Dispersant*
Tioxide TR-92	288.24	*Pigment*
Durcal 2	208.86	*Extender*
Primal SF-015	534.69	*Latex polymer*
Ropaque OP-96	117.09	*Opaque polymer/extender*
Acrysol RM 2020(20%)	24.79	*Thickener*
	1380	

Formulating parameters.

Density	1.380	PVC	48.3%
Mass solids	63%	volume solids	43%
VOC content	0 g/L		

Table 8.40 Low VOC waterborne alkyd solvent-free ceiling paint formulation

Raw material	**Kilograms**	**Function.**
Demineralised H_2O	185.5	*Carrier medium*
Natrosol 250 HR	3.0	*Rheology modifier*
Orathon 731 25%	23.1	*Dispersing agent*
Agitan 295	2.5	*Anti-foaming agent*
Hydrocarb	123.5	*Extender*
Omyalite BLP 2	117.1	*Extender*
Calibrite SL	76.3	*Extender*
Tioxide TR 92	254.4	*Pigment*
Uradil AZ554 Z-50	194.9	*Alkyd polymer*
Demineralised H_2O	17.7	*Carrier medium*
Troysan 174	2.0	*Biocide*
	1000	

Formulating parameters.

Density	1.664 Kg/L	PVC	67.1%
Mass solids	67.8%	Volume solids	46.4%
VOC content	0g/L		

8.10 Exterior wall paint for masonry, brick and stucco.

The same situation applies for exterior flat wall applications as for interior. The current acrylic latex technology offers the lowest VOC formulations available for that category. A value of 35g/L VOC content is quoted in the starting point formulation. Values of between 60-120g/L VOC content, have been measured for these products.

Table 8.41 Low VOC waterborne exterior masonry paint formulation

Raw material	**Kilograms**	**Function.**
Water	109.60	*Carrier medium*
Natrosol 250 MBR	2.60	*HEC rheology modifier*
Aqueous ammonia	2.00	*pH control*
Dowicil 75	1.60	*Preservative*
Nopco NXZ	5.90	*Defoamer*
Orotan731K	15.00	*Dispersant*
Sudranol 340	11.20	*Wax*
Triton CF10	2.00	*Surfactant*
Ropaque OP-62LOE	90.90	*Opaque polymer/extender*
Primal AC-532K	310.60	*Latex polymer*
Tioxide TR-92	111.00	*Pigment*
Durcal 5	116.90	*$CaCO_3$ extender*
Mikal 00160	49.80	*Extender*
Mikal 00180	144.20	*Extender*
Texanol	24.40	*Coalescing solvent*
Ammonia or water	2.10	*pH control*
	1000	

Formulating parameters.

Density	1.43	PVC	60%
Mass solids	61.4%	Volume solids	45%
VOC content	35 g/L		

Table 8.42 Low VOC waterborne exterior masonry paint formulation

Raw material	Kilograms	Function.
Water	67.9	*Carrier medium*
Acrysol RM-2020	6.7	*Thickener*
Orotan 1124	7.2	*Dispersant*
Byk 023	1.9	*Dispersant*
KTPP	1.10	*Dispersant*
Tiona RCL-535	188.4	*Pigment*
Talc AT-1	44.5	*Extender*
Calibrite SL	82.9	*Extender*
Socal P2	41.6	*Extender*
Kathon LXE	2.3	*Biocide*
Kathon 893	4.2	*Biocide*
Water	8.3	*Carrier medium*
Water	55.4	*Carrier medium*
Primal SF-015	370.20	*Latex polymer*
Ropaque OP-3000	91.9	*Opaque polymer*
Byk 023	6.7	*Surfactant*
Acrysol RM-2020	8.00	*Thickener*
Acrysol SCT-275	10.8	*Thickener*
	1000	

Formulating parameters.

Density	1.38 Kg/L	PVC	N/A%
Mass solids	56.3%	Volume solids	42.4%
VOC content	*14 g/L		

*quoted value. No apparent VOC in the formulation.

Current solventborne products, that are available for application during adverse weather conditions, represent the lowest available VOC content, 450g/L, for exterior masonry. Levels of VOC at 480 g/L have been measured for current products.

Table 8.43 Low VOC solventborne exterior masonry paint formulation

Raw material	Kilograms	Function.
Pliolite AC80	4.630	*Styrene acrylic polymer*
Pliolite AC4	2.49	*Styrene acrylic polymer*
Cereclor 54DP(85%)	5.62	*Plasticiser*
Soya lecithin	0.24	*Dispersant*
Tioxide TR92	17.95	*Pigment*
Omya BLP3	7.69	*Extender*
Calibrite SL	28.51	*Extender*
Celite 281	4.10	*Flattening agent*
White Spirit 17	23.02	*Hydrocarbon solvent*
Solvesso 100	5.75	*Hydrocarbon solvent*
	100	

Formulating parameters.

Density	N/A Kg/L	PVC	64.4%
Mass solids	N/A %	Volume solids	44.9%
VOC content	450g/L		

8.11 Low VOC full and semi-gloss finishes for wood.

Conventional coatings for wood were described in section 8.6 and were comprised mainly of formulations based on solventborne alkyd technology. Low VOC alternatives are available for the same applications and these technologies currently rely on acrylic latex, alkyd emulsion and high solids alkyd polymers. Alkyd emulsions are the most recent technology to emerge to offer low VOC contents. These waterborne polymers are true emulsions, mixtures of one immiscible liquid in another, and therefore the VOC requirement is minimal since coalesence is not needed. Both full gloss and low gloss finishes are possible. VOC contents of 16g/L for full gloss (Table 8.44) and 25 g/L for satin finish (Table 8.45) are possible from the formulations below. The volume solids of 38% for full gloss and 42% for satin finishes manifest the differences between these alkyd emulsions and acrylic latices. Acrylic latex film formation has been described in section 8.3.1.2, and it was explained that the solid nature of the polymer particles means that they form part of the solid vehicle competing for available space with the extenders and pigment as the film dries. Alkyd emulsions however, phase-invert, meaning that the system changes from being a dispersion of alkyd polymer droplets in water, to a system of water droplets in an alkyd medium. This allows for higher %volume solids contents in the formulations and no coalescing solvent is required, although other solvents may be required for rheological purposes.

Table 8.44 Low VOC waterborne alkyd high gloss finish.

Raw material	**Kilograms**	**Litres**	**Function**
Demineralised H_2O	81.0	101.9	*Carrier medium*
Acrysol RM 8	4.0	4.7	*Rheology*
Byk 024	0.10	0.12	*Defoamer*
Disperbyk190	12.5	15.6	*Antifoam*
Kronos 2190	240.0	73.3	*Pigment*
Demineralised H_2O	76.5	96.3	*Carrier medium*
Uradil AZ554 Z50	530.0	639.2	*Resin*
Acrysol RM 8	7.5	8.8	*Rheology*
Acrysol RM 2020	29.0	35.8	*Rheology*
Additol VXW 4940	3.0	3.9	*Drier*
BYK 348	3.0	3.6	*Levelling*
Propylene glycol	12.5	15.4	*Solvent*
	1000	1000	

Formulating parameters.

Density	1.258	PVC	19.4%
Mass solids	50.6	Volume solids	38.0%
VOC content	16g/l		

Table 8.45 Low VOC waterborne alkyd satin finish for wood.

Raw material	**Kilograms**	**Litres**	**Function**
Demineralised H_2O	94.3	138.1	*Carrier medium*
Disperbyk 190	21.4		*Dispersant*
BYK 024	1.0	1.4	*Defoamer*
Acrysol RM 8	4.8	6.5	*Rheology*
Kronos 2190	221.4	79.1	*Pigment*
Microdol A 1	161.9	83.2	*Extender*
Finntalc MO5	47.6	25.8	*Extender*
Demineralised H_2O	47.6	69.7	*Carrier medium*
Uradil AZ554 Z-50	333.3	467.8	*Alkyd emulsion*
Durham VX 71	16.7	25.2	*Drier*
Acrysol RM 2020	28.6	41.0	*Rheology*
Propylene glycol	9.5	13.7	*Solvent*
Demineralised H_2O	11.9	17.4	*Carrier medium*
	1000	1000	

Formulating parameters.

Density	1.464	PVC	45.7%
Mass solids	60.7%	Volume solids	42.3%
VOC content	25 g/l		

Significant development activity has taken place in the high solids alkyd sector. This has been catalysed by the requirement for low VOC contents, for products to acquire the Ecolabel status, which specifies 250g/L for certain instances. VOC contents are still high compared to those of the alkyd emulsions, however, 191g/L from Table 8.46, offers a significant reduction from 350-400 g/L measured for conventional products. Volume solids of 78% means that these products offer better covering capability than other alternatives, although this could mean higher coating thicknesses.

Table 8.46 Low VOC high solids alkyd gloss finish.

Raw material	**Kilograms**	**Litres**	**Function**
UralacAH263	72.5	96.8	*Alkyd*
White spirit	75.0	127.1	*Solvent*
BentoneSD1	2.5	2.2	*Rheology*
Durham Ca 10	10.0	13.5	*Drier*
Tioxide TR92	375.0	123.9	*Pigment*
Uralac AH263	393.5	525.6	*High solids alkyd*
Durham Co10	3.0	3.8	*Drier*
Durham Zr12	20.0	26.7	*Drier*
Isobutanol	6.0	8.6	*Solvent*
Exkin2	6.0	8.6	*Solvent*
White spirit	37.5	63.5	*Solvent*
	1000	1000	

Formulating parameters.

Density	1.321 Kg/L	PVC	16.7%
Mass solids	85.5%	Volume solids	75.8%
VOC content	191g/L		

Acrylic/vinyl latices have been available since the early eighties, however, their uptake has been slow due to difficulties associated with their application and with lower levels of gloss compared to conventional alkyds. The reasons for this have been outlined in section 8.3.1.2. However, commercial products are readily available and offer a potential reduction in VOC content over conventional alkyd products. Table 8.47 represents a high gloss formulation, which has an associated VOC content of 98g/L. The 33% volume solids content is lower than that of the alkyd emulsions of 38% for that application.

Table 8.47 Low VOC acrylic latex high gloss finish.

Raw material	**Kilograms**	**Function**
Propylene glycol	29.5	*Freeze thaw/wet edge*
Orotan 731(35%)	29.5	*Dispersing agent*
Kathon LXE	0.8	*Biocide*
Aqueous ammonia(28%)	0.8	*pH control*
Methyl carbitol	16.4	*Coalescing solvent*
Tegofoamex K-1488	3.0	*Defoamer*
Acrysol RM-1020(20%)	28.7	*Thickener*
Tioxide R-HD2	210.5	*Pigment*
Water	24.6	*Carrier medium*
Tegofoamex K-1488	2.0	*Defoamer*
Texanol	34.4	*Coalescing solvent*
Primal HG-74D(42%)	550.4	*Latex*
Acrysol RM-1020(20%)	12.3	*Thickener*
Water	57.1	*Carrier medium*
	1000	

Formulating parameters.

Density	1.22 Kg/L	PVC	19.4%
Mass solids	44.4%	Volume solids	33.1%
VOC content	98 g/L		

VOC free formulations are also on offer from the suppliers of the acrylic waterborne latices for wood. However, it is suggested that 2-3% propylene glycol or ethylene glycol can be added to improve open-time, suggesting that drying is rapid and could present a problem on application. This would be particularly pertinent if the ambient temperature was high during application. An addition of 3% solvent would constitute a 37 g/L VOC content for the formulation. VOC free latices have been reported in the technical review and are a more recent development in the low VOC sector of decorative coatings. It has been suggested that the almost negligible requirement for VOC comes from the oxidatively driven curing reaction in the dry film, which helps achieve the films final properties. Thus, the need for significant interdiffusion of the particles is lessened and the therefore the need for coalescing solvents. However, this would not solve difficulties of short open times, which leads to the option of adding the cosolvent. An additional benefit claimed for this technology has been the lowering of the minimum film formation temperature (MFFT) with application at 0°C reported to be possible. Although, the latex suppliers claim that an MFFT of +1°C has been observed, they do not recommend application of these products below +5°C.

Table 8.48 VOC-free acrylic latex high gloss finish.

Raw material	Kilograms	Litres	Function
Water	40.44	40.44	*Carrier medium*
Orotan 1124	4.13	3.49	*Dispersing agent*
Byk 024	1.21	1.23	*Defoamer*
Acrysol RM-2020(20%)	8.09	7.74	*Thickener*
Tioxide R-HD2	206.38	50.69	*Pigment*
Primal SF-021	589.50	556.13	*Latex*
Acrysol RM-2020(20%)	31.89	30.52	*Thickener*
Water	118.35	118.35	*Carrier medium*
	1000	808	

Formulating parameters.

Density	1.236 Kg/L	PVC	18%
Mass solids	46.9%	Volume solids	34.6%
VOC content	*0.5 g/L		

8.12 Interior and exterior varnish and stains for wood.

The majority of interior wood varnish has traditionally been based on solventborne alkyd polymers. In the same way that waterborne latex paints have begun to compete with these products, low VOC waterborne alternatives are available for varnishes and stains. Table 8.49 and 8.50 show starting point formulations for waterborne acrylic latex lacquers and woodstains respectively. There is significant VOC reduction potential over conventional technologies with 67g/L possible for the varnish and 81 g/L possible for the stain. VOC contents of 70-132g/L for woodstains and 132-166 g/L for varnish have been measured for commercial products, therefore, as with previous formulations, these VOC values are probably ambitious.

Table 8.49 Low VOC waterborne acrylic interior clear varnish.

Raw material	Kilograms	Litres	Function
Primal HG-74D(42%)	695.0	672.9	*Latex*
Methyl Carbitol	30.0	29.4	*Coalescing solvent*
Water	50.0	50.0	*Carrier medium*
Dehydran 1620	3.0	3.0	*Carrier medium*
Texanol	35.0	36.8	*Coalescing solvent*
Permanol HDL	20.0	20.0	
Acrysol RM-5(15%)	100.0	94.7	*Thickener*
Water	66.5	66.5	*Carrier medium*
	1000	973	

Formulating parameters.

Density	1.027 Kg/L	PVC	
Mass solids	29.6%	Volume solids	28.4%
VOC content	66.7 g/L		

Table 8.50 Low VOC waterborne acrylic woodstain for interiors.

Raw Material	Kilograms	Function
Primal HG-74D(42%)	535.5	*Latex*
Propylene glycol	61.6	*Freeze thaw/wet edget*
Texanol	18.1	*Coalescing solvent*
Sudranol 340	6.2	*Wax*
Tegofoamex K-1488	1.0	*Defoamer*
Acrysol RM-2020(20%)	18.5	*Thickener*
Water	359.1	*Carrier medium*
	1000	

Formulating parameters.

Density	1.02Kg/L	PVC	
Mass solids	22.8%	Volume solids	21.7%
VOC content	81.3 g/L		

Alkyd emulsions, offer yet another alternative to conventional alkyd polymers for the decorative varnish sector. In common with the alkyd emulsion alternatives to conventional trim paint, alkyd emulsions have not had significant market penetration. Table 8.51 outlines a formulation for a high gloss topcoat and for the same reasons as for paint formulations, the VOC requirement is very low being at 12 g/L for this formulation. The volume solids is relatively high at 47.6 % due to the phase inversion mechanism outlined previously. Consequently, the mass solids content is high at 59% compared to latex formulations.

Table 8.51 Low VOC waterborne alkyd high gloss topcoat.

Raw Material	Kilograms	Function
Demineralised H_2O	120	*Carrier medium*
Orathan 731(25%)	6.0	*Dispersant*
Borchigen DFN	4.0	*Rheology modifier*
Acrysol RM 8	8.0	*Thickener*
Agitan 295	10.0	*Defoamer*
Kronos 2190	284.5	*Pigment*
Demineralised H_2O	25.0	*Carrier medium*
Uradil AZ516 Z-60	500.0	*Alkyd emulsion*
Acrysol RM 2020	25.0	*Thickener*
DurhamVX 71	14.5	*Drier*
Exkin 2	2.5	*Anti-skinning agent*
Demineralised H_2O	9.5	*Carrier medium*
	1000	

Formulating parameters.

Density	1.288Kg/L	PVC	19.2%
Mass solids	59.4%	Volume solids	47.6%
VOC content	11.6 g/L		

8.13 Low VOC primers and sealers (especially for wood).

The acrylic latex formulation for wood priming shown in Table 8.52, has a PVC of 35% while the volume solids is 35%. The volume solids in the case of a latex does not govern penetration of the substrate. The concentration and type of coalescing solvent and cosolvent used has considerable influence. Additionally, the size of the polymer particles dictate the substrate dimensions into which the latex will penetrate. Penetration of the substrate is much poorer than with the conventional alkyd formulations, as the carrier medium is not a solvent for the binder and penetration is governed by the particle size of the softened polymer particles. The typical particle size of the latex does not allow penetration into the wood grain. In addition, incomplete coalescence or film-formation is a feature of latex films and therefore water barrier properties are not as effective as those for conventional systems. Often, alkyd resin additions are made to the formulation, by simple high-speed-stirring emulsification, to facilitate adhesion, penetration and barrier properties. The higher water transport properties of the latex systems can be advantageous in preventing blistering due to water build-up behind the film, if the latex particle size distribution and compositions are carefully chosen. The VOC figure of 10g/L shows a significant reduction over the VOC content for conventional alkyd primers, which have been measured at 270g/L. However, a VOC content of 165g/L has been measured for a commercial waterborne primer. Substrate penetration is a key requirement for a wood primer in order to provide the entire paint system with good adhesion, especially under wet conditions. The barrier properties are also a key requirement and products such as aluminium wood primers are formulated to provide this attribute.

Table 8.52 Acrylic waterborne wood primer.

Raw material	Kilograms	Function
Water	113.6	*Carrier medium*
Oratan 681(35%)	17.4	*Dispersant*
Foamaster NXZ	3.0	*Defoamer*
Aqueous ammonia(28%)	1.5	*pH control*
Acrysol RM-1020(20%)	5.3	*Thickener*
Tioxide TR-92	161.4	*Pigment*
Zinc oxide Neige C	9.1	*Fungicide*
Talc AT-1	49.2	*Extender*
Millicarb	89.4	*Extender*
Water	44.8	*Carrier medium*
Nopco NDW	2.3	*Defoamer*
Dowanol DPnB	7.8	*Coalescing solvent*
Primal MV-23LOE(43%)	452.8	*Latex*
Acrysol RM-1020(20%)	18.9	*Thickener*
Acrysol RM-8(35%)	8.0	*Thickener*
AcrysolASE-60(1/2)	2.1	*Thickener*
Water	13.4	*Carrier medium*
	1000	

Formulating parameters.

Density	1.32Kg/L	PVC	34.9%
Mass solids	50.4	Volume solids	34.6%
VOC content	10.56 g/L		

The alkyd emulsion outlined in Table 8.53, has a PVC of 33% and volume solids of 42%, which increases the coverage of the paint. The overall VOC content of 1.3g/L reflects the very low requirement of VOC with alkyd emulsion formulations. The phase inversion described previously means that in the latter stages of drying, the wet film is no longer an emulsion and therefore penetration of the substrate can occur by the alkyd polymer. This facilitates good adhesion and lends itself to application in priming technology. Alkyd emulsions dry to form an alkyd film, which should possess the same characteristics as that of a conventional alkyd film. However, the alkyd polymer backbone may have some differences in order to facilitate the mobility of the inverted alkyd film. This could be achieved by manipulation of the molecular weight to control viscosity, as well as solvent addition. Therefore, the properties of the alkyd emulsion primer may not exactly mimic those of conventional alkyd primer. Additionally, the point at which phase inversion occurs is crucial if conventional type characteristics are to be achieved. In the worst case, the inverted water droplets could remain in the film presenting permeability drawbacks especially in uncontrolled conditions where the temperature or humidity of application may not be ideal. Theoretically, alkyd emulsions achieve the same levels of gloss as the traditional systems but suffer the same drawbacks in terms of cracking. The continued reliance on active metal driers is an important drawback from the point of view of environmental impact and personal health.

Table 8.53 Low VOC alkyd emulsion wood primer.

Raw material	**Kilograms**	**Function**
Demineralised water	111.5	*Carrier medium*
Orathan(Rohm&Haas)	22.0	*Dispersion*
Borchigen DFN	4.5	*Wetting*
Acrysol RM 8	5.5	*Rheology*
Agitan 295	1.0	*Anti-foam*
Kronos 2190	123.0	*Pigment*
Microtalc AT 1	36.5	*Extender*
Microdol A 1	*113.5*	Extender
Omyalite 95 T	47.5	*Extender*
Zinkoxid aktiv	*11.0*	Extender
Demineralised water	103.0	*Carrier medium*
Uradil AZ516 Z-60	364.0	*Alkyd emulsion*
Acrysol RM 2020	27.5	*Rheology*
Durham VX 73	3.5	*Drier*
Demineralised water	26.0	*Carrier medium*
	1000	

Formulating parameters.

Density	1.310 Kg/L	PVC	32.6%
Mass solids	55.8%	Volume solids	42.2%
VOC content	1.3 g/L		

Wood priming is less critical indoors where wet adhesion characteristics are less demanding. However, overcoat adhesion of waterborne latex paints and varnishes to conventional systems can present serious difficulties especially when excessive humidity is involved. Sanding of these surfaces is a basic requirement to ensure overcoat adhesion. Extensive coating delamination can occur. The problem occurs due to the low surface energy of the existing conventional films and the relative high surface tension of water (72 dyne/cm^2). The addition of solvent such as propylene glycol aims to overcome this drawback. Undercoats are an important product, in some markets, which can have a dual function. They are used to provide cost efficient hiding with good surfacing so that the final finish coat can be formulated with primary emphasis on appearance attributes such as gloss. In addition, they need to be quick drying with low odour. Normally, no differentiation is made between indoor and outdoor formulations where consideration would have to be given to the different drying conditions, and therefore different solvent blends, inside and out. An acrylic latex undercoat is presented here in Table 8.54. A VOC content of 49g/L is quoted and compares to 165g/L, which has been measured in a readily available waterborne undercoat.

Table 8.54 Low VOC acrylic latex undercoat for wood.

Raw material	**Kilograms**	**Function**
Water	111.9	*Carrier medium*
Propylene glycol	16.0	*Freeze thaw wet edge.*
Dowanol PM	7.5	*Coalescing solvent*
Orotan681(35%)	10.7	*Dispersant*
Tegofoamex K-1488	2.2	*Defoamer*
Kathon LXE	0.7	*Biocide*
Triton CF-10	0.7	*Dispersant*
Acrysol RM-1020(20%)	14.9	*Thickener*
Ammonia(25%)	0.7	*pH control*
Tioxide R-XL	69.4	*Pigment*
Durcal 2	77.2	*Extender*
Durcal 5	183.8	*Extender*
Talc AT-1	53.0	*Extender*
Water	14.9	*Carrier medium*
Tegofoamex	1.5	*Defoamer*
Texanol	12.7	*Coalescing solvent*
Primal HG-74D(42%)	230.0	*Latex*
Ropaque OP-62 LO-E(37.5%)	77.3	*Opacifying pigment*
Water	107.1	*Carrier medium*
	992	

Formulating parameters.

Density	1.358 Kg/L	PVC	65%
Mass solids	51.45%	Volume solids	35%
VOC content	49 g/L		

There are many substrate stains which can be presented to the painter, such as stains which may be transported by means of solution, and which may be soluble in the paints by which they must be overcoated. This is particularly true of water-soluble stains such as those introduced from plumbing leaks, to which waterborne products are particularly vulnerable. Waterborne acrylic latex, employing a wide particular size distribution to achieve better packing during coalescence, can be used on many common stains encountered. Latex film formation does not provide the barrier properties of a solution-derived polymer film and permeation values, due to percolation pathways, are always higher. Additionally, cosolvents used in latex formulations extract water and therefore water-soluble stains. Solventborne products still dominate as they provide the best blocking for most stains. VOC contents for waterborne stain blocking formulations are shown in Table 8.55. A VOC content of 34 g/L is quoted, however a value of 157g/L has been measured for a waterborne stain block product.

Table 8.55 Low VOC acrylic latex stain block for wood.

Raw material	Kilograms	Function
Ethylene glycol	19.9	*Freeze thaw/wet edge*
Water	117.9	*Carrier medium*
Orotan 850(30%)	14.0	*Dispersant*
Triton CF-10	2.7	*Wetting agent*
Foamaster NXZ	2.0	*Defoamer*
Tioxide TR-92	139.8	*Pigment*
Zinc oxide Neige C	51.4	*Stain blocking agent*
Calbrite SL	108.3	*Extender*
Talc AT-1	54.0	*Extender*
Micro Mica W1	40.2	*Extender/blocking agent*
Celite 281	28.2	*Extender*
Water	39.9	*Carrier medium*
Foamaster NDW	2.1	*Defoamer*
Texanol	3.4	*Coalescing solvent*
Primal MV-23 LOE(43%)	218.1	*Latex*
Ropaque OP-96	56.8	*Opacifying/extender*
Acrysol RM1020	27.4	*Thickener*
Acrysol TT-935(30%)	73.9	*Thickener*
	1000	

Formulating parameters

Density	1.46 Kg/L	PVC	65.8%
Mass solids	53.7%	Volume solids	35%
VOC content	34 g/L		

In common with the earlier formulations for interior flat walls, a VOC free stain block formulation is available from raw material suppliers and an example is presented in Table 8.56. The final film properties may require some time to be achieved if oxidative cross-linking is involved and this may impact on the overcoating time required for the film to be effectively stain blocking. The absence of hydrophilic cosolvent may be beneficial for waterborne stain blockers.

Table 8.56 VOC-free acrylic latex stain block

Raw material	Kilograms	Function
Water	39.9	*Carrier medium*
Orotan 731 K(25%)	13.60	*Dispersant*
Tegofoamex K-1488	1.48	*Defoamer*
Tioxide TR-92	149.75	*Pigment*
Kathon LX 1.5	1.5	*Biocide*
Talc AT-1	49.94	*Extender*
Durcal 2	27.65	*Extender*
Ropaque OP-3000	70.89	*Opacifying/extender*
Primal PR-29(43.5%)	459.66	*Latex*
Acrysol RM2020(20%)	13.7	*Thickener*
Acrysol RM-8W(17.5%)	5.06	*Thickener*
Water	166.78	*Carrier medium*
	1000	

Formulating parameters.

Density	1.219 Kg/L	PVC	35%	VOC content 0 g/L
Mass solids	45.4%	Volume solids	35%	

8.14 Primers, sealers and stabilizing solutions for other applications.

In common with the previous categories, low VOC alternatives are available for low volume categories of decorative coatings and varnishes. Substitution is not suggested for these categories and a simple outline of the alternative products is presented here.

8.14.1 Water repellants/stabilisers.

The same considerations apply to stabilizing solutions as with other penetrating products. The limitations of latex dispersions are associated with the high molecular weight polymer particles, which can impede penetration into very fine substrates and would require significant coalescing solvent if film formation is a requirement.

Table 8.57 Low VOC stabilising dispersion.

Product	**Low VOC**
Waterborne acrylic latex	100-150g/L

8.15 One-pack specialty products.

Previously, the requirements for this category of product were outlined as having to provide decoration and protection to certain substrates, such as floors and metal work. Typical applications were described as follows,

- Primer and finish coat for plastic.
- Primer coat for ferrous substrates.
- Primer coat for reactive metals such as zinc and aluminium.
- Anticorrosion finishes.
- Floor coatings, including wood and cement.

It is therefore clear that these products have a demanding role to fulfill, especially in the case of floor coatings. Waterborne dispersion coatings do not lend themselves well to use as anticorrosive coatings due to the associated degree of permeability. In order to provide corrosion protection the coating must impede the ingress of water, oxygen and aggressive ions. It can be argued that traditional alkyd coatings do not provide the necessary level of barrier properties and are susceptible to adhesion failure where cathodically generated OH^- increases the pH locally. The combination of OH^- and Na^+ in saline conditions generates caustic soda, which saponifies the binder. However, where the definition of decorative coating is strictly adhered to, then the requirements of these products would not be considered to equal that of heavy-duty products. Low VOC variants are available for these applications and examples of VOC contents are given in Tables 8.58 and 8.59.

Table 8.58 Low VOC metal primers.

Product	**Low VOC solventborne**
Metal primer coating	187 g/L
Plastic primer coating	133 g/L

Floor varnish is a category of product, which belongs in this grouping. In recent years, the principal European paint manufacturers have offered waterborne floor varnishes and they claimed exceeded the hardness of traditional solventborne products. These products have appeared to have gained acceptance in the retail outlets. Although they are reported to work effectively under ideal conditions, fresh and untreated flooring, there have been problems associated with adhesion over aged flooring. This is due to the requirement of a floor varnish to be oil, grease and contaminant tolerant. Solventborne products are more tolerant of these organic contaminants. The traditional coating tolerates these contaminants due to the high levels of hydrocarbon solvent present, which dissolves and incorporates them into the dry film and thereby maintaining adhesion. This presents a problem for a waterborne product, which would have difficulty with low surface energy contaminants where high levels of coalescing solvents are not used. Additionally, significant time would be required for the film to achieve full properties.

Table 8.59 Low VOC metal primers.

Product	**VOC content**
One-pack floor paint/varnish	160 g/L

8.16 One and two-pack reactive coatings.

Waterborne alternatives are available for these reactive coatings and waterborne epoxies have become increasingly common. They can be made water dispersible due to the hydrophobic/hydrophilic components involved in their cross-linking process. There is an initial water sensitivity as the film dries, however, as the full properties are derived from the chemical curing reaction, high levels of performance can still be expected. A typical VOC content for a waterborne epoxy floor coating is presented in Table 8.60.

Table 8.60 Low VOC epoxy floor coating.

Product	**VOC content**
Two-pack floor coating	267 g/L

Chapter 9 Comparison of conventional and low VOC decorative paints and varnishes and proposal for a VOC-reduction scheme.

The following section proposes and compares a conventional benchmark product with a low VOC equivalent for each category. The discussion draws on the data and arguments presented in the previous sections and will result in a proposal for a classification of decorative paints and varnishes, with associated VOC content targets for each class. The targets proposed are expected to follow a two phase timescale after implementation of a directive on VOC content for decorative coatings and varnish.

9.1 Comparison of properties of interior matt paints for walls and ceilings.

Table 9.1 Interior matt paints for walls and ceilings

1= Very poor, 2=poor, 3=adequate, 4= good, 5=excellent.

Properties	**Conventional S/B**	**Conventional W/B**	**Low VOC W/B**	**Comment**
VOC content	312 g/L	100 -135* g/L	21-56* g/L	Tinters add up to 35g/L to the VOC content of waterborne.
Appearance	5	3	3	Matt finish expected.
Application	5	3	3	
Cost	3	3	3	Equivalent.
Health & Safety	2	4	4	Low VOC content WB. Cobalt dryers in alkyds.
Odour	1	4	5	Reduced odour hydrocarbons available.
Mar resistance	5	3	3	Incomplete coalescence or high PVC for latex can give lower resistance.
Scrub resistance	5	3	3	Lower VOC content can result in poorer film coalesence and lower film integrity.
Environment	2	3-4	4	WB not ‘excellent’due to potential water pollution
Durability	5	3-4	3	Lower VOC content could result in the use of lower Tg polymers with less durability and increased dirt pickup.

* Including tinters

Comment

VOC free latex and alkyd emulsion formulations are available from the raw material suppliers, which reflect the development activity of the resin suppliers and the likely direction in which this sector can be expected to go. However, these polymers are recent developments and VOC free paint formulations based upon them are not common and formulating experience is not extensive. Therefore, it is too early to provide a proven track record in service.

Solventborne decorative paints for walls have become uncommon in certain markets. Waterborne latex paints dominate the sector. The use of solventborne paint for this application is associated with the appearance and the expectation of better durability in the form of scrub resistance and impermeability to water. Conventional solventborne paints do offer better penetration and sealing capability than latex paints. This market requirement is now fulfilled either by waterborne latex technology in this category or elsewhere by other products, category for primers and sealers, and will be discussed in that section. Alkyd paints are prone to breakdown over alkaline surfaces such as cement. There appears to be a low level requirement for solventborne, interior matt wall paint in the future.

Option 1.	**Phase 1**	**Phase 2**
Proposed VOC targets for waterborne interior matt paints	55g/L	30g/L
Proposed VOC targets for solventborne interior matt paints	350g/L	NLA
Option 2.	**Phase 1**	**Phase 2**
Proposed VOC targets for waterborne interior matt paints	55g/L	30g/L
Proposed VOC targets for solventborne interior matt paints	NLA	NLA

NLA = no longer available

9.2 Comparison of properties of glossy paints for interior walls and ceilings.

Table 9.2 Glossy paints for interior walls and ceilings

1= Very poor, 2=poor, 3=adequate, 4= good, 5=excellent.

Properties	**Conventional S/B**	**Conventional W/B**	**Low VOC W/B**	**Comment**
VOC content	312 g/L	120-155* g/L	46-81* g/L	Glossy waterborne paints may require higher VOC to achieve higher gloss, scrub resistance and water barrier properties.
Gloss	5	3	2-3	High gloss required. Latex cannot achieve gloss levels of solventborne
Appearance	5	3	2-3	Expectations of higher surface finish for this category
Application	5	2-3	2-3	
Cost	4	3	3	High gloss W/B more costly than low-gloss W/B.
Health & Safety	2	4	4	Low VOC content W/B. Cobalt dryers in alkyds.
Odour	1	4	5	Reduced odour hydrocarbons available.
Mar resistance	5	3	3	Incomplete coalescence or high PVC for latex can give lower resistance.
Scrub resistance	5	3-4	3	Lowering the VOC may result in incomplete coalescence and therefore poorer scrub resistance. Repeated cleaning is expected for this category
Environment	2	3-4	4	WB not ‘excellent’due to potential water pollution
Durability	5	3-4	3	Lower Tg polymers may be used to lower VOC content therefore resulting in less durable films. Durability is a particular requirement for this sector. Ease of cleaning is required.

* Including tinters

Comment

Higher water resistance, gloss, scrub resistance and durability may be required for this category e.g. silk or gloss finish. Therefore, higher VOC demand.

Similar issues as those presented in section 9.1, apply to zero VOC, alkyd emulsion in terms of performance track records. Additionally, there appears to be a low level requirement for solventborne, interior matt wall paint in the future.

Option 1.	**Phase 1**	**Phase 2**
Proposed VOC targets for interior glossy paints	150g/L	100g/L
Proposed VOC targets for solventborne interior matt paints	350g/L	NLA
Option 2.	**Phase 1**	**Phase 2**
Proposed VOC targets for interior glossy paints	150g/L	100g/L
Proposed VOC targets for solventborne interior matt paints	NLA	NLA

9.3 Comparison of properties of exterior wall paints.

Table 9.3 Exterior wall paints

1= Very poor, 2=poor, 3=adequate, 4= good, 5=excellent.

Properties	**Conventional S/B**	**Conventional W/B**	**Low VOC S/B**	**Low VOC W/B**	**Comment**
VOC content	480 g/L	62-155* g/L	450 g/L	35-70* g/L	Higher VOC content reflects the performance demands of exterior applications.
Gloss	5	3	5	3	High gloss possible with S/B. Latex gloss levels lower.
Application	5	3	4	3	Exterior wall paints must be able to be applied at low temperature and high humidity. Latex should not be applied below +5°C and between rainfall showers. Poor penetration occurs with W/B where S/B has an advantage..
Cost	3	3	3	3	Equivalent
Health & Safety	2	4	2	4	Lower VOC content of W/B.
Mar resistance	5	3	5	3	Incomplete coalescence or high PVC for latex can give lower resistance.
Odour	3	4	3	5	Reduced odour hydrocarbons available.
Environment	2	3-4	2	4	Lower VOC content W/B.
Durability	4	3	4	3	S/B offers good mechanical properties but suffers from chalking. Low Tg latex can suffer from dirt-pickup. Tg of latex may lower to allow for lower VOC content.
Water resistance	5	3	5	2-3	Water barrier properties of S/B higher than W/B. Lowering VOC content could increase permeability with W/B

*including tinters

Comment

Waterborne latex does not perform well if applied at low temperature and in between showers of rainfall. Substrate penetration is not as good as conventional and therefore poor performance over friable substrates. W/B latex has good UV resistance, is relatively permeable to water and is easy to apply. Algicide/fungicide are required.

Aromatic free solvents now used for S/B styrenated acrylics to address health concerns during application. S/B systems are inherently biocidal. Can be applied at low temperature and between rainfall showers and therefore the working season for professional painters is extended. Good penetration is available from solventborne.

Option 1.	**Phase 1**	**Phase 2**
Proposed VOC targets for waterborne exterior wall	60g/L	40g/L
Proposed VOC targets for solventborne exterior wall	450g/L	430g/L
Option 2.	**Phase 1**	**Phase 2**
Proposed VOC targets for waterborne exterior wall	60g/L	40g/L
Proposed VOC targets for solventborne exterior wall for adverse conditions.	450g/L	430g/L

9.4 Comparison of properties of decorative paints for wood trim, cladding and for metal.

Table 9.4 Decorative paints for wood, trim cladding and for metal.

1= Very poor, 2=poor, 3=adequate, 4= good, 5=excellent

Properties	**Conventional S/B**	**Conventional W/B**	**Low VOC S/B**	**Low VOC W/B**	**Comment**
VOC content	355-433* g/L	105-268* g/L	250 g/L	100-130* g/L	Higher VOC content required to achieve appearance attributes and penetration.
Gloss	5	3	5	2-3	Gloss often a key requirement. W/B latex gloss will be lower.
Gloss retention exteriors	2-3	3-4	2-3	3	Solventborne alkyd susceptible to UV degradation Gloss loss unlike acrylic latex.
Colour retention interiors	2	5	1-2	5	Solventborne alkyd yellow indoors.
Application *Large areas*	5	2-3	4	2	HS facilitate one-coat application. W/B difficult to apply over large areas (doors) due to short open times.
Application *Small areas*	5	4	4	4	Open time not as significant for small areas such as trim.
Scrub resistance	5	3	5	3	S/B can tolerate frequent cleaning. Lower Tg W/B can soften at higher temperatures and suffer from dirt-pickup
Mar resistance	5	3	5	3	Incomplete coalescence or high PVC for latex can give lower resistance.
Cost	4	3	2	3	HS S/B higher price
Health & Safety	2	4	2	4	Lower VOC content WB. Cobalt dryers SB.
Odour	2	4	2	4	Reduced odour hydrocarbons available.
Environment	2	3	3	4	VOC content major issue.
Durability	3	3	3	3	Some S/B continues to cross-link and becomes brittle. W/B have outperformed S/B in some tests.
Water resistance	5	3	5	2-3	Water permeability of W/B will be higher than S/B. Barrier properties required for dimensional stability under humid conditions.

*including tinters.

Comment

Alkyd emulsions offer very low VOC content with good penetration, barrier properties and gloss, however, the technology has not exhibited significant market penetration as yet, although products are commercially available.

Superior gloss is a characteristic of conventional solventborne alkyd films. A layer free of pigment separates at the surface which contributes to the higher gloss. The film stays fluid longer than an equivalent acrylic waterborne latex and therefore surface imperfections level out. This attribute lends itself to application by professionals who are skilled in achieving a high degree of surface finish. The water barrier properties are superior to latex films. A drawback for the solventborne alkyd has always been, the continued oxidative crosslinking mechanisms, which lead to film embrittlement and eventual cracking. Exterior exposure results in loss of gloss and the gloss advantage over waterborne latex can be lost in the first twelve months of exposure. Interior yellowing has also been problematic and results in repainting when all other properties are intact. Waterborne latex films can exhibit certain enhanced exterior exposure characteristics. The initial lower levels of gloss are maintained and crosslinking does not occur after the film has coalesced. This means that latex films are more flexible during their service lifetime, although in some instances, if they are too flexible, they can suffer from dirt pickup. Poor open times, lower gloss levels and higher water permeability are drawbacks. The short open times can be tolerated in small areas such as window trim, however, over larger areas such as doors, this can lead to difficulties. Levelling is not as good as for conventional solventborne films and this detracts from achieving a good final finish e.g. brush marks can be frozen into the finish. Concern has been expressed over the higher water moisture and vapour permeability of latex films and conflicting evidence exists over the susceptibility of wood trim and joinery exposed to high moisture and vapour levels.

Two proposals are presented due to concerns over impending directives on wood preservation and factory applied joinery coating. The solvent directive could influence joinery manufacturers to replace solventborne wood priming/preservation operations with waterborne systems. Waterborne preservative technology is said to be based on micro-emulsions that rely on surfactants. It is likely, therefore, that these will enter the wood during treatment and stay there. Further surfactants enter the wood if waterbased primers are used. This overloading of the wood with these materials may increase the hydrofilicity and increase the vulnerability of the wood to osmotic forces. This could lead to blistering of the complete coating system. The durability of wooden joinery may be in question if too many variables alter at the same time, especially when product performance arising from of a change-over in the factory has not yet been fully tried. Therefore the first proposal allows for good barrier properties inside and out, when and where needed. The second proposal recognises the current technical position of W/B technology where joinery pretreatment requirements have been met and application conditions are not adverse.

High solids solventborne, offer application of wood coatings at lower temperatures and between rainfall episodes. Therefore, application by professionals is possible throughout the year. However, care must be taken as the combination of S/B outside and W/B inside can lead to blistering of the exterior film, due to water egress from buildings. A solventborne primer for wood is available in the proposal for interior/exterior use, which can account for this. Otherwise W/B can be used inside and out for trim.

Proposal 1.

	Phase 1		**Phase 2**	
	S/B	**W/B**	**S/B**	**W/B**
Proposed VOC targets for interior/exterior trim, cladding wood and metal paint	250	130 g/L	250	130 g/L

Proposal 2.

	Phase 1		**Phase 2**	
	S/B	**W//B**	**S/B**	**W/B**
Proposed VOC targets for interior trim, cladding wood and metal paint	NLA	130 g/L	NLA	130 g/L
	Phase 1		**Phase 2**	
	S/B	**W//B**	**S/B**	**W/B**
Proposed VOC targets for exterior trim, cladding wood and metal paint	250	130 g/L	250	130 g/L

9.5 Comparison of properties of decorative varnish and lasures for wood and metal.

Table 9.5 Decorative varnish and lasures for wood and metal.

1= Very poor, 2=poor, 3=adequate, 4= good, 5=excellent

Properties	**Conventional S/B**	**Conventional W/B**	**Low VOC S/B**	**Low VOC W/B**	**Comment**
VOC content	504-607 g/L	132-166 g/L	250 g/L	67 g/L	Higher VOC content required to achieve appearance attributes and penetration.
Gloss	5	3	5	2-3	Gloss a key requirement. W/B latex will always have lower gloss. Solvent stays in the S/B film longer and promotes levelling and re-working. W/B latex dries rapidly necessitating high levels of cosolvent.
Gloss retention exteriors	2-3	3-4	2-3	3	Solventborne alkyd susceptible to UV degradation and gloss loss unlike acrylic latex.
Application *Large areas*	5	2-3	4	2	HS facilitate one-coat application. W/B difficult to apply over large areas such as doors due to short open times.
Application *Small areas*	5	4	4	4	Open time not as significant for small areas such as trim.
Scrub resistance	5	3	5	3	S/B can be tolerate frequent cleaning. Lower Tg W/B can soften at higher temperatures and suffer from dirt-pickup
Cost	4	3	2	3	HS S/B higher price
Health & Safety	2	4	2	4	Lower VOC content WB. Cobalt dryers SB.
Mar resistance	5	3	5	3	Incomplete coalescence or high PVC for latex can give lower resistance.
Odour	2	4	2	4	Reduced odour hydrocarbons available.
Environment	2	3	3	4	VOC content major issue.
Durability	3	3	3	3	S/B continues to cross-link and becomes brittle. W/B have outperformed S/B in tests
Water resistance	5	3	5	2-3	Water permeability of W/B will always be higher than S/B.

Comment

Although the VOC contents are higher in conventional systems the same issues apply to varnishes and lasures as to paint. Therefore, the advantages and disadvantages of S/B and W/B, outlined in the previous section for paints (9.4), equally apply. The definition of varnish and lasure for the purpose of this study is defined as being any liquid transparent medium, applied by brush, roller or spray, which leaves a continuous surface film after drying.

Proposal 1.

	Phase 1		**Phase 2**	
	S/B	**W//B**	**S/B**	**W/B**
Proposed VOC targets for interior/exterior trim, cladding wood and metal, varnish and lasures	250	130 g/L	250	130 g/L

Proposal 2.

	Phase 1		**Phase 2**	
	S/B	**W//B**	**S/B**	**W/B**
Proposed VOC targets for interior trim, cladding wood and metal, varnish and lasures	NLA	130 g/L	NLA	130 g/L

	Phase 1		**Phase 2**	
	S/B	**W//B**	**S/B**	**W/B**
Proposed VOC targets for exterior trim, cladding wood and metal, varnish and lasures	250	130 g/L	250	130 g/L

9.6 Comparison of properties of woodstains.

Table 9.6 Woodstains.

1= Very poor, 2=poor, 3=adequate, 4= good, 5=excellent.

Properties	Conventional S/B	Conventional W/B	Low VOC S/B	Low VOC W/B	Comment
VOC content	750 g/L	71-132 g/L	500 g/L	81 g/L	Penetration of wood is a key requirement, necessitating the high VOC content.
Application	5	2-3	5	2-3	Penetration of wood by the pigment, and in some cases polymer, is facilitated by the solvent permeating into the substrate. W/B cannot achieve this as effectively and can cause grain raising.
Cost	3	4	3	4	Solvent versus water cost.
Health & Safety	1-2	4	2	4	High VOC content for S/B
Odour	2	4	2	4	Reduced odour hydrocarbons available.
Environment	1-2	3-4	2	3-4	High VOC conent for S/B
Durability	5	3	5	3	Surface preservation where possible, better using S/B due to penetration. Important for the treatment of wood with fungicide.
Water resistance	2-3	2-3	2-3	2-3	No water barrier properties.

Comment

Woodstains for the purpose of this study are defined as any liquid transparent medium, applied by brush, roller or spray, which does not eaves a continuous surface film after drying. Wood stains for exterior use are used to treat wood with preservatives such as fungicide. Solventborne solution polymers migrate into the substrate with the additives leading to good surface preservation where this is possible. This is only the case where factory applied preservatives have already been applied to the substrate. There is some debate as to the ultimate capabilities of W/B woodstains, that are applied in situ, in terms of preservation (fungicide/algaecide) and appearance attributes (grain raising). Therefore two proposals are presented.

Proposal 1.	**Phase 1**	**Phase 2**
Proposed VOC targets for waterborne woodstains	140 g/L	100 g/L
	Phase 1	**Phase 2**
Proposed VOC targets for solventborne woodstains	500 g/L	500 g/L

Proposal 2.	**Phase 1**	**Phase 2**
Proposed VOC targets for waterborne woodstains	140 g/L	100 g/L
	Phase 1	**Phase 2**
Proposed VOC targets for solventborne woodstains	500 g/L	NLA g/L

9.7 Comparison of properties of primers, sealers for wood and stain block for walls and ceilings.

Table 9.7 Primers, sealers for wood and stain block for walls and ceilings.
1= Very poor, 2=poor, 3=adequate, 4= good, 5=excellent.

Properties	**Conventional S/B**	**Conventional W/B**	**Low VOC S/B**	**Low VOC W/B**	**Comment**
VOC content	274-398 g/L	165 g/L	350 g/L	10 g/L	High VOC required for wood penetration
Application	5	2	5	2	Penetration of wood key requirement for wood primer. S/B facilitates this penetration. W/B does not offer good penetration.
Odour	2	4	2	4	Reduced odour hydrocarbons available.
Health & Safety	2	3	2	4	VOC major issue
Environment	2	3	2	4	VOC major issue
Durability	5	2-3	5	2-3	Adhesion of the full paint system depends on the primer. Preservation of the substrate depends on penetration of preservatives.
Water resistance	5	3	5	2-3	Barrier properties can have negative and positive aspects. Low permeability can lead to blistering while higher permeability can alleviate this. Good barrier properties can prevent ingress of water. High permeability can have the opposite effect, which could lead to wood rot.

Comment.

Penetration for adhesion and preservation is a key requirement for wood primers. Barriers properties are also important where existing treatments are in question. The integrity of the entire paint system, including subsequent layers, depends on the primer applied to the uncoated substrate. W/B does not possess the same level of penetration or barrier properties as S/B. Therefore both systems are required.

	Phase 1	**Phase 2**
Proposed VOC targets for waterborne primers, sealers and stainblock	50 g/L	30 g/L

	Phase 1	**Phase 2**
Proposed VOC targets for solventborne primers, sealers and stainblock	450 g/L	350 g/L

9.8 Remaining categories

Those categories for which the market share is considered to be non-negligible, constituting no more than 10% combined, of the market, section 8.1., have been discussed, conventional products compared with low VOC equivalents and benchmark products proposed with VOC limit targets. It is proposed that the remaining categories be defined in their current state, no discrimination be made between solventborne and waterborne possibilities and that the VOC content levels be fixed at their current levels. Table 9.8 outlines those benchmark products identified and their associated VOC contents.

Table 9.8 Remaining categories

				Proposed	
Product	**Sample description**	**Type**	**Current VOC g/L**	**VOC limit 1**	**VOC limit 2**
One-pack specialty products	Metal primer coat	W/B	187	140	140
	Plastic primer coat	W/B	133		
	One-pack floor paint/varnish	W/B	160		
	Metal primer coat	S/B	400-500	500	500
	Metal finish coat	S/B	400-500		
	One-pack floor paint/varnish	S/B	400-500		
Water repellants /stabilisers	Waterborne acrylic latex	W/B	100-150	50	30
	Solventborne silicone or acrylic	S/B	350-750	750	750
	Acrylic solution (high build)	S/B	327		
One-pack reactive coatings	Moisture-cured polyurethane floor varnish	S/B	597	600	600
Two-pack reactive coatings	Two-pack floor coating	W/B	267	140	140
	Two pack concrete coating	S/B	479	550	500

9.9 Summary of response to questionnaires.

Austria.

National association and 1 Paint Manufacturer.
Wood preservatives should be included. No need to discriminate between low, semi and high gloss varnish. Many products restricted in the Austrian due to the Austrian solvent ordinance LMVO. The association fear that if an EU-wide directive is not introduced, competition for Austrian producers will be distorted. Austria is too small a market to develop special products for its own market. Certain LMVO compliant products have disadvantages such as not fulfilling legal requirements (e.g. customer guarantees). Only EU legislation will enhance market penetration of low VOC products.

Categorisation of applications and subsequent limits carefully chosen, is essential. Cannot have an all-encompassing limits for w/b and s/b. This is why the Austrian association could not respond to options 2-5.The most ambitious option for internal walls already exists. Other cases, such as anti-corrosive finishes, cannot be achieved in 10 years. Temperature and humidity restrict exterior application in certain areas of Austria to 4 months a year. This is crucially important when considering waterborne products. Life-cycle analysis is important but a sensitive approach could benefit everyone as it would stimulate raw material suppliers to produce low VOC products. EU harmonisation is strongly recommended but must be done sensitively. Lessons should be learned from the solvents ordinance in Austria.

Belgium.

Response from one paint manufacturer.
Concern expressed over the inability of waterborne primers to adequately seal water sensitive substrates and previously weathered and painted substrates.

Even high solids materials could present difficulties. Examples are plaster-filled imperfections in flat walls which are filled with non-shrinking, water swellable gypsum based materials. Waterborne coatings are more sensitive to swelling if overcoated too soon. Differences in gloss levels can result. High solids not effective as sealing primers.

Additional concern was expressed over waterborne exterior paint for porous walls, applied during humid conditions. Waterborne can also be affected by moisture content of the substrate. Solventborne products difficult are to replace in this role.

Britain.

Response from British Coatings Federation.
All solventborne products reported in the questionnaire responses, have been placed in the conventional categories and waterborne in the low VOC category. A large market exists for fences and sheds in the UK, which are not categorised.

Section 4. Impact of various directive options.

Option 2	waterborne	150g/L by 2005 then 130g/L by 2010
	solventborne	400g/L by 2005 then 300g/L by 2010

Generally achievable now for mainstream products, whereas 300 g/l not possible for niche products.

Option 3	waterborne	130g/L by 2005 then 80g/L by 2010
	solventborne	300g/L by 2005 then 220g/L by 2010

Waterborne would require reformulation for 2010 limit. 2010 solventborne limit may not be technically feasible. Large R&D costs associated.

Option 4	waterborne	80g/L by 2005 then 30g/L by 2010
	solventborne	220g/L by 2005 then 30g/L by 2010

limits for 2010 would mean only waterborne could be supplied. This is technically feasible for walls ceilings. Acceptance of such products for trim would depend on the end users. Waterborne only would eliminate painting during certain months in the UK. Significant R&D costs and raw material increases which would affect SME's. 30 g/l by 2005 would put smaller companies out of business.

Section 5. Factors influencing penetration of low VOC products.
Some manufacturers consider cultural reasons as important, specifically related to the requirement for high gloss. Perceived poor performance of waterborne products over joinery.

Particular reference is made to waterborne products and their performance. According to research by the BRE, low VOC coatings can be expected to be similar to or exceed the performance of existing products. Attention was drawn to limitations on application of waterborne coatings during adverse conditions.

Denmark.

National Paintmakers Association and the Master Painters Association.
MAL code system introduced in 1972, initiated the pursuit for competitive advantage in having the lowest MAL code. This has been a significant driver for the introduction of low VOC products. 1982 saw the introduction of the substitution principle by a Government Order in pursuance of the Working Environment Act, and this has been crucial for the development and demand for low VOC products. 98% of all products used indoors are waterborne and 90% used outdoors are waterborne. Many are VOC-free. There has been an increasing share of the market by VOC-free products.

Research at the Copenhagen School of Business Economics in 1984 has shown that with each new legislation introduced, there has been jump upwards in the introduction of new waterborne products.

High solids are not used much in decorative and are mainly restricted to the industrial sector. The Danish government is now considering which highly coded products the DIY user can use.

The following problems were encountered in the Danish decorative sector during the move to waterborne,

1) Low gloss
2) Poor levelling
3) Temperature at application
4) Less shear resistant
5) Scrub resistance and lifetime

The solutions found were,

i) Waterborne products need to be applied in a different way and training is important here.
ii) Client habits must change. Acrylic coatings are now fully accepted in Denmark.

Temperature requirement may still not be resolved. Some outdoor sites are heated to allow the application of paint. Lifetime of the coating is a question of correct substrate preparation. With great care and effort, good results are possible with waterborne. There are some special instances where solventborne is still required. The surface finishes are fully accepted today. The successes enjoyed in the Danish industry have been achieved through co-operation and agreement among all of the parties concerned.

Information campaigns aimed at the DIY user and legislation aimed at the professional has proved highly successful. Success in Denmark has been based on the cooperation of the manufacturers, users and authorities.

France

Response of 17 companies was supplied by M Joly on behalf of FIPEC.
Classification and limits.

It is difficult to obtain the qualities of solventborne primers/sealers by waterborne products. Difficult to obtain the same smoothness and ease of application for wood and metal waterborne products as with solventborne. The high performance coatings represent little volume compared to the other categories. A distinction is made between shop-primers (~500g/L) and on-site primers (~350-400g/L). The same is true for two-pack primers (SP ~350-400g/L and on-site ~300g/L). Shop-primers are not part of this study and will be covered by the requirements of the Solvent Directive.

Factors influencing the penetration of low-VOC products.

Cultural reasons, experiences in the past and investment in R&D and production equipment were seen as the most important factors. Communication is seen as important as well as the broadness of the product range. Multinationals rate the investment in R&D and equipment, as well as user awareness as the most important factor. SME’s consider that cultural awareness, training and experiences in the past as the most important.

Coatings performance.

Hiding power, gloss, yellowing, gloss retention, washing and application characteristics are considered important for low VOC in general. Open-time or wet-edge time is considered by far the most important factor associated with low VOC products. Additionally, difficulty in wetting-out and smoothness are seen as important drawbacks. End users have a poor knowledge of low VOC products and their characteristics. Comparing SME answers to multinationals, SME’s consider that washing out of brushes, and UV resistance also as important. Multinationals consider yellowing as important.

The number of classes is too large. Many feel that the CEPE proposal of 11 classes is too large. The effort would be much more beneficial if the limits applied only to those classes that represent the majority of VOC emission. In addition, the solventborne classes in these sectors alone represent the majority of VOC emission and efforts could concentrate on these. The CEPE proposal represents consensus already achieved and would lead to rapid implementation.

One must consider the life cycle of the products and avoid increased maintenance schedules which could increase VOC emission. Decorative coatings also protect as well as decorate.

Finland.

National manufacturers association
Agreement between manufacturers, employers and employees that solventborne be removed for indoor use.

Germany

National paint manufacturers association.

Wood preservatives important. Low, semi and high gloss does not need differentiation. Heavy duty category of little relevance to the decorative paints industry.

Legislation is important for the penetration of low VOC products but may result in dramatic changes. Substrate replacement could be an outcome which could also have environmental impact.

The commission should accept the proposal of the Dutch government. The target values for VOC are fixed after discussions with CEPE and seem achievable in most cases. This is the fastest way to achieve significant reductions of VOC with the support of industry. In some cases the limit seems too tight. Over-regulation can result in higher VOC emissions by shortening renovation cycles because of loss in quality.

Replies from German Professional Painters.

Same = 1 Better=2

Characteristic	Water based	Solvent based
Coverage		2
Hiding power	1	1
Appearance		2
Barrier properties		2
Scrub resistance	1	1
Impact resistance	1	1
Weathering	1	1
Flexibility	1	1
Corrosion resistance		2
Overcoating time	1	1
Wet edge time		2
Levelling		2
Ease of sanding		2
Penetration		2
Adhesion		2
Odour	2	
Stain resistance		2
Filling		2
Cleaning	2	

Greece.

Greek industry considered VOC content as confidential.

Option 3 considered the most realistic for the Greek market.

waterborne	130g/L by 2005 then 80g/L by 2010
solventborne	300g/L by 2005 then 220g/L by 2010

Legislation considered the most important factor for the penetration of low VOC products.

Ireland.

1 Paint Manufacturer.

Price profiles will depend on the strategy of the resin suppliers.

Coverage of paints dependant on the texture of the surface.

Italy.

National Paint Manufacturers Association.
2-Pack products and high gloss products for walls are not used in the buildings sector. High build stains not produced.

Performance and experiences in the past are the most important factors influencing low VOC product penetration.

Paint manufacturer.
In Italy, architectural coatings for metal and wood are solventborne. They offer performance benefits such as,

1) Ease of formulation
2) High gloss
3) Ease of application under all conditions
4) Ease of cleaning of the finished surface.

Netherlands.

National Paintmakers Association, 1 Professional Painter, 1 Resin Manufacturer and 1 Paint Manufacturer.

Legislation will drive the penetration of low VOC products. High gloss interior and exterior wall paint do not exist in Holland. No information on 2-pack primers and finishes for walls. No need for discrimination between low, semi and high gloss paints and varnishes. The ambitious option for a directive would lead to durability problems. Legislation, perception of performance and awareness are the most important factors restricting the penetration of low VOC products.

Norway.

Response from Hempel.
Hempel IFA to close their factory after the 31/12/99. No views in this instance.

Portugal

Response of 6 companies.
1 Paint manufacturer.
The aim should be to remove solventborne paints. Heavy fines should be imposed on those that don't comply with the law.

VOC of waterborne products available from one manufacturer are

Wood full gloss	150 g/L
Wood semi-gloss	35 g/L
Wood special varnish for floors	40 g/l
Alkali resistant primer for walls	15 g/L
Full gloss for internal walls	30g/L
Semi-gloss for internal walls	35 g/l
Matt finish for internal walls	35 g/l
High gloss for external masonry	36 g/l
Low gloss for external masonry	30 g/l

Spain.

National association, 1 paint company and professional painters.

There should be no differentiation between low gloss, semi-gloss and high gloss varnish. Wood preservatives need to be included. Section 3.3 products (high-performance) of low relevance to decorative sector except for durable exterior masonry paint. Legislation seen as the most important factor in the penetration of low VOC products. VOC description according to AENOR and eco-label should be used. Painters and consumers should be contacted.

Professional painters comments.

No. 1

- "Painting companies strongly desire that waterbased paints become available (to a larger extent), which do not have the 'nasty' properties that solvent based paints have."
- "Waterbased acrylics have been accepted already for both interior and exterior use."
- "A reduced tax rate for low-VOC paints would be beneficial".
- "Low-VOC paints should enter specifications and should be made obligatory".
- "The authorities should start with prescribing low-VOC paints for their own (public) works, and subsequently for everyone".
- "Health protection should have priority in all cases".

No.2

- "I thinks it's excellent that the EC has the intention to reduce the VOC-content. I think the only way to do this is by legal regulations".
- "Besides, the current product range that's on the market should be adapted."
- "The paint producers should "regulate their costs "Entrepreneurs should in the first place determine which paint is most suitable for a given application, and should subsequently arrange the market according to paints with a low VOC-content or paints without VOC

No.3

"As far as I'm concerned, the measures should concentrate on the following, in order to be successful:

- Adapt the current legal regulations with respect to VOC-emissions, by forbidding the production of VOC-based paints, or putting limits to it (up to a certain percentage)
- Raise the awareness of the negative environmental effects of VOC-based paints, among both consumers and manufacturers".

No.4

- "In our company, the use of low-VOC or waterbased paints has proven to be beneficial to the health of our employees and to our production".
- "Low-VOC or VOC-free products are very advisable for the following reasons:
    - Workers' and consumers' health;
    - Easy to use;
    - From a safety-perspective (low fire risk);
    - Good storing possibilities (i.e. without many safety measures)
    - For the environment."
- "A label which indicates the VOC-content should be obligatory for all products. The underestimation of health hazards brings about risks for the users".
- "All VOC-based products should contain the phrase: 'Forbidden for interior use'".
- "Paint manufacturers should raise the production of low-VOC and waterbased products".
- "The authorities should put and end to the 'tax advantage' of solvent based paints."

No.5

- "Reducing the tax on low-VOC products would result in a stronger position for these products in competition, and would increase their use".
- "As an entrepreneur, user and citizen, I think that for many reasons we should do all we can for the environment".

- "More attention should be paid to the recycling of paint".

No.6

- "We would certainly agree with a substitution of high-VOC paints by waterbased paints".
- "We oppose the production of high-VOC paints"
- "The proposed changes would be very beneficial for health and environment".
- "There too little information available for users on the measures that should be taken to prevent health damage. Also, a 'classification' of products should be made".
- "The "macro-merger" of paint manufacturers on a global level will be harmful for professional painters and consumers".

No.7

- "From a safety perspective, acrylics are still the most suitable paints".
- "Because of their ease-of-use and shelf life, waterbased paints have nothing to fear from solvent based paints. Besides, they are more environment friendly".
- "Paint manufacturers should pay attention to ease-of-use".
- "High –VOC paints should be penalised much more".
- "A reduction of the tax level on low-VOC paints would increase their consumption".
- "I think that the waste problem should be mentioned".
- "We would be very happy if we – as professional painters - could contribute our small part to the elimination of harmful substances".

No.8

- "Trade paints should contain a first-class binder in order to be able to guarantee a first-class paint job".
- "A reduction of the tax level on low-VOC paints would be an efficient measure."
- "A critical attitude of the authorities regarding the reduction of the manufacture of VOC-based paints may result in a significant change. This would mean an improvement of the health of workers and the environment".

Sweden.

Response of SVEFF (Swedish Association) and 2 paint companies.
Significant DIY painting in Sweden and therefore restrictions should incorporate these users. Professional users now aware of health implications having seen the effects of VOC on the previous generations. VOC definition should be B.P. less than 250°C.

Cultural reasons important for penetration of low VOC as the Swedish professional painters have only used waterborne indoors since 1987.

Summary.

- Temperature and humidity restrict exterior application in certain areas of Austria to 4 months a year.

- High solids not effective as sealing primers.

- Concern over waterborne exterior paint for porous walls, applied during humid conditions.

- Waterborne only would eliminate painting during certain months in the UK.

- Perceived poor performance of waterborne products over joinery.

- In Denmark, 98% of all products used indoors are waterborne and 90% used outdoors are waterborne.

- The Danish government is now considering which highly coded products the DIY user can use. Temperature requirement may still not be resolved. Some outdoor sites heated to allow the application of paint.

- The CEPE proposal represents consensus already achieved and would lead to rapid implementation.

- Substrate replacement could be an outcome which could also have environmental impact.

- In Spain, legislation seen as the most important factor in the penetration of low VOC products. All VOC-based products should contain the phrase: ‘Forbidden for interior use’. The “macro-merger” of paint manufacturers on a global level will be harmful for professional painters and consumers. We would certainly agree with a substitution of high-VOC paints by waterbased paints.

Table 9.9 VOC-reduction scheme - OPTION 1 products based on VOC g/L ready to use.

Category	Type	Phase 1	Phase 2
1.1 Interior matt walls and ceilings*	W/B	55	30
1.2 Interior matt walls and ceilings*	S/B	350	NLA
2.1 Interior glossy walls and ceilings**	W/B	150	100
2.2 Interior glossy walls and ceilings**	S/B	350	NLA
3.1 Exterior masonry walls	W/B	60	40
3.2 Exterior masonry walls	S/B	450	430
4.1 Interior/exterior trim and cladding paint, varnish and lasures for wood and metal.	W/B	130	130
4.2 Interior/exterior trim and cladding paint, varnish and lasures for wood and metal	S/B	250	250
5.1 Interior/exterior trim woodstains	W/B	140	100
5.2 Interior/exterior trim woodstains	S/B	500	500
6.1 Primer/sealer for wood and stain block for walls and ceilings.	W/B	50	30
6.2 Primer/sealer for wood and stain block for walls and ceilings.	S/B	450	350
7.1 One pack speciality coatings	W/B	140	140
7.2 One pack speciality coatings	S/B	600	500
8.1 Binding primers to stabilise loose substrate particles and to impart hydrophobic properties.	W/B	50	30
8.2 Binding primers to stabilise loose substrate particles and impart hydrophobic properties.	S/B	750	750
9.1Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	W/B	140	140
9.2 Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	S/B	550	500
10 One pack reactive coatings for specific end use such as floors e.g moisture curing polyisocyanate.	S/B	600	600

NLA = no longer available
*gloss levels <25 @ 60°
**gloss levels >25 @ 60°

VOC = any organic compound that has a boiling point of up to 280°C. This would include some coalescing solvents used in waterborne latex. 2,2,4-trimethyl-1,3-pentanediol mono(2-methylpropanoate) has a boiling point of 255-260°C and a vapour pressure of 1.3Pa@20°C, while tri-propyleneglycol-n-butyl ether has a boiling point of 274°C and a vapour pressure of 1Pa@20°C.This proposal identifies the VOC content as that being the content ready to use. This includes added tinters at point of sale, which can add up to 35g/L VOC to the product, and the addition of thinners which can be added up to 10% by weight.

Table 9.10 VOC-reduction scheme - OPTION 2 products based on VOC g/L ready to use.

Category	Type	Phase 1	Phase 2
1.1 Interior matt walls and ceilings*	W/B	55	30
1.2 Interior matt walls and ceilings*	S/B	NLA	NLA
2.1 Interior glossy walls and ceilings**	W/B	150	100
2.2 Interior glossy walls and ceilings**	S/B	NLA	NLA
3.1 Exterior masonry walls	W/B	60	40
3.2 Exterior masonry walls for adverse conditions	S/B	450	430
4.1 Interior trim paint, varnish and lasures, for wood and metal	W/B	130	130
4.2 Interior trim paint, varnish and lasures, for wood and metal	S/B	NLA	NLA
5.1 Exterior trim and cladding paint, varnish and lasures for wood and metal	W/B	130	130
5.2 Exterior trim and cladding paint, varnish and lasures for wood and metal	S/B	250	250
6.1 Interior/exterior trim woodstains	W/B	140	100
6.2 Interior/exterior trim woodstains	S/B	500	NLA
7.1 Primer/sealer for wood and stain block for walls and ceilings	W/B	50	30
7.2 Primer/sealer for wood and stain block for walls and ceilings	S/B	450	350
8.1 One pack speciality coatings	W/B	140	140
8.2 One pack speciality coatings	S/B	600	500
9.1 Binding primers to stabilise loose substrate particles and to impart hydrophobic properties.	W/B	50	30
9.2 Binding primers to stabilise loose substrate particles and impart hydrophobic properties.	S/B	750	750
10.1Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	W/B	140	140
10.2 Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	S/B	550	500
11 One pack reactive coatings for specific end use such as floors e.g moisture curing polyisocyanate.	S/B	600	600

NLA = no longer available
*gloss levels <25 @ 60°
**gloss levels >25 @ 60°

It is the view of the study team that g/L alone is not an effective means for limiting VOC in decorative coatings. A VOC limitation proposal, based on coverage is now presented and the above classification will be presented in those terms at the end of the section.

9.10 Determination of VOC content of decorative paints and varnishes.

A final draft of ISO/FDIS 11890 has been issued with voting commenced on the 18-11-1999. Part 1 refers to VOC determination by difference and outlines a calculation for expressing VOC. The calculation is performed according to 4 methods as follows.

Method 1. VOC content as a percent by mass

$$VOC = 100\text{-}NV\text{-}M_w$$

Where NV = non volatiles
Mw = mass% water

Method 2. VOC content in grams per litre, ready to use including water

$$VOC = (100\text{-}NV\text{-}M_w)\times density_{paint}\times 10$$

Method 3. VOC content in grams per litre, ready to use, excluding water

$$VOC = \frac{(100\text{-}NV\text{-}M_w)\times density_{paint}\times 1000}{100\text{-}(M_w\times density_{paint}/density_{water})}$$

Method 4. VOC content in grams per litre, ready to use, excluding water and less exempt compounds.

ASTM D3960-90 has recently been modified (1998) from a method which allowed determination of VOC g/l including water, for water reducible coatings, to a method which allows determination of VOC g/l excluding water only.

VOC content according to the ASTM method can be expressed in three ways,

Method 1. Mass of VOC per unit volume of coating less water and exempt volatile compounds.(US EPA compounds)

$$VOC = \frac{(100\% - wt.\%nonvolatiles - wt\%H_2O)density_{coating}}{100 - (wt.\%H_2O)\left(\dfrac{density_{coating}}{density_{water}}\right)}$$

Method 2. Mass of VOC per unit volume of coating solids.

$$VOC = \frac{(100\% - wt.\%nonvolatiles - wt.\%H_2O)density_{coating}}{volume\ solids_{coating}}$$

Method 3. Mass of VOC per unit mass of solids.

$$VOC = \frac{(100\% - wt.\% nonvolatiles - wt.\% H_2O) density_{coating}}{mass\ solids_{coating}}$$

Therefore, there are available five methods that have been established to determine VOC content.

1. Wt % of coating weight.
2. Wt% per unit volume of coating including water.
3. Wt% per unit volume of coating excluding water.
4. Wt% per unit volume of coating volume solids.
5. Wt% per unit mass of coating weight solids.

Another approach is to relate the VOC in weight to the area over which is covered by the paint or g/m^2. This can be achieved by dividing the VOC in g/L by the coverage of that litre of paint. Therefore, an expression for coverage is required that does not rely on a physical or subjective laboratory measurement.

9.10.1 Discussion on the inclusion of coverage into the classification of decorative paints & varnishes.

Throughout this report, the VOC content has been expressed as weight (grams) of solvent per unit volume (litres) of paint. This is in line with the procedure used by CEPE and others addressing this issue. This is satisfactory provided that one is concerned only with the VOC generation potential of each type of paint as it exists in its container. It implies however that any two paints manufactured for the same purposes, and which have the same VOC contents, are on an equal footing in terms of the quantity of VOC that they will actually generate when they are used for the purposes for which they were intended. This is not necessarily so. Take for example two matt water based masonry paints, each of which contains 70 g/litre of VOC. The manufacturer of one of these products specifies its maximum coverage as 10 m^2/litre, while the other specifies 16 m^2/litre. Painting a 100m^2 wall, the former therefore generates 700g of VOC while the latter only generates 437.5g. To take this a step further, if the former product contains 50 g/l of VOC and the latter 70 g/l the former generates 500g VOC for the same wall while the latter remains at 437.5g. Under the currently accepted format, the two products would enjoy equal status in the first scenario, while the former would be favoured in the second. However, in practical use, the latter is clearly the better material from the environmental point of view.

This has further serious implications for any solvent reduction scheme that depends on in-can VOC limits for its effectiveness. If these limits are set at 30 g/l, the former will generate 300g VOC for the wall, while the latter will only generate 187.5g. While both achieve a reduction in VOC usage, the overall actual reduction is not in proportion to that expected arising out of the anomaly associated with coverage. It will be clear from this that any directive based solely on in-can VOC content will not be effective, and will not deliver an even playing pitch for all paint manufacturers. It may even induce some manufacturers to reduce the coverage of their products for competitive reasons, giving rise to a VOC increase rather than a decrease following the introduction of the directive.

It is evident from this that specifying solvent content by itself will not necessarily deliver the expected VOC reduction, and a new approach must be devised if the directive is to be effective. The main problem is to find a means of incorporating a consumption, or other factor, into the classification, which will more accurately reflect the environmental impact of using specific paint types. As might be expected this gives rise to problems of its own.

9.10.2 Coverage.

The first of these concerns the definition of the term coverage or covering power. Many paint manufacturers provide data on their containers or product information sheets in terms of the surface area that may be expected to be covered by a litre of their product e.g. 10 m^2 per litre. Some qualify their claim by stating that it applies to surfaces of average porosity and/or that it represents the maximum coverage that may be expected. Purchasers are often advised to use this data as a guide for calculating the volume of paint required to carry out a particular job. Representatives of the Professional Users Association, UNIEP have confirmed (13) that they use this data in this way and find it reliable. However, paint manufacturers do not state how they establish their coverage data. Some have confirmed to the writer(14) that they rely on hiding power data established by means of contrast ratio, at least for quality control purposes.

Since contrast ratio only deals with the ability of the paint to obliterate the substrate on which it is applied, it does not adequately address the issues involved. A black paint for example might obliterate a substrate at 5µm thickness, but it would not be reasonable to assume that this would be adequate for general performance purposes. Others(14) use the concept of “natural spreading capacity” to establish coverage. A brush is filled with the paint in question, which is then applied over the maximum area possible. This is obviously highly subjective in nature, and will also be heavily influenced by the nature of the substrate involved.

Clearly coverage is related to the solids content of the paint concerned, and since decorative paints are applied, in the main, by brush or roller, the solids transfer efficiency is close to 100%. A facile approach to this problem would therefore be to express the VOC content in terms of g/litre of solids or g/kilo of solids. This has the advantage of not being theoretical in any respect and can be determined both experimentally and from formulation data.

Volume solids for in-can products can be established empirically using standardised techniques, section 10.9.6. Some manufacturers may currently use this formula having first established the film thickness which will deliver the properties required from, or claimed for, the coating in question. Others may opt for a higher than optimum dry film thickness in their calculations in order to avoid complaints from consumers that their products are not performing as specified during application in terms of m^2 covered. Others may take the opposite line for promotional reasons. While professional users appear to be satisfied with manufacturer’s coverage data for their particular purposes, it will be evident that this would not be adequate for the purposes of a directive. However, the purposes of the directive could be met by specifying an arbitrary dry film thickness which will be used for calculating the coverage of all paints. This does not imply that all paints are applied at a dry film thickness of 30µm. Indeed many coatings are applied above and below this thickness, and some, such as concrete sealants, may not form a measurable film at all on concrete. It nevertheless provides a workable basis for calculating VOC emission per m^2 painted, in the same way that the consumption of fuel in cars is expressed in terms of kilometres per litre at a specified speed.

9.10.3 VOC emissions in terms of m^2 covered.

The VOC content (g/L) of solvent borne and water borne paints can be established experimentally by standardised techniques, or will be known to the manufacturers from formulation data. Once VOC content is known it can be combined with the coverage data determined to give the mass of VOC emitted per m^2 painted.

Advantages and Disadvantages.

We now have three expressions which may be used to describe the VOC content of paints:

- g VOC/litre paint
- g VOC/mass or volume solids in the paint
- gVOC/m^2 painted, based on a theoretical dry film thickness.

The following section, 9.10.4, derives an expression which demonstrates that coverage in m^2/ litre is equivalent to the volume solids. In Table 9.11 the apparent advantages and disadvantages associated with each of the three approaches is shown.

Table 9.11 Comparison of common methods of expressing VOC content.

Approach	**Can label**	**Advantages**	**Disadvantages.**
A. **g/l paint**	Maximum Solvent content=60 g per litre or This product contains a maximum of 300 g Solvent.	1. Easily expressed 2. Indicates the VOC generation potential of the product.	1.Does not necessarily lead to VOC reduction. 2.In certain circumstances may result in VOC increase in real terms. 3.Is meaningless in terms of the objectives of a directive.
B **VOC/Solids**	Maximum VOC Content=120g per litre of Solids. or The maximum VOC content of this product is 10% of solids.	1. Can give a linear measure of the differences in VOC released from different coatings used for the same purposes 2. Is not theoretically derived. 3. Is coverage related. 4. Is not easily manipulated.	1. Not easily expressed.
C **gVOC/m^2**	This product generates a maximum of 5g of solvent per m^2 painted*. *Film thickness =Xµm	1. As above except 2	1 Is theoretically derived.

9.10.4 Determination of spreading rates for decorative paints and varnishes.

Spreading rate is defined as the area of a surface that can be covered by a unit volume (1 litre) of paint. This property is characteristic of the paint formulation and does not define the hiding power of the formulation which is determined by the pigmentation package chosen. Spreading rate or coverage associated with a particular paint formulation in practice is designed within the formulation to provide an optimum film thickness for that application.

Theoretical spreading rate (TSR) = area(m^2)/litre a paint will cover at a nominal *dry film* thickness

$$\text{Wet paint spreading rate} = \frac{area(m^2)}{volume(litres)}$$

Equation 1.

Wet film spreading rate is also related to the reciprocal of the wet film thickness as follows,

$$volume = thickness \times area$$

$$thickness = \frac{volume}{area}$$

Therefore $\frac{1}{thickness} = \frac{area}{volume} =$ spreading rate **Equation 2.**

(where thickness is the wet film thickness.)

Thus, the spreading rate is equal to the reciprocal of the wet film thickness. Wet film thickness can be easily calculated,

Wet film thickness t_w(µm) $= \frac{volume(litres)}{area\,(m^2)} \times \frac{1000}{1}$ **Equation 3.**

(X1000 to convert to µm)
A knowledge of the volume solids (theoretical) NVV_t of the formulation allows calculation of the dry film thickness (DFT).

Dry film thickness DFT(µm) $= \frac{volume(litres)}{area(m^2)} \times \frac{1000}{1} \times \frac{NVV_t}{100}$ **Equation 4.**

Using equation 4 to derive an expression for volume,

$$\text{volume(litres)} = \frac{area(m^2) \times DFT \times 100}{1000 \times NVV_t}$$

Returning to the original expression for spreading rate and using the expression for volume from equation 4 to find the dry film spreading rate,

Dry film spreading rate = $\frac{1}{thickness} = \frac{area}{volume} =$ **Equation 2.**

$$TSR_{(dry\ film)} = \frac{area\,(m^2)}{volume(litres)} = \frac{10 \times NVV_t}{DFT} m^2 / litre.$$

If the TSR calculation is based on a DFT of 10µm, then equation 5 becomes,

$TSR_{(10\mu m)}$ = NVV_t m^2/litre **Equation 5**

Coverage or spreading rate of any paint film applied at 10µm, can now be related to the volume solids of the formulation giving a measure of the g/m^2 of VOC emitted. This allows a comparison between a selections of similar products for the same application to determine their VOC emission in terms of area. The actual nominal film thickness chosen is irrelevant as 10 or 100µm can be used. The comparison simply compares the VOC emission of the coatings if they were applied at the same film thickness. The benefit of this expression is that the theoretical volume solids can be used directly from the formulation and there is no reliance on measurement of physical or optical properties such as opacity or water permeation.

The $TSR_{(10\mu m)}$ can be divided into the g/L including water, VOC value.

$$\text{VOC} = \frac{\left(100 - \%nonvolatiles - \%H_2O\right)density_{paint}10}{NVV_t} \qquad \textbf{Equation 6.}$$

The resulting equation equates to the second method of **ASTM D3960-90** for expressing VOC g/L and is quoted as being the only expression that provides a linear measure of the difference in VOC emitted from different formulations for the same application. The first method expresses the VOC g/L based on the liquid component of paint less water and solvent. The expression does not allow for a comparison of the area that can be covered by that liquid component.

The following section characterises typical generic products available from starting point formulations using the first three methods and includes the fourth method described by equation 6 based on g/L VOC per unit volume solids.

9.10.5 Comparison of four available methods for describing VOC content of paints and varnishes.

Method 1. VOC content as a percent by mass
Method 2. VOC content in grams per litre, ready to use including water
Method 3. VOC content in grams per litre, ready to use, excluding water
Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

The aim of this exercise is to compare four of the identified methods of expression of VOC content. The Wt% per unit mass of coating weight solids method is not used here, as similar arguments to wt% alone as an expression apply. The impact of each method VOC content description on starting point formulations for typical decorative products is presented. The formulation parameters taken from the formulation data, are outlined in the appendix 7.

Summary points from Table 9.9;

- Conventional solventborne formulations appear to have the highest levels of VOC content.

- High solids appear to offer some reduction of VOC content for solventborne, as they have half the VOC content of conventional, but have higher levels than acrylic emulsions.

- The volume solids of acrylic emulsions has an impact on the actual VOC generated from the surface covered and is reflected in the calculations based on VOC/volume-solids. The alkyd emulsions are formulated at, at least 10% higher volume solids.

- The exterior masonry paint has an in-the-can VOC of 34.9 g/L yet the VOC emission is 0.78 g/m^2. By comparison, the matt wall paint based on the same technology has a VOC in-the-can of 20.9 g/L and a VOC of 0.82 g/m^2. This is due to the difference in volume solids and therefore coverage capability of the two formulations. The interior vinyl acrylic formulation has a volume solids of 25.6% compared to the exterior acrylic formulation at 45%.

- Acrylic woodstains contain 81 g/L in-the-can or 8% by weight and have a VOC of 3.75 g/m^2 due to a volume solids of 21.7%.

- Alkyd emulsions appear to offer the most promising route to potential VOC reduction due to their volume solids characteristics and the lack of requirement for a coalescing solvent.

Table 9.12 Summary table of comparison of VOC calculation methods.
(* DFT = Dry-film-thickness)

Description	**A VOC Wt.%**	**B VOC g/L (including $H_2$0) in-the-can**	**C VOC g/L (excluding$H_2$0)**	**D g/m^2 Based on coverage @10μmDFT***
Matt wall *Interiors*				
Vinyl/acrylic latex	1.56	20.9	68	0.82
Bathroom/kitchen				
Vinyl/acrylic latex	3.74	46.3	117.4	1.43
Alkyd Eggshell solution	36.5	426	N/A	9.4
Masonry *exteriors*				
Acrylic latex	2.4	34.9	72.25	0.78
Acrylic latex Low temp.(ºC)	2.6	34.6	81.8	0.865
Styrene/Acrylic solution (Pliolite)		450		10.0
Trim topcoats *interiors*				
Acrylic latex	8	98	233	2.96
Alkyd emulsion	0.6	7.8	17.2	0.18
Alkyd solution conventional	30.5	359	N/A	6.6
Alkyd solution high solids	19.4	246	N/A	3.6
Trim undercoats/sealers *interiors*				
Acrylic latex	0.78	10.56	29.68	0.305
Alkyd emulsion	0.1	1.3	3.1	0.031
Alkyd solution conventional	17.3	312	N/A	5.2
Trim Topcoats *exteriors*				
Acrylic latex	7.11	86.7	208.5	2.6
Alkyd emulsion	0.9	11.6	23.7	0.243
Alkyd solution conventional	30.5	358.7	N/A	6.6
Trim varnish *exteriors/interiors*				
Acrylic latex	6.1	62.7	184.6	2.2
Alkyd emulsion	0.9	11.6	23.7	0.243
Alkyd solution conventional	30.5	358.7	N/A	6.6
Trim Woodstains *exteriors/interiors*				
Acrylic latex	8	81.3	276.7	3.75
Alkyd emulsion	0.1	1.31	3.10	0.03
Alkyd solution conventional	36.5	425.6	N/A	9.4

Table 9.13 OPTION 1(a)
***VOC based on VOC/coating's volume solids ready to use.**

Category	Type	Phase 1	Phase 2
1.1 Interior matt walls and ceilings*	W/B	2.2	1.2
1.2 Interior matt walls and ceilings*	S/B	7.8	NLA
2.1 Interior glossy walls and ceilings**	W/B	6.0	4.0
2.2 Interior glossy walls and ceilings**	S/B	7.8	NLA
3.1 Exterior masonry walls	W/B	2.0	1.3
3.2 Exterior masonry walls	S/B	10.0	9.6
4.1 Interior/exterior trim and cladding paint, for wood and metal	W/B	6.5	6.5
4.2 Interior/exterior trim and cladding paint, for wood and metal	S/B	3.7	3.7
5.1 Interior/exterior trim and cladding varnish and lasures for wood and metal	W/B	10.0	10.0
5.2 Interior/exterior trim and cladding varnish and lasures for wood and metal	S/B	3.7	3.7
6.1 Interior/exterior trim woodstains	W/B	10.8	7.7
6.2 Interior/exterior trim woodstains	S/B	166.7	166.7
7.1 Primer/sealer for wood and stain block for walls and ceilings.	W/B	2.5	1.5
7.2 Primer/sealer for wood and stain block for walls and ceilings.	S/B	11.8	9.2
8.1 One pack speciality coatings	W/B	7.0	7.0
8.2 One pack speciality coatings	S/B	20.0	16.7
9.1 Binding primers to stabilise loose substrate particles and to impart hydrophobic properties.	W/B	6.3	3.8
9.2 Binding primers to stabilise loose substrate particles and impart hydrophobic properties.	S/B	93.8	93.8
10.1Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	W/B	3.7	3.7
10.2 Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	S/B	11.5	10.4
11 One pack reactive coatings for specific end use such as floors e.g moisture curing polyisocyanate.	S/B	15.0	15.0
12.1 One pack coating for floors	W/B	10.8	10.8
12.2 One pack coating for floors	S/B	35.3	29.4

* grams of VOC per unit volume of coating solids calculated according to, g/L divided by the coatings %volume solids.

Table 9.14 OPTION 2(a)
VOC based on VOC/coating's volume solids ready to use.

Category	TYPE	Phase 1	Phase 2
1.1 Interior matt walls and ceilings*	W/B	2.2	1.2
1.2 Interior matt walls and ceilings*	S/B	NLA	NLA
2.1 Interior glossy walls and ceilings**	W/B	6.0	4.0
2.2 Interior glossy walls and ceilings**	S/B	NLA	NLA
3.1 Exterior masonry walls	W/B	2.0	1.3
3.2 Exterior masonry walls for adverse conditions	S/B	10.0	9.6
4.1 Interior trim paint for wood and metal	W/B	6.5	6.5
4.2 Interior trim paint for wood and metal	S/B	NLA	NLA
5.1 Interior trim varnish and lasures for wood and metal	W/B	10.0	10.0
5.2 Interior trim varnish and lasures for wood and metal	S/B	NLA	NLA
6.1 Exterior trim and cladding paint for wood and metal	W/B	6.5	6.5
6.2 Exterior trim and cladding paint for wood and metal	S/B	3.7	3.7
7.1 Exterior trim and cladding varnish and lasures for wood and metal	W/B	10.0	10.0
7.2 Exterior trim and cladding varnish and lasures for wood and metal	S/B	3.7	3.7
8.1 Interior/exterior trim woodstains	W/B	10.8	7.7
8.2 Interior/exterior trim woodstains	S/B	166.7	NLA
9.1 Primer/sealer for wood and stain block for walls and ceilings	W/B	2.5	1.5
9.2 Primer/sealer for wood and stain block for walls and ceilings	S/B	11.8	9.2
10.1 One pack speciality coatings	W/B	7.0	7.0
10.2 One pack speciality coatings	S/B	20.0	16.7
11.1 Binding primers to stabilise loose substrate particles and to impart hydrophobic properties.	W/B	6.3	3.8
11.2 Binding primers to stabilise loose substrate particles and impart hydrophobic properties.	S/B	93.8	93.8
12.1Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	W/B	3.7	3.7
12.2 Two pack reactive coatings for specific end use such as floors e.g. polyisocyanate plus polyol and epoxide plus amine coatings.	S/B	11.5	10.4
13.1 One pack reactive coatings for specific end use such as floors e.g moisture curing polyisocyanate.	S/B	15.0	15.0
14.1 One pack coating for floors	W/B	10.8	10.8
14.2 One pack coating for floors	S/B	35.3	29.4

9.10.6 National and international paint standards

Standards that have significant relevance to the development of a directive on the limitation of VOC content for decorative coatings are presented here. The most important of these, in the context of this study is an ISO/FDIS standard (FDIS-final draft international standard).

ISO/FDIS 11890-1 and 2; Determination of Volatile Organic Compound (VOC) Content by means of a Difference Method and by Gas-chromatographic method.

ISO/FDIS 11890-1 and 2 specifies a method for the determination of volatile organic compound (VOC) content by means of a difference method and by gas-chromatographic method. These methods have already been discussed in section 9.10 in order to compare the different ways of expressing VOC content. The difference method is specified for the determination of VOC content of paints, varnishes and their raw materials where the VOC content is greater than about 15% by mass. The gas-chromatographic method is specified for those paints, varnishes and raw materials when the VOC content is expected to be greater than 0.1% by mass and less than 15% by mass. The methods assume that the volatile matter is either water or organic. The method also identifies that the product must be ready for use, in that the determination is done on the product when mixed in accordance with the manufacturers instructions in the correct proportions and thinned using the correct thinners so that it is ready for application by the approved method. The principle of the method is that the non-volatile matter is determined in accordance with ISO 3251 and where water is present, the water content is determined either by Karl Fischer titration ISO 760 or by gas chromatography (GC). No standard is specified for the GC method and the method is outlined within the standard. Where the identity of the volatile matter is unknown, there may be a requirement to use Mass Spectroscopy or Fourier Transform Infrared Spectroscopy. Most waterborne formulations would have VOC contents that fall within the 0.1 to 15% by mass category, therefore, the mass of the volatile matter for waterborne coatings would have to be measured by GC if this standard method is followed. This may prove difficult for many small, manufacturing enterprises that may be required to measure VOC content by this method. The voting mechanism for the acceptance of this method as an ISO standard was due to have been completed by the 18-January-2000. However, as at the 11-May-2000, the method has not been identified in the public domain as having been approved.

ASTM 3960-98; Determining Volatile Organic Compound Content of Paints and related Coatings.

In contrast, ASTM 3960 98 referred to in ISO/FDIS 11890, allows for the determination of the volatile matter by heating for 1 hour at 110°C±5°C and the determination of the water content by means of Karl Fischer titration. The method also identifies the importance of expressing the VOC content as a function of the %volume solids. It is explained how only the expression of VOC content as a function of the volume of the coating solids, gives a linear measure of the difference in VOC released from different coatings used for the same application.
ISO 760-1978; Determination of water-Karl Fischer method.

Water in the sample is reacted with a solution of iodine and SO_2 in a pyridine/methanol mixture (Karl Fischer reagent). This reagent is previously standardised by titration with an exact known mass of water.

ISO 3233:1998 Determination of percentage volume of non-volatile matter by measurement of the density of a dried coating.

This method specifies a procedure for determining the volume by percentage of non-volatile matter in paints, varnishes and related products by measuring the density of a dried coating for any specified temperature range and period of drying or curing. This method is unsuitable for coatings formulated at or above their CPVC. The volume solids parameter is considered to be the most meaningful measure of the coverage (area of surface covered at a specified dry film thickness per unit volume).

ISO 2811-4:1997; Determination of density by the pressure cup method.

This method specifies the determination of the density of paints, varnishes and related products using a pressure cup. The method is important for those products that can suffer from aeration such as latex paints, and it is believed that the pressures introduced, allows for the higher solubility of the entrapped air in the paint. Any remaining air bubbles are compressed to a fraction of their original size.

ISO 3251-1995(E); Determination of non volatile matter of paints, varnishes and binders for paints and varnishes.

This standard specifies a method for the determination of the non-volatile matter of paints and varnishes, as well as resins and resin solutions that are intended for use as binders for paints and varnishes. Drying times for various products are identified. Air-drying paints are specified to be dried at 105°C for 1 hour while synthetic resins are to specified to be dried at 125°C for 1 hour.

Conclusion.

The review of decorative paints and varnish formulation technology compared conventional formulations with low VOC options. In addition, the formulation characteristics of decorative coatings were outlined in the context of the particular function and application circumstances in each case. Particular emphasis was placed on the VOC content, performance expectations, technical requirements, ease of use, application and cleaning operations, as well as professional versus DIY considerations associated with each product category.

Waterborne latex formulations have dominated the interior and exterior wall sector for several decades and only small technological changes are evident. These changes have been primarily associated with control over viscosity for application, enhancing durability in terms of scrub resistance and dirt pick-up, and the formulation of very low VOC ambient cure latices. The latter development is more recent and therefore has not had significant impact on market characteristics. In some instances, there has been continued use of solventborne technology for walls. One case is that of the application of exterior wall paint where conditions are adverse and good bridging properties are required. It is the study teams view that there are many instances, supported by comments from the questionnaires (chapter 9 section 9.9), where waterborne latex is vulnerable due to either low temperature or sporadic rainfall. The outcome can be lack of film formation and the film being washed from the substrate. While this can be avoided by the DIY user, by choosing an appropriate painting season, such a restriction would have a serious impact on the professional user especially in Western Europe. (Bergen has reported 250 days rainfall in one year). The same requirement for interior use is not relevant and the need for continued use of solventborne wall paints is questioned.

Waterborne latex has not had the same impact on trim/cladding paint and varnish applications. The technical difficulties which affect flow, lack of separation of a clear unpigmented layer and the short open film times, all detract from the application of waterborne to trim. Latex paints and varnishes do have significant advantages. They offer low VOC alternatives to conventional solventbore equivalents, they maintain gloss outside, do not yellow and remain thermoplastic which means that they are less prone to cracking. The main advantages of solventborne coatings have been, cheap raw material supplies, good appearance characteristics initially and good application characteristics for professional users. An important advantage has been the ability to use these products at lower temperatures and in between rainfall episodes. The conventional solventborne systems however, have serious drawbacks. Conventional alkyds can suffer from yellowing indoors, necessitating their overcoating even when other functional characteristics were maintained. Outdoors, continued oxidative cross-linking leads to embrittlement and eventual cracking especially with varnishes. Odour and clean-up have always been a problem. The interior gloss advantage lost for exteriors, as these materials quickly loose gloss outside. There is widely accepted opinion that waterborne trim coatings have established a performance track record and experiences in Denmark have been positive, although not without reservations. Spanish professional painters have endorsed the idea of the use of waterborne paints. It has been concluded that wood rot in Scandinavian countries, associated with the use of waterborne, could have been avoided if a solventborne primer had been applied to the substrate as soon as the substrate had been exposed.

Although waterborne technology can perform most functions to satisfaction, and in some cases better than conventional, there is still concern over the application of these products during adverse conditions. Additionally, the impact of the solvent directive and the biocide directive could place the performance capabilities of factory treated and coated joinery, under duress. High solids trim coatings have evolved significantly over the last 15 years and offer a route to VOC reduction and a product that would be crucial for professional painters during winter painting seasons. There are drawbacks such as cost, time to achieve full hardness properties and faster yellowing. This would probably concentrate their use to professionals, who would employ them when and where they are most appropriate. High solids have been compared to conventional in terms of VOC emission square metre. The comparison between high solids, conventional and even waterborne at the same film thickness presents high solids VOC emissions in a good light, especially when two coats of conventional or waterborne might be needed to achieve good hiding. However, the resultant film thickness for high solids tend to be significantly higher and compared on that basis no longer appear attractive. The accelerated yellowing over conventional could necessitate more frequent overcoating indoors.

There have been instances where blistering has occurred when waterborne was used to coat interior joinery and a conventional solventborne system was used on the exterior joinery. The blistering occurred due to egress of water from humid quarters within the building. The availability of a solventborne wood primer for this reason, as well as others, necessitates their inclusion in the market for the future.

The concern over this risk and the changes in the joinery industry due to impending directives, has led to the proposal of two approaches. One approach includes high solids solventborne for interior and exterior use, while the other eliminates high solids for interiors. Other differences between the two proposals are the identification of products for adverse conditions, the elimination of solventborne woodstains and the early elimination of interior solventborne wall paint. The identification of a product for use under adverse conditions generates perceptions of superior performance and may increase its consumption. Elimination of interior solventborne wall coatings from the outset would have serious impact on certain markets that have retained these products for cultural reasons. The need for woodstains has been reiterated in the questionnaire responses and the performance and application capabilities of waterborne has been questioned. The penetration limitations of waterborne latex systems has also limited their use in the priming, sealing and stain blocking sector and currently, solventborne products offer better flexibility and capability.

The study has focused on the most significant categories of decorative coatings from the point of view of a proposal for potential VOC reduction. The remaining classes have been described and characterised in terms of VOC content. It is proposed that current levels of VOC content be maintained in this sector which is negligible in terms of VOC contribution. This position protects an important niche product market which is satisfied by many small manufacturing enterprises across the European Union.

Aerosols have not been treated in depth in the study as it would be more efficient to include them in a separate study examining the use of all aerosols in general.

The study team challenges the use of g/L as a means of expressing VOC content, in that it does not provide an effective means of comparing the total VOC emissions during a painting operation, due to the application of similar products used for that same application. In the worst case, the VOC emission could increase in a particular sector where formulations are altered to attain the VOC limit, yet provide a much reduced level of efficacy. The proposals have therefore been presented in the form of g/L for easy comparison with quoted figures in the public domain and as g/L VOC as a function of the coating volume solids.

10. VOC-reduction potential

Introduction

In this chapter, the VOC-reduction potential corresponding to the two reduction options has been estimated. It has been necessary to make a number of assumptions, which will be explained in the text.

Because many different categories of decorative paint are identified, consumption figures of the products in all of these classes should be available in order to calculate the VOC-reduction potential in detail. However, this is not the case. For 10 European countries, consumption data for each of the classes 1-6 from the CEPE scheme are available. For the other countries, only data on the consumption of all decorative coatings together are available. Therefore, only a rough estimate of the VOC reduction potential is possible.

The estimation of the VOC-reduction potential has not been performed for each individual country, but for three groups of countries that are most relevant in the light of a Directive:

- The ten countries for which data from CEPE were available (9 EU member states + Norway);
- The 15 EU member states
- The 15 EU member states + 6 accession countries.

The estimates (see tables 10.1 and 10.2) have been prepared as follows:

- CEPE-figures for the consumption of decorative coatings within each of the first 6 classes of the CEPE-reduction scheme in ten countries have been taken as a start (see table 4.2.10);
- The corresponding VOC emission has been calculated on the basis of the ‘current VOC-levels’ that were defined in chapter 9 (from own measurements, starting point formulations, literature and the questionnaires).
- Assumptions had to be made on several issues, as the CEPE data was not specific enough (see footnotes under the tables as well):
    - The current and future VOC-levels of interior wall and ceiling coatings have been estimated by taking the *average* of the current levels for flat coatings and glossy coatings, because these are fitted into only one class in the CEPE-data.
    - For trim paints, it has been assumed that 25% is exterior use and 75% is interior use. No market data on this split were available, but experts in the market have been consulted. The relatively large surface area of interior doors that has to be painted was a major consideration in making this estimate.
    - Given the 63 ktonnes of waterbased trim paints that are used in the 10 countries covered by the CEPE-data, it has been assumed that for exterior trim paints ~10% is waterbased and for interior trim paints it is ~ 24%.
    - Because varnishes and stains are fitted into one single class in the CEPE-data, it has been estimated (partly for BCF-data) that 50% of the consumed amount is a woodstain and 50% a varnish.
    - In those cases where both high solids and waterbased trim paints are allowed in the proposed scenarios (option 1: exterior and interior; option 2: only exterior), it has been assumed that nevertheless in 50% of the cases waterborne coatings will be used. User friendliness and price are two of the reasons for this.
- The current VOC emissions and future VOC-emissions for the above-mentioned 10 countries have been linearly extrapolated to the EU15 countries and to the EU member states plus 6 accession countries.
- The reduction potential for the year 2010 is based on current consumption levels. The growth in the consumption of decorative coatings may result in a limited *absolute* decrease of the reduction potential. However, both the regulated and the non-regulated situations will be subject to the trend of growing consumption. Therefore, the *relative* reduction potential will remain equal.
- The reduction potential for the use of white spirit for thinners and cleaning agents has been estimated *at bewteen 50% and (at a theoretical maximum) 100%*. This results in major additional reduction. The use of white spirit as a cleaning agent will have to be strongly discouraged in this case, and the alternatives mentioned in chapter 8 should be fully adopted.

Table 10.1 - ***VOC reduction calculation – Option 1 for the 2nd phase***
(see text for explanation). WB = Water-borne; SB = Solvent-borne; HS = High Solids

Category	**VOC emissions**	
	Current situation	**Option 1 – 2nd phase**
1. Interior walls and ceiling paints	1407 kT WB x 8%[1] = 113 kT 157 kT SB x 35% = 55 kT *168 kT*	1564 kT WB x 5%[1] = 78 kT *78 kT*
2. Exterior wall paints	419 kT WB x 6% = 25 kT 91 kT SB x 35% = 32 kT *57 kT*	419 kT WB x 3% = 12.5 kT 91 kT SB x 33% = 30 kT *42.5 kT*
3. Trim paints for wood and metal		
- Exterior[2]	69 kT SB[3] x 35% = 24 kT 8 kT WB x 10% ~ 1 kT	58 kT HS[11] x 20% = 11.5 kT 19 kT WB x 10% = 2 kT
- Interior	178 kT SB[4] x 35% = 62 kT 55 kT WB x 10% = 5.5 kT *92.5 kT*	116 kT HS[12] x 20% = 23 kT 117 kT WB x 10% = 11.5 kT *48 kT*
4. Clear coatings, varnishes and stains	45 kT SB varnish[5] x 40% = 18 kT 45 kT SB stain x 60% = 27 kT 55 kT WB stain/varnish x 10% = 5.5 kT *50.5 kT*	37 kT SB stain[6] x 38% = 14 kT 36 kT HS varnish x 20% = 7 kT 72 kT WB stain/varnish x 10% = 7 kT *28 kT*
TOTAL 10 COUNTRIES	*368 kT*	*196.5 kT*
TOTAL EU-15 COUNTRIES[9]	***444 kT[10]***	***237 kT***
TOTAL EU-15 + 6 ACCESSION	**511 kT**	**273 kT**
Use of thinners and cleaning agents (white spirit)	140- 255 kT[7]	0 – 127 kT[8]

1. Average VOC-content of flat and glossy wall coatings
2. Assumption: interior applications account for 75% of the trim paint consumption (large surfaces of internal doors).
3. Assumption: ± 10% of the exterior trim paint is water-borne
4. Assumption: ± 24% of interior trim paint is water-borne (based on total amount of WB trim paint used: from CEPE-data).
5. Assumption: 50% of this category is varnish and 50% is woodstain. VOC-contents of waterborne products do not differ, however, VOC-contents of solvent-borne stains are higher than those of solvent-borne varnishes.
6. Assumption: 50% of the stains and varnishes are for exterior use. 50% will remain solvent borne (much exterior) and 50% waterborne (much interior). For varnishes, VOC-levels comparable with high solids are proposed.
7. See chapter 5 for estimate.
8. Maximum theoretical reduction potential in case of very strict regulation and full uptake of alternative cleaning methods is 100%. A range has been estimated for the reduction potential of 50-100%.
9. Linear extrapolation assumed.
10. "Current VOC levels" may have been a little too optimistic. Therefore: 444 ktonnes instead of the 475 ktonnes VOC that have been estimated for the EU-15 (chapter 5) in the current situation.
11. Assumption: under the proposal, 75% of exterior trim paint will be high solids and 25% waterbased.
12. Assumption: under the proposal, 50% of interior trim paint will be high solids and 50% waterbased (user friendliness plays a role here).

Table 10.2 - ***VOC reduction calculation – Option 2 for the 2nd phase***
(see text for explanation). WB = Water-borne; SB = Solvent-borne; HS = High Solids

Category	**VOC emissions**	
	Current situation	**Option 2 – 2nd phase**
1. Interior walls and ceiling paints	1407 kT WB x 8%[1] = 113 kT 157 kT SB x 35% = 55 kT *168 kT*	1564 kT WB x 5%[1] = 78 kT *78 kT*
2. Exterior wall paints	419 kT WB x 6% = 25 kT 91 kT SB x 35% = 32 kT *57 kT*	419 kT WB x 3% = 12.5 kT 91 kT SB x 33% = 30 kT *42.5 kT*
3. Trim paints for wood and metal		
- Exterior[2]	69 kT SB[3] x 35% = 24 kT 8 kT WB x 10% ~ 1 kT	58 kT HS[10] x 20% = 11.5 kT 19 kT WB x 10% = 2 kT
- Interior	178 kT SB[4] x 35% = 62 kT 55 kT WB x 10% = 5.5 kT *92.5 kT*	233 kT WB[11] x 10% = 23 kT *36.5 kT*
4. Clear coatings, varnishes and stains	45 kT SB varnish[5] x 40% = 18 kT 45 kT SB stain x 60% = 27 kT 55 kT WB stain/varnish x 10% = 5.5 kT *50.5 kT*	36 kT HS varnish x 20% = 7 kT 144 kT WB stain/varnish[6] x 10% = 14.5 kT *21.5 kT*
TOTAL 10 COUNTRIES	*368 kT*	*178.5 kT*
TOTAL EU-15 COUNTRIES[9]	***444 kT[10]***	***215 kT***
TOTAL EU-15 + 6 ACCESSION	**511 kT**	**248 kT**
Use of thinners and cleaning agents (white spirit)	140- 255 kT[7]	0 – 127 kT[8]

1.Average VOC-content of flat and glossy wall coatings
2.Assumption: interior applications account for 75% of the trim paint consumption (large surfaces of internal doors).
3.Assumption: ± 10% of the exterior trim paint is water-borne
4.Assumption: ± 24% of interior trim paint is water-borne (based on total amount of WB trim paint used: from CEPE-data).
5.Assumption: 50% of this category is varnish and 50% is woodstain. VOC-contents of waterborne products do not differ, however, VOC-contents of solvent-borne stains are higher than those of solvent-borne varnishes.
6.Assumption: 50% of the stains and varnishes are for exterior use. 50% of the varnishes will remain solvent borne (much exterior) and 50% waterborne (much interior). For varnishes, VOC-levels comparable with high solids are proposed. No solventborne stains allowed.
7.See chapter 5 for estimate.
8.Maximum theoretical reduction potential in case of very strict regulation and full uptake of alternative cleaning methods is 100%. A range has been estimated for the reduction potential of 50-100%.
9.Linear extrapolation assumed.
10.Assumption: under the proposal, 75% of exterior trim paint will be high solids and 25% waterbased.
11.Assumption: only waterbased interior trim paint allowed.

Table 10.3 Summary of reduction potential for the EU-15 + 6 accession countries:

Option	**Reduction potential**		
	Paints and varnishes only	*Thinners and cleaning agents*	***Both***
Option 1	238 kT (*46.5%)*	127 - 255 kT	**365 - 493 kT** ***(51-60%)***
Option 2	263 kT *(51%)*	127 – 255 kT	**390 - 518 kT** **(54-62*%)***
Differences option 1 and 2	*25 kT*		

1. Estimate based on data from chapter 5, and adapted to include only EU-15.

As can be seen, option 2 provides an additional VOC-reduction potential of 25 kT, or ~ 5% when only VOC from the coatings themselves are considered.

Annex 3 provides some estimates on the impact of the proposal on resin and solvent demand.

11. Costs and benefits of various regulatory options, and the economic effects of a possible Decopaint-Directive.

Introduction

This economic part of the Decopaint study is made up of three main segments. The first segment is an introduction to the approach used in assessing the economic consequences of possible ways of designing regulation aimed at lowering VOC-emissions from decorative paints. In essence, the approach is to determine direct, indirect and associated costs & benefits from a dynamic perspective, i.e. as they change over time, and to juxtapose these figures onto the industry and market structure in order to determine final economic effects. All of the major costs and benefits throughout the paint-chain have been identified and the research has resulted in a fair and reliable estimation of the magnitude of the economic consequences, even though some questions remain partially unanswered. Where possible we have provided quantifications of the likely economic effects, especially in the last segment on the particular limits proposed by the Decopaint-team. Some of these quantifications are based on considered assumptions, and the rationale behind these assumptions is clarified in the relevant sections. The economic team has gathered the necessary information from the large amount of questionnaires that have been sent, as well as from follow-ups on these questionnaires. In addition, specifically economic one-on-one interviews with many players throughout Europe from every link of the paint chain, have been held, again with verbal and written follow-ups. Annual financial and environmental reports and other corporate and paint-related industry documentation has also been gathered and analysed and of course the body of relevant scientific literature has contributed significantly also throughout.

The second segment of the economic contribution discusses the general economic effects of the five main regulatory instruments as in use throughout Europe. Labelling, Information and Training Campaigns, Financial Instruments, Voluntary Agreements and Command-and-Control limits are the instruments that Decopaint team has found and consequently assessed on their general economic and technical consequences. Possible synergies between different instruments are explored as well as the impacts of the different instruments applied singularly.

The third segment of the WIMM-contribution is the detailed analysis of the economic effects of the strategy behind the proposed limits to VOC-content in the different classes of paint. This segment details the consequences of VOC-content limits across the whole paint chain, all the way down from raw material suppliers to paint waste processors. Each of the five main links is dealt with separately, with the most attention paid to those links where the economic consequences are largest. Within each of these links, the economic consequences for each different sub-group in each link are explored as well as the difference in effects upon large and small players. This segment is followed by an executive summary, summing up in short the likely economic consequences of the proposed limits.

11.1 The approach to assessing the effects of environmental regulations.

There is a persistent traditional view that environmental policy instruments by definition erode competitiveness and economic performance. Studies aimed at assessing the effects of environmental policy instruments consequently focus only on the direct costs of these instruments, and do so from a static perspective. This perspective falsely assumes that technology, products, processes and customer needs are fixed but in reality they are not, they are dynamic (Porter and van der Linde, 1995a). This past research, regulatory and corporate focus on the static costs of environmental regulation has created the self-fulfilling prophecy of increasingly more costly regulation deterring innovation with companies in permanent opposition rather than innovatively, proactively responding (Porter and van der Linde, 1995a).

However, this study does not argue that environmental regulation does not cost. But it does argue that (some of) these costs may, due to learning and innovation effects, become less over time and in particular may also be offset by dynamically evolving benefits based on environmental or other innovations. This is in line with ecological modernisation theory (Gouldson & Murphy, 1998; Jacobs, 1997) that stipulates that stimulated by proper environmental regulation, environmental innovations and improvements in both pollution prevention, products and processes will lead to increased firm-specific and national competitiveness and consequently to increased socio-economic as well as environmental well-being. However, undisputed evidence on either a negative correlation between environmental and economic performance in general is still far from available (Jaffe et al., 1995, Palmer et al., 1995) but it is certain the environmental regulation can lead to economic benefits as well as entail compliance costs.

The paint and paint related industries are relatively old and mature industries, where R&D expenditure as a percentage of turnover is quite low. The paint application sector especially, is highly traditional, and as such many of the innovations that have taken place in paint manufacturing have not successfully penetrated the market. As such environmental regulations can be a prime mechanism for stimulating new innovations as well as the successful diffusion and penetration of past and present innovations.

In as much as innovations have occurred they stem mostly from the large multinational paint and raw material manufacturers, who have in recent years been quite innovative in response to environmental pressures. Environmentally friendlier low-VOC alternatives have been developed and are marketed for most of the decorative paint applications, sometimes successfully but more often not so successfully. Clearly regulation can stimulate the further success of these past innovations, resulting not only in environmental benefits but also in a increased return-on-past-investment in developing low-VOC technologies.

In recent years a number of different labelling schemes have emerged across Europe, with varying success rates, and information and training campaigns are run by a number of companies aimed at increasing the use of low-VOC paint. CEPE, the European Paint Manufacturers Federation, has even gone so far as to propose a self-regulatory scheme likely to result in a 40% reduction in VOC emissions from decorative paints. The first phase of this scheme has already been implemented in the UK.

Financial instruments in the form of taxes on solvents have been adopted in various European nations, albeit to limited effect, and voluntary agreements between governments and industry have been achieved, substantially reducing VOC-emissions from decorative paints in the relevant countries.

Thus clearly the decorative paint industry has responded to environmental pressures. Innovations aimed at reducing the environmental impact while maintaining or improving paint performance are targeted and achieved. Regulation, primarily the industrial Solvent Directive, has been an important driver of these innovations, as many large paint manufacturers are active in both the industrial and decorative paint markets. Still, even in the cases where environmentally friendlier technologies in general, and low-VOC technologies in particular, are available, market penetration of these technologies generally remains fairly low. This is due to the strongly traditional professional paint application sector, where low-VOC alternatives are not easily marketed. Paint application habits, consumer and painter expectations, quality and performance concerns are the main barriers that restricting the success of existing low-VOC technologies. Many of the professional painters that responded to the questionnaires, as well as interviewees indicated that painters need a lot of time to accept and get used to working with low-VOC paint systems. As one painter put it very aptly: “They [the paint manufacturers] were wrong to be right too soon [in developing low-VOC technologies]”

Research in the US suggests that innovations originating in the industrial paint sector will, if applicable, find their way quickly to the decorative market and likewise vice versa (MEB, 1994a; MEB, 1994b). As such a product orientated Decorative Paint Directive will spur innovations that can not only be used in the decorative sector but likely also in an industrial setting. Considering the fact that the Solvent Directive is expected to cost up to 80 Billion Euro, partly for end-of-pipe measures, innovations resulting in a more cost-effective approach to reducing VOC-emissions resulting from the product-orientated Decopaint Directive may reduce the costs of compliance with the Solvent Directive as well. This is a prime example of a potential costs-of-compliance offsetting benefit, whereby the efforts undertaken to achieve compliance with one regulation may reduce the costs-of-compliance with another regulation.

The research approached the assessment of the likely economic consequences in two steps. The first step, has been the determination, from a dynamic perspective, of the effects in general of the five relevant environmental policy options that have been distinguished:

1. Labelling
2. Information and Training Campaigns
3. Financial Instruments
4. Voluntary agreements
5. Command-and-Control Limits

Research has worked from the premise that the economic effects of environmental policy instruments are determined by three interdependent and dynamic factors. The first factor is the type, content and timing of the policy instruments. The second factor is the affected industries' and individual companies' structure. The third factor is the response by the affected companies.

Particularly whether industry responds innovatively and proactively is a crucial determinant of the likely economic consequences of proposed regulations (Kolk, 2000). In relation to the effects on innovation of environmental regulation Porter and van der Linde (1995a, 1995b) have drawn up a number of criteria that regulation should meet in order to stimulate innovation:

'Regulation should:

1 Focus on outcomes, not technologies
2 Enact strict rather than lax regulations
3 Regulate as close to the end user as practical, while encouraging upstream solutions
4 Employ phase-in periods
5 Use market incentives such as taxes and labels.
6 Harmonise or converge regulations in associated fields
7 Develop regulations in sync with other countries or slightly ahead of them
8 Make the regulatory process more stable and predictable
9 Require industry participation in setting standard from the beginning
10 Develop strong technical capabilities among regulators
11 Minimise the time and resources consumed in the regulatory process itself.'

An important part of the research approach has been to assess the extent to which the different possible regulatory instruments in general, and the proposed limits in particular, meet these criteria formulated by Porter and van der Linde and might consequently have economic benefits that may even outweigh the costs. Although no significant economic benefits were found that could result from the proposed VOC-regulation, innovation is nonetheless relevant because it will reduce the cost of implementation over time.

In the second step of the approach, the effects of the proposed command-and-control limits have been explored in more detail as much as possible, using the model (EPA, 1999; Tellus, 1999) first elaborated upon in the Decopaint interim report as well as the Porter criteria for the design of environmental regulations.

This model juxtaposes the likely costs and benefits of the proposed regulation to the financial strength within the affected sectors as well as to the market position. The idea behind this approach is that the costs imposed by environmental regulations may either be passed on to the market if the market position is strong or they will inevitably have an effect on the financial position of the industry. This puts the costs and benefits in perspective, as the same financial burden for a company in a weak position will have more impact and may ultimately result in concentration and unemployment. Also the ability to pass compliance costs on down the chain is of crucial importance when attempting to assess the eventual economic consequences of particular compliance-costs.

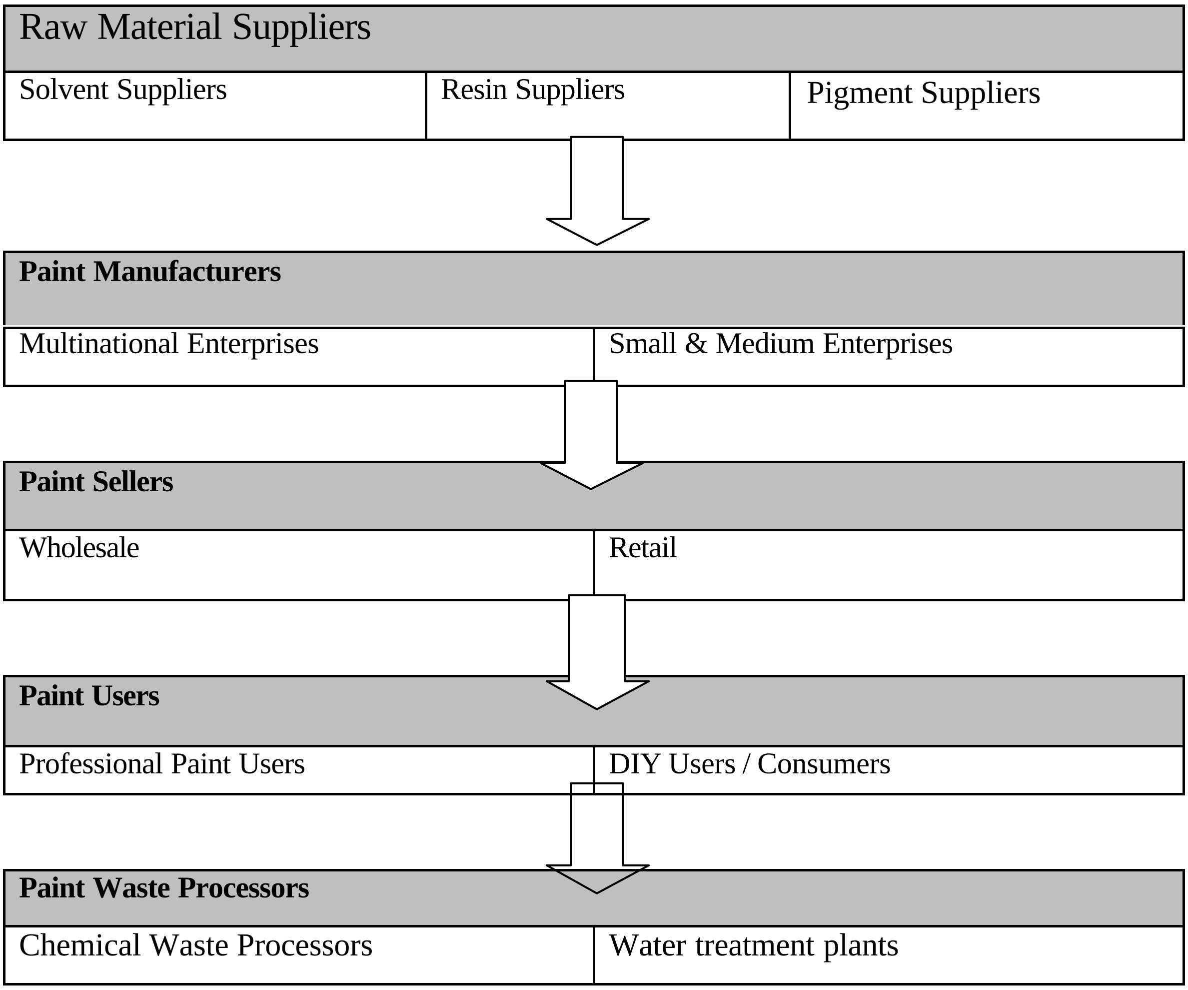
The researchers have split the costs and benefits in five categories (Bennet & James, 1998):

1. Direct costs and benefits
2. Indirect costs and benefits
3. Contingent (or uncertain) costs and benefits
4. Long-term costs and benefits
5. Strategic, competition and innovation related costs and benefits.

In relation to these costs, two factors complicated the economic analysis, the first being the fact that it was decided not to disclose the limits proposed to the industry before reporting the limits to the European Commission. The response from industry to the questionnaires appeared to be far to qualitative to use in economic calculations. The researchers consequently focused on studying the effects of limits in general to the VOC-content in decorative paint, based on the strategy outlined by the rest of the Decopaint team. The researchers then addressed the companies that had been relatively open for interviews in which more detailed and quantitative financial information was gathered.

The model below details the subject of the WIMM-research, i.e. the decorative paint chain in five links and the different types of corporations active in each link:

Model 1, The decorative paint chain.



In conclusion, the research approach consists of an extensive assessment of five different economic costs and benefits and their likely evolvement over time. Particular attention is paid to the innovation effects of different possible regulations, especially of the proposed command and control limits. The subject of the approach is not only the paint manufacturing industry, but the whole paint chain, and as the next sections demonstrate, the research has resulted in a extensive description of the dynamically evolving economic effects throughout this chain.

11.2 The effects of different environmental policy instruments in general

11.2.1 The effects of labelling

‘If all else fails, read the instructions’, is the text of an actual label put on the lid of the cans of a small Australian paint manufacturer. This notion is highly indicative of the effectiveness of information provided on decorative paint cans sold across Europe. However, it is important to note that there is a decided difference between the influence of paint-can information on purchasing decisions and on eventual application. Even while the bulk of the information on paint cans is ignored during purchasing, before application this information should get more of the attention it deserves.

The information that can be found across Europe on paint cans is diverse and often unclear. It is often not even clear whether the paint is water-borne or solvent-borne. Any kind of environmental labelling is therefore likely to go unnoticed amidst the confusing small print prevailing on paint cans, unless regulation is formulated to structure the information available on cans.

Three different approaches to environmental paint labelling have been tried in different parts of Europe. In Germany the ‘Blue Angel’ scheme was introduced whereby paint meeting certain environmental criteria can be granted permission to display the ‘Blue Angel’ logo on the paint can. The initial response to the Blue Angel label reportedly was a significant decrease in overall paint turnover but an increase in turnover in paint with the label. However, recently these developments have taken another turn with less and less companies applying for and displaying the logo, and customer purchase decisions being increasingly less influenced by the presence or absence of the ‘Blue Angel’ logo on the desired can of paint. Thus while the label initially appears to have sorted some effect currently the ‘Blue Angel’ scheme, at least for paint, appears to be past its prime. It is argued that the binary yet incomprehensive nature of the scheme, in combination with the complicated criteria and insufficient capacity of the issuing organisation, is behind the demise of the ‘Blue angel’. Paint that actually met or surpassed the ‘Blue Angel’ criteria appeared on the market without the logo, partly because of the complex and time-consuming application procedure, which bore no relation to the value manufacturers and consumers attached to the ‘Blue Angel’ logo appearing on cans. An important lesson that can be learned from the ‘Blue Angel’ experience is that labelling systems can affect manufacturers and consumers alike, but that the scheme has to be relatively simple, comprehensive and adequately managed in order to work.

On a European level the Eco-labelling ‘Daisy’ scheme, which is essentially similar in nature to the ‘Blue Angel’ scheme has fared even worse. Whereas the ‘Blue Angel’ scheme was accompanied by an extensive information campaign, the European ‘Daisy’ scheme never was accompanied by such informative support and consequently has been largely ignored from the start by manufacturers and users of paint alike.

In the UK B&Q, and later the British Coatings Federation, has pioneered another, more comprehensive and relatively simple scheme. The strength of this system lies in its combined simplicity and comprehensiveness. The labels state the VOC-content of paint in five classes, varying from low-VOC on a green label, to very high-VOC on a red label. The labels cover the whole range of paints, are applied to all cans in the B&Q stores and by now even on half the paint cans sold in the UK.

According to B&Q, their labelling scheme has increased awareness of the VOC-content with paint suppliers, leading to re-formulations of paints in order to attain ‘better’ labelling and consequently significantly lower VOC-emissions from decorative paints. Although customers have not been heeding the labels at all, B&Q expects this to happen to happen in the future.

A similar labelling scheme was introduced in 2000 by the Dutch association of paint manufacturers VVVF. The main incentive for this voluntary scheme was the compulsory use by professional painters of water-borne paint for indoor applications. The Dutch labelling scheme will state both professional and DIY-paint in three classes of VOC-content.

The costs of any labelling scheme are relatively low, especially when the implementation of such a scheme can be designed to align with the ‘regular’ paint can appearance updates. A forced, short-term introduction of labels on cans, however, may entail substantial costs.

In conclusion, labelling itself can increase awareness of VOC-content with suppliers and also influence purchase-decisions with environmentally conscious consumers. To increase the effectiveness of labelling the labelling should be comprehensive, i.e. applied to all decorative paint on the market, and easily understood. A combination of comprehensive and comprehensible labelling with a regulation-forced standardization of information (restriction on use of terms) available on paint-cans may very well result in a significant decrease of VOC-emissions from decorative paint at relatively low costs. Especially in combination with other policy instruments, such as Information Campaigns the labelling instrument, if properly designed and implemented at a European level, could significantly contribute to VOC-emission reduction from decorative paints. However, the support, both from within and from outside industry, for any kind of labelling is minimal, due to the past negative experiences with particularly the ‘Daisy’ and ‘Blue Angel’ schemes. Still, based on the lessons that can be drawn from these past negative experiences, support for a well designed and implemented labelling system can be increased.

11.2.2 The effects of information and training campaigns

The professional painters sector in Europe is quite conservative in its approach to materials. Painters are used to the application characteristics, mainly in terms of flow, open time and smell, of the paints they use and are generally reluctant to use paints with different characteristics.

Large multinational paint corporations such as AKZO and ICI operate training campaigns aimed at informing professional painters on the proper use of new, mostly water-borne, paints. Yet while on a personal level these trainings often result in the painters becoming convinced of the possibilities of using low-VOC paints, ‘on the job’ these programs result in little change. What does get noticed, however, are the occupational health implications of working with high-VOC paints. While generally older painters are reluctant to change, younger painters are far more willing to heed information on the VOC-content of paint, if only for the benefit of their own long-term health.

DIY painters in turn hardly consider environmental issues when purchasing paint (Van Raaij, 1992). Expected performance, brand, price, availability and colour are the predominant factors influencing purchasing decisions. DIY users, with the exception perhaps of some North-West European users, are not aware of the environmental issues associated with VOC’s in paint, nor of other environmental issues such as biocide use in paints. Various paint companies and retailers have marketed paint on environmental merits but to very limited success. Still, other qualitative properties of particularly water-borne low-VOC paints, such as their low-smell, non-yellowing and ease of cleaning application materials are successfully used as marketing issues. Paint marketed on environmental merits is often perceived to be inferior quality and thus less likely to be used.

Because the application characteristics of low-VOC paints are quite different from conventional alkyd paints, re-training is very necessary for professional painters in order to be able to keep providing the same quality service, finish and durability. At present, apprentice painters by and large, are already educated on these different application requirements, and the amount of on-the-job re-training required for painters previously untrained in applying low-VOC paints is such that this could be relatively easily be incorporated in existing training programs or be achieved through a little practice. The hardest part is to convince ‘conventional’ painters of the need for using low-VOC paints.

For DIY-users information needs to be available on the environmental and health issues associated with paint, as well as on the required methods of application and performance of low-VOC paints, if the penetration and application of low-VOC paints is to be successful. Even then, without additional measures this will not result in a significant decrease of VOC-emissions from decorative paints and the economic costs of such information campaigns can be considerable. Thus far proof of the effectiveness of a paint related information campaign remains lacking and as such information alone can not be an effective instrument in reducing VOC-emissions from decorative paints.

In conclusion, information and training campaigns as a sole policy instrument will not lead to any significant VOC-emission reductions, while potentially entailing significant economic costs.

Still, corporations manufacturing low-VOC paints have an interest in providing the required training and information, as apparent from the fact that such programs are already provided. Yet these corporations will only go so far as they perceive a sufficient return-on-investment likely. This will only be the case if the market for low-VOC paints is sufficiently large, which will only happen on either a very significant increase in the price of high-VOC paints or as a result of a limited availability of high-VOC paints due to regulation. As such, upon regulation that restricts the availability of high-VOC paints, the market itself is likely to self-educate its professional paint applicators on the right application methods, minimizing the need for externally organised or stimulated information campaigns.

11.2.3 The effects of financial instruments

A tax on solvents or on solvent-containing paint is the most likely financial instrument that can be used when targeting VOC-emissions reduction from decorative paints. Some European countries have already instituted such a tax, with the example of Switzerland taxing solvents at the rate of 1 Swiss franc, or just over 50 Eurocents per litre. Regular white spirit, the most commonly used solvent in conventional and high-solids paints, costs about 30-40 Eurocents a litre so this tax more than doubles the price of the most commonly used solvent. On a European scale, total decorative use of around 400 kilotons of solvents, this tax would roughly amount to about 235 Million Euro.

There are no data available on the effects of the tax on the use of high-solvent paints in Switzerland but a calculation of the resulting price increase of paints and professional paint jobs is illuminating.

Conventional alkyd paints contain anywhere from 25-85% solvents per litre so the Swiss tax rate leads to a price increase of conventional paints somewhere between 15 to 50 Euro cents per litre. These conventional alkyd paints vary enormously in price, from a few cents to tens of Euro's per litre, but on a paint costing 10 Euro a litre, with maximum VOC-content, the resulting price increase of the paint will be a modest 5%. On paint containing 40% solvents, the average figure for conventional alkyds, the price increase will be an even more modest 2%.

So on a medium price, high-solvent paint, the Swiss tax rate will lead to a price increase of around 5%, on more conventional lower-solvent, higher price paints this will be even less. When considering that the costs of the actual paint are around 20% of the total costs of a paint project, the up to 5% increase in paint costs will results in a 1% increase of the price of a whole paint project. This is not very significant and certainly not enough to encourage shift towards low-VOC paints.

If one were to design a tax aimed at making a professional paint-job using the same high-VOC paint 10% more expensive, the tax rate would have to be 5 Euro per litre, ten times the Swiss rate. On a European scale this would generate, or cost, depending on the perspective taken, over 2 Billion Euro's annually based on the current market. Even then it will be highly doubtful whether such a tax will lead to a significant increase in the use of low-VOC paints. In the DIY-market, where paints are sold in smaller quantities at higher prices than in the wholesale market, such a charge will lead to a relatively lower increase in paint price, while performance, colour and availability are equally, if not more, important considerations in paint purchasing decisions.

Still, the 1996 European Commission's 'Feasibility study on the implementation of economic measures to reduce emissions of organic solvents' details the design of a possible tax on the use of organic solvents. Consequently this is followed by an assessment of its expected environmental effectiveness and structural economic effects. (EC, 1996:III)

Two possibilities for an EU-wide tax are suggested: First of all a partial system to tax only paints which contain organic solvents, a paint-only tax. Secondly, a comprehensive system where volatile organic compounds are taxed as they are brought on the market, while a refund system allows for taking into account that:

- solvent-likes may be used as feedstock for non-solvents;
- solvents may not enter the atmosphere after use, e.g. incineration of solvent vapours in vented gases;
- solvents (and products which contain solvents) may be exported to non-EU countries.

However, the partial system was not considered attractive. In summary the advantages of a generic tax over a paint-only tax are:

- its being more in line with the Polluter Pays Principle;
- its greater environmental effectiveness;
- its relatively limited costs of administration.

As for the economic effect, at the macro-economic level effects of the proposed tax could not be traced, as the costs are only a minor fraction of GNP and overall consumptive expenditures. At the sectoral level it was concluded that the economic impact of a solvent tax would vary. Producers of solvents, the oil refinery industry and the petrochemical industry would lose markets. However, a VOC-charge would have a major structural impact on the paint & lacquer industry. Yet it is also concluded that this impact would not necessarily be adverse; non-VOC paints and low-solvent content paints have already been developed and marketed, and expectations are that low-solvent content alternatives will be available for all types of applications. (EC, 1996:VIII)

However, this EC-study has failed to look extensively at the price-elasticity for solvent-demand. From the questionnaires and one-on-one interviews held over the last year for the Decopaint-study, it has become clear that a modest to high price increase of solvents due to a tax will by no means automatically lead to a decreased use of solvents in paint nor high-solvent paint use. As such it seems more likely that while generating a large amount of government revenue, a solvent-tax will not be all that effective in limiting the use of high-VOC paints. Still, the relative attractiveness of high-VOC paints over low-VOC paints will at least from an economic perspective be decreased by a solvent-tax, but the difference in price is not the major issue for choosing a conventional high-solvent paint or a low-VOC water-borne alternative for example.

Other economic measures, such as subsidies and marketable rights, as well as ecolabelling, voluntary agreements and other communicative instruments are also assessed on their merits in the above-mentioned EC-study, yet the conclusion remains firm that a EU-wide tax would be more efficient and effective from an environmental perspective. Particularly marketable rights were considered as a possible alternative to a tax but they were considered not, yet, viable for two reasons mainly. First the necessary institutions are lacking and, second, the initial distribution of rights to emit (market) solvents will bring about too many controversies. Distribution on the basis of historical production ("grandfathering") would punish the early reducers while auctioning would create the risk of speculation and monopoly formation. (EC, 1996:113)

In the final conclusion it is stated that both environmental effectiveness and the minimisation of economic distortion can be achieved by a stepwise progressive introduction of the tax. The requirements of a sufficient predictability of future tax rates – important for business strategies and treasuries – and the fundamental uncertainty about the required level of the tax rates lead to the proposal of a periodic adjustment of envisaged tax rates. (EC, 1996:121)

The Decopaint-project economic sub-group's findings are in line with the conclusion that a step-wise introduction would minimise economic distortion but as previously stated, the barriers to a tax high enough to be effective will be insurmountable while the effectiveness of a low to modest tax (0.5-2 Euro per litre) in reducing VOC-emissions from decorative paints will be doubtful at best.

However, this does not mean that financial instruments can play no role in reducing VOC-emissions from decorative paints. In the USA a combination of financial measures and VOC-limits for paints is used. Paints containing less than a certain amount of VOC, which varies by category of paint, are exempted from paying any charges, but for paints containing a higher amount of VOC a substantial exceedance fee is charged.

In conclusion, a tax on solvents or on solvent-containing paints as sole policy instrument, would in order to be effective have to be enormously, prohibitively, high. Yet a specific phase-out tax on paints containing more VOC than allowed for the relevant paint category could, without distorting the market substantially, be used to, even temporarily, protect small and medium enterprises dependent on paints for special applications with VOC-contents that exceed the proposed limits. The funding generated by imposing such a temporary exceedance fee could then be used to assist these small and medium enterprises in finding lower-VOC solutions for their specific niches (Andersen, 1994). But again, support from within and outside industry is for any kind of negative financial instrument is very small, with the exception of mostly Southern European manufacturers who have indicated on the questionnaires that given the need for a policy instruments, they would prefer taxes. However, this preference does not originate from the perceived effectiveness of a tax, but more from the notion that it will provide paint manufacturers with the option to preserve the status quo, and simply pass on the charges levied, to the final consumer.

11.2.4 The effects of voluntary agreements

Voluntary agreements between governments and industry can be very effective and efficient in achieving environmental goals on a national scale. The main economic advantage of voluntary agreements is the efficient compliance by co-operative industries with the agreements.

One example of an existing voluntary agreement is that between the Dutch government and industry on limiting VOC-emissions in a number of sectors (the so-called KWS 2000 project). It has been observed that the agreement has resulted in significant decrease in the average VOC-content of decorative paints and varnishes, although it has been questioned whether this would not have occurred without the agreement as well..

In theory voluntary agreements can make an economically efficient contribution to the reduction of VOC-emissions from decorative paints. A Europe-wide voluntary agreement to use low-solvent paints where feasible could results in a reduction of VOC-emissions from decorative paints of between 40% to 60%. Unfortunately the chances of reaching such an agreement with the strongly traditional professional painters sector are slight.

As such voluntary agreements, as economically efficient as they can be, can not be relied upon as the sole instrument for reaching a signification reduction in VOC-emissions from decorative paints. However, they can be used as precursors for European regulation or complementary to a European Decorative paints directive. Their main advantage lies in the co-operation of the affected industries' and the ability to achieve environmental targets most efficiently based on the knowledge base of the affected industries’. The same limits or targets set in voluntary agreements will as a rule be reached more efficiently than if those limits or targets were set in imposed command-and-control limits largely opposed by industry.

11.2.5 The effects of command-and-control limits

Command-and-control limits traditionally receive firm opposition from industry, even if industries indicate their preference for this particular instrument. The negotiations between governments and industry over limits set in regulations can constitute over 50% of the economic costs associated with the limits, and even more in the US where the approach to regulation is decidedly more adversarial still. Acton & Dixon (1992) concluded in their study that of all the money paid out between 1986 and 1989 on Superfund (soil remediation) claims, 88% went to pay for legal and administrative costs, while only 12% were used for actual site clean-ups.

So the costs of limits set in regulation, depend not only on the actual limits, but also, and perhaps even more so, on the response of the affected industries. Therefore generalisations on the economic effects of command-and-control limits are impossible to produce. Still, the preference that many, especially paint manufacturers, parties throughout the paint chain have for limits to VOC-content indicates that the industry does not expect a costly negotiating process.

In the Netherlands and Denmark, command-and-control measures exist on the use of exclusively non-solvent-borne paints for interior use. The rationale behind these measures is far more occupational health than environment based.

VOC-emissions from decorative paints have dropped as a result of these measures but the trend toward ex-situ painting has been exacerbated. This ex-situ painting is consequently done more efficiently in industrial settings, where VOC-emissions can be controlled.

It is too soon to tell if this ban on the use of solvent-borne paints indoors will have major negative economic consequences, through for example a decreasing overall paint market. On the positive side is has been reported from Denmark that the use of water-borne paint has resulted in a large decrease in the cases of OPS (*see chapter 12)*. Research in The Netherlands has estimated that 1 -3% of the profession painters is nowadays confronted with OPS during their working life. A significant reduction of OPS therefore has the potential to reduce sick leave with a share of these percentages. However, the very existence of OPS is hotly debated and as such the actual costs saved are very difficult to calculate, and even more difficult to extrapolate to a European scale. An estimation of the economics of this reduced OPS-effect, as well as an estimation of the effect on paint labour costs in general will therefore prominently come to the fore in the section on the economic consequences of the proposed limits on the paint application sector.

In conclusion, the costs of command-and-control limits depend on the actual limits set, i.e. the content of the regulation, but also on the form of the regulation, its timing and also to a large extent on the response of the affected companies. The next section will therefore look in detail at the likely costs of the command-and-control limits proposed by the Decopaint team.

11.3 Estimation of the economic consequences of the proposed command-and-control limits.

11.3.1 Introduction

The strategy underlying the limits proposed focuses on those decorative paints that cause the bulk, up to 90%, of the VOC-emissions (see chapter 9). Trim paint and to a lesser extent wall and ceiling paint are the categories of paint in question. In our interviews we confronted companies with an extreme scenario in which by 2010 water-borne paints should be used for almost all applications. The cost figures in this part of the research are based on these interviews and are therefore maximum estimates.

The strategy that has been studied for the economic analysis can be described as follows:

Paint Category	End-target (2010)
Interior walls and ceilings	No more solvent-borne
Exterior walls	Solvent-borne only for adverse conditions
Interior trim	No more solvent-borne
Exterior trim	Solvent-borne primers only

Although this strategy has not become one of the final VOC-reduction proposals, the differences with option 2 are relatively small, as well as the differences in the economic impacts that have been described. The economic effects of this strategy will be dealt with by moving down the paint-chain, starting with the raw material suppliers and ending with the painters. The effects on paint recycling, chemical waste management, effluent treatment and paint wholesale have also been analysed but as the consequences turned out to be very marginal they will not be elaborated upon.

11.3.2 The economic effects of the proposed limits on raw material suppliers

11.3.2.1 The solvent suppliers

Industry Structure

Leading solvent producers are often part of large multinational oil companies, for whom solvent production is a very small but profitable niche-activity. The production of hydrocarbon solvents for use in decorative paints is estimated to be 263 kilotonnes in 2000, with a market value of about € 90 million. In addition 253 kilotonnes of hydrocarbon solvents are used for thinning and cleaning purposes, representing a value of another € 90 million (*see chapter 5).* ESIG estimates that the solvent industry employs 10.000 people.

Within the paint chain the market concentration is especially strong with the solvent manufacturers. The market is dominated by large multinational corporations like Shell, BP, Total-Fina, Exxon, BASF and Hoechst. Companies were not prepared to provide information on their market shares in different types of solvent, but it is clear that the concentration is even stronger in market segments like oxygenated solvents.

Industry Position

The solvent industry, as represented by ESIG, has indicated that they neither see the need for a Decopaint Directive nor foresee major environmental benefits resulting from a possible Decopaint Directive. ESIG does expect a directive to have major adverse economic consequences on the solvent industry, especially since the Solvent Directive is already reducing the solvent market so considerably. In short the industry position is that a Decopaint Directive will hardly improve environmental quality while entailing very substantial costs.

Industry Reaction

The solvent industry will have no other option then to reduce the production of particularly hydrocarbon solvents (- 61-78%) or find alternative markets. One of the formerly largest players in the solvent market has already made this change and is currently injecting its hydrocarbon solvent production into jet fuel. The sales value of jet fuel is similar to the sales value of regular white spirit, albeit it largely depends on the quantities and locations where the jet fuel is sold.

Even the demand for oxygenated solvents, which are used in waterborne paints will be reduced (- 13-26%), due to the substantial decrease of average solvent content in water-borne paints which will be one of the results of the proposed limits. An alternative market for these solvents is the industrial paint and cleaning agent market, but the absorption capacity of, and relative sales value of oxygenated solvents for, these market remains obscure.

ESIG, on the contrary, expects the demand production of oxygenated solvents, based on the strategy outlined above, to increase by 30 kilotonnes, or 50% based on their figures for the current market of oxygenated solvents for use in decorative paints. One major company has indicated that they expect to loose the entire decorative paint solvent supply sector within ten years or so. Temporary solutions like de-aromatising may postpone this loss of a market but eventually, over a period of ten years or so from now, they expect to loose the market entirely.

Economic Consequences

The reduction of solvent emissions through limits to solvent content in paint will inevitably impact solvent suppliers and distributors. The European Solvent Industry Group (ESIG) argues that there will be a substantial direct and indirect social economic impact, jeopardising thousands of jobs and the existence of hundreds of SMEs.

A decline in hydrocarbon solvent use of 160-205 kilotonnes due to the directive under study would lead to a revenue loss of around € 65 million from sales to the decorative paint manufacturers. However, as indicated before this loss of the decorative paint market may at least be partially offset by injecting the production of hydrocarbon solvents into the jet fuel market. The effect on the use of oxygenated solvent may range from a loss of 24 to 46 kilotonnes (or € 24 to 46 million) to an increase (according to ESIG) of 30 kilotonnes (or € 30 million).

Of the 10.000 people employed in the production, distribution, marketing and sales of solvents, ESIG estimates that 2.000 up to 4.000 would loose their jobs. However, based on the current markets of around 2000 kilotonnes production of both hydrocarbon and oxygenated solvents a reduction of around 250 kilotonnes equals a reduction of the market by around 12,5% due to the proposed limits. In addition, a reduction of 100-250 kilotonnes of hydrocarbon solvents for thinning and cleaning purposes could result in a revenue loss of again 12,5%.

One large player (Shell) that does produce oxygenated solvents as well as hydrocarbon solvents is expected to increase its market share. The smaller players in the solvent industry are expected to be disproportionately affected. Through the shrinking demand from the decorative paint market, but even more so from the shrinking market for solvents for use in industrial paints (Solvent Directive), prices and margins of solvents will come under pressure and the advantage of economies of scale is substantial in such a market.

In conclusion, the solvent industry will be negatively affected, with lost sales of potentially over 100 million Euro annually But in view of the availability of the alternative markets and especially in view of the relative economic insignificance of solvents for the big oil companies the economic consequences will be bearable.

11.3.2.2 The resin suppliers

Industry structure

Leading resin suppliers are often part of large multinational companies in the chemical industry, for which the supplies to the decorative paint sector make up for only a few percents of their total production. At the level of business units and production sites, European resin suppliers are however highly dependant on the demand from the decorative paint industry. The European Resin Manufacturers Association (ERMA), for example, states that 90% of alkyd resins produced by their members find their way into decorative paints, and that 40% of emulsion polymers and elastomers is produced for decorative paints too. Yet ERMA is certainly not fully representative of the resin industry, many, especially small, resin manufactures, are not ERMA-members.

In addition to the number of 40 to 50 leading resin suppliers, there are perhaps over 100 small, independent resin manufactures. These small manufacturers will mostly produce alkyd resins for small paint manufacturers. During our research we did not succeed in getting sufficient first-hand insight in their economic situation. In general, other parties asserted that these small manufacturers use simple and old technologies and are fully dependant on their supplies to the paint industry.

Industry position

One major resin manufacturer stated it would be possible to develop more new resins to help replace most of the conventional paints with lower-VOC paints, albeit after considerable investment in production facilities and R&D. Already many resins have been developed that are suitable for use in low-VOC paints, but clearly improvements in this area will be crucial for the success of low-VOC paints and the consequent reduction in VOC-emissions from decorative paints.

Maintaining the performance of paints while lowering VOC-content requires substantially more high-tech and expensive resins. DSM, as a major alkyd resin manufacturer stressed that policy makers should not focus only on acrylic resins for waterbornes, as DSM could produce a water thinnable alkyd resin too. ERMA perceives solvent-born trim paints as superior to acrylic trim paints, both interior and exterior but still. ERMA would support an updated CEPE proposal.

Industry reaction

Manufacturers of conventional alkyds will have to invest in R&D to develop alternative resins and in modification or replacement of production facilities. One of the leading resin suppliers estimated that it would have to develop about 100 new resins, about 75% of its current portfolio. The development of just one of these resins that has to perform up to the same high standards as its solvent-borne predecessor recently took almost 3 years of R&D. Other resins may be developed with none or only limited R&D effort. The total R&D effort for this company was estimated to be 45 man/year. The production of waterborne resins is more complex, as for example the production of alkyds for water-borne paints needs an extra emulsification step and more extensive process control. In general, the resin manufacturers will continue on their path of developing new resins for use in low-VOC paints and this will be substantially stimulated by the proposed limits.

Economic consequences

One resin supplier estimated that due to the proposed regulations, paint resin would become 1,3 to 2 times (in relation to the same solid content) more expensive. This rough estimate was confirmed by several paint producers. Some of their raw materials would become more expensive, but this would be partly compensated by the reduced costs of less solvent use. The cost rise will largely result from the extra emulsification step necessary in production. Also, the cost of R&D can be considerable in cases where a new resin has to meet very demanding specifications. If 100 resins can be redefined in 45 man/year and we suppose the R&D costs per man/year to be about € 100.000, then based on these data from one large resin manufacturer, the cost of R&D per new resin may very roughly be estimated to be € 45.000.

If paint manufacturers accept that they have to pay up to 100% more for the necessary resins, which at least depends to some extent on the power relation between paint and resin manufacturers, then the economical consequences for the resin production industry as a whole will be modest. An important consequence will be the increase in revenues of up to € 211,2 million. (see section on economic consequences for the paint manufacturers) It seems obvious that paint manufacturers have no alternative than to accept a price increase, especially as the regulation will effect all suppliers the same way. The dominant resin makers are often part of large multinational firms, for whom the necessary investments in new equipment and R&D are negligible. But it is clear that the resin producers are not the most powerful players in the paint production chain. There will be a strong pressure on the resin suppliers to make the change over in the most efficient way and to guarantee the same performance as before the regulations. This may result in a shake-out of manufacturers with relatively high production costs or less R&D capacity. It is also questionable whether the small resin producers would be able to invest in new equipment. Probably they will try to survive by strong price competition on the remaining market for traditional alkyds. In conclusion, we expect increasing revenues and a strong acceleration of the concentration process in the resin sector.

11.3.3 The effects of the proposed limits on paint manufacturers

Industry structure

The European market for decorative paint is characterised by a high degree of concentration. On average, the 4 to 5 largest paint manufacturers in any given European country, produce over 70% of the total volume. The remaining 30% is shared by a great number of sometimes very small paint manufactures. However, this split between large and small companies does differ throughout Europe, with especially Italian small manufacturers together having a larger market share than their small counterparts in North-western Europe.

Although the major paint companies are relatively large, they often consist of many small, local production sites. Economies of scale are therefore more important in R&D and marketing than in production equipment. The entrance barriers for the paint manufacturing market seem to be rather low, as the necessary equipment is relatively simple, raw materials are easy to obtain and R&D-spendings are no more than 3 – 5 % of sales. There is however a strong tendency towards further concentration .

Industry position

The interviews and questionnaires result in a variety of very diverging views on the feasibility and consequences of the five regulatory scenarios provided in the questionnaires. . Most of the responses, both from small and from large companies, argue that an ambitious directive will be advantageous for the large multinationals. This is also supported by the EPA-study, that points at the higher relative costs of R&D for small companies. But from the individual responses of small companies, we learned that there are also small companies that expect to gain from strict regulation while other small companies expect to loose significantly . The paint manufacturing industry, as represented by CEPE, as a whole is in favour of a Directive, but naturally would prefer their own (CEPE, 1996) regulatory proposal over the stricter limits proposed by the Decopaint team. However, technology has not been at a standstill since the original CEPE proposal and in combination with the longer time horizon proposed by the Decopaint team the industry position to a Decorative Directive is not expected to change substantially.

Industry reaction

Small paint manufacturers are supplied with standard formulations by their raw materials suppliers and may copy the basic formulations of the larger competitors, who are the largest patent holders in the paint field. As such, small manufacturers may compensate for their limited R&D capacity. However, one manufacturer complained about resin suppliers not being very considerate of small clients and making new resins available to small manufactures much (years) later than to large manufacturers. Due to the replacement of solvent-borne trim paint with water-borne trim conventional alkyd resins will have to be replaced by water-thinnable resins . White spirit will have to be replaced by water and/or smaller volumes of glycol ethers and other solvents. The change-over to waterborne systems will make it necessary to install stainless steel production equipment. In many cases companies will have to run, at least for some years, the production, distribution and marketing of several paint systems simultaneously. As these costs seem to be temporary and might be compensated by opposite and positive effects, the economic consequences of these last aspect will not be covered.

Economic consequences

It is difficult to make a reasonable estimate of the cost of the additional R&D, but we can refer to the EPA-study as this study exclusively considered the costs of reformulation. R&D (“reformulation”) costs have been estimated at $ 87.000 per product reformulation and $ 204.042.231 for the US in total in a similar study for the EPA in 1998. These reformation cost were annualised at around $ 18.000 dollars per product reformulation. Annualised reformulation cost were equal to 0.4% of sales on average, but for small firms they were estimated to be up to 2.5% of sales. As labour costs in the EU are considerably lower and European paint manufactures can profit from the US experiences, reformulation costs of $ 87.000 are assumed to be a strong overestimation. If we assume that the additional R&D-effort should be related to the sales volume and that this relation is about the same in the EU and in the US, then this would result in € 14 million annually. (Assuming that the 352 kilotonnes of decorative, conventional alkyd based trim paints are now sold for an average price of € 10 per kilo). It is not clear for how long this additional R&D effort will be needed. A medium sized firm reported that their products had an average life time of 10 years. If a directive allowed paint manufacturers enough time, then a redirection of the normal R&D capacity could tackle a considerable part of the research needed.

The raw materials costs are generally higher for low solvent paints. Resins may be 1.3 to 2 times as expensive (based on the same solid content), for example from € 1,50 for an oil alkyd resin, to € 3,00 for a water-thinnable alkyd or acrylic resin. The costs of solvents may rise from € 0,30 per kg for white spirit, to € 1,00 per kg for glycol ether. It seems that the higher costs of solvents per kg will be more than offset by reduction of solvent content. The net effect on raw materials costs would therefore be limited to a maximum of 40% (assumed average resin content of conventional paint) of the price rise per kg (€ 1,50), or € 0,60 per kg of paint. When these higher costs are fully passed on to the paint users , the 352 kilotonnes of decorative, conventional alkyd based trim paint which is now sold annually in Europe (EU-15) will become up to € 211.2 million more expensive.

The costs of stainless steel equipment is up to 30% higher than non-stainless equipment, according to Den Hartog Consulting. For many small producers the limits would necessitate the replacement of their entire production facilities. A reliable figure on the average value of invested capital was not available but a medium sized firm in Belgium reported depreciation and amortisation to be about 5% of sales. The annual report of Akzo Nobel (1999) reports a figure of € 157 million on a net sales of the coatings division of € 5.504 million, or less then 3%. It seems therefore reasonable to assume that 3 - 5% is a fair estimate. Higher costs of equipment would in the long run cause a price increase of (30% * 3 - 5%) about 1 - 1,5% of sales. Replacement at once could in the short run cost (130% * 3 - 5 %) about 4 - 5,5% of sales. Assuming again that the 352 kilotonnes of decorative, conventional alkyd based trim paints are sold for an average price of € 10 per kilo, trim paints would become € 0,15 more expensive per kilo, or up to € 52,8 million for the total volume sold.

In conclusion, a substantial permanent increase in raw material costs and a temporary increase in production costs will be the result of the proposed limits for paint manufacturers. As past R&D has resulted in the availability of low-VOC paints the limits will increase the return on this past investment. More R&D in the development of low-VOC paints will result from the proposed limits with the larger paint manufacturers having an advantage over their smaller counterparts due to their larger R&D capacity and R&D economies of scale. However, this R&D advantage for large manufacturers is at least partially offset by the availability of R&D results of raw material suppliers to small manufacturers. Also many small manufacturers expect to be able to copy and partially modify low-VOC formulations developed by the larger players.

Small manufacturers, particularly in Southern and Eastern Europe, are expected to be more strongly affected than the larger players, with closures and take-overs in store for those not able to make the necessary investments for a successful change-over to the production of low-VOC paints. To a large extent the extra costs for paint manufacturers will be able to be passed on down the chain, and also the margins and added value realised on low-VOC paints is expected to increase as low-VOC products suffer less competition from cheaper, conventional high-VOC paints. The economic consequences for the paint manufacturing sector as a whole are not expected to be substantial, with the exception of those small manufacturers that don’t have the financial strength and change-absorption capacity to make the change-over.

11.3.4 The economic effects of the proposed limits on paint sellers

Industry structure

The power of the retail sector within the paint chain differs from country to country. In some countries like the UK, large DIY retailers wield considerable power over their suppliers, while the retailers in The Netherlands complain about the dominant position of large paint manufacturers. But even in The Netherlands, a relatively large part of the value added on paint is realised by retailers. Although consumers may compare prices between different retailers, price is not the major determinant in the selection of a paint. One retailer states that their current margins on water-borne, which are generally more expensive, are lower than those on conventional paints because they have to compete with the cheaper alkyd paints and in common with the paint manufacturers this will change upon limiting the availability of the conventional paints. However, a fair comparison of prices is difficult because differences in coverage are unclear. Quality is often more important than price. As a representative of a large retailer in The Netherlands put it: “Our consumers think in jobs, not in products. They first decide that they want to redecorate a room, come to our shop and only then select the paint. A special price is not an incentive for doing the job.”

Industry position

The retailers that were interviewed were unanimous in their opinion that it should be possible to replace high-solvent content paint for most applications. The retailers that were interviewed, are already experienced in the sales of high-solids and water-borne paints. B&Q initiated the comprehensive BCF labelling scheme to indicate the solvent content on all cans of paint sold through their stores. This scheme is reported to have had considerable effect on solvent contents, as paint manufacturers were made more aware of the solvent content of their paints and reformulated to be able to put a ‘greener’ label on their paints. In The Netherlands a similar, voluntary labelling system will be introduced industry-wide, albeit with only three classes rather than the British five.

Retailers were not unanimous as to whether the use of high-solids should still be permitted after 2010. According to one retailer there hadn’t been any complaints about the quality of their water-borne acrylics. Another retailer, however, did fear a loss of quality, price increases and a further concentration in paint manufacturing. The retailer stressed that high-solids should also be permitted. A large Dutch retailer that was in favour of an almost complete change over to water-borne paint already offers water-borne acrylics through its in-shop tinting system. The rising demand for in-shop tinting is therefore favoring a growing share of waterborne paint in this particular case. Another incentive for the use of water-borne by DIY-users in The Netherlands is expected to come from the obligatory use of water-borne by professional painters for indoor applications.

Industry reaction

Within the total chain, it seems to be relatively simple for retailers to make a change over to selling other types of paint. In many cases the retailers already have experience in selling water-borne. In some cases, where retailers have own brands, they might have to look for new suppliers. Retailers will have to inform the consumers about the correct application of the new paints and supply the right tools. If high-solvent content paint were to remain available for certain applications, they would have a task in communicating that this paint should not be used unnecessarily. Generally speaking the paint retail as well as wholesale sectors do not fear the consequences of the proposed limits as long as manufacturers will remain able to deliver paint that will get the paint job done without compromising quality.

Economic consequences

The effects of higher selling prices for water-borne paints might result in a slight decrease of sales volumes but it is more likely that there will be no effect at all, because as some retailers have put it, the decision to do a paint job is not influenced by the price of paint. Some parties have put forward a potential negative effect on sales due to a presumed loss in quality and applicability. The painting season for outdoor applications especially would be shortened by several months, while an indoor job, like the painting of doors, would become a more difficult task.

If professional painters could not produce a better result then DIY-painters, then this might have a negative effect on their business in favour of DIY. It is however unclear how important a better appearance of a professional job is for the decision of private consumers. A reverse effect is also conceivable: as the application of water-borne paint is more difficult in some cases and requires a better preparation of the substrate, the DIY-sector may also loose in favour of the professional painters.

The margins on water-borne paint are said to be smaller than on solvent-borne paints because they now have to compete with their cheaper solvent based alternatives. When these alternatives disappear, retailers will have the opportunity to increase their margins on water-borne. An effect that will certainly take place and may have an impact on margins is an acceleration of the concentration process in the paint and paint supplying industries. In a country like The Netherlands where companies like AKZO NOBEL already have considerable market power, this may effect consumer prices and retail margins.

Finally, two potential positive economic effects can be mentioned. In the first place, the phasing out of high-VOC paints will result in a reduction of the range of products that now fills the expensive metres of shelf and have to be marketed. These metres could be used to sell other products or to differentiate on other product characteristics of paint. In the second place, retailers are now held responsible by consumers for selling a hazardous product. A change over to low-VOC paints will help the retail sector to realise a pro-active environmental management strategy and consequently improve their public image.

In conclusion, the marginally negative economic effects for paint sellers of the proposed limits are likely to be compensated by the slightly less marginally positive economic effects of the proposed limits. As such, from an economic perspective the limits proposed are not very significant for either the paint retail or the paint wholesale sectors.

11.3.5 The effects of the proposed limits on professional painters

Industry structure

According to UNIEP, the European Painters Federation, they represent 165.000 companies employing 1.658.000 people. This illustrates both the economic significance of the sector and the fact that on average the companies are very small. The European professional paint sector is a very traditional sector that seems to be reluctant to change. Essentially it is the flexibility of this sector that to a large extent will determine the economic effects of the proposed limits.

Industry position

The Dutch and Danish organisations of professional painters seem to have been very cooperative in the change over to waterborne paint exclusively for interior applications. An important consideration in this respect has been OPS. The UNIEP, the French and the German organisations seem to be less enthusiastic. Their objections are that low-VOC paint is often inferior, more expensive and more labour intensive. While OPS considerations, where prevalent, favour regulation limiting VOC-content, quality considerations and the traditional nature of the industry will likely pit the industry against the proposed limits.

Industry reaction

Painters will have to learn to paint with new systems and for some painters it may take quite some time before they will accept the change-over. Training, especially if companies are allowed several years as under the Decopaint proposal, can take place on the job, as an integral part of normal professional training and be initiated by industry organisations. There has been a great reluctance in voluntarily adapting to the use of low-VOC paints but forced by regulation painters are likely to quickly pick up on the different application requirements for low-VOC paints.

Economic consequences

A first clear consequence is that paint on average will become more expensive. The Dutch painters organisation FOSAG calculated that the prices of professional quality waterborne paint are 5 to 30 percent higher. But in general, material costs are only 15-25% of the costs of a whole paint project, with labour costs making up 75-85%, depending on the price of labour. According to UNIEP, the net economic effect of a change-over to high solids would be neutral, as the higher material costs would be compensated by the labour saving.

The overall economic consequences are difficult to predict, but clearly will stem more from labour effects than from paint price effects. Claims of painters organisations that they will loose market because of quality loss or because they will become more expensive, cannot be verified. Also, we do not know what share of the painting market relates to the use of conventional trim paint. Specific market research will have to determine in how far the clients of the professional painters are prepared to accept higher prices. It is certain that the proposed limits will affect labour costs because of the different paint application and paint performance characteristics of low-VOC paints.

Assuming that the total labour costs of European painters are (2 million painters * € 30.000) around € 60 billion, the significance of any effect on labour time becomes immediately apparent. One percent more could increase the costs of European paint jobs to a maximum of € 600 million annually extra.

11.3.6 The effect on DIY users, consumers

DIY painters will have to bear slightly higher average paint prices, but this will not affect them significantly, or their paint purchasing decisions. Assuming that quality and performance of paints can be kept up to standard, there is no reason to believe the DIY paint market will be affected economically significantly to any extent.

However, clients of professional painters will have to pay for the increased labour intensity of using water-borne paints, but as the extent to which this labour intensity will increase remains unclear this is a factor of which the effects are impossible to calculate without extensive market research.

In conclusion, more research is needed on the effects of the proposed limits on paint labour intensity and the limits mitigative effects on OPS. Consequently market research can follow determining the likely eventual economic effects on both professional painters and consumers of the proposed limits. However, while entailing potentially the most significant economic effects of the proposed limits, these effects will in any case be so diffuse that neither professional painters nor consumers will be substantially affected.

11.4 Conclusions

In relation to the criteria formulated by Porter and van der Linde is seems likely that the proposed command-and-control limits will very significantly contribute to the application and diffusion of past innovations, as well as stimulate further innovations.

The first criterion formulated was that regulation should focus on outcomes, not on technology. In a sense the proposed limits do favour one technology, waterborne, over another, solventborne, but not entirely so. The proposed limits do leave the option for the use of other technologies open, as long as VOC-content is significantly reduced. The regulation focuses on various outcomes, namely a significant reduction of VOC-emissions from nearly all different classes of paints. As is, the regulation focuses on outcomes as much as is possible and in this respect will certainly lead to more success for low-VOC technologies.

The second criterion was that the regulation should set strict rather than lax standards. Clearly the standards set are reasonably strict, the hydrocarbon solvent emissions are likely to be reduced by over 60% and even the oxygenated solvent emissions are expected to decrease by around 15%. Consequently the limits are strict enough to stimulate innovation.

The third criterion is the use of a phase-in period, which in the proposal is up to ten years. As the normal life of a paint formulation is around this time as well, the proposal creates a sufficient window for innovation and adaptation in order to eventually meet the proposed limits.

Market incentives are not proposed, but the possibility remains for the use of labelling and/or exceedance fee instruments which can be used in synergy with the proposed limits. In this respect the paint application sector especially, differs from other industries', as from the previous analysis it has become apparent that market incentives as sole instruments cannot lead to the desired results. However, the use of market incentives in addition to the proposed limits can increase the cost-effectiveness and efficiency of the proposed limits.

Harmonisation or convergence with regulation in associated fields, the fifth criterion, is clearly sought. Regulatory pressure on industrial VOC-emissions has mounted over the years, and occupational health regulation, at least in parts of Europe, has also focused especially on the reduction of interior VOC-emissions.

The proposed limits are ahead of the limits in most of the world. As similar regulations are likely to follow eventually throughout the world, European corporations can expect to be able to use the experience gained, on the basis of the European regulation in non-European markets, to their advantage.

Stability and predictability of regulation is the seventh criterion. The proposed limits will stabilise the European regulatory situation, whereas now, widely diverging regulatory approaches to reducing VOC-emissions are in use in the different European countries, this will be harmonised and stabilised across Europe. Due to the long time horizon of the proposed limits they are predictable. Thus the proposed limits will provide much needed clarity to industry as to where regulation is going and consequently facilitate innovations in order to comply with the regulatory requirements.

Industry participation is the eighth criterion, but it is early days yet for meeting this criterion. Industry has extensively been consulted in the pre-regulatory stage of this project, but it will be up to the regulator to facilitate industry participation in the actual formalising stage.

The ninth criterion, the need for strong technical capabilities of the regulator, is less crucial here, as the regulation proposed is relatively simple and because external expertise can and is used to assist the regulator. Already in this pre-regulatory stage the regulator is using the technical expertise of Enterprise Ireland, the technical partner in this Decopaint project.

The tenth and final criterion is the requirement to make the regulatory process more efficient. As a possible Decopaint Directive is still in its pre-regulatory stage, it is difficult to judge the extent to which this requirement will be met. However, particularly for the multinational players in the paint chain, a European standardisation of VOC-emissions from decorative paints regulation is certain to make the compliance part of the regulatory process more efficient.

The following scheme summarises the potential economic effects in the paint chain if the industry had to make an almost complete change-over to water-borne paints by 2010.

paint chain	major economic effects
solvent suppliers	• revenues from hydrocarbon solvents in decorative paint: minus € 65 million • revenues from hydrocarbon solvents for thinning and cleaning : minus € 65 million • revenues from oxygenated solvents: minus € 24-46 million or plus € 30 million (ESIG) • employment: minus 2.000 - 4.000 people (ESIG) • strong concentration • effects are modest in relation to the economic strength of largest companies
resin suppliers	• additional R&D: € 45.000 per new resin • investment in new equipment • resins will become 1.3 - 2 times more expensive • revenues: up to plus € 211 million • concentration, shake out of small alkyd resin suppliers
paint manufacturers	• reformulation costs: 0,4% of sales • resins will become 1.3 - 2 times more expensive, additional resin cost up to € 211 million • stainless steel equipment: € 53 million • concentration, advantages for large companies
retail, wholesale	• no major effects
professional painters	• more expensive paint • more labour time per paint job (1% = € 600 million) • effects on quality and subsequently on demand
DIY users, consumers	• more expensive paint
waste processors	• no major effects
water treatment	• no major effects

If regulations will spur innovations, it is likely that most of the above mentioned costs will decrease. If the expected concentration process occurs, the larger companies will profit from economies of scale which will lower the cost of implementation even further. Such a concentration process will especially effect small alkyd resin and paint manufacturers and have an impact on employment. For the larger companies in the paint chain, that are often part of multinational industries, the costs will be relatively modest.

Cost effectiveness

In comparing the roughly estimated cost effectiveness of a possible decorative paint directive to the cost effectiveness of the EU VOC directive, the first seems to be superior. The cost of the VOC directive were estimated at € 80 billion for a 1,5 million ton reduction, or over € 53 thousand per ton reduction. The cost of a possible decorative paint, excluding the costs of additional labour by professional painters, have only be analysed for trim paints and were estimated to be less than € 300 million annually for a 56 kiloton reduction, or about € 5 thousand per ton reduction. In comparing the cost effectiveness of both regulations, it is a complicating factor that the VOC directive is evaluated in one lump sum, while we have calculated the annual costs for the decorative paint directive. However, as the cost will decline over time due to innovation, we worked with an extreme scenario of a complete change-over to waterborne paint and because other parts of the proposal like the replacement of waterborne wall paint for indoor use are probably less costly, we conclude that a decorative paint directive will be more cost effective than the EU VOC directive. If we add the reduction in solvent use for cleaning and thinning purposes as a side effect of the change-over in trim paints and we assume that this reduction will be largely beneficial, than the cost effectiveness would be even better.

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12. Environmental and occupational health impact

12.1 Tropospheric ozone and VOC from decorative paints

The problem of tropospheric or ‘ground-level’ ozone is one of the major environmental issues addressed in current policies of DG Environment and the UN/ECE. It is one of the three environmental problems addressed in the proposed Council Directive on National Emission Ceilings for certain atmospheric pollutants (‘NEC-Directive’), together with acidification and soil eutrophication (EC, ’99). In addition, the UN/ECE Protocol on Long-Range, Transboundary Air Pollution deals with the same problem in a wider setting (see chapter 6). In this section, the possible role of a ‘Coatings Directive’ in solving the ozone problem, in addition to the Solvents Directive, will be discussed.

12.1.1. Tropospheric ozone

Tropospheric ozone is a secondary pollutant formed by the reaction of the main precursors nitrogen dioxides (NO_x) and volatile organic compounds (VOC). This reaction is initiated by sunlight, and therefore highest ozone loads occur during summer, in particular on days with high temperatures (EC, ’99). Especially in case of stable weather conditions, with a lack of wind, relatively high ozone concentrations can occur. Ozone and its precursors can be transported over hundreds of kilometres. Thus, photochemical pollution is a widespread transboundary phenomenon (EC, ’99).

Effects of tropospheric ozone and threshold values

Ozone is a powerful oxidant, which can react with a wide range of biological materials. Thus, ozone can cause damage to human health and to natural vegetation and agricultural crops.

The main *human health* effect of ozone is damage to the respiratory tract. Ozone is a strong irritant, inducing adverse effects at very low concentrations. People suffering from asthma or heart diseases are particularly sensitive to ozone. Indeed, studies in European and US cities have pointed out that elevated ozone levels increase mortality (EC, ’99). Therefore, in many countries it is recommended that strenuous exercise should be avoided during ‘episodes’ of high ozone concentrations. Detailed data on health effects are not available. A study in the UK estimated the health impact of the emissions of VOC from road transport (850 ktonne) at 1010 premature mortalities and ‘significant morbidity effects’, due to the combination of ozone formation and particulate matter (EC, ’99). Studies in the Netherlands have shown decreased lung function among schoolchildren (de Leeuw, ’91).

With regard to its impact upon natural and agricultural *vegetation*, ozone is known to affect photosynthesis producing lesions and discoloration of leaves. At the concentrations of ozone which currently prevail during the summer growing season in the EU, production losses may amount between 5 and 10% (EC, ’96).

The World Health Organisation (WHO) has developed a set of guideline *threshold val*ues for the effects of ozone (Amann et al., ’99). For effects on human health the threshold has been set at 60 ppb (or 120 $\mu g/m^3$); for the effects on vegetation at 40 ppb (or 80 $\mu g/m^3$). Based on these threshold values, two types of parameters are used to assess the likelihood of adverse effects due to current ozone concentrations:

- The *number of days* (per year) on which exceedences of the threshold values occur;
- The *Accumulation Over Threshold*-values: AOT60 for human health and AOT40 for vegetation.

The AOT60 and AOT40 values are combinations of two figures: the *duration* of an exceedence of the threshold value (in days or hours), and the *magnitude* of these exceedences. Thus, the unit of the AOT-values is *ppb.days or ppb.hours*.

Ozone modelling

Within the framework of the EU-funded EMEP programme (Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air pollutants in Europe) mathematical models have been developed to assess the transportation and impact of transboundary air pollutants such as ozone and its precursors. With respect to ozone, its formation from the reaction of NO_x with VOC is modelled as well as its transport and environmental impact. These models have been incorporated in the RAINS-model, which was developed by the International Institute of Applied Systems Analysis (IIASA). The RAINS model was used to assess the impact and the costs and benefits of the proposed NEC-Directive (Amann et al., '99).

The RAINS/EMEP models use grid cells of 150x150 km to assess transportation of air pollutants across Europe. For each of these grid cells, the above-mentioned parameters such as AOT60 and AO40 as well as the number of days on which exceedences of threshold values occur, are calculated. With the help of the model, the impact of specific NO_x-reductions or VOC-reductions can be assessed. Besides, it can for example be assessed which countries should take these measures in order to reduce ozone formation most effectively.

The POCP value and VOC-speciation

One of the issues when discussing the impact of VOC on ozone formation is the so-called Photochemical Oxidant Creation Potential, or POCP-value, of specific VOCs. The POCP-value is mainly a measure of the *reactivity* of a specific VOC, with respect to ozone formation. This reactivity, or reaction rate, is defined against the reaction rate of a reference compound (Derwent et al., 1996).

Several interest groups have pointed out that a VOC-reduction scheme for decorative paints should take the POCP-values of the solvents involved into account. This is common practice for example in the Californian VOC-regulations. However, *both* VOC with a high POCP-value and VOC with a low POCP-value contribute to ozone formation. However, as the reaction *rates* differ, it is mainly the *location* of ozone formation, caused by a specific emission of VOC, that differ:

- 'High-POCP VOC' cause ozone formation *close* to the source of emission;
- 'Low-POCP VOC' cause ozone formation *further* from the source of emission.

As the Californian VOC-regulations concentrate on peak values of ozone in the Los Angeles area, VOCs with low POCP values give lower peak ozone concentrations. However, these low-POCP VOC result in *higher* ozone concentrations further away from the source of emission. In the case of California, these higher ozone concentrations occur in the deserts around Los Angeles, and are not regarded as a problem. In Europe the situation is quite different: because of the fact that Europe is more densely populated, ozone formation further away from the source of emission will still cause problems. These may either be health problems or damage to crops.

Because of this reason, IIASA does not use POCP-values in its RAINS model, and POCP-values have not been used in defining the Solvents Directive and NEC-Directive (Amann, '99). Therefore, the Decopaint study team has concluded that the POCP-values are *not relevant* for a future 'Coatings Directive'.

12.1.2 Impact of a Coatings Directive

While road transportation is the main emission source of NO_x as an ozone precursor, many human processes contribute to the emission of VOC. The Solvents Directive deals with reducing these emissions as far as industrial sources are concerned, but leaves the use of decorative paints unaffected. Full implementation of the Solvents Directive should reduce VOC emissions from 14,000 ktonne to 7,000 ktonne (Amann et al., '99). As indicated in chapter 5, the contribution of VOC from decorative coatings will be close to **10%** of the total man-made VOC-emissions in that situation (thinning and cleaning included). Thus, the use of decorative coatings would be one of the major remaining sources of VOC-emissions. Therefore, when further VOC-reductions (i.e., reductions of tropospheric ozone formation) are to be achieved, the use of decorative coatings will have to be a major target for action (Amann & Klimont, '99). Consequently, a large part of the additional 1500 ktonne of emission reduction proposed in the NEC-Directive (from 7000 to ~ 5500 ktonne) may be achieved through reduction of VOC-emissions from decorative coatings.

As presented in chapter 10, the VOC-reduction potential resulting from the study team's proposals (the options 1 and 2) option 2 - may range from **365** to **518 ktonne** for the EU-member states plus 6 accession countries, when thinners and cleaning agents are regulated as well. This would mean a **51** to **62%** reduction of VOC-emissions connected to the use of decorative paints and varnishes.

The formation of ground-level ozone is a complex process with many influencing (local) factors (availability of NO_x, temperature, sunlight etc.). However, it is assumed that the overall effect is a more or less *linear* relationship between VOC-reduction and ozone reduction (Amann, '99).

Representatives of the European Solvents Industry (ESIG) have studied the effects of reductions of VOC from decorative paints on the exceedence of ozone threshold values (Kersey & Pearson, '99). In this study, the EMEP ozone models have been used, and the impacts of VOC-reductions of 150 and 350 ktonnes have been calculated. The authors conclude that these VOC-reductions, beyond the reductions achieved through the Solvents Directive, have only a minor effect on ozone reduction (~ 3%), which is mainly confined to Northwest Europe. The authors state that further ozone reductions could be achieved much more effectively through local measures instead of a pan-European Coatings Directive.

The Decopaint study team has assessed these conclusions with the help of the studies performed by IIASA within the framework of developing the NEC-Directive (Amann et al., '99). In addition, the conclusions have been discussed during a meeting at IIASA (Amann & Klimont, '99). It was concluded that the statements of the Solvents Industry-study *cannot* be fully justified and that in fact ***a Coatings Directive*** **may** ***have a significant contribution to further ozone reductions***. The following reasons can be given for this conclusion:

- Reductions up to 518 ktonne may be achieved, instead of the 350 ktonne studied by ESIG;
- The ESIG conclusions were based on *human health* effects only. When the effects of ozone on *vegetation* are taken into account as well, it appears that at the moment, practically *everywhere* in Europe the threshold values are exceeded. In particular the Mediterranean countries are problematic areas in this respect, in addition to Northwest Europe.
- For the estimation of human health effects, the ESIG-study uses the AOT60-value only (see description above). In this case, Northwest Europe (NL, B, D, F) is currently the region with the highest values. This is due to the *magnitude* of the exceedences of the ozone threshold values. However, when *number of days* on which exceedences of the threshold occur is taken as a parameter, it appears that other parts of Europe (in particular Italy) are highly problematic areas as well.
- In the ESIG study only *rural* ozone concentrations were taken into account. When *urban* ozone is taken into account the ozone problem is certainly *not confined* to Northwest Europe. The Mediterranean countries, in addition are problematic areas in this respect. *Further VOC-reductions* have a relatively *large effect* on *urban ozone reduction*.
- In general, *all* individual contributions to the ozone problem are small. Only many measures together produce a significant reduction of the problem of tropospheric ozone. The contribution from decorative paints is relatively large (see above). Other measures may be more costly. Finally, a study within the framework of the "AUTO-Oil II" project has shown that, in contrast to that suggested by ESIG, there are *no 'local measures' available* that work (Amann & Klimont, '99).

In reaction to these conclusions, ESIG has prepared some additional modelling results (Kersey, '00). In addition to the above-mentioned study, which only included human health effects, effects of VOC-reduction on vegetation-related thresholds were modelled. These results indicate that a potential coatings directive will result in a reduction of ozone concentrations not only in north-western Europe, but also in Italy.

In summary: reduction of VOC-emissions associated with the use of decorative coatings result in ozone reductions that are proportional to the VOC-reduction (Amann, '99), although local circumstances may have significant effects. This means, that when the VOC-reduction potential for

decorative paints accounts for 5 to 6% of total VOC emissions (5 to 6% of 10%; see above), the **resulting ozone reduction may be about 5 to 6% as well**. The question whether reductions of this magnitude are 'significant' remains a political one.
The differences between the two reduction options in terms of ozone reductions are not considered significant. They may be relevant, however when direct health effects at painters are considered (see section 12.4 and 12.6).

The role of 'natural' VOC

As indicated in chapter 5, 'natural' VOC may contribute ± 20% to total VOC emissions. It has been stated that at locations with high emissions of 'natural' VOC (large forests), NO_x-emissions are low or absent, due to the absence of human activities. Therefore, the contribution of 'natural' VOC to tropospheric ozone formation would be limited. However, as VOC - 'natural' VOC as well - may be transported in the atmosphere, these may contribute to ozone generation elsewhere. It's not known whether other routes of degradation will be able prevent this.

On the other hand, a modelling experiment by IIASA has raised some doubts about the contribution of natural VOC to ozone formation. Model calculations with the help of the RAINS/EMEP models pointed out that the tropospheric ozone problem *diminished* when the *man-made* emissions of VOC were set at zero (Amann & Klimont, '99). In addition, investigations within the framework of the EMEP project have pointed out that emissions of isoprenes from biogenic sources are "not sufficient to affect production or loss rates of key-radical species significantly" (Simpson, '95b).

Industry in turn has replied to this with the remark that most 'natural' VOC-emissions occur during summer, while most 'ozone episodes' would occur during summer as well, as a result of higher temperatures (Kersey, '00). However, generally the presence of NO_x and direct sunlight are regarded as main triggers to the formation of ozone. Therefore, both in summer *and* in winter situations, in particular in the southern countries, with stable atmospheric conditions, ozone episodes may occur.

In conclusion, much is yet unknown about the potential contribution of 'natural' VOC to ozone formation. For example, it's not known whether alternative routes of degradation may prevent 'natural' VOC from taking part in reactions leading to ozone formation. Also, the estimates of the magnitude of natural emissions are far from reliable yet (see chapter 5).

Effects of the ozone reduction

Apart from contributing to the targets that have been set within the framework of the UN/ECE Protocol and the NEC-Directive, the VOC-reduction from decorative coatings may contribute to reductions in negative effects due to high ozone concentrations.

As mentioned, production losses due to crop damage may range from 5-10% at the concentrations of ozone which currently prevail during the summer growing season in the EU (EC, '96). An ozone reduction of 5 to 6% may considerably contribute to preventing part of the losses, although the magnitude of this effect is very hard to estimate.

As far as human health effects and effects on vegetation are concerned, the UK Committee on the Medical Effects of Air Pollutants has conducted some modelling work for the UK-situation (COMEAP, 1998). In this work, one has assumed a no-threshold approach for human health effects (Ritchie, '00). The method and the results have been described in the draft report of the EC DG Environment study on VOC-reduction in the vehicle-refinishing sector (Ritchie, '00). In this report, acute health effects and crop losses have been estimated on the basis of a VOC-reduction potential for the vehicle-refinishing sector of 84 ktonne. Chronic health effects could not be estimated. In the table below, the results of re-calculating the figures from the vehicle-refinishing sector for the decorative paints sector are presented.

Table 12.1 – Quantified benefits from a VOC-reduction of up to 518 ktonne, connected to the use of decorative paints and varnishes in the EU-15 countries plus 6 accession countries.

Parameter	**Annual benefit for the EU-15 + 6**
Number of deaths due to acute effects of ozone *not* brought forward	148
Number of respiratory hospital admissions due to acute effects of ozone *not* brought forward	209
Reduction in crop damage (EURO)	312 million

Summary of the main conclusions:

- A Coatings Directive may have a significant contribution of about 5-6% to further ozone reductions.
- Benefits may be expected in reduced acute and chronic health effects due to ozone, the value of which is subject to discussion.
- Benefits may also be expected in a reduction of crop damage of ± 312 million EUROs.
- It's not advisable to distinguish between VOC on the basis of POCP-values. Eventually, all VOC contribute to ozone formation.
- The contribution of 'natural' VOC to tropospheric ozone formation is not clear.

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12.2 Water pollution due to the use of waterborne paints and varnishes

Due to their nature, it has been assumed that waterborne coatings might bring about an increase in paint discharges to sewage systems or surface waters, resulting in water pollution. The background of this idea is the fact that consumers, and some professional painters as well, tend to clean brushes and rollers under the tap when waterborne coatings have been used. Even more: in the early days of the introduction of waterborne coatings the ease of cleaning equipment under the tap was used as a marketing argument.

A study that was carried out in The Netherlands pointed out that no significant effects were expected (Tauw, ’88). In addition, interviews with representatives of the Dutch institute of water management and wastewater treatment (RIZA) revealed that no problems were expected (RIZA, ’00). However, the Dutch study was performed in 1988, while only the Dutch situation was covered. Therefore, a short study on the extent of the potential problem and on the type of effects that might be expected was carried out within the framework of the Decopaint project (van de Sande, ’00). This section provides the main results of this study. This section concentrates on water pollution at application and after application. For the life-cycle perspective, i.e. water pollution at the manufacturer, we refer to section 12.3.

12.2.1 Estimation of the current amount of paint discharged

In The Netherlands, estimations of the fraction of the total amount of waterborne paint used, that is discharged to the sewage system have been made. At work sites of professional painters, the working habits were observed and painters were questioned. Based on this research, it was estimated that this fraction was *0.15%.* It appeared that most professional painters do not wash their brushes each day, but store them in a can of water. Once a week these cans were emptied in the sink. In order to make the same type of estimate for the situation among consumers (DIY-painters), it was assumed that these painters in fact *do* clean their brushes and rollers after each paint job. Therefore, the estimated fraction of the total amount of waterborne paint used, that ends up in the sewage system was set at *0.75%* for consumers (i.e. five-fold higher).

These estimates have been applied to the consumption figures of decorative coatings that have been given in chapter 4. In addition, data on the relative share of DIY versus professional paint use and of the use of waterborne coatings in these two market sectors have been used. As a result, the following estimate of the total amount of waterbased paint that is discharged into sewer systems appears (van de Sande, ’00):

Table 12.2 Waterbased paint discharged into sewer systems.

Total consumption of decorative coatings (EU-15)	3344 ktonne
Amount of waterborne paint discharged into the sewer by professional users	1.9 ktonne
Amount of waterborne paint discharged into the sewer by DIY users	8.3 ktonne
Total amount of waterborne paint discharged into the sewer	**10.2 ktonne**

After discharge to the sewer, paint components may either first enter a wastewater treatment plant (WWTP), or directly enter surface waters. The relative share of the two options varies from country to country, and depends on the percentage of households that are connected to wastewater treatment plants. This percentage ranges from only 10% in Greece up to 98% in Denmark. Data on this percentage for the 15 EU member states was used to calculate the amount of paint that might directly enter surface waters, after being discharged in the sewer. It was found that about **3 ktonnes** of waterborne paint may enter surface waters in this way, i.e. without passing a WWTP first.

12.2.2 Potential harmful effects from paint components after discharge

Three types of potential effects may be considered:

- Effects to the sewage system;
- Effects to micro-organisms that are responsible for the biodegradation in a WWTP;
- Effects to organisms in aquatic ecosystems (surface waters).

Effects to the sewage system itself might be expected when very large amounts of paint are discharged at one location. The effects that are considered possible in such a case are blockage of the system as a result of settlement of large amounts of binders, pigments or extenders, and damage to the system as a result of pH-changes. However, experts do not regard this type of extreme discharges and this type of effects very likely (RIZA, ’00). Therefore, we will concentrate on effects at WWTP’s and in surface waters. The main components of waterborne paints will be described.

Binders
As far as binders are concerned, acrylic polymers used in latices and trim paints are the most significant group of polymers. At the moment, waterborne alkyds are used to a small extent only, but this might change within a few years.

Binder particles in emulsion or dispersion paints have molecular weights of 100,000 to 1,000,000 (Breedveld & van Loon, ’97). They are not soluble, and the emulsion or dispersion will break at dilution in the sewer. When the water flow is sufficiently low, the particles will precipitate. In many cases, this will be in the wastewater treatment plant. However, when direct emission to surface waters occurs, precipitation may take place in the environment. In addition to precipitation, adsorption to organic material may take place. Therefore, it is assumed that binder particles may be quite efficiently removed from wastewater in a WWTP.

When direct emission to surface waters occurs, binder particles may have adverse effects. Acrylic polymers are poorly biodegradable, and thus may accumulate in the soil of surface waters (Sande, ’00). Alkyd polymers are partly biodegradable, and may be slightly preferable when discharges to water are likely. Because of their high molecular weight, the particles are not taken up by aquatic organisms. However, suspended particles in high concentrations may clog the lamellae of fish, and thus impede the oxygen uptake through the gills. It’s not likely that such high concentrations often occur, but at localised spots it is not precluded.
Residual monomers, such as methacrylate, acrylonitrile and styrene may be present in acrylic binders in very low concentrations, i.e. at a level of ‘parts per million’ (ppm). Acrylonitrile especially, is toxic to aquatic organisms. However, the amounts concerned are very low. Assuming that 10 ppm monomers are present in the binder and that the binder constitutes 20% of the paint, a direct emission of 6 *kilo’s* of monomers to surface waters might annually occur throughout the EU.

Solvents
In waterborne trim paints, and to a lesser extent in waterbased wall paints, glycols and glycolethers are used as cosolvents or coalescing agents. Most of these have shown low toxicity in fish (Sande, ’00), although some ethyleneglycolethers are teratogenic in mammals (see section 12.5 for more details).

Glycolethers may be expected to have a reasonable biodegradability, because of the presence of oxygen in the molecule. The contents in waterborne paints ranges from about 2% for most wall paints to about 10% for many trim paints. Direct discharges of glycolethers to surface waters may be in the order of 60 tonnes, as most waterborne paints currently used are still wall paints.

Pigments and extenders
By far the most used pigment is Titanium dioxide (TiO_2), which accounts for about 90% of the total pigment consumption (see chapter 4). This is an inert substance, just like another widely used class of inorganic pigments, the iron oxides (Sande, ’00). The same holds true for the extenders that are most widely used: calcium carbonate (80-90%), talc, kaolins etc.

Pigments and extenders are present as insoluble particles, and settle out as soon as the dispersion is broken. The same potential effects as those described under ‘Binders’ may occur.

In decorative coatings, heavy-metal based pigments are used only to a very limited extent. Therefore, these have not been dealt with here.

Preservatives
The use of preservatives or biocides, which have toxic properties due to their function, is one of the main concerns when potential water pollution is concerned. One of the issues addressed is the question whether the functioning of micro-organisms in wastewater treatment plants might be affected.
In order to prevent tainting in the can small amounts (0.1% or even less) of biocides are used. In order to prevent fungi from growing on painted surfaces somewhat higher percentages of biocide may be added. The formerly much used organomercury compounds are now forbidden in most countries,

because of their relative harmfulness (Bieleman, ’00). Nowadays, common biocide types for in-can preservation include (see section 12.5 as well):

- Formaldehyde or formaldehyde-releasing compounds;
- Isothiazolinone derivatives;
- Quaternary ammonium compounds;
- Acids (e.g. boric acid)
- Phenol-derivatives (e.g. p-chloro-m-cresol)
- Alcohols (e.g. Bronopol).

The use of formaldehyde is decreasing, while quaternary ammonium compounds and especially isothiazolinone derivatives are widely used. The latter two types of compounds are generally not very biodegradable (Sande, ’00). Both are relatively toxic to aquatic organisms.

Assuming a content 0.1% for in-can preservatives (the most relevant group), the estimated amount of preservatives that may reach WWTP’s throughout the EU is 10.2 tonnes, the amount that may be discharged directly to surface waters is 3 tonnes throughout the EU. However, it’s very hard to predict if any effects will occur in practice, as the emissions will be very diffuse. In addition, reactions with other components in wastewater may deactivate the preservative before it reaches a WWTP or the surface water.

Surfactants

Surfactants form the second class of additives around which a debate is on-going. The debate concentrates on the use of the non-ionic alkylphenol ethoxylates (APEOs). It is suspected that especially the metabolite of nonylphenol ethoxylates, i.e. nonylphenol, may cause aberrations to the reproductive organs of fish and other aquatic organisms (Sande, ’00). Therefore, these compounds are more and more substituted by other surfactants (CEPE, ’00). In Denmark, the use of APEOs in waterborne paints has been prohibited recently (Petersen, ’00). In a European setting such measures are still discussed. Thus, the ban on these surfactants is not yet complete.

The ultimate biodegradability of APEOs is poor, and in particular the intermediate nonylphenol may accumulate. A considerable part of the APEOs entering the WWTP may pass through, as only part adsorption to sewage sludge occurs (Sande, ’00). Based on a 100% share of APEOs among the surfactants, an upper estimate in the range of 20 tonnes of APEOs may enter surface waters throughout the EU annually (Sande, ’00). The total amount of APEOs *used* in the Netherlands only has been estimated at 696-1006 tonnes annually (Westra & Vollebregt, ’95). Therefore, on a European level, the use will be in the order of *at least* 15,000 tonnes. It’s not known how much of this amount is emitted.

Again, the emissions will take place very diffusely. However, local effects due to high discharges to small volumes of surface water may not be ignored. Therefore, the use of this type of surfactant should be further discouraged.

12.2.3 Impact of the VOC-reduction proposal

The VOC-reduction proposals that have been presented in chapter 9 will result in an increase in the use of waterborne coatings. This increase may for the most far-reaching of the two options (option 2) be estimated at 525 kilotonnes for the EU-15 (from 2346 to 2871 ktonnes; see Annex 3 as well). This means a 22% increase. The reason for this relatively small increase is the fact that most wall paints are waterborne already, and these account for by far the largest painted surface.

This means, that the impact of the VOC-reduction proposal to the issue of water pollution is in fact limited. However, existing emissions to water are reason for concern in some cases already. Therefore, the practice of cleaning equipment under the tap should be more strongly discouraged. In addition, the use of certain additives, such as APEOs and isothiazolinone compounds, should be prevented or limited to what is absolutely necessary.

Main conclusions

- The practice of cleaning equipment under the tap results in an estimated 10 kilotonnes of waterborne paint that is discharged into sewage systems. Of this, about 3 kilotonnes may directly enter surface water without passing a wastewater treatment plant (WWTP).
- Damage to the sewage system is not likely to occur.
- Binders, pigment, extenders and solvents are not expected to cause significant adverse effects in waste-water treatment plants or to aquatic environments.
- Some preservatives used are relatively persistent in the environment. Local effects may not be precluded, although as the emissions are very diffuse these are very hard to predict.
- Alkylphenol ethoylate surfactants (APEOs) or their metabolites may be persistent in the environment and may cause reprotoxic effects in water organisms. Again, as the emissions are very diffuse the effects are very hard to predict. Local effects may not be ignored.
- The use of APEO surfactants and of isothiazolinone preservatives should be limited to what is absolutely necessary. APEOs are being phased out already.
- The practice of cleaning equipment under the tap should be more strongly discouraged.

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12.3 Environmental impact from a life-cycle perspective

Introduction

In discussions about the environmental impact of paints it is often mentioned that the whole life cycle of paint needs to be taken into account in order to compare the environmental impact of paints properly. One of the reasons is that solvent borne and waterborne paints may have adverse environmental effects at different stages in their life-cycle, e.g. at production or at application. An environmentally oriented Life Cycle Assessment study (LCA) may be a proper way of comparing the environmental impact of products.

In this method, contributions to environmental effects arising during production phase, user phase and waste phase of the product are added to produce a single "environmental profile". This profile consists of contributions to different environmental effects, such as global warming (the 'greenhouse effect'), tropospheric ozone formation (‘summer smog’), ozone depletion, etc. Such an environmental profile can be made for every product (if data are available). These profiles are used for comparison. Two important aspects are complicating this comparison.

1. To be able to compare the environmental profiles of products a Functional Unit must be defined. For example, when it’s possible to cover only 5 m^2 with 1 liter of paint A and 10 m^2 with 1 liter of paint B, the environmental profile of paint A must be multiplied by a factor 2 before comparing it to the environmental profile of paint B. Unfortunately, it is not that simple to define a proper Functional Unit, which will be discussed later. In the absence of a proper Functional Unit, no comparison can be made, and the environmental profiles can only be used to identify the major contributions to environmental effects.
2. Moreover, paints may contribute to different environmental effects. For instance, solventborne paints contribute mainly to air pollution, whereas waterborne paints contribute mainly to water pollution. In comparing different paint systems, the impact of both air pollution and water pollution, have to be taken into consideration. These two types of pollution are not additive, and comparison between the relative importance of each is debatable.

Nevertheless, in this section, a number of existing LCA-studies of decorative paints are compared and discussed. First, a very short description of the contents of the studies used is given. Then, the assumptions made in the studies are summarised and discussed and the results of the studies are given. Next, the influence of the assumptions on the environmental impact is discussed, leading to the conclusions.

The LCA-studies that have been reviewed

The studies used to compare and discuss are:

1. De milieubelasting van vier verfsystemen - CREM, 1992
2. Milieumatenstudie van vier bouwverven - Manders-Maanders, 1992
3. Vergleichende okologische bewertung van anstrichstoffen im baubereich - BUWAL, 1992
4. Milieukeur voor verf concept eindrapport - CREM, 1992
5. Milieumaten watergedragen alkyd-emulsieverf - TAUW, 1993
6. The ecolabelling criteria and how they have been obtained on the basis of the life cycle analysis of eleven indoors decorative paints - Ecobilan Company, 1994
7. Levenscyclusanalyse voor acht witte buitenverven - Merkx, 1995

A search for more recently performed LCA-studies resulted in a study performed by NIBE (1998). However, this turned out to be a study in which only a different comparison method was used, departing from the data in the above mentioned studies. In addition, the same important assumptions were used. It is remarkable that most studies use data from one another.

Table 12.3.1: Overview of the LCA-studies analysed.

LCA-study	Studied paints	Functional unit	Dry paint film thickness
1	White outdoor trim paints	Amount of paint necessary to paint 100 m^2 over 40 years	Depending on paint type
2	White outdoor trim paints	Amount of paint necessary to paint 100 m^2 over 40 years	400µm per 40 years
3	Construction paints	Amount of paint necessary per m^2 with an opacity of 98%	Depending on paint type
4	White wall paints White trim paints	Amount of paint necessary for a paint film of demanded quality in gr/m^2	50µm
5	White outdoor trim paints	Amount of paint necessary to paint 100 m^2 over 40 years	400µm per 40 years
6	White indoor wall paints	Amount of paint necessary to cover 20 m^2 with an opacity of 98%	Depending on paint type
7	White outdoor trim paints	Amount of paint necessary to paint 25 m^2 over 40 years	40µm

In the studies the following assumptions were used:

- All studies use representative compositions in order to be able to compare *types* of paints. However, due to the fact that for every application with unique demands a special paint is developed, it is very difficult to define representative compositions. Within a certain type of paint large differences may exist. Therefore, it is difficult to express preference for a certain paint type based on a comparison of representative compositions.
- All paints are white, using TiO_2 as pigment. This assumption is legitimate, because the majority of paints are white. Moreover, many other coloured paints contain, besides the coloured pigment, also TiO_2 for its excellent hiding power.
- Ingredients present in a quantity of less than 5% are not taken into account, meaning that none of the additives are taken into account. Some of the additives are toxic, for instance biocides (in waterborne paints) and driers (in chemically drying paints) (section 12.5).
- Every paint is applied at an equal dry paint film thickness. This is disputable, and is further described in the discussion.
- The frequency of repainting is based on the technical lifetime of the paint. This is not the case, especially for indoor painting.
- Waterborne acrylics are assumed to be totally stripped with methylene chloride. Other less polluting removers are available and in use currently, making this assumption no longer legitimate.

The paints that were compared were a traditional alkyd paint, a waterborne acrylic paint, a waterborne alkyd emulsion paint, an alkyd high solids paint and a paint made from renewable materials. LCA studies 1, 2 and 5, completed with 4 and 7, are used for comparison. Using the above mentioned assumptions, the following conclusions are drawn in this LCA-studies (not necessarily valid):

- The contribution of the pigment to the environmental profiles is relatively large. TiO_2 is made from the raw material ilmenite, which is a non-renewable resource. During the production of TiO_2 a lot of waste is produced. Furthermore, SO_x-emissions during production contribute to ‘acidification’ and CO_2-emissions from energy used for production contribute to “global warming”. However, since the amount of TiO_2 is of the same order of magnitude in the different types of paints, all paints contribute equally to the mentioned environmental effects.
- Not all paints contain TiO_2. In the case of transparent coatings (varnishes) the contribution to depletion of non-renewable resources depends on the amount of ingredients made out of mineral oil (resins and solvents). Therefore, waterborne alkyd varnishes and waterborne natural varnishes are preferred in this respect.
- The contributions to the environmental effects caused by the paint remover are also relatively large. The most significant contribution is to the environmental effect ‘ozone depletion’. Due to the fact that acrylics are always assumed to be removed by methylene chloride and only in 20% of the cases for other paints, acrylics contribute more to this effect.
- Unfortunately, the contribution of the solvents to the environmental effect ‘tropospheric ozone formation’ is not taken into account in the studies mentioned. Instead, the emission of hydrocarbons *as such* is taken as an environmental effect. The most important sources of emissions of hydrocarbons are evaporation of solvents during application and evaporation of methylene chloride during removal of old paint films. The contribution of methylene chloride is disputable since there are other removers available nowadays. Therefore, contribution to tropospheric ozone formation is directly related to the solvent content per Functional Unit. High solids and acrylics are preferred in this respect.
- For the production of acrylics a relatively large amount of energy is needed. This is caused by the high process temperatures needed during production. This effect is magnified by the fact that more acrylic paint is needed per Functional Unit. All together, acrylics are disfavoured in this respect.
- Contributions to solid waste come from paint residues and cans. Since more acrylic paint is needed per Functional Unit, more cans are used and as a consequence more waste is produced.
- Other significant effects are: fertilizers contribute to ‘eutrophication’, therefore all paints containing vegetable oil or vegetable oil derived binders (alkyds) contribute to this effect. Solvents

contribute to ‘human toxicity’. CO_2- emissions from energy production contribute to the ‘global warming’.

Discussion

The influence of some assumptions made in the LCA-studies used is significant. The Functional Unit is disputable especially, and the effect of the assumption that the thickness of the dry paint film is equal for all paints is significant. First, the Functional Unit is discussed. Next the consequences are presented of the assumption that the thickness of the dry paint film is equal for all paints. The discussion ends with a summary of major contributions to environmental effects caused by paints, without comparing one type to another.

Functional Unit

To be able to compare the environmental profiles of paints, a Functional Unit must be defined. There are two important parameters: coverage and durability. The coverage determines the amount of square meters painted surface at the optimal thickness of the dry paint film and the durability determines the period that this paint film will last. The durability depends on the technical lifespan of the paint.

The most appropriate Functional Unit would be “the amount of paint necessary to paint a certain area in the technically demanded dry paint film thickness over a certain period of time”. However, the time factor is disputable. This is due to the fact that people redecorate indoors for aesthetic reasons (for instance caused by change in fashion) instead of technical reasons. Paint does have a technical lifespan, but no ‘aesthetic lifespan’. In some LCA-studies a time factor is used in the functional unit. This is based on a professional maintenance scheme. However, for consumers this scheme is not relevant.

Another point of discussion is the technically required thickness of the dry paint film. In most LCA-studies it is assumed that this thickness is equal for all types of paints. However, experts are not in agreement on this. The amount of paint used per Functional Unit strongly depends on this film thickness. One can imagine that doubling the thickness, would also double the amount of paint needed per Functional Unit. In the Ecobilan study, by defining the coverage instead of the paint film thickness this problem is solved. The impact of the assumed thickness of the dry paint film is discussed below.
It does not seem to be useful to use either of the proposed Functional Units due to the fact that the frequency of indoor repainting is not known and experts do not agree on the technically demanded dry paint film thickness. Without a proper functional unit it is impossible to compare the environmental profiles of different paint types.

Influence of technically required thickness of the dry paint film

The assumption that the thickness of the dry paint film is equal for every paint type, results in the fact that more waterborne acrylic and less high solids solventborne paint is needed per Functional Unit compared to traditional alkyd paint. This is due to the fact that waterborne acrylic paint has a lower binder content while high solids paint has a higher binder content than traditional alkyd paint. As a consequence, the benefit of the lower TiO_2-content of acrylics is lost by the higher amount needed per functional unit.

Some experts, however, hold the opinion that the optimal thickness of the dry paint film for waterborne acrylics is 40μm, for traditional alkyd is 60μm and for high solids is 75μm. In this case, less acrylic paint is needed per Functional Unit compared to traditional alkyds. Since acrylics contain less pigment, there is a preference for acrylics in this case.

The same effect is shown with respect to energy use. Since more energy is needed for the production of waterborne acrylic paint and the amount needed to paint a certain area is larger, the effect of the more energy demanding production is multiplied. However, when less paint is needed, the effect of the more energy demanding production is counterbalanced. The same holds true for waste production.

Major environmental effects and discussion

As a consequence of difficulties in finding proper data to establish the Functional Unit for specific paint products, the mutual comparison of different paint products is disputable. However, the environmental profiles can be used to identify the major contributions to environmental effects, which are important for possible product improvement.

The LCA studies show three major sources of environmental effects: production of TiO_2, emission of solvents during application of the paint and emission of methylene chloride (stripper).
Since 1992 a European Directive concerning TiO_2-production is effective (Directive 92/112/EEG). Basically, this directive restricts the acidic waste volume and the emissions during production. Nevertheless, the TiO_2-production process is one of the major sources of environmental pollution. Therefore there is a preference for the paint type that uses the least TiO_2 per functional unit. For optimal hiding power, a minimal TiO_2-content is necessary. However, since TiO_2 is expensive, manufacturers currently reduce the TiO_2-content in their formulations as far as possible.

With respect to solvents, differences do exist among the different paint types. The paint type with the lowest solvent content per Functional Unit is preferred. Although paints cannot be compared due to problems concerning the proper Functional Unit, it seems a natural conclusion that traditional solvent borne paints are not preferred in this respect. For instance, even if the amount of waterborne paint per Functional Unit is three times the amount of traditional solvent borne paint (which is an extreme worst case situation), the emission of solvent is lower in case of waterborne paints.
Since paint removers other than methylene chloride are available and are in use nowadays, the relevance of this source is limited.

Evaluation

It is complicated to produce a well-balanced environmental comparison of types of paint. This is due to the fact that representative compositions never cover the whole range of used products. Furthermore, any Functional Unit is disputable. A time factor is disputable because of the fact that people redecorate indoors for aesthetic reasons instead of technical reasons. Also, the thickness of the dry paint film is of significant influence on the environmental impact. Experts argue technically, over the thickness required.

Although one would expect to prove the better environmental performance of waterborne paints with LCA, it has to be concluded that the current LCA-studies do not concur with this expectation. However, it can be concluded from the studies that the major contributions to the environmental profiles of paints come from TiO_2-production and emissions of solvents during application.

Main conclusions

- It is complicated to produce a well-balanced environmental comparison of types of paints. Experts dispute various aspects of the ‘Functional Units’ that have been used.
- Consequently, current LCA-studies do not result in any preference for a specific type of paint.
- However, it can be concluded from the studies that the major contributions to the environmental profiles of paints come from TiO_2-production (all paints) and emissions of solvents during application (conventional solvent-borne paints).

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12.4 Occupational exposure to volatile organic solvents

12.4.1 Introduction

Additional to the environmental effects, the occupational health effects of exposure to VOC are of growing concern and give rise to initiatives for further reduction of the use of products with a high VOC content. Most important in this respect is their effect on the central nervous system: the *Organic Psycho Syndrome – OPS*.

Organic solvents may have many different adverse health effects: contact with the skin may dissolve the protecting fatty layer of the skin, causing dermatitis or eczema, forming of blisters or other skin diseases. The mediate polar solvents like glycol ethers used in water-borne paints as co-solvents, have the ability to penetrate the intact skin up to a significant amount, not only after direct contact (solvent-skin) but also after skin exposure to airborne solvents. The smaller aromatic hydrocarbons like benzene, toluene and xylene also penetrate the skin.

Depending on their specific nature organic solvents exhibit systemic effects on different organs like the hart, kidney, liver, bone marrow, blood, stomach, reproductive system, nose, even the ears (hearing loss), eyes, the nervous system: peripheral and central etc[1].

Benzene is carcinogenic and causes leukaemia. Methanol affects the optic nerve and may cause blindness. Swallowing ethylene glycol may cause severe renal necrosis. Hexane causes neuropathy. Exposure to toluene combined with exposure to high noise levels may show ototoxic effects: hearing loss. Aromatic hydrocarbons like toluene and xylene have toxic effects on reproduction.

As a rule of the thumb it can be assumed that most types of organic solvents have a neurotoxic potential: aromatic hydrocarbons, n-, iso- and cyclo-aliphatic hydrocarbons, oxygenated hydrocarbons as well as chlorinated hydrocarbons. A ranking made by the Danish Arbejdstilsynet[2] ranks commonly used solvents like heptane, octane, nonane, mineral spirits, toluene and xylene as solvents with (significant) risk for serious harm on the nervous system during normal work. Many glycol ethers are ranked with a lower neurotoxic potential, but some of them like ethyl glycol and methyl glycol (as well as their acetates) show reproductive toxicity.

The term *OPS*, abbreviated as *Organic Psycho Syndrome*, is used to describe the complex pattern of health effects on the *Central Nervous System*, caused by the exposure to volatile organic solvents at the workplace. The word *”Organic”* shows the connection that the divergent behaviour is caused by the damage of the tissue or a disturbance of processes in the brain, *“Syndrome”* means that it is a combination of different health effects. In other words: brain damage caused by organic solvents.
Medical/toxicological literature use the equivalent name: *“chronic toxic encephalopathy”* (CTE) for the same disease to describe the same set of health complaints. It uses the term *chronic* because we are dealing with long term effects, *toxic* because we are dealing with the exposure to toxic substances (organic solvents) and *encephalopathy* because it is a brain disease.

In Scandinavian countries in the 70’s and 80’s, and more recently in the Netherlands, the discussion on the effects of volatile organic solvents on central nervous system, has led to serious governmental efforts to reduce the exposure of VOC’s to all professionals at risk. Starting the year 2000, in the Netherlands the professional indoor use of paints will be restricted to wall paints with a VOC content lower then 75 gr/l and trim paints with a VOC content lower then 125 gr/l. This regulation for a general compulsory replacement is included in the Working Conditions Decree article 4.62b.
Under the Finnish presidency (second half 1999) the EU took the initiative to make a start with this discussion on a European level. The first European milestone was set in December 1999 in the Netherlands at a conference that discussed the reality of OPS as an occupational disease due to the exposure to volatile organic solvents.

12.4.2 Paint solvents

The most commonly used solvents in high-VOC alkyd paints and high solids alkyds are white spirits. White spirits are distillates from mineral oil and can be characterised as a mixture of more than 200 organic compounds. The composition varies and depends on the source of the mineral oil and the boiling point fraction of the distillate.

Low boiling fractions have a higher vapour pressure and generally a higher evaporation rate. Higher boiling fractions have a lower vapour pressure and a slower evaporation rate.

Traditional white spirits generally have a lower aromatic hydrocarbon content ranging from 15-20%. Analysis of a white spirit by the industry and of a high aromatic white spirit by CR&M Technical Centre (Harwich)[3] show the following distribution of the organic compound groups (totally 220 compounds):

Table 12.4.1 Examples of a composition of white spirit

Class	*Weight percentage* **Industry analysis**	*Weight percentage* **CR&M Technical Centre Analysis**
Aromatics	20,44	25,55
Naphthenes	21,47	20,07
n-Paraffins	22,15	20,70
Isoparaffins	35,34	33,03
Unsaturated	0,01	0,01
Unidentified	0,47	0,44

Although a large percentage of the white spirits used still have a high percentage of aromatics there is a tendency to prefer dearomatised hydrogenated products as paint solvents. In this chemical process aromatic hydrocarbons are hydrogenated to form naphtenic compounds (non-aromatic aliphatic rings). In France white spirits with an aromatic hydrocarbon content of < 5% have been used for some time.

Recently isoparaffinic solvents were introduced in the market as "*low-toxic*", odourless paint solvents and are presented by the chemical industry as suitable alternatives for white spirits. Isoparaffinic hydrocarbons are synthetic products, synthesised by polymerising ethylene, propylene and butylene, followed by hydrogenating and finally distillation of a boiling point fraction.

An important argument for the chemical industry to introduce these (volatile) products is the fact that isoparaffinic hydrocarbons are odourless and are presumed to have a low toxicity. In a reference made to the German Technical Guidance for Hazardous Substances (TRGS 404)[4], a paint manufacturer compares isoparaffins with de-aromatised hydrocarbon mixtures with a limit value of 350 ppm. As will be shown, the chemical industry is active in advising to use of their guidance values for a safe use of those compounds that lack a thoroughly established occupational exposure limit. They advise guidance values of 300 ppm for isoparaffinic compounds.

Nevertheless, in the next paragraphs it is argued that there is a strong need for objective OELs established by an independent scientific expert commission (abbreviated as SCOEL). As a consequence general acceptance of the use of these guidance values as safe exposure limits is not advised.

12.4.3 Occupational Exposure Limits

To protect the health of workers many European countries have developed a system in which Occupational Exposure Limits -OELs- play a central role. The OEL is defined as:

"*The maximum permissible concentration of a chemical compound as gas, vapour, particulate matter present in the air within a working area which, according to the current knowledge, generally does not impair the health of the employee nor causes undue annoyance, under the conditions that exposure can be repeated and in long-term duration over a daily period of 8 hours constituting an average work week of 40 hours. As a rule the OEL is integrated as an average concentration over periods of up to* *one workday or one shift…Scientifically based criteria for health protection rather than their technical or economic feasibility are applied".*

The operational definitions for the OELs as applied in EU Member States may differ[5]. The Dutch authorities for example added to the protection of workers' health also: "protection of workers' offspring." This may be done implicitly in other countries. Nevertheless, in general terms the definitions are quite comparable.

In short the European procedure for setting OELs is as follows[6,7]:

- The first step is the establishment of a health based recommended OEL (HBR-OEL), established by an independent scientific expert group: toxicologists, epidemiologists, chemists, occupational hygienists etc. This Scientific Committee for Occupational Exposure Limits to Chemical Agents (SCOEL) prepares a scientific dossier for review, evaluates this dossier and develops a recommendation to the Commission services for a scientifically based OEL.
- The next stage is the development of a proposal for an OEL by the Commission services.
- Subsequently, the Advisory Committee for safety, Hygiene and Health Protection at Work is consulted. In this step the practical feasibility is examined.
- Finally the Commission services will finalise their preparation of a proposal to be agreed by the Commission and finally followed by a publication in the Official Journal of the OEL. This is presented as an indicative limit value (ILV) for implementation by member states in their national legislation, establishing a MAC (NL), a MAK (DE) etc.

National standard setting procedures are comparable to the described procedure for the EC.

The emphasis on the independence of scientific expert groups is serious. Reason for this is the fact that in the 80's in the US it was shown that many TLVs, established by the ACGIH, were influenced by the interests of the industry[8,9]. For many TLVs it could be demonstrated that they had been set too high (apparently to benefit companies interests). In Europe this led to a discussion that emphasised the importance of the independence of the scientific expert group and the openness of the standard setting procedure[10].

In total around 700 – 800 OELs for different inorganic and organic chemical compounds have been established in European member states and the US. National procedures for OEL establishment are increasingly harmonised and progress is being made in the mentioned countries to divide the enormous task for the development of new OELs.
In general new scientific evidence about the toxicological properties of compounds leads to a reduction of current OELs.

For many single component organic solvents OELs have been established. Nevertheless OELs are available for only a minority of the total number of components used in paint solvents. Solvent mixtures are commonly used and pose a specific problem in standard setting.

12.4.4 Reciprocal Calculation Procedure

In high-VOC alkyd and high solids alkyd paints the most commonly used solvents are hydrocarbon mixtures. Only for a very limited number of mixtures has an OEL been established due to the limited available toxicological data, especially for mixtures.
Wood turpentine and white spirit (Stoddard solvent – an aromatised hydrocarbon mixture) are exceptions in this respect. The Stoddard solvent OEL has been adopted from the TLV from the ACGIH (American Conference of Governmental Industrial Hygienists)

An overview of OELs for some white spirits in some EU-member states is presented in the next table.

Table 12.4.2 OELs for white spirit like hydrocarbon mixtures

Country	***OEL-TWA***	
	mg/m^3	ppm
Belgium	525	100
Denmark	145	25
France	150	
Germany	560	100
Netherlands	575	100*
Norway <22% aromatics	275	50
>22% aromatics	120	25
Sweden	300	50
UK	575	100
Short term, 15 min	720	125

** This value is in discussion and might have to be reduced to 30 or 25 ppm.*

Mixtures might have an OEL, but controlling the actual exposure level necessitates environmental or personal air sampling. Analysis of these samples (of for example emissions of white spirit based paints) will introduce the problem of ending up with many single components in different concentrations.

An overview of different hydrocarbon mixtures is presented in the next table

Table 12.4.3 Overview of different hydrocarbon mixtures

Solvent description	**Boiling range °C**	**Carbon number range**
Pentanes	24-50	C5
Technical hexane	65-70	C6
Isohexanes	55-65	C6
Aliphatic solvents 60-95, low n-hexanes	60-100	C6-C7
Dearomatised heptane fraction	94-100	C7
Aliphatic dearomatised solvents 80-100	75-115	C6-C8
Aliphatic dearomatised solvents 100-140	95-140	C7-C9
Aliphatic dearomatised solvents 135-165	130-170	C8-C10
Mineral spirits 150-200	140-200	C9-C11
Dearomatised mineral spirits 150-200	145-200	C9-C11
Mineral spirits 175-220	175-220	C10-C13
Dearomatised mineral spirits 175-220	180-220	C10-C13
Aliphatic solvents 200-250	190-250	C11-C14
Aliphatic dearomatised solvents 200-250	190-250	C11-C14
Aromatic solvents 160-185	155-185	C9
Aromatic solvents 180-215	180-215	C9-C10
Isoparaffinic solvents 150-190	150-195	C10-C11
Isoparaffinic solvents 180-220	175-220	C11-C13

For the problems of calculating an OEL for a hydrocarbon mixtures without an established OEL, the reciprocal calculation procedure[11] has be proposed by the chemical industry:

$$\frac{1}{OEL_{mixture}} = \frac{c_1}{OEL_1} + \frac{c_2}{OEL_2} + \ldots\ldots\ldots\ldots + \frac{c_n}{OEL_n}$$

This procedure may be used for those compounds sharing the same structural and toxicological profile. A generally accepted assumption amongst toxicologists is that most hydrocarbons have

neurotoxic properties. The critical acute effects on the central nervous system (CNS) can be used to set OELs to protect against the effects of the mixture. Nevertheless, one of the problems with compounds forming the white spirit mixture is that an OEL has been established for only a minority of the pure compounds by the official, thorough independent scientific procedure.
Therefore recently, the chemical industry (ESIG) proposed as general guideline to use the following *”guidance values”* for use in the reciprocal calculation procedure (RCP).

Table 12.4.4 The chemical industry proposed substance grouping & guidance values for use in RCP calculations[12]

C5-C8	Aliphatics/cycloaliphatics	1500 mg/m^3
C9-C15	Aliphatics/cycloaliphatics	1200 mg/m^3
C7-C8	Aromatics	200 mg/m^3
C9	Aromatics	100 mg/m^3
C10-C15	Aromatics	200 mg/m^3
Others	n-hexane	176 mg/m^3
	Naphthalene	52 mg/m^3

Some remarks must be made in this respect:
In a recent draft document of the Health Council of the Netherlands (the scientific expert group that advises the minister on the OELs) advice was given to lower the current Dutch OEL for n-nonane (aliphatic C9) from 1400 mg/m^3 considerably to an OEL of 100mg/m^3 (20ppm). This reduction is based on the neurotoxic properties of n-nonane[13]. At the same time however, advice on an adaptation of the OEL for octane could not be given due to lack of scientific evidence. For toluene (aromatic C7) in many member states the OEL recently has been lowered to 40ppm (150mg/m^3). In the Netherlands cyclohexane (cycloaliphatic C6) has an OEL of 875mg/m^3 (= 250ppm). As far back as the 80’s, it was suggested that the acute toxicity of aliphatic hydrocarbons increases with the number of C-atoms[14].

Therefore many of the “guidance values” suggested by ESIG seem rather high.

12.4.5 Peak exposure

In general the OEL is expressed as a time weighted average (TWA), a mean over the 8-hour working day. In practice the daily exposure for many workers fluctuates strongly, making it very likely that the exposure will not exceed the OEL as a TWA. Nevertheless, in general in many working situations regular incidences of high peak exposures (>OEL) occur. This means that although the OEL-TWA during the working day is not exceeded, there might be incidents of high peak exposure during the daytime. There are well-known working situations in which short-term peak exposures to volatile organic solvents occur with peaks up to 10 times the current OEL. It is generally thought that these high peak exposures, may be one of the important triggers of the OPS[15].
In the mentioned recent study, carried out by the Health Council of the Netherlands, the following conclusion is drawn.

“The committee concluded there probably is a relationship between peak exposures to organic solvents and the development of CTE, however a biological mechanism explaining this relationship is not available. This assumption, however plausible, can neither be denied nor accepted on the basis of the available information. In case peak exposures clearly cause CTE, it is still not clear whether the total dose or the maximum concentration determines the development of CTE. Further complicating factors in the available data are the complex composition of many solvents and differences in susceptibility of individuals to exposure to organic solvents. Notwithstanding this, the committee is of the opinion that peak exposures would provide an important additional source of exposure to organic solvents to organic solvents and its reduction may contribute to the reduction of the risk for CTE”.

12.4.6 Standards for short-term exposure

For a limited number of compounds a short-term exposure limit is developed (OEL-15 min) as a guide to restrict the short-time high exposure. Many specific volatile organic compounds (solvents) lack a scientifically established short term exposure limit in national (and European) legislation. Therefore the Health Council of the Netherlands in their advice to the Dutch minister recommended the following generic guideline for organic solvents for short-term peak exposures:

- a peak exposure should be defined as the mean exposure over a period of 15 minutes
- a peak exposure above two times the OEL should not occur
- within a peak exposure the maximum concentration should not exceed a value of ten times the OEL
- during a working day the number of peak exposures should be limited to only four and the interval between two peak exposures should at least be one hour.

12.4.7 OAR - Occupational Air Requirement

One of the tools that can be used to inform the user about the health risk of paint by labelling the paints can is the OAR, the occupational air requirement. The OAR was designed in Norway for solvent-borne products[16]. It is partially equivalent to the Danish MAL-code.
The OAR, as well as the MAL-code expresses the amount of ventilation needed indoors to reduce the solvents concentration to an acceptable level. Using a relatively simple calculation method a code is allocated to a specific paint product.

The OAR and the MAL combine the evaporation rate of volatile chemicals with the OEL and the weight percentage of the VOC in the product. Since it combines the toxicity (OEL) with the volatility it supports the user in making a choice for the paint with the lowest risk: a high OAR-value (or MAL-code) of 4 or 5 means that you are dealing with a hazardous paint, while a low OAR-value of 00, 0, or 1 indicates low toxic paints.
The OAR is expressed as follows:

$$OAR = \boldsymbol{d} \times \sum \frac{\mathrm{P_i} \times \mathrm{k} \times 10^4}{\mathrm{OEL_i}}$$

The unit of the OAR is m^3 air / litre product

Where $\boldsymbol{d}$ = density of the paint (kg/l)
P_i= weight percentage of the component i
k = coefficient determined on the basis of the relative evaporation rate versus n-butylacetate (at 20°C). k can be calculated using a conversion table.
OEL_i= Occupational Exposure Limit of component i

A traditional alkyd paint containing 25% alkyds, 50% hydrocarbon solvents and 25% pigments and fillers can be calculated to have an OAR-code of 2. A water-borne acrylic paint containing 30% acrylic polymer, 40% water, 10% butyl glycol and 20% pigment and fillers is calculated to have an OAR-code of 1.

This coding system is strongly promoted by CEFIC (ESIG) and the paint manufacturers associations in the discussion on the prevention of OPS-risks as an alternative for the generic measure of maximum levels for VOC in indoor paints.

In favour of this labelling approach is the Danish experience with the MAL-code as indicated in chapter 6.3. The use of this system for nearly thirty years has led to an almost exclusively use of water-borne paints indoors in Denmark.

An environmental argument against the use of this coding system is the fact that this labelling system does not prevent the use of solvent born paints. Besides the volatility the OEL is an important parameter in establishing the OAR and MAL. A high OEL means a low OAR, which might stimulate the use of volatile compounds with lower (human) toxic effects. Nevertheless these products are still VOCs (like for example the high solid paints). Therefore this OAR system is not an alternative for environmental legislation but can be seen as an option for complementary occupational health measures.

12.4.8 Air Change Index

A further elaboration of the OAR, resulting in the *Air Change Index (ACI)* is promoted by the HSPA (Hydrocarbon Solvents Producers Association)[17]. The ACI uses the approach of the OAR but extends it with the introduction of the volume of the room to be painted. The ACI is expressed as follows:

$$ACI\,(\text{per litre paint}) = \frac{\text{solvent content }(mg/l) \times \text{f (volatility factor)}}{\text{solvent OEL }(mg/m^3) \times \text{room volume }(m^3)}$$

This model assesses the potential for vapours released from solvent-based paints to exceed the OEL when painting indoor surfaces. The ACI predicts the number of times the air needs to be changed (ventilated) to ensure that the solvent vapour concentration remains below the OEL of the solvent when applying one litre of paint under standard conditions. If the ACI is less than one, the volume of air in the room is sufficient to dilute the vapours to a safe level. Otherwise additional ventilation is required.

The model assumes instant evaporation of all solvents in the working room and in this respect it can be seen as a worst case approach. However, on the other hand it assumes an optimal mixing of the evaporated solvent in the air in the working room (a homogeneous concentration). Practice shows that the (peak) exposure near the source (the place where the painter works) is higher than the assumed optimal distribution. This suggests the risk of underestimation. Therefore it is good practice to always ensure adequate ventilation when painting indoors even when using paints with very low air change indices.

12.4.9 OPS

It is extremely difficult to distinguish between patients suffering OPS and patients with comparable complaints (for example people suffering Alzheimer disease or a whiplash). Therefore in Nordic countries and recently in the Netherlands solvent teams were established for medical diagnosis and treatment. Solvent teams combine the expertise of occupational physicians, neurologists, neuropsychologists and occupational hygienists.

In 1985 the World Health Organisation standardised the clinical diagnostic criteria for determining solvent-related mental disorders[18]. In the case of acute intoxication one talks about incidental (accidental) short term high exposures of several times the OEL. Chronic intoxication may occur after an exposure of several years (mostly more than 5 years) without necessarily exceeding OEL-values.

The stages are summarised in the next table.

Table 12.4.5 Stages in OPS development

		Health complaints	Durance health effects	Reversibility
Acute intoxication		Reduced conscience, concentration disturbances, co-ordination problems, nausea (drunkenness, "high feeling", headache	effects last minutes / hours	Effects Reversible
Acute toxic encephalopathy		Confusion, coma, epileptic fits	effects last hours	Sometimes irreversible cognitive disturbances
Chronic intoxication				
Stage 1.	**Neurasthenic effects**	depression, irritability, fatigue, concentration disturbances	effects last days - weeks	Reversible effects
Stage 2.	**Mild chronic toxic encephalopathy**	fatigue, mood disorders , (irritability, depression), forgetfulness (loss of short term memory), concentration disorders , orientation disorders, visuospacial deficits	effects last months - years	Without further exposure improvement of complaints but cognitive disorders may be irreversible
Stage 3.	**Serious chronic toxic encephalopathy**	*More serious cognitive and emotional complaints, dementia, progressive reduction of intelligence and serious loss of memory*	effects last years	Irreversible complaints

12.4.10 Professions at risk

Professional painters are well known as an exposed group and initially OPS was called *the Danish painters disease*. Recently this nickname changed to the *Dutch painters disease*.
Inventories carried out in Scandinavian countries for *all* professions show a decrease in reported solvent-related central nervous system disorders after the implementation of solvent exposure reduction measurements in recent years. Differences in figures are strongly influenced by differences in the diagnostic criteria used. Harmonisation of these criteria is currently in progress.[19]

Table 12.4.6 Number of reported solvent-related cases in Scandinavia[20]

Country	**Period**	**Total number of cases**	**Cases/year**	**Cases/year/10^6 inhabitants**
Denmark	1979-1988 1991	3900 110	433 110	86,6 22
Finland	1964-1979 start 1980 start 1990	486	6,4 100 10-20	6,4 20 2-4
Norway	1980-1987	936	134	33,5
Sweden	1980-1987	364	52	6,5

Based on these data it is estimated by Kulig and Emmen for the Netherlands that the number of cases of toxic encephalopathy (OPS) is 30-330 workers per year or 2-22 workers per 10^6 inhabitant using a total figure of 15 million inhabitants.

A large study carried out by Stichting Arbouw[21] amongst painters in the Netherlands in 1995-1996 shows that 1,1% of the Dutch painters suffer neurasthenic complaints: (first OPS signs). This study expects yearly 49 new painter-patients.
A comparable study carried out by the Chemiewinkel of the University of Amsterdam in 1998 amongst workers in paint manufacturing show a prevalence of 5,3% of workers with neurasthenic complaints (total number of paint manufacturing workers in the Netherlands is 6500)[22]. An important

trigger for the development of this neurasthenic complaints, as was suggested in this study, are the cleaning activities of paint manufacturing equipment (vessels, etc.).

12.4.11 Occupational exposure of painters

Since 1975 many different research groups have carried out epidemiological studies[23] to find out a relation between health complaints and the occupational exposure to organic solvent. Professional painters are frequently subject of the research. Unfortunately only a very limited number of these studies are accompanied by exposure measurements. Those that are reported, quote that for indoor use of solvent-borne alkyd paint vary from about 25 ppm up to 210 ppm for painting large surfaces for white spirits as a TWA exposure using normal manual painting equipment (a brush or a roller).

The indoor use of water-borne paints results in a considerable reduction of the exposure of the painter to organic solvents (glycol ethers instead of white spirits). A Swedish study of Norbäck et al. demonstrates that the total VOC exposure of painters using water-borne paints is approximately 1% of that experienced during indoor painting with solvent-based paints[24]. This study also measured a maximum concentration of 4mg/m^3 of Texanol and low levels of Texanol-isobutrate (TXIB) in the indoor air after painting.

In 1995 the British Building Research Establishment (BRE) published a study that established the development of the airborne concentration following trim painting in a standardised room[25]. For comparison different paints were used: a paint based on a traditional white spirit, a paint based on a D40 and one on a D60 solvent (de-aromatised white spirits with flash points of 40^{o}C and 60^{o}C) and paints based on different isoparaffinic hydrocarbon products. All paints were formulated as traditional alkyd paints with a high solvent content, as well as in the form of high solid paints.

Monitoring data from a Miran infrared gas analyser using a continuous record of the vapour concentration in the room was presented. This showed the development of a maximum of 250 ppm for high solvent-borne alkyd paint in a non-ventilated room after one hour, followed by a slow removal. Low solvent-borne paints in poorly ventilated rooms showed a peak concentration in the middle of the room of 50-60 ppm. It was concluded that the use of low VOC paints based on solvents with a lower vapour pressure (D60 and isoparaffinics) was the most favourable showing airborne concentrations considerably below the OELs or the advised guidance values, especially if the room was subject to poor ventilation.

Nevertheless, as has been said, the study did not measure personal exposure but measured the airborne concentration in the middle of the room. As a consequence the personal exposure of the painter, breathing at a distance of around 30-50 cm. from the evaporating film, is expected to be higher (practice shows that this can be at least 10 times higher than the concentration in middle of the room[26]). Furthermore the figures presented for natural ventilation in the experimental situation seem rather optimistic. Finally the use of high guidance value of 300 ppm for the isoparaffinic hydrocarbons is disputable.

Recently TNO Nutrition and Food Research Institute started a study, supported by the Dutch ministry of Social Affairs, the Dutch Association of the Chemical Industry, the Association of Paint Manufacturers and the painters Association[27], to identify the exposure of painters to organic solvents during painting of a standardised room with different paint types. In this study the painters are measured with personal monitoring equipment, elucidating on their actual exposure. The goal of this study is to measure the exposure of painters using “traditional” alkyd paints and the reduction that is realised using low VOC content solvent-borne paints. Furthermore the utility of the OAR as a tool in hazard assessment will be examined.

As a general conclusion it can be stated that a strong reduction in exposure of the painter is realised using low VOC content solvent-borne paints for interior trim painting, but that nevertheless an efficient ventilation is needed for safe indoor painting with solvent-borne paints.

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[5] Different countries use different names for comparable defined OELs. For example: NL: MAC (Maximale Aanvaarde Concentratie); DE: MAK (Maximale Arbeitsplatz Konsentration); FR: VLE (Valeur Limite d’Exposition – 15 min) and VME (Valeur Moyen d’Exposition – 8hrs); UK: MEL (maximum exposure limit – ceiling), OES (Occupational exposure standard). The US uses the TLV – threshold limit value established by the ACGIH and the PEL-permissible exposure limit established by the OSHA (Occupational Safety and Health Administration).

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12.5 Health effects of waterborne paints

Waterborne paints are available in all kinds of compositions. Acrylics are the most widely used and well known waterborne paints, but also vinylacetate, alkyds, epoxies, polyurethanes or combinations of these binders are available as waterborne. The common feature is their water content and their low solvent content.

In many cases where waterborne paints are introduced as a substitute for solvent borne paints, it is questionable whether health problems are solved or just replaced by others. The expected increased potential for skin irritation/allergy as a consequence of exposure to waterborne paints is especially mentioned. In order to clarify these questions, possible health effects are further dealt with in this section.

Polyurethanes and epoxies are mainly industrial or heavy-duty paints, which are sometimes used by professional painters. It is not very likely that these paints are widely used by DIY consumers. Moreover, the ‘decorative’ nature of these products is debatable. Therefore the risks of these paints are described separately.

12.5.1 Binders

The most important health effects in relation to binders are skin irritation or sensitisation (allergy). These health effects may be caused by monomers, which are highly reactive. Monomers are (in contrast with polymers) volatile molecules. However, their evaporation is a relatively slow process. Exposure may occur by inhalation or skin contact. Monomers are present in binders in *very low* amounts, i.e. in the ‘parts per million’-range (Hansen, ’87). They differ in their potential to cause irritation or allergy. Monomers of some binders (alkyds, PU) may react with air components like oxygen or water, inhibiting their reactivity and thus their potential to cause irritation or allergy. Therefore, under normal conditions it is not very likely that high exposure to monomers leading to health effects will occur.

Ethylacrylate and acrylonitrile, both monomers that may be used in acrylics, need special attention since they are a suspected carcinogen and a carcinogen, respectively. Styrene, used in acrylic-styrene copolymer is mutagenic and may have adverse effects to the central nervous system. These compounds need special attention, because their possible health effects have in principle no threshold concentration (i.e. are stochastic). However, because of the stochastic mechanism of the effects, the actual risk *does* depend on the concentration. Because of the very low concentration of monomers in the binder, as a consequence the actual risk is very low.

Although the risk is not very significant, in order to avoid exposure totally, ventilation is advisable when applying waterbased paints. This is even more so in the light of the use of solvents (see below). Skin contact with paint should also be avoided.

12.5.2 Solvents

Waterborne paints may be solvent free, or contain a relatively low content of co-solvent or coalescing agent. Although these co-solvents are of low volatility, they do evaporate out of the drying paint film. Glycols or glycolethers are used in waterborne paints. Due to their relatively low evaporation rate, peak exposure is not very likely to occur. However, there is a risk of skin penetration by these less volatile glycol ethers, emphasising the need to avoid skin contact.

In particular, the relative volatile ethyleneglycolethers EGME (ethyleneglycolmonomethylether) and EGMEA (ethyleneglycolmonomethyletheracetate) are harmful. The two compounds are reprotoxic at low concentrations (Health Council of the Netherlands, ’96), and have adverse effects on the nervous system and kidneys. They may cause irritation of skin or eyes. As a result of their high toxicity, EGME and EGMEA are increasingly substituted and the use of less volatile and less toxic glycol ethers is becoming more common. In fact, the European suppliers of glycolethers have agreed to restrict the supply of the most toxic glycolethers (such as EGME and EGMEA) to some specific industrial applications. The compounds are not used anymore, at least in consumer products, and probably not in most trade products (OSPA, ’98).

While originally the above-mentioned glycolethers used to be substituted by di-ethylene glycolethers (such as ‘DEGME, DEGEE and DEGBE’), these in turn are being substituted as well, as a result of similar health risk, though occurring at much higher concentrations only. Therefore,
it is to be assumed that the use of ethylene glycol ethers as well as the use of di-ethylene glycol ethers has been minimised at least in Western Europe already (Sannes, ’97; Winkelaar, ’97). Substitutes that are used include propylene glycol, hexylene glycol and Texanol (Wahlberg, ’92).

Texanol (2,2,4-trimethyl-1,3-pentanediolmonoisobutyrate) is a very low volatile solvent. Exposure may cause irritation of eyes or skin. Health effects are not sufficiently known, however, making precaution necessary. Another widely used co-solvent is n-methyl pyrrolidone. N-methyl pyrrolidone is a low volatile solvent also, which may cause irritation of skin or eyes.

In summary, it can be stated that the OPS-risk is significantly reduced in case of using waterborne paints (see section 12.4). At the same time, potential health risks connected to co-solvents used in waterbased systems are low, as a result of their low volatility and because the most hazardous compounds have been substituted.

12.5.3 Additives

In general, waterborne paints contain a larger diversity of additives than solvent borne paints. This is caused by the difference in technology. Waterborne paints are dispersions or emulsions and consequently contain an emulsifier, while solventborne paints are solutions. The emulsifier may cause a foaming effect of the paint, which is prevented by adding an anti-foaming agent. Moreover, waterborne paints are susceptible to tainting and so they contain a biocide, while in solvent borne paints the solvents prevent tainting. Depending on the technical demands of the paint, other additives may be added, such as wetting agents, pigment dispersants, thickeners, anti-cratering agents, thixotropic agents, dryers, curing agents, anti-skinning agents, stabilisers and corrosion inhibitors.

There is a difference between wall paints and other (waterbased) paints in this respect. Since the technical demands put on wall paints are not as strict as the demands put on other paints, wall paints contain a relatively low amount of additives.

The diversity among additives is too great to describe the health effects of all possible additives. Therefore, some important and commonly used additives are discussed.

Emulsifiers

All waterborne paints contain an emulsifier (for instance alkylarylpolyethersulphonates or alkylpolyethylenegloycolethers). Surfactants in general are known for their potential to cause skin irritation. This is a consequence of their ability to influence surface tension. The irritating potential differs among the different surfactants. Surfactants are not very volatile, so skin contact is the major route of exposure.

Biocides

In addition to emulsifiers, biocides are practically always added to waterborne paints. Biocides can be divided into in-can preservatives and paint film protectors. The use of paint film protectors is most common in specifically designed mould-preventing wall paints, e.g. for bathrooms. In order to prevent tainting in the can small amounts (0.1% or even less) of biocides are used. In order to prevent fungi from growing on painted surfaces a higher percentage of biocide may be added. It has been noted that the amount of in-can preservatives used may vary considerably from manufacturer to manufacturer. At advanced manufacturing plants, with high hygiene standards at production, much lower amounts of in-can preservatives are needed than at plants with lower hygiene standards (CEPE, ’00). The difference may be a factor of five.

As a consequence of their function, biocides will always be harmful. In general, many biocides may cause skin-irritation or sensitisation.

The formerly much used organomercury compounds are now forbidden in most countries, because of their relative harmfulness (Bieleman, ’00). Nowadays, common biocide types for in-can preservation include:

- Formaldehyde or formaldehyde-releasing compounds;
- Isothiazolinone derivatives;
- Quaternary ammonium compounds;
- Acids (e.g. boric acid)
- Phenol-derivatives (e.g. p-chloro-m-cresol)
- Alcohols (e.g. Bronopol).

With the exception of formaldehyde, skin contact is the major exposure route with respect to biocides. Formaldehyde is a suspected carcinogen at high concentrations. Therefore, formaldehyde-releasing compounds such as n-methylolchloroacetamide or 2-{(hydroxymethyl)amino}-alcohol) have replaced formaldehyde, although this does not rule out the risk completely. However, regarding the low concentrations in the paint, the actual risk is not regarded as very high.

Both isothiazolinone derivatives and quaternary ammonium compounds may be sensitising to the skin. Phenol derivatives are long known for their harmful effects. Therefore, effort has been put into developing less harmful varieties of these compounds. For example, p-chloro-m-cresol is regarded as a relatively harmless phenol derivative (Bieleman, ’00). Among the isothiazolinone compounds, methylchloroisothiazolinone is regarded a suitable alternative. Very small amounts of methylchloroisothiazolinone (MCI) are sufficient to prevent paint from tainting. The compound is widely used together with methylisothiazolinone, a combination that is known under the trade name *Kathon*. The maximum MCI-content in waterbased paints is as low as 0.003% (Hansen, ’87). However, due to its widespread use in cosmetics, Kathon has been known as a main sensitiser for some years (Bohn et al., ’00). This is probably caused by the intensive skin contact that occurs in applications such as skin creams, shampoos etc. Therefore, the relevance for applications in waterbased paints is limited.

Driers – in particular Cobalt-compounds

Just like solvent borne alkyds, waterborne *alkyds* contain a drying agent to catalyse the curing process. In most cases cobalt- and zirconium-salts are used. Certain cobalt-compounds (in particular: cobalt sulphate) are suspected to be carcinogenic. However, no data on the cobalt-compounds used in paints are yet known. Most commonly used cobalt dryers include cobalt (2+) salts of branched fatty acids C_6-C_{19}. A particularly commonly used compound is cobalt-ethylhexanoate (C_8). At the moment, industry-funded research is being conducted on the potential carcinogenicity of this type of compounds (Wiskemann, ’00).

In addition to the suspicions of carcinogenicity, cobalt dryers are skin sensitisers, unlike most other metal dryers, which cause skin irritation only (Bieleman, ’00).

Assuming that there is a significant risk, this risk will occur for *all* types of alkyd paints: traditional solvent rich, high solids and waterbased alkyd emulsions. However, although the concentration of cobalt dryers that is needed in waterbased emulsions is slightly higher than those needed in solvent based products, in both types of products these concentrations are very low (< 0,1%). In section 12.5.6 the results of some measurements of cobalt-exposure are presented.

pH stabilisers

Ammonia or amines are used to stabilise the pH of waterborne acrylics. These are very volatile additives, which may cause irritation of the respiratory track and the eyes. Ammonia is used in very small amounts (ca. 0.1%). However, in absence of ventilation, an irritating concentration may be build up. It is not likely that irreversible damage can occur.

A summarising remark on additives may be made here. Regarding the above-described, it may be stated that although additives may cause health effects, they are used in such small amounts that it is not very likely that high exposure will occur.

12.5.4 Polyurethanes and epoxies

Polyurethane is composed of the ‘monomers’ polyisocyanates and polyols. Polyisocyanates are known for their toxicity. In particular, toluene diisocyanate (TDI) is harmful. TDI is relatively volatile and suspected to be carcinogen and reprotoxic. TDI is increasingly being replaced by less volatile polyisocyanates. All polyisocyanates may cause irritation or sensitisation in case of skin contact. In the case where an allergy to one polyisocyanate is developed, it is very likely that all polyisocyanates may stimulate this allergy. Inhalation of vapour of polyisocyanate, or dust containing polyisocyanate may cause irritation of the respiratory tract. Polyurethanes are available as one- and two-component systems. One-component systems make use of prepolymers of polyisocyanates and polyols. It is not very likely that harmful polyisocyanate monomers are present in these systems. In case of two-component PU, one component may be the polyisocyanate and the other the polyol. In that case, the risk of exposure to polyisocyanates is significant. However, due to their toxicity, also in case of two-component systems generally prepolymers of polyisocyanates and polyols are used instead of the pure substances.

The most important health effect of epoxy products is sensitisation. Epoxies are made of epichlorohydrin and bisphenol-A (or –F). The diglycidylether of bisphenol A and epichlorohydrin is responsible for this sensitising effect. The monomers as such may contribute. Epichlorohydrin is a volatile and carcinogenic compound. Bisphenol A is suspected to be a reprotoxic compound. Due to the harmful effects of these monomers, the use of prepolymers has become more common. These prepolymers are not carcinogenic, nor reprotoxic, but still contain a sensitising ability.

Epoxies are in general two-component systems: one component is the epoxy resin and the other is a curing agent. Curing agents initiate and sustain the curing process of epoxies. In most cases amines or polyaminoamides are used. Both may cause skin irritation/allergy in case of intensive skin contact, which easily occurs because the curing agent needs to be added to the resin just before use. Although amines may be volatile, the major route of exposure is skin contact, which obviously needs to be avoided. In order to reduce the hazards, a developments towards using adducts (‘pre-polymers’) of amines and epoxy resins are evident.

12.5.5 Evaluation of health *hazards*

Using waterborne paints instead of solvent borne paints significantly reduces the OPS-risk. However, waterborne paints are not free of health risks. The most important health effect seems to be skin irritation or sensitisation, which may be caused by monomers, co-solvents and additives. Depending on the technical demands, more or less additives are used. Generally, wall paints contain less additives than other paints. Monomers, co-solvents and additives are present in low amounts. Exposure to high levels is not very likely to occur. Even skin sensitisers are usually present in concentrations not capable of causing sensitisation in practice (Hansen,’87). Nevertheless, painters should be aware of the fact that they are working with chemical substances, making sufficient ventilation and prevention of skin contact necessary.

12.5.6 Practical experiences regarding health *risks*

Skin irritation is by some people expected to be an increasing problem for painters, since the use of waterborne paints is increasing. Potentially irritant components in waterbased paints would be responsible. However, skin irritation due to skin exposure to white spirit is a common effect connected to the use of solvent-based coatings, especially when white spirit is used as a skin cleaning agent.

In the Netherlands this increase has not occurred over the last years (Spee, ’00; Bruynzeel, ‘00). Starting from the 01-01-2000 professional painters in the Netherlands have been obliged to use waterborne paints indoors. This obligation will result in a significant increase in the use of waterborne paints. At the same time a study has started in relation to skin irritation problems. Painters are asked to complete a questionnaire concerning skin problems at their periodical visit to the company doctor. The time period is too short, however, to have any results yet. However, about twenty years ago in Denmark and Sweden, painters had already started to use waterborne paints much more frequently. Also in Sweden and Denmark no increase in painters suffering skin problems is noticed (Hansen, 2000).

Although waterborne paints contain a significantly larger amount of potentially irritant and sensitising additives than their solvent borne equivalents, no increase in skin diseases is observed. This holds true for many more countries than the above-mentioned, as the use of waterborne products has increased in most European countries over the last years (see section 4).

The level of exposure to potentially sensitising compounds is not sufficient to generate effects, as the concentrations used in paint products are very low. Another factor of influence may be the lack of a need to clean hands or arms with solvents after the paint job. When using solvent based paints many painters use white spirit to clean hands and arms. It's generally known that white spirit has a strong degreasing effect to the skin and causes irritation. Generally, waterbased paints can be easily washed-off with water alone.

One exception to the absence of skin problems is a description of some rare cases of *airborne* contact dermatitis that occurred among occupants of freshly painted rooms (Bohn et al., '00). The contact dermatitis could be related to the use of the isothiazolinone preservative *Kathon* in the waterbased wall paint that was used. The cause of this remarkable effect was found in the fact that the five persons involved – all women - were already sensitised to this preservative(Bohn, '00). As mentioned, *Kathon* is widely used in cosmetics, and is a well-known cause of sensitisation in this type of applications (Bohn, '00). Therefore, the relevance for the evaluation of this preservative in paints as such is limited, although one could argue that other preservatives may be preferred.

With respect to *respiratory* exposure to cobalt-compounds that are used as driers in solvent based and waterbased alkyd paints, some measurements have been performed in Sweden (Norbäck et al., 1995). It was found that the average 8-hour exposure to cobalt as a result of inhaling paint dust during sanding ranged from < 0.001 to 0.003 mg/m^3, while current exposure standards for various cobalt-compounds (some of them being carcinogenic) range from 0.02 to 0.1 mg/m^3 (e.g. SZW, '99). Thus, there seems to be a safety factor of at least 15 when it is assumed that cobalt-driers are carcinogenic as well. However, it might appear that cobalt-driers are not carcinogenic at all, which will further reduce the estimate risk.

In the same study, exposure to ammonia (pH stabiliser) and formaldehyde (preservative) during indoor painting of walls was found to be very low compared to the exposure standards (Norbäck, 1995). The same holds true for the exposure to the glycolethers that are used as cosolvents of coalescing agents. For three major di-ethyleneglycolethers and one ethylene glycolether, the measured average 8-hour concentrations were a factor 61 to 1622 below the current exposure standards (Norbäck, '95; SZW, '99).

Main conclusions

- Using waterborne paints provides clear improvements from an occupational health point of view, compared to the use of traditional white-spirit based paints, as was already concluded in 1987 (Hansen, '87).
- The risk of developing an Organic Psycho Syndrome is minimal when waterbased paints are used.
- Residual monomers and additives are usually present in sufficiently low concentrations to prevent health effects such as irritation or sensitisation.
- An exception may be one specific preservative, in the case of an already developed sensitisation.
- Further improvements to waterbased paints can be made by limiting the use of formaldehyde and ethyleneglycolethers (the latter have already been substituted in most cases), and by limiting the concentration of isothiazolinone compounds as preservatives (Hansen, '87).

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12.6 Specific health hazards connected to high solids alkyds

Although the proposed VOC-reduction scheme (Chapter 9) will probably result in a move towards the application of waterborne technology in many cases, solvent borne technology will not be phased out completely. In fact, the use of low-VOC content solvent borne coatings will remain possible for exterior trim in any case.

Looking backwards, it is assumed that the development of the Ecolabel and the German Blaue Engel have enhanced the development of decorative coatings with a VOC-content of less than 250 gr./litre. One common type of product fulfilling these requirements is the high solids alkyd. Indeed, the cost benefits associated with using these high solids alkyds has been recognised by a number of painting contractors. In Germany in particular, and to a lesser extent in the Netherlands, the possibility of applying a one-coat finish instead of the conventional two-coat finish is appreciated as an option that may significantly reduce labour-costs (see section 11).

Reactive diluents' use

In order to reduce viscosity of high solids alkyds, reactive diluents are used. Following application, reactive diluents react with the binder and are incorporated into the dry film. Therefore, policy makers do generally not regard them as being VOC. However, as some of them (pinene, limonene) are VOC on the basis of their vapour pressure (around 2 mbar or 200 Pa at 20°C), some of the reactive diluent may evaporate at application.

Practically all high solids alkyds currently on the market contain 10-20% reactive diluents (Hofland, '00). Compounds used as reactive diluents should react with the binder, but not too quickly, as this would reduce storage stability. Therefore, monomer acrylates are not used (Hofland, '00). Widely used reactive diluents in high solids alkyds include:

- Trimethylolpropane trimethacrylate
- Esters of Fumaric acid
- Esters of Crotonic acid
- Esters of Cinnamic acid
- 'Natural' unsaturated compounds such as pinene, limonene and linseed oil
- Esters of heavily unsaturated fatty acids such as linseed oil.

Health hazards of reactive diluents

Generally speaking, the main health hazards connected to reactive diluents are *irritation* of skin, eyes and the respiratory tract (ref.: various Material Safety Data Sheets). As a result of their reactivity, irritation due to reactive diluents can be severe. Substances such as trimethylolpropane trimethacrylate, pinene and limonene have to be labelled with the symbol X_i (irritant) for this reason. At least limonene is a known sensitisiser (i.e. causes allergies).

A number of the above-described substances have been characterised in rather general terms only. Therefore, no specific data can be found on these compounds. However, based on their reactive nature one might assume that most of the compounds used cause irritation. One exception might be linseed oil. This 'drying oil' has been used for centuries in the past, and has not been known to cause specific health effects. The same may hold true for other drying oils.

Health risks of reactive diluents in practice

When confined to conventional decorative uses (i.e. application by roller or brush), the irritative nature of reactive diluents will in most cases result in an increased risk of skin diseases only. Painters should then be advised to take care in protecting their skin. This would mean that skin contamination should be prevented by working carefully and hygienically and/or that protective clothing should be used.

In case of spray applications *and* in the case where more volatile reactive diluents are used (e.g. pinene or limonene), an increased risk of eye irritation and irritation of the respiratory tract may occur in addition to skin irritation. The diluents especially, that may cause sensitisation (limonene) should be handled with great care, or should rather be avoided.

In conclusion, an increased use of high solids products may induce skin problems among professional painters. This is in particular true because of the relatively high concentrations of reactive diluents used in high solids products (10-20%), as opposed to the low concentrations of potentially irritant additives in waterbased coatings. If strict limits for both water borne and solvent borne coatings are implemented, this might result in an increase in the use of reactive diluents in high solids. Care should be taken about which diluents are used in that case.

Main conclusions

- Practically all high solids alkyds currently on the market contain 10-20% of reactive diluents
- The main health hazard of reactive diluents is *irritation* of skin, eyes and the respiratory tract.
- An increased use of high solids product might induce skin problems among professional painters. Painters will have to work hygienically or protect their skin.

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Glossary

ACI	see Air Change Index
Air Change Index	Instrument to compare the occupational health risks of various types of paint. The ACI predicts the number of times the air needs to be changed (ventilated) to ensure that the solvent vapour concentration remains below the OEL* of the solvent when applying one litre of paint under standard conditions.
Alkylphenol ethoxylate	A surfactant* that is used as an emulsifier in waterbased paints. Due to its environmental risks more and more substituted.
AOT40 – AOT60	*Accumulation Over Threshold*-values: parameters which estimate adverse effects of tropospheric ozone* by combining the *duration* of an exceedence of the 'threshold values', and the *magnitude* of these exceedences. The unit of the AOT-values is ppb.days or ppb.hours. AOT40: effects on vegetation. AOT60: human health effects.
APEO	See Alkylphenol ethoxylate
APME	Association of Plastic Manufacturers in Europe
BCF	British Coatings Federation
Binder	Film forming medium that contains the pigment and other additives in the dry coating.
Biocide	An additive that inhibits the growth of micro-organisms (fungi, algae, bacteria) that may cause decay of paint in the can, or attack a paint film. Also: preservative.
Biogenic VOC	Volatile Organic Compounds that are emitted by natural organism, such as trees and plants.
Blaue Engel	German ecolabelling scheme.
Captive outlet	Retail outlet, owned by a (paint) manufacturer.
Carcinogenicity	The potential to cause cancer.
CEFIC	European Chemical Industry Council
CEPE	European Council of Paint, Printing Ink and Artists' Colours Industry
Coalescing agent	A solvent which temporarily reduces the Tg of latex particles to facilitate film formation.
CORINAIR	An inventory of emissions of air pollutants in Europe, initiated by the European Environment Agency Task Force
Cosolvent	In this instance, a solvent which modifies the properties of water
Covering power/Hiding power	The thickness of coating required to completely obliterate a substrate when using an opaque paint.
CTE	Chronic Toxic Encephalopathy – a complex pattern of health effects on the *Central Nervous System*, caused by the exposure to volatile organic solvents at the workplace (also called: *OPS*).
Curing	The process of condensation or polymerisation of a coating by heat or chemical means, resulting in the development of full properties.
De-aromatised white spirit	White spirit* without aromatic compounds.
Decorative coatings	Products that are applied to buildings, their trim and fittings, for decorative and protective purposes. They are applied in situ by professional or private users. While their main function is decorative in nature, they also have a protective role.
Diluent	A volatile liquid, which while not a solvent for a binder, may be used with a true solvent without causing precipitation.
Dispersion	A two phase system in which one (solid) phase is permanently distributed as small particles through the second (liquid) phase, e.g. latex.
DIY	Do It Yourself (in casu: the consumer-sector of the decorative paint market)
Drier	Substance which when added in small amounts to paints and varnishes based on drying oils* bring about appreciable reductions in drying times at ordinary temperatures.

Drying oil	A vegetable oil, having the property of hardening by oxidation to a tough film when exposed to air. E.g. linseed oil.
Dye	Colourant which is soluble in either water, solvents or oils.
Ecolabel	Environmental hallmark.
Eggshell	Gloss level between matt and semigloss. Typically 20-35 on a 60° meter.
EMEP	Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe.
Emulsion	A dispersion of one imiscible liquid in another, manifest in paint as droplets of polymer in a continuous medium.
Emulsifier	An additive that enhances the formation of an emulsion and/or stabilises the emulsion. Generally surfactants*.
Enamel	A hard glossy paint.
EPDLA	European Polymer Dispersion and Latex Association.
ERMA	European Resin Manufacturers’ Association.
ESIG	European Solvents Industry Group
Eutrophication	Distortion of ecosystems caused by an abundant addition of nutrients as a result of human activities.
Extender	An inorganic powder with a low refractive index which is used in paint formulations to improve anti-settling or other properties.
Fatty acid ester	Compound that is formed as a result of the reaction between fatty acids (from vegetable oils) and an alcohol.
Film preservation	Inhibiting the growth of micro-organisms (fungi, algea, bacteria) that may attack a cured paint film. Achieved by using a biocide*.
Finish	The final coat of a paint in a multi-coat system. Also the appearance of a coating, e.g. gloss finish or textured finish.
Matt (flat) coating	A paint finish with essentially no gloss.
Functional Unit	A standardised basis for comparison of the environmental impacts associated with a certain product throughout its life-cycle.
Grain raising	The condition of wood surfaces whose fibres from the wood structure have become unduly prominent due to wetting with water or materials containing water.
High solids paint	A paint that has a higher content of solids, and consequently a lower solvent content than conventional products. Usually, a boundary of 250 grams solvent per litre is used.
Hydrocarbon solvent	Solvent, generally a mixture of many components, originating from distillation fractions of mineral oil, and blends thereof. Components present solely consist of carbon and hydrogen atoms. Various types exist: aromatic~, aliphatic~, cyclo-aliphatic~, isoparaffinic~* etc.
IIASA	International Institute of Applied Systems Analysis
In-can preservation	Inhibiting the growth of micro-organisms (fungi, algea, bacteria) that may cause decay of paint in the can. Achieved by using a biocide*.
Isoparaffins	Solvent that solely consists of branched, aliphatic hydrocarbons.
Isoprene	One specific class of ‘natural’ VOC*, mainly originating from trees.
KWS2000	‘Koolwaterstoffen2000’ (Hydrocarbons2000). Dutch voluntary agreement between government and industry, involving a range of measures aimed at VOC-reduction.
Lacquer	A non-convertible coating, which dries only by solvent evaporation, and retains its solubility in its own solvent throughout its life.
Latex paint	A paint based on a dispersion of hard resin particles in a water phase.
Levelling	The ability of a coating to flow out so that signs of imperfections and brush marks are reduced.
Life Cycle Assessment (LCA)	A method of assessing the environmental impacts associated with a certain product throughout its life-cycle, i.e. from the extraction of its raw materials to its disposal.
MAL-code	Danish obligatory code-number labelling system, indicating the health hazards associated with paint products. See OAR*.
Mar resistance	The property of a paint film which enables it to remain unimpaired by light abrasion.

Morbidity	The frequency of occurrence of a certain health effect in a certain population, due to a certain exposure.
Mortality	The number of deaths occurring in a certain population due to a certain exposure.
National Emission Ceilings Directive	Proposed EU council directive, setting national limits to the emissions of four key air pollutants.
Natural VOC	Volatile Organic Compounds that are emitted by natural organism, such as trees and plants.
NEC-Directive	See National Emission Ceilings Directive
OAR/ Occupational Air Requirement	The OAR, as well as the MAL-code* expresses the amount of ventilation needed indoors to reduce the solvents concentration to an acceptable level. Using a relatively simple calculation method a code is allocated to a specific paint product.
OEL	Occupational Exposure Limit
Oil length	The ratio of oil to resin in a paint medium.
Open time	see Wet edge time
OPS	Organic Psycho Syndrome – a complex pattern of health effects on the *Central Nervous System*, caused by the exposure to volatile organic solvents at the workplace (also called: *CTE*)
Photochemical oxidants	Reaction products (mainly ozone) from the reaction of VOC and nitrogen oxides in the atmosphere, catalysed by direct sunlight. Ozone gives rise to adverse effects to human health and vegetation.
Pigment	Particles of organic or inorganic compounds which provide colour and hiding power, as well as other physical and electrochemical properties to a paint.
POCP-value	Photochemical Oxidant Creation Potential. A measure of the reactivity of a certain VOC in the presence of nitrogen oxides and sunlight in the atmosphere, i.e. the rate at which ozone is formed.
Pot life	The period following the mixing of the two components of a two-pack paint during which the paint remains usable.
Preservative	See 'Biocide'
Primer	The first coat of paint applied to a previously unpainted surface, over which further coats are subsequently applied.
R & D	Research & Development
RAINS model	Regional Air pollution Information and Simulation. A mathematical model describing transportation of air pollutants, cost-effectivity of abatement strategies etc.
Reactive diluent	A liquid that is added to a paint to reduce viscosity, and which takes part in the curing process to become an integral part of the cured paint film.
Renewable raw material	Raw material from natural sources that can be regenerated within a reasonable time-span, e.g. vegetable oils.
Sealer	Barrier coat. A coating applied to isolate a paint system from the surface to which it is applied in order to prevent interaction between them.
Sensitisation	The process leading to the generation of an allergic response.
Significant paint producer	All paint producers other than very small, only locally operating (family) businesses.
Solvent	A volatile liquid which is able to disperse or dissolve a binder, reduces viscosity of the paint and may provide penetration into porous substrates (e.g. wood). Has to evaporate after application.
Spreading rate	The surface area which may be covered by a litre of coating.
Stabilising solution	A solution of low molecular weight resins applied to friable or unstable surfaces in order to penetrate and bind up the unstable materials.
Summer smog	Alternative term used for photochemical oxidants*.
Surfactant	A substance that reduces surface tension of a liquid.
Thixotropic	A paint which while free-flowing under the brush or roller, sets to a gel within a short time. The trivial name is 'non-drip'.

Through dry	Dry throughout and able to resist pressure.
Touch dry	Dry to the finger. Not able to resist pressure.
Tropospheric ozone	Ozone, originating from photochemical reactions at the level in the atmosphere at which human activities take place. Also called: ground-level ozone. Also: Photochemical Oxidants*/ Summersmog*
Undercoat	A coating with good hiding and levelling power which is applied after the primer and before the finish coats.
UN/ECE	United Nations Economic Committee for Europe.
UNIEP	European Painting Contractors' Association
Varnish	A transparent coating essentially based on drying oils, resins and solvents.
VOC	Volatile Organic Compound
VVVF	Dutch association of paint manufacturers
Wet edge time	The time during which it is possible to over-paint a paint edge without the edge showing in the dried film.
White spirit	Hydrocarbon solvent*, consisting of a mixture of aromatic, aliphatic and clyclo-aliphatic compounds.

Annex 1 Mailing lists for the remaining questionnaires

For the mailing lists of the questionnaires for ministries of environment, associations of paint manufacturers and individual paint manufacturers, we refer to the Decopaint Interim Report.

Resin and Polymer Suppliers
Composed of all APME-member companies and additional companies identified.

Air Products Chemicals Division Europe – Utrecht (NL)
Air Products – Clayton (UK) - Mr. Neil T. Hunt
Aiscondel – Barcelona (E)
Akzo Nobel Resins B.V. – Bergen op Zoom (NL) – Joan Veltman
Appryl S.N.C. – Paris la Defence (F).
Ausimont S.p.A. – Bollate (I)
Bakelite AG – Iserlohn (D)
BASF AG – Ludwigshafen (D) – Dr. Peter Pföhler
Baxenden Chemicals Ltd. – Droitwich (UK).
Bayer AG – Leverkusen (D)
Borealis A/S – Lyngby (DK)
BP amoco – Sunbury-on-Thames (UK)
CIBA Specialty Chemicals Inc. – Basel (Ch)
CIRES S.A. – Lisboa (Pt)
Clariant UK Ltd. – Houndslow (UK).
Cray Valley Waterloo Works – Gwent (UK) - Mr. Ray Herbert
Cray Valley Kunstharze GmbH – Tönisvorst (D)
Crestchem Ltd – Bucks (UK)
Croda Resins Ltd. – Belvedere (UK)
Degussa-Hüls – Marl (D).
DIC UK Ltd – Feltham (UK).
DOW Europe S.A. – Horgen (Ch)
DSM Resins – Zwolle (NL) – Jan Vriens
Du Pont de Nemours International SA – Grand-Saconneux (Ch) – Mrs. Sandra Jonckheer
Dyneon GmbH – Burgkirchen (D)
E.V.C. International SA – Bruxelles (B)
Eastman Chemical B.V. – Den Haag (NL) - Joel Weismann.
Elenac S.A. – Strasbourg (F)
Elf Atochem – Serquigny (F) - Mrs. Chantal Roidot
EMS-Primid – Domat (Ch)
Enichem Spa – Donato Milanese (It)
Exxon Chemical Europe Inc. – Machelen (B)
Gabriel Technologie SA – Baudour (B)
Galstaff Resins S.P.A. – Mornago (It.)
General Electric Plastics B.V. – Bergen op Zoom (NL).
Goodyear Chemicals Europe – Les Ulis (F) – Mrs. Evelien Dufour.
Henkel Performance Chemicals – Leeds (UK).
Henkel KgaA – Coatings & Polymere – Düsseldorf (D) - Mr. Wolfgang Gress
ICI Chemicals & Polymers – Blackpool (UK)
ICI Autocolor – München (D) - Mr. Heinz Liebscher
Italpet Preforme Spa – Verbania Pallanza (It)
Johnson Polymer B.V. – Nijehaske (NL) - mw. Helen Ruiter.
Kaucuk a.s. – Kralupy nad Vltavou (Cz)
KoSa – Frankfurt am Main (D)
LVM N.V. – Tessenderlo (B)
M.A. Hanna Company – Assesse (B)
Montell Polyolefins b.v. – Hoofddorp (NL)

Mutiresine – Agrate Brianza (It) - Antonella Fabbri
Norsk Hydro ASA – Oslo (N)
Plascon International – Gateshead (UK).
Polimeri Europa – Milano (It)
Polymer Latex GmbH & Co. KG – Marl (D) - Mr. Ulrich Albers.
PP Polymer – Vallingby (Se) - Ann-Christin Paul
Repsol Quimica S.A. – Madrid (E)
Rohm & Haas – Sophia Antipolis (F) – Robert Krasnansky
Rovin V.O.F. – Amersfoort (NL)
SASA – Adana (Tr)
Scott Bader Company Ltd. – Wellingborough (UK) - Att. Mr. Antony Phillips
Shell Chemicals Ltd – London (UK)
SIR Industriale – Macherio (It)
Solvay SA – Brussels (B)
Styrochem Finland Oy – Porvoo (FIN)
Sud Chemie – Middlewich (UK).
Sunpor Kunststoff GmbH – Pölten (Au)
Targor GmbH – Mainz (D)
Tikkurila – Fantaa (FIN) - Minna Hilkos
TotalFina – Feluy (B)
Union Carbide Europe S.A. – Meyrin (Ch)
Vianova Resins GmbH & Co KG – Wiesbaden (D)
Vinavil – Villadossola (It) – Massimo Aramini.
Vinnolit Kunststoff GmbH – Ismaning – (D).
Wacker Polymer Systems GmbH – Burghausen (D) – Mr. Peter Heiling
Whitchem Ltd – Newcastle-under-Lyme (UK).
Zeneca Resins B.V. – Waalwijk (NL) - R. Arnoldus.

Solvent Manufacturers:
All members of the European Solvents Industry Group (ESIG; 30 major companies).

Professional Painting Contractors
Through UNIEP and national associations – 52 questionnaires.

Distributors
Alltek Vertriebsgesellschaft GmbH & Co KG – St. Pölten Spratzern (A)
Amicolor – Torino (It)
Art & Decor – Brussel (B)
B&Q Plc. – Eastleigh (UK)
Baumax AG – Klosterneuburg (A)
Brico Dépot – Saint-Michel-sur-Orge (F)
Brico Recup Center – Brussel (B)
Bundesverband Deutscher Heimwerker-, Bau- und Gartenfachmärkte – Bonn (D)
C.F.C. Centro Fiorentino Colore – Firenze (It)
Caron – Brussel (B)
Cassia Bricolage – Roma (It)
Castorama – Templemars (F)
Centro Colori Marco srl – Milano (It)
Colorcenter – Brussel (B)
Colorificio Candiani – Milano (It)
Deco-home – Leusden (NL)
Decorette – Gouda (NL)
Dubois Matériaux – Lesquin – (F).
Hagebau Handelsgesellschaft für Baustoffe – Soltau (D)

Homebase Ltd – Wallington (UK)
Hubo – Waddinxveen (NL)
Intergamma B.V. – Baarn (NL)
Karwei – Baarn (NL)
Kingfisher Plc – London (UK)
NOMI – Kielce (Pol)
NVVW – Voorburg (NL)
OBI Bau- und Heimwerkszentrum AG – Wels (A).
Praxis Doe-het-zelf Centrum B.V. – Diemen (NL)
Stadlbauer Baubedarfszentrum AG – Wels (A)
Tirolack Berghofer GmbH & Co KG – Schwaz – (A)
UNIBAL – Paris (F)
VW DHZ – Zoetermeer (NL)
Wickes Building Supplies Ltd. – Harrow (UK)
VVVH – Den Haag (NL).

Annex 2 – Basic consumption/production data of decorative paint from various sources (ktonne)

	IRL, '98 (consumption '96)	CEPE (production '97)*	**IIASA '98** (consumption '90)	Consultium '92 (consumption '90)	**Data national associations** '97	Paint File'98-00 (production '97)**
Austria	61.2	-	54.3	-	65	-
Belgium	78.7	33.2	56.7	62 (+ Lux)	35	-
Denmark	57.4	-	49.0	45	52.4	-
Finland	43.5	28.6	36.6	-	32.4	-
France	361.0	335.0	467.7	433	432	466
Germany	563.0	820.0	847.9	442	860	1338
Greece	56.2	-	22.6	65	90	-
Ireland	22.6	-	12.8	20	25.4	-
Italy	407.7	269.3	217.2	540	350	383
Luxembourg	-	-	2.7	-	-	-
Netherlands	150.7	98.7	136.5	230	179	238
Portugal	94.1	-	62.1	70	87	-
Spain	138.4	465.0	418.6	267	489	466
Sweden	67.3	66.8	95.7	-	65.5	109
UK	290.0	387.8	307.0	365	377	378
Subtotal EU-15	***2392***	***2551*** *('EU-10')*	***2787***	***2539*** *('EU-12')*	***3139.7***	*(**3378** – EU8)*
Czech Republic	51.4	-	47.4	-		-
Hungary	30.5	-	-	-		-
Poland	171.6	-	102.0	-		159
Subtotal 'EU-18'	*2645.3*	-	*2936.8 ('EU-17')*	-		
Slovenia	15.2	-	-	-		-
Slovakia	27.1	-	-	-		-
Bulgaria	-	-	-	-		-
Romania	-	-	-	-		-
Turkey	178.7	-	-	-		-
TOTALS	**2866.3**	**-**	**-**	**-**	**-**	**-**

* Covering the first 6 classes of the CEPE-scheme, i.e. 90% of the market, by estimation.

** 'Architectural paint'; probably more paint types included than in the other data.

Annex 2 - continued - Data on VOC emissions from decorative coatings

	IIASA (CORINAIR) estimates ’99 (for 1990)	Questionnaire Ministries ‘99	Estimate industry ‘99	CEPE-data ’97 + own calculations*	Consultium ’92 (data 1989)**
Austria	18.0	-	12	-	-
Belgium	19.6	~ 6.3 (’95)	16	4.6	12.6 (incl. Lux.)
Denmark	10.6	(33.8, all paints and glues)	8	-	4.2
Finland	8.6	-	1 (too low)	4.4	-
France	150.8	50 (’97)	95	67.7	92.4
Germany	141.5	±~50 (’95)	90	58.3	60.9
Greece	8.6	-	12	-	-
Ireland	4.9	4.5	4	-	2.5
Italy	67.8	-	71	32.3	39.9
Luxembourg	0.8	-	0.5	-	-
Netherlands	29.2	(65, all paints)	26	27.3	36.1
Portugal	22.5	(29.8, all paints)	18	-	8.4
Spain	45.5	-	18 (too low)	44.1	50.4
Sweden	12.2	-	14	18.2	-
UK	50.0	-	55	42.9	58.0
Czech Rep.	23.2	-	-		
Hungary	-	(34.6 all VOC in products)	-		
Norway	10.8	-	-		
Poland	32.0	(66, all paints)	-		
Total	656.6		440	310	365

***** See next page: CEPE production data on 1997 have been coupled to assumed VOC-contents, and corrected for the % of the market covered by the first 4 classes of the CEPE classification

** Only emissions from *solvent borne* decorative paints

Annex 2 (cont'd) – VOC-emissions from decorative paint use (in tonnes), given the assumed VOC-contents (2nd column)

Paint type	Assumed VOC-content	**Belgium**	**Finland**	**France**	**Germany**	**Italy**	**Netherlands**	**Norway**	**Spain**	**Sweden**	**U.K.**
Interior walls and ceiling paints	WB: 2%	283	269	1785	10600	2873	*Wall paints:* WB: 948 SB: 2928	378	5890	587	4518
	SB: 35%	206	831	28831	0	8873		1760	5425	210	5951
Exterior wall paints	WB: 5%	468	263	5358	7350	2178		123	3393	27	1794
	SB: 35%	16	680	8797	1050	1694		4889	3549	9343	1876
Pigmented opaque trim paints for wood or metal	WB: 10%	124	-	83	2700	766	*Other paints:* WB: 1030 SB: 11414	-	330	237	1273
	SB: 35%	1635	-	4521	22050	10724		-	21945	1353	14911
Clear coatings, woodstains, varnishes	WB: 10%	56	222	261	2000	68		114	110	152	3286
	SB: 35%	890	1163	5168	10500	4489		1824	3465	648	5412
SubTotal		**3678**	**3428**	**54804**	**56250**	**31665**	**16320**	**9088**	**44107**	**12557**	**39021**
	WB	931	754	7487	22650	5885	1978	615	9723	1003	10871
	SB	2747	2674	47317	33600	25780	14342	8473	34384	11554	28150
% Market coverage		79.2	78.5	81.0	96.5	97.9	59.8	91.3	100	68.8	91.0
Total		**4644**	**4367**	**67664**	**58290**	**32344**	**27291**	**9932**	**44107**	**18251**	**42880**

Total 10 countries: 309800tonnes (309 kilotonnes)

Annex 3 - Effects of VOC-reduction proposal on resin and solvent demand

The effects of the second phase of two options are estimated below, based on tables 10.1 and 10.2. (extrapolated to cover the EU-15 member states)

Resin demand

Paint consumption in the EU-15 countries

Paint type	**Consumption 2000**	**Option 1 (% change)**	**Option 2 (% change)**
Waterbased – general	2346 kT	2644 kT (+ 13%)	2871 (+ 22%)
Solvent based – general	706 kT	408 kT (- 42%)	223 kT (- 68%)
Traditional	*706 kT*	*154 kT (- 78%)*	*110 kT (- 84%)*
High Solids	*- kT*	*253 kT (+)*	*113 kT (+)*
Alkyd paints – total	402 kT[1]	357 kT[2] (- 11%)	308 kT[2] (- 23%)
Traditional	*402 kT*	*- (-100%)*	*- (-100%)*
High Solids[3]	-	*253 kT*	*113 kT*
Waterbased	-	*104 kT*[2]	*195 kT*[2]
Solvent borne acrylics (i.e. exterior wall paints)	110 kT	110 kT (-)	110 kT (-)
Water borne acrylics (current WB trim&wall paints)	614 kT	609 - 713 kT[4] (-1/ + 16%)	702- 896 kT[4] (+14/ +46%)

1. 50 kT solvent-based alkyd interior wall paints assumed (only in France)
2. The potential future market share of waterbased alkyd emulsions versus waterbased acrylics is estimated rather optimistically at 50%. If a breakthrough of alkyd emulsions does not occur, the decrease in alkyd demand may be considerably higher, and the increase in acrylics as well.
3. Current market share of high solids is very low.
4. The lower end of the range occurs in case waterbased *alkyds* have a breakthrough; the higher end of the range occurs in case alkyds do *not* have a breakthrough.

Effects of VOC-reduction proposal on demand of oxygenated solvents

Amount of oxygenated solvents used in coatings

Consumption 2000	**Option 1 (% change)**	**Option 2 (% change)**
181 kT	134 kT (- 26%)	157 (- 13%)

This decrease may seem unexpected. However, the proposal reduces VOC-contents in waterbased coatings as well.

Effects of VOC-reduction proposal on demand of hydrocarbon solvents

Amount of hydrocarbon solvents used in coatings

Consumption 2000	**Option 1 (% change)**	**Option 2 (% change)**
263 kT	103 (- 61%)	58 kT (-78%)

Annex 4 – Written position statements of European industry associations

- CEPE – paint manufacturers’ association
- UNIEP – painting contractors’ association (only on hard-copy available)
- ESIG – solvents industry association
- ERMA – one smaller resin manufacturers’ association

VOC DECOPAINT STUDY

Question: Thinking of financial measures (subsidies, taxes/tax reduction):

Does price have an influence after all?
If yes: how big is the group of consumers looking mainly at price?

Answer: In case of special taxes put on paint products containing VOC we assume that the industry/trade will transfer these additional costs to the end-user by increasing sales prices of the paint products.

Evaluation: From the professional painter's point of view material cost amounts to only 15-18% of his total cost. Labour cost has first priority. If the use of VOC containing paint would result in labour or other cost savings (e.g. complains), higher prices will most likely not be regarded as a main barrier. Professional painters will even not be motivated to use lower priced low VOC paint as long as higher prices of alternative paint containing higher amount of VOC can be compensated by considerable application or follow up cost savings.

From the DIY painter's perspective his very important motivation is driven by cost saving purposes. His knowledge of paint technology and quality aspects is very limited. Therefore, product prices are a decisive factor unless there is high awareness for a special brand.

Result: For the professional painter we assume that neither tax measures on VOC containing paint nor subsidies on waterborne paints will automatically lead to an increased use of low VOC products (see Switzerland). Higher prices of VOC containing paint may however influence the decision of the DIY painter towards increasing use of low VOC or waterborne products.

Question: Information campaigns and training:

Would it be useful to organise Europe-wide training campaigns for professional painters, e.g. to improve their skills in applying water-based acrylic trim paints (e.g. in an EU-funded project)?

Answer: In order to increase awareness and ability to use low VOC paint EU could offer subsidies for special training and educational programs.

Evaluation: Successful use of water-based trim paint requires special skills and experience. Painting is highly based on tradition and culture, which cannot be changed on short notice or simply by legislation. Paint industry is already investing an enormous amount of money for special training programs to their customers.

Due to the large number of professional painters in Europe and limited financial resources of the paint industry, it would take a long period of time to reach everybody and to change old traditions.

Countries with highly developed educational programs for painters could be financially supported to put special emphasis on low VOC trim paints in theory and practice.

Result: Development and implementation of a special educational program for professional painters financed by the EU would help to motivate and to train the (young) painter from the very beginning how to use low VOC paint efficiently.

Hans-Joachim Witte
Chairman POG Decorative Paints

CEPE	*Conseil Européen des Industries des Peintures, Encres d'Imprimerie et Couleurs d'Art* *Europäische Vereinigung der Lack ,-Druckfarben und Künstlerfarbenindustrie* *European Council of the Paint, Printing Ink and Artists' Colours Industry*

Responses to EU VOC Project Team

What is the impact of the Solvents Directive on VOC emissions due to the use of decorative paints?

The impact on the market scope considered within your project is negligible.

The SED applies to installations and operators of installations is defined in such a way that the SED could in no way be construed to apply to the general public (articles 2.1 and 2.6).

Professional painters, painting contractors and decorators could fit the definition of operator and a site where architectural painting was being conducted could be seen as an installation.

Furthermore an installation is defined as within the scope of the SED if the activity is listed in Annex I. Coating of metallic, plastic and wooden surfaces are all listed in Annex I but not masonry, plaster, etc.

If a liberal definition of the above is to include certain architectural painting then the emission from the coatings used on metal, wood and plastic would need to be above 5 tonnes per annum (Annex 11A). Very few architectural painting contracts will approach this size of operation. It is possible, of course, for an industrial factory to use a coating, normally sold as a decorative coating, in an industrial context. If the emission exceeds the 5 tonnes p.a. then the activity could fall within scope.

In general, Decorative coatings manufacturers will not have to change the VOC content of their products in order to comply with SED either in manufacture or in use.

The additional emissions from thinners etc. are approximately 500K tonnes

We have little data on this, however the data we do have suggests the market for EU15 is between 100 and 200K tonnes, certainly not as high as 500K tonnes. We do not know what percentage of this is associated with decorative paint and what with other uses.

Expression of VOC

This has been widely debated within the industry for many years. We have never identified the perfect expression and the reference you gave (D3960-98) illustrates just some of the ways of expressing it. The European Decorative Coatings Industry chose and has supported grams per litre mainly for the following reasons:

1. It is easy to understand
2. It is easy to calculate from a known formulation
3. It is easy to use in models, etc.

Please do not under estimate the amount of detailed work the industry will have to undertake to ensure compliance with any given VOC limit. It is important that the method of calculation can be easily installed and run in the various formulation databases.

Whilst adding a functional unit gives the expression a sounder technical base, it inevitably brings with it other anomalies, e.g.

g/l/covering power	-	not suitable for transparent or semi-transparent coatings.
g/l/ m^2	-	perhaps the most logical expression to use but coatings have widely different spreading rates; spreading rates are dependant on application conditions and substrate.
	-	spreading rates quoted are usually a guide and are not absolute figures.
g/l/nominal dry film thickness	-	decorative coatings are used for quite widely differing applications, e.g. penetrating primer and high solids gloss.

To further illustrate the points, the following table shows (Appendix 1) the wide range of volume solids and spreading rates encountered within decorative coatings. Arguably, the column giving grams of VOC per square metre painted is the most truthful expression of VOC emission but, as pointed out above, this includes units, which are far from verifiable on a scientific basis. The expression grams per litre per volume solids adds a level of complication without really improving on the data given by grams per litre.

We have previously discussed the issue of definition of VOC, but would point out again that a common definition across Europe will be highly desirable.

Proposed limits based on possibilities in the early nineties?

The proposal developed in 1995/1996 was based on knowledge at that time but the team working on it did consider emerging technologies in their thinking. The VOC levels given as current have undoubtedly changed since then and the data collected by the project team from the National Associations will supersede that given in the CEPE proposal. Whilst the emerging technologies considered in 1996 have either moved on in capability, e.g. alkyd emulsion, or come up against limitations, e.g. high solids, it is probably true to say that no further technologies have emerged that will enable us to significantly change our views on being able to lower VOC at acceptable costs and quality.

The project team has already identified that, in most product areas, it is possible to produce very low VOC products but often with severe quality and or cost implications. The CEPE proposals reflect a position that is challenging but realistic and furthermore a position that is agreed across the cultural, geographic and market spread that CEPE represents.

Rationale of the classification

The decorative paint markets across Europe have differing end use characteristics, e.g. the distinction of 'trim' and walls is far less pronounced in France than in some other countries. In some sectors the destination between interior and exterior is very pronounced e.g. most markets have exterior masonry paints. However, in others it is far from distinct, e.g. many of the countries have products for windows which are used both inside and outside. The classes therefore were agreed with points of this kind in mind.

There was a need to keep the overall number of classes to a minimum and consequently there are many cases where it is possible to identify opportunities to sub divide a class. It should be remembered however that more classes will make the proposal more complex and may give further opportunities for class swapping. The problem of creative product allocation or class swapping was recognised and a team did look at the definitions and produced a guidance chart to assist correct allocation.

Market penetration of water-based emulsions

Overall, of course, the penetration with EU15 is high, around 70-80%, but this skewed in that the penetration in the walls and ceiling area is much higher than in the trim and floor areas. The level of penetration varies significantly between countries and market segments. The project team should now have a good insight into the detail of this issue and into the reasons why penetration in the trim and floor areas has been restricted.

Current position on acrylic/alkyd hybrids for exterior wood

This question is probably best answered by companies who specialise in such coatings. It is clear that these coatings can have a role in the market but the history of these products should serve as a general warning. New technologies of any kind present a risk, which is considerably higher with exterior coatings. We cannot assume that a new technology, low or high VOC will work. We must allow adequate time for real experience in the market place.

Performance of high solids alkyds

We would agree that the penetration of high solids alkyds into the paint market has been limited by cost, slow drying and strong yellowing.

VOC free technology

There are several technologies that can be used top formulate VOC free coating. Some are aimed at removing the small amount of solvent typically found in a paint designed mainly for walls and ceilings, e.g. a matt paint, others are designed to offer higher performance products. Each will have a role to play in the market but we could again repeat the statements about cost and quality. To date there is no VOC free technology that can provide replacements for solvent-based paints at acceptable cost and quality across the product classes within the various national markets. The CEPE proposal is aimed at severely restricting the use of conventional paints with high solvent content. This is a vital step in any VOC reduction programme, in many cases the markets have to learn to walk before they can attempt to run. The fact that competing technologies are emerging will however ensure that healthy competition will inevitably increase the opportunities for VOC reduction.

The Technical Committee will be very willing to discuss the advantages and disadvantages of any technology in which you have an interest.

Ray Leggetter
Chairman TC Decorative Paints

UNION PROFESSIONNELIE PEINTURE FINITIONS

Mister Pieter van BROEKHUIZEN
Chemiewinkel Universität von Amsterdam
PO Box 20242
NL - 1000 HE Amsterdam

Paris, le 7 avril 2000

Cher Monsieur,

Suite aux différents entretiens que nous avons eu l'occasion de mener dans les derniers mois, entre les adhérents de l'UNIEP et votre groupe DECOPAINT, j'ai plaisir á vous confirmer la position des entrepreneurs de peinture qui nous ont mandatés.

Nous sommes en phase avec les réflexions menées pour la protection de l'environnement et la protection encore plus accrue de la santé de nos compagnons.
Nous qui contribuons dans notre métier á l'amélioration de notre cadre de vie, avons la volonté de contribuer également á sa protection dans le cadre de mesures écologiques.

C'est un bon point de départ, je crois.

Pour l'avenir, nous sommes donc favorables, vous le savez, á la réduction des émissions de COV.

Pas dans n'importe quelles conditions, vous le savez aussi.

Nous avons eu en effet l'occasion de vérifier que les fabricants de résine n'étaient pas encore parfaitement préts á remplacer les matières premières solvantées par des matières premières totalement en phase aqueuse.

Nous savons également que les produits en phase aqueuse ne sont pas encore adaptés á différents travaux et á différents résultats. Ils ne permettent pas, par exemple, le traitement des bois en extérieur; les produits d'accrochage sur support pulvérulents sont, en phase aqueuse, médiocres; enfin, le brillant profond, attendu par nos clients, n'est pas non plus fourni par des produits en phase aqueuse.

Les fabricants de résine ont fait valoir que seul le temps permettrait de résoudre ces problèmes á l'avenir.

Quant á nous, entrepreneurs de peinture, nous avons aussi besoin de temps. Il nous faut en effet former nos compagnons á de nouveaux gestes, les convaincre des performances des produits en phase aqueuse, lorsque celles-ci seront optimales et équivalentes á celles des produits en phase solvant.

Tout ceci représente un changement de culture radical. Il faut du temps á chacun des acteurs de notre filière pour intégrer ces changements.

Enfin, nous souhaitons souligner auprès de vous que, si nous sommes favorables á la réduction des émissions de COV, il ne nous appartient pas de définir, seuls ou unilatéralement, les pourcentages de réductions á appliquer par catégorie de produit, ni de préciser le laps de temps dans lequel ces objectifs pourraient étre atteints.

C'est conjointement avec les fabricants qu'il nous faut mener ces discussions.

C'est pourquoi il me semble extrémement souhaitable que notre prochaine réunion puisse se dérouler en présence de leurs représentants.

Je vous remercie de prendre en compte ma demande, et d'organiser dans les prochaines semaines, avant la remise définitive de votre rapport á la Commission, une réunion commune avec les fabricants.

Je reste á votre disposition pour fixer une date, et, dans l'attente, en renouvelant mes remerciements pour votre écoute, je vous prie d'agréer, Cher Monsieur, l'assurance de mes meilleurs sentiments.

Le Président

Francois FOULON

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Mr. Pieter van Broekhuizen March 28, 2000
Director
Chemiewinkel
Consultancy and Research Centre on Chemistry, Work and Environment
Universiteit van Amsterdam
Nieuwe Achtergracht 166
P.O. Box 202242
NL-1000
HE Amsterdam

Dear Mr. van Broekhuizen,

Re: European Union Cost Benefit Study on Decorative Coatings

I am writing to you with respect to the above study and on behalf of the European Solvent Industry Group, and with particular regard to the questionnaire sent by you in November 1999.

European Solvent Industry Group (ESIG)

The European Solvent Industry Group (ESIG) represents 31 producers of hydrocarbon and oxygenated solvents with operations throughout the European Union and with production facilities in Belgium, France, Italy, Finland, Germany, Portugal, Sweden, Spain and the United Kingdom (see Attachment I for a full list of companies). The goal of ESIG is to strive to ensure that customers, consumers and society as a whole continue to benefit from the use of hydrocarbon and oxygenated solvents and solvent-containing products, and to do so in a safe and environmentally acceptable manner. To this end ESIG is:

- Leading the implementation of Responsible Care and Product Stewardship on behalf of its members
- Promoting best practice in health, safety and environmental protection with respect to solvent use
- Sponsoring research on the health and environmental aspects of solvents
- Serving as a focal point for information on hydrocarbon and oxygenated solvents
- Working jointly with customers, regulators and other interested parties to help ensure the safe and environmentally responsible use of solvents

In addition member companies are developing new and improved solvents on an ongoing basis.

Some concrete examples from the past 3 years of ESIGs activities are:

- Production of Best Practice Guidelines on Measuring Solvent Vapours in the Workplace
- Distribution of the ESIG Abatement Advisor - easy to use software which provides guidance on how to reduce solvent emissions. This is now available from the ESIG website with over 400 down-loadings to-date.
- Promotion of continual improvement and best practice in solvent use and safety, health and environmental protection via the ESIG Solvent Stewardship Awards.
- Development of safe occupational exposure limits (OELs) for hydrocarbon solvents. During the last 3 years ESIG's hydrocarbon solvent members have been working with regulatory authorities to develop OELs and during the second quarter of 2000 these will be widely communicated to downstream solvent users. To support the development of

these OELs ESIG has recently completed a M$2 research programme on the neurobehavioural effects of solvents, at the Dutch TNO Institute. This work will be published in the scientific literature in the near future.

- Completion of a comprehensive literature survey on exposures to solvents demonstrating that in key end-uses, exposures have reduced significantly during the last 20 years and that exposures are within OELs.
- Completion of simulated exposure studies that demonstrate for the large majority of solvents and end-uses, relatively simple methods of ventilation (general or local exhaust ventilation) can ensure that exposures remain within safe limits. For those minority of products and end-uses where exposure can potentially exceed the OELs appropriate engineering controls are recommended.
- Development of the Air Change Index model - an easy to use approach which provides a ventilation index which supports the safe use of solvent containing indoor decorative trim and special surface coatings.

VOCs and the environment

Tropospheric ozone is created by the reaction of nitrogen oxides and VOCs in the presence of sunlight and high temperatures. Under the large majority of circumstances hydrocarbon and oxygenated solvents breakdown rapidly in the environment into water and carbon dioxide; this fact precludes their build-up in the environment and as such should be seen as a positive factor with respect to environmental impact (e.g. there is no impact on stratospheric ozone depletion). Whilst reducing tropospheric ozone levels is important it should not be forgotten that ozone episodes are a summertime phenomenon, and that natural VOC emissions from trees and vegetation are most abundant during the summer months.

Taking into account the VOC "big picture" of which solvents are only a part, it should be noted that VOC emissions for the EU 15 have reduced during the last 10 years from approximately 19 million tonnes to 15 million tonnes today. This is approximately made up of 5 million tonnes from natural sources (trees and vegetation), 4.5 million tonnes from transportation, 3 million tonnes from solvent use, with the remainder from power generation, combustion, fuel distribution and production processes. The current level of 10 million tonnes of man-made emissions will, through legislation, which is already in the pipeline, be reduced to approximately 7 million tonnes by 2010 (see Attachment II). The Solvent Emissions Directive makes a relatively large contribution to these additional 3 million tonnes of emission reduction. The other relevant legislation includes the Integrated Pollution and Prevention Control Directive (impacting large industrial installations), the Auto-Oil directives, and the Large Combustion Plant directive. So, it should be clear that industry in general, and the solvents industry in particular is already making a major contribution to improving air quality via VOC emission reduction and the associated reduction of tropospheric ozone.

The Solvent Emissions Directive

During recent years the solvent industry, including both producers and users have worked closely with the European Commission and member states to develop the Solvent Emissions Directive (adopted by the European Council in March 1999 with transposition into member state law due by April 1, 2001). This directive affects a wide range of solvent uses, including the production of coatings, vehicle coating and refinishing, metal coating, wood and coil coating, and many non-coatings applications. The directive is estimated to impact upon approximately 400,000 enterprises, the large majority of which are small, medium and/or family-run businesses. The solvents industry is supportive of the directive since it does provide the flexibility to maintain the distinct benefits of using solvents with abatement of emissions or to use alternative technologies where performance and economics allow. Nevertheless, the directive does represent a significant challenge for the entire solvent industry to implement, with an estimated cost of 80 billion Euro over 20 years. Because of the technological and economic challenges involved, existing installations have been given until 2007 to implement the directive. The directive will result in a dramatic reduction of VOC emissions from solvent use which will have a significant impact on ozone air quality in Europe.

Has the directive achieved the balance between environmental protection, socio-economic impact and continued performance and quality of finished products? It is probably too early to say, and undoubtedly there will be an impact on small, medium sized and/or family-run businesses throughout Europe. In order to minimize this impact it is essential that the above referred to flexibility is maintained during the transposition process at member state level. In addition, the European solvent industry will be working closely with the European Commission to help ensure exchange of information which will support best practice in the implementation of the directive. ESIG has also made available on its web site the ESIG abatement advisor (a user-friendly piece of software, which helps companies select the most appropriate abatement option).

Decorative Coatings

Solvent-based decorative coatings are still used because they have widely recognized performance advantages for decorative trim, woodwork and special surfaces. These include:

- High performance treatment of stained, damp, porous and chalky surfaces
- Ease of application under all atmospheric conditions
- Durability of the finished surface (both indoors and outdoors)
- Long term protection of building exteriors and woodwork
- Ease of cleaning of the finished surface
- High gloss professional finish

Of the approximate 1.5 million tonnes of oxygenated and hydrocarbon solvents for both industrial and decorative coatings, industrial coatings account for about 75% of the consumption and decorative coatings for about 25%. VOC emissions from the use of solvents in industrial coatings have been addressed by the Solvent Emissions Directive. In terms of total man-made VOCs, decorative coatings represent only about 4%. Ozone modelling carried out by the European Solvent Industry Group has shown that even if all use of solvents in decorative coatings was eliminated there would be minimal improvement in ozone air quality (see Attachment III). The Commission's own ozone modelling work has shown that reducing VOCs substantially beyond that which will be achieved by existing legislation will result in very marginal improvement in ozone air quality in limited areas in Europe (Attachment IV - please see the ozone maps in the enclosed recent edition of Solutions newsletter). Further pan-European legislation would thus require measures which would potentially mean significant socio-economic impact with no environmental benefit for the large majority of Europe. There are many hundreds of small, medium-sized and family-run businesses that rely on solvent-based coatings in niche markets. There would be serious socio-economic impact on these companies if proposals for restricting solvents in decorative coatings were to be adopted.

Solvent-based and water-based coatings have existed side by side for over 25 years on the European Decorative market, with today water-based coatings representing about 70% by volume. Where possible the market has already moved from solvent-based to water-based coatings; in effect the market is self-regulating, meeting the many varied performance requirements throughout the length, breadth (and altitude) of Europe, through the choice of high performing water-based, solvent-based, and other coatings technologies which are available. Lower performing alternatives could also lead to increased environmental impact, through the need for multiple and/or more frequent application of coatings. The Humber

Bridge Life Cycle Assessment study carried out by ESIG is an example of this. Needless to say, from all of the above, it should be clear that the balance between environmental protection, socio-economic impact, and the performance and quality of finished products will be seriously undermined if the European Commission moves ahead with legislation in these areas.

Any additional ozone air quality measures should now be addressed at the local level through the action of local government and communities rather than through further pan-European legislation, which will penalize the entire European economy for environmental benefits which are highly localized.

Responses to the questionnaire for solvent producers

Information relevant to questions 1., 2., 3. - tonnage figures refer to EU 15

- 31 suppliers of oxygenated and hydrocarbon solvents
- Largest companies are Shell, BP Amoco, ExxonMobil Chemical, TotalFina Elf, BASF, Dow (see Attachment I for the full list).
- Number of employees engaged in activities relevant to solvents production and marketing in the 31 producers is estimated to be approximately 10,000.
- It is estimated that approximately 1.55 million tonnes of solvents are used in industrial and decorative coatings.
- Of this approximately 380 kilotonnes (320 kilotonnes hydrocarbon solvents and 60 kt oxygenated solvents) are used in in the production of both solvent-based and water-based decorative coatings. In addition approximately 50 kilotonnes of white spirit is used for thinning of decorative paint and for cleaning of brushes.
- The 60 kilotonnes of oxygenated solvents are used as coalescing agents in "water-based" paints.
- There are approximately 1300 paint companies in Europe, two thirds of which employ less than 50 people. The leading paint companies are: Akzo-Nobel, ICI, Dupont, BASF, Sigma-Kalon, PPG Industries, Becker Industries, Tikkurila.

Position of ESIG with respect to a possible EU Directive covering Decorative Paints and possible other measures to restrict VOCs from decorative coatings - Question 4 and 5

- As indicated above, in terms of improving ozone air quality such a directive would result in minimal environmental improvement for the large majority of Europe. It would also potentially have a major socio-economic impact for a large number of SME and family-run coatings and resin companies. In addition product performance would be compromised in certain key applications with the potential for greater overall environmental impact. There is therefore no rational justification for such a Directive.
- Whilst there will also be an impact for suppliers of solvents the major impact would be for the above mentioned SME coatings and also resins companies. Clearly hydrocarbon solvent suppliers would be significantly impacted since use of such products in decorative coatings represents an important use. However, it is very difficult to put a financial figure on this, although it would undoubtedly have a major impact on the market, with the associated possibility of job losses and plant closures. Overall, prices for hydrocarbon solvents would fall with the associated impact for supplier companies. There would be a small increase in sales of oxygenated solvents for use in water-based coatings, but the positive economic impact of this would be dwarfed by the overwhelming negative impact for hydrocarbon solvent producers.

- This impact for both SME coatings and resin companies would be felt starting with Option 2 and obviously will increase dramatically through to Option 5.
- With respect to possible other measures, I would like to underline the importance of ensuring appropriate training of painters on the safe use of all types of coatings both in the workplace and with respect to the environment. Any product can be misused if not correctly handled in accordance with appropriate procedures. This includes also water-based coatings which contain a variety of additives and which of course have the potential to impact the aquatic environment if not handled correctly. ESIG is working together with other associations to help ensure the safe and environmentally acceptable use of solvents and solvent containing products and is committing significant resource to this effort. In addition we are supporting a risk based approach to the use of solvent containing indoor decorative coatings, known as the Air Change Index. This pragmatic approach could be the basis for possible labelling of paint products. This approach demonstrates that modern hydrocarbon solvent containing paints can be safely used indoors providing appropriate ventilation is employed.

To summarize our overall position:

- The solvents industry in Europe is currently engaged in implementing a major piece of European legislation - the Solvents Emissions Directive - together with legislation affecting other sources of VOC this will lead to a significant improvement in ozone air quality. It is important that the industry can focus on cost-effective implementation of this directive in order to ensure minimum negative socio-economic impact. "Changing the rules" by introducing product type legislation will have serious consequences for the implementation of the Solvent Emissions Directive.

- There is no environmental benefit for the large majority of Europe through the development of further pan-European legislation affecting VOCs. Further efforts should now focus on solving residual local ozone problems through the action of local government and communities. Pan-European legislation would bring minimal environmental improvement with potentially major economic impact, particularly for small and medium sized and family-run businesses. In addition such legislation could lead to reduced product performance in certain key applications with the associated potential for greater overall environmental impact.

Thank you for the opportunity to provide input to your survey. We hope that the above input is useful and can be incorporated into the survey report. If you require any further information please do not hesitate to contact us.

Yours sincerely

N.J. Sarginson
ESIG Chairman

cc. Mr. J. Terwoet Chemiewinkel
Mr. P.J. Thornton Enterprise Ireland

EUROPEAN RESIN MANUFACTURERS ASSOCIATION

EUROPEAN COMMISSION DG XI STUDY

This paper states the position of the European Resin Manufacturers Association in respect of the European Commission DG XI study of the potential for reducing VOC emissions associated with the decorative paints and varnishes sector.

This view reflects the broad spread of opinion of Association members further supported by a number of non-member companies.

INTRODUCTION

The European Resin Manufacturers Association (ERMA) is a trade association comprising some thirty members located throughout the EEC.

Members, who must have at least one manufacturing site in the continent of Europe, produce a wide variety of synthetic resins, both aqueous and solvent based, finding application in a diverse range of industries.

Decorative paints and varnishes are a significant market for Association members.

The Association is charged by its members to promote best practice for the manufacture , sale and export of resins manufactured in Europe and to support its members in matters, such as this study, that may affect their interests.

Members of the Association have an excellent record in conforming to EC directives , and co-operating with Governmental and Commission partners on all issues leading to ‘best practice’ , particularly where based on sound science.

EUOPEAN COMMISSION DG XI STUDY

The study administrators have issued a questionnaire for Resin and Polymer Manufacturers on the 23rd November 1999 and received by member companies in December 1999 and January 2000.

The questionnaire is aimed at collecting company and market details together with opinions on various factors and impacts that may result from further moves towards even lower VOC decorative paints.

The eleven page questionnaire is requested to be returned within one month.

The study commenced in March 1999 and is expected to report in April 2000, although it may be postponed until June 2000.

We would comment that .....

- the study questionnaire is both detailed and complex and apparently offered only in English which may prove problematic for some members.
- not all of our members have received a questionnaire, nor have a number of other resin producers.
  A list of companies approached is required to assess the spread and credibility of response.
- data on market size, values and numbers employed is notoriously difficult to obtain especially in niche markets with technologically demanding needs servicing very varied applications.
- The timescale for response will be difficult, if not impossible , to meet.

MARKETS

The market for decorative paints and varnishes in Europe is not only large but , more especially , very diverse both in terms of cultural preferences and performance needs when choosing paint systems.

The performance requirements within Europe are probably the most demanding in the world with interior applications subject to these cultural preferences in addition to substrate diversity.

For exterior applications climatic conditions and substrate variation markedly affect resin system choice, with some regions suffering high UV exposure , extremes of temperature for long periods, cycling of temperatures over short periods or conditions of high and persistent humidity.

Together with substrates, both porous and non-porous, ranging from wood, brick , concrete and plastic on virgin or previously coated material the demands on the resin systems which provide the binding capability and adhesion are significant.

This very diversity of substrate and conditions in use has determined the development of niche markets and the evolution of resin systems both aqueous and solvent based able to meet these market needs.

ERMA would contend that.......

- the diversity of conditions throughout Europe dictates the performance requirements of resins used
- the ‘volume’ decorative markets have naturally embraced new technologies, for example - aqueous dispersion paints , when genuine benefits are evident.
- the performance demands have led to the development of niche markets using unique resin systems.
- these niche markets are highly profitable, employ many people in small and medium sized companies and help off-set low margins in high volume applications
- only the market-place can decide , based on cost and performance needs , which resin systems are most appropriate for a particular application..

TECHNOLOGY

Throughout its history the resin industry has researched , developed and embraced technical innovation thereby providing cost effective products for the decorative paint sector.

Advances promoting durability, formulating flexibility , adhesion , binding efficiency have all led to longer lasting paint systems capable of application to many substrates thus contributing significant environmental benefits to the sector.

These advances are provided by a wide selection of resin and polymer types carried in aqueous and solvent borne systems but driven by market requirements and market choice.

ERMA.....

- will not be divisive on the issue of aqueous or solvent borne systems for any application.
- believe only cost/performance requirements should dictate resin system choice
- asserts both aqueous and solvent based systems can be safely used in the market-place.
- believes the environmental disadvantages of either aqueous or solvent based resin systems are heavily outweighed by the protective and aesthetic benefits they confer to paint systems.
- contends the VOC content of a paint only constitutes one aspect of environmental impact. Indeed many of the raw materials used by the resin industry are derived from sustainable and renewable resources.

- suggests spending on R&D effort as a result of further reductions of VOC's in decorative paints will dilute effort aimed at achieving greater environmental benefits elsewhere.

CURRENT LEGISLATION & INITIATIVES

The Association believes its members have always co-operated with and have been sympathetic to all initiatives aimed at improving the health and safety of its workers , customers and the general public as well as minimising environmental impact through accreditation schemes such as ISO 14000.

Presently enacted legislation and initiatives in-train include......

- IPPC directive - regional and national initiatives
- Solvent emissions directive
- Large combustion plants directive
- Dangerous preparations directive
- Chemical agents directive
- Biocidal products directive
- Responsible care programme
- ISO 14000 initiatives

ERMA does not believe further stringent regulation will be materially productive and could have severe economic impacts with particularly damaging implications for the many hundreds of small and medium sized enterprises operating in niche markets.

Likely impacts would include......

- consolidation leading to loss of competition in the paint industry
- significant loss of SME's operating in niche markets'
- significant loss of margins
- loss of exports and the danger of import replacement
- the above factors seriously affecting present and future employment in that sector.

THE SCIENCE

ERMA understand that.....

◆ halogenated solvents reaching the stratosphere contribute to significant ozone depletion and thus need to be minimised or eliminated.

◆ hydrocarbon and oxygenated solvents break down rapidly in the troposphere to water and carbon dioxide, albeit with some ozone generation if nitrous oxides are co-incidentally present with sunlight

◆ detailed ozone modelling work over the EEC demonstrates minimal ozone air quality improvement even if all solvents are eliminated from decorative coatings.

◆ initiatives already in-train predict useful reductions of ozone in localised ‘hot-spots in the EEC.

◆ VOCs whilst influencing ozone levels, it is in fact nitrous oxides which provide the chemical mechanism for ozone generation and the real issue should be their reduction - an issue over which decorative paints has no effect whatsoever since they have no such output.

CONCLUSIONS

In conclusion the ERMA......

➔ will co-operate with the study to determine impacts upon the sector

➔ will request more time to allow more widespread circulation of the questionnaire and considered response by participants.

➔ will support further reductions to VOC levels in decorative paints only if demonstrated to our satisfaction by sound science.

➔ will not be divisive among its members, many of whom manufacture both aqueous and solvent based products.

➔ does believe current legislation and initiatives in-train provides for and protects the environment. Local ‘hot-spots’ could be dealt with individually.

➔ does believe the general swing in recent years from 70 : 30 solvent based to water based to nearer 50 : 50 throughout the EEC is a function of normal technical innovation adopted and determined by the market place - and should remain so.

➔ does believe further pressure on profitable niche markets will have serious social and economic impacts on suppliers , manufacturers and applicators without benefiting either end-use or the environment.

MARCH 2000

Any questions or comments regarding this position paper should be addressed to :

European Resin Manufacturers Association
8 Waldegrave Road
Teddington
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TW11 8LD
UK

Annex 5

EEB Position on the Precautionary Principle

December 1999

Introduction

In his speech to the European Parliament from 5th of October 1999, European Commission President Romano Prodi announced that a Commission paper on the precautionary principle might be expected by the end of 1999.
The discussion on the application of the precautionary principle has received new momentum as the result of several recent highly contentious policy issues, such as the BSE-crisis, Belgian dioxin in chicken, genetically modified foods and phthalates in baby toys. Its interpretation has wider ramifications for EU chemicals, water and waste policy, as well as for international trade issues.

The Precautionary Principle was introduced into the EU Treaty in 1992, but not defined there. (Schuette 1996).

Nevertheless much early environmental legislation, especially in the field of water protection, has been based upon a precautionary approach. The EEB believes the principles set forth in these early Directives can form the basis for the Commission's interpretation of the precautionary principle, particularly as they have repeatedly been supported by the case-law of the European Court of Justice.

The EEB notes considerable pressure both from within the Commission and from EU and foreign economic stakeholders to attach cost-benefit qualifications to the principle. A formal Cost-Benefit analysis is in contradiction with the precautionary principle, since it assumes certainty where, by definition, certainty does not exist. We are not opposed to economic assessment, but a cost-benefit analysis would render the principle less effective in future.

This paper has been discussed mainly by the EEB chemicals working group. While representing an official EEB position for the time being it must be considered as work in progress.

Essential Elements of Precaution

2.1 The Precautionary Principle justifies early action to prevent harm and an unacceptable impact to the environment and human health in the face of scientific uncertainty.

The precautionary principle justifies early action in the case of uncertainty and ignorance in order to prevent potential harm. There are different possibilities to characterise different types of 'uncertainty' (Hunt 1999; Stirling 1999). One can distinguish between risk, uncertainty, ignorance and indeterminacy.

- **Risk :**
  The boundaries of the system in question are deemed to be known; relevant factors can be quantified.
- **Uncertainty :**
  There is knowledge about the parameters of a system, but there is no information as to the quantitative significance of the relevant factors. → a framework of understanding where we know enough to identify what we don’t know.
- **Ignorance :**
  That which is not known; this also includes that which we are not aware that we don’t know – this is unmanageable and potentially limitless.
- **Indeterminacy :**
  That which cannot be known, either because it is produced through unforeseeable and thus unpredictable actions of the respective actors which themselves entail feedback to the systems in question – or because of certain ontological considerations, recognising the open-ended and conditional nature of all knowledge, which precludes any absolute certainty.

A wide definition of the precautionary principle should not omit any of these dimensions of uncertainty. The EEB believes that provisions are also necessary to act in the case of ignorance and indeterminacy.

2.2 Precaution places the burden of proof on the proponents of the activity.

The reversal of the burden of proof is a fundamental principle of precautionary action. The reversal of burden of proof creates incentives for the proponents of an activity to prove that their product or activity is safe. The traditional burden of proof, which lies with legislators, may cause considerable delays before action is initiated. Furthermore, in the case of « uncertainty » the traditional burden of proof may not work. Yet failure to act may in some cases impose considerable costs upon society and health as has been pointed out by the European Environment Agency (see : EEA 2000).

2.3 Precaution applies the substitution principle, seeking safer alternatives to potentially harmful activities, including the assessment of needs.

Where safer alternatives are available or may be marketed in the forthcoming future, these should be promoted as a substitute to the activity, giving rise to « reasonable suspicion ». The substitution principle allows for technology driven changes (best environmental option) instead of waiting for the proof of harm. The principle should be applied in a wide sense including the consideration of alternative products or services to serve the same function in addition to alternative materials for the same product - a principle whose usefulness has already been recognised in the Community’s biocides Directive, and by a number of environmentally advanced Member States. (Greenpeace 1999).

2.4 Precaution requires public participation in decision-making.

Risk perception has a cultural dimension. There is a considerable degree of subjectivism in choosing for a risk averse or a risk friendly approach, different within and between different societies. Decisions on the acceptability of technologies and activities, as well as on the intensity of their control cannot be defined by « sound science » alone, but requires a mechanism to identify the preferences of the society. Therefore, accountable, transparent public and democratic decision-making within the Community institutions is a prerequisite to intelligent decision-making that will serve all the citizens of the EU according to the principles set out in the Treaty.

Critique of misleading approaches

The EEB notes that several misleading definitions of the principle are being discussed, which eventually might undermine the precautionary principle. The following chapter identifies some of these and discusses some of the major problems associated with them.

3.1 Precaution as a preliminary measure

Many actors on the international stage consider the precautionary principle justified on the ground that full scientific certainty is not available *yet*. Thus, they presume that it is only a matter of time until such certainty can be reached. This means that the precautionary principle is accepted only as a temporary measure.
This approach is too narrow. Uncertainty may not only be preliminary but systemic. There are areas where even time may not allow for full certainty *ever*.

The EEB supports the idea of the revision of precautionary measures in the light of new evidence – but regular review is something different to preliminary measures. Naturally regular review also applies in cases when the decision not to act has been taken.

3.2 Precaution only if potential damage is serious or irreversible

As is already laid down in various international conventions, the precautionary principle is often restricted to damages or effects that are considered serious or irreversible.
This qualification cannot be accepted. In some cases, the extent and seriousness of damage is uncertain, especially in a long-term perspective. The precautionary principle therefore has to apply to all cases of uncertainty based on the probability of occurrence and the extent and seriousness of damage.

3.3 Precaution only on sufficient grounds for assuming a causal link between an activity and damage

Some stakeholders ask for "sufficient grounds", requiring "sufficient body of evidence" for damage as a precondition for action. They ask also for a "significant threshold of plausibility and gravity".

This threshold is incompatible with the principle's design for situations where such information is not available or uncertain. Asking for a "sufficient body of evidence" for harm imposes the burden of proof on regulators – and, by extension, on society as a whole.

The EEB believes that "reasonable suspicion" is a sufficient threshold to trigger action. Therefore the EEB also does not accept that Risk Assessment might become the "filter" before precautionary action may be triggered. Risk Assessment has been proved to be a cumbersome, bureaucratic approach in chemicals policy leading to considerable delays in action and hence not being in line with precaution.

3.4 Precaution based on cost-benefit analysis

Cost –Benefit Analysis is no appropriate methodology to manage uncertainty. A cost-benefit analysis can only be applied as a tool to identify the efficient level of environmental protection if there is full knowledge of the cost of the damage that is to be prevented. It is not the precautionary principle but the prevention principle which applies to such cases (De Sadeleer 1999). . It must be kept in mind that precautionary action is not based on demonstrated actual risk, but very often on anticipated risks that are considered plausible.

The EEB does not reject economic assessment. Once the environmental goal is set, a Cost-Effectiveness Analysis may help to identify the least-cost options of precautionary action, benefiting all actors involved.

In general the precautionary principle rather requires qualitative approaches as well as a wider public discussion on what is acceptable.

3.5 Precaution must be based on proportionality

In line with a demand for a cost-benefit analysis, it is widely argued that any precautionary measure taken must be proportionate to the benefits to be achieved by it. The EEB accepts that proportionality must be considered, but this itself should be based upon a precautionary approach. One way to implement such an approach would be to make worst case assumptions on social and environmental impacts in cases where uncertainty or ignorance prevail.

3.6 Precaution subject to scrutiny concerning its restriction of freedom of EU entities

Freedom of market players must always be linked to social responsibility. The Amsterdam Treaty allows Member States under certain conditions to protect the environment and human health even if this might impede free trade (Art. 95). The EEB has in various statements insisted upon a flexible and non-restrictive interpretation of this safeguard clause.

3.7 Restrictions of the substitution principle

Some industrial stakeholders only accept substitution of an activity or product if a wide range of conditions are met, such as:
The substitute has a comparable function or effectiveness;

- Risk assessment and risk benefit analyses are performed and compared for the original activity;
- As above, for a product and the alternative proposed (Adequate and comparative documentary evidence should always be provided);
- The economic impact is proportionate to the environmental benefit;
- The substitute is already available on the market;
- The substitute is not likely to cause an equally or more burdensome effect on health, safety or environment;

- A comparative life-cycle analysis has been made, taking into account functions and circumstances surrounding the activities and/or products.

The EEB is concerned that such a formalised set of approval conditions would undermine innovation and the promotion of substitution. On the other hand, it is evident, that some evidence must exist that substitutes are less harmful than the potentially hazardous activities being replaced. The precautionary principle should also apply to substitutes in order to avoid simply shifting problems. The conditions for potentially hazardous activities and their substitutes must be set on an equal footing.

Conclusions : Prevention of Harm not Zero Risk

The application of precaution will not necessarily lead to « zero risk ». However, the EEB insists on an open and transparent procedure to identify the best options to avoid potential harm.
The preparatory process for the Commission Paper on the Precautionary Principle has been intransparent and non-participatory. Stakeholders were not officially consulted and not informed. Therefore the EEB expects the Commission to allow for wider public discussion at earliest possible stage.
The precautionary principle allows early action under the conditions of scientific uncertainty and ignorance. It draws lessons from the past, that late action may cause greater burdens for society than early proportionate measures based upon reasonable suspicion. Its use therefore should be encouraged and not restricted.

Literature :

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De Sadeleer, Nicolas : General Introduction to the Principle of Environmental Law and in Particular the Precautionary Principle, Paper for the ELNI Conference on the Precautionary Principle, Ghent, November 1999

Greenpeace (Santillo, David, Johnston Paul, Singhofen, Axel) : The way forward> : An Alternative, Precautionary Approach to the Regulation of the Manufacturing, Marketing and Use of Chemicals in Europe, February 1999

Hunt, J.: Constructing precaution: from incorporation to deliberation. Lancaster 1999.

Schwarzenberger, Astrid : Theoretical Concepts of the Precautionary Principle, Discussion Paper for the EEB, August 1999

Schütte, Peter : Das Vorsorgeprincip im europäischen Gemeinschaftsrecht und dessen Anwendung in der politischen Praxis, EEB, 1999

Stirling, A. et al.: On science and precaution in the management of technological risk. Sussex 1999,

Tickner, Joel : A Map Towards Precauitonary Decision-Making, in : Raffensperger, C and J. Tickner eds (forhtcoming : Protecting Public Health and the Environment : Implementing the Precautionary Principle. Washington D.C : Island Press

Annex 6 – Major meetings and contacts

The survey below presents only the *major* meetings and symposia. In addition to these, numerous contacts through phone, mail or E-mail have taken place, e.g. with raw material suppliers, paint suppliers, Ministries of Environment or Environmental agencies, Health and Safety Agencies, associations of paint manufacturers, raw material suppliers and professional painters, research institutes etc.

Meetings

- European Coatings Show, Nuremberg; April 13-15 (initial contacts - raw material suppliers)
- CEPE, Brussels; April 27, 1999
- DGXI, Brussels; April 28, 1999
- Decopaint team meeting, Amsterdam; April 29, 1999
- Den Hartog Consultancy, Amsterdam; May 11, 1999
- Dutch Ministry of Environment, The Hague; May 12, 1999
- CEFIC, Brussels; May 1999
- CEPE, Brussels, May 1999
- British Ministry of Environment; May 1999.
- DSM Resins, Zwolle; June 11, 1999
- Eisma’s Vakpers (Dutch professional magazine), Amsterdam; May 15, 1999
- OMG (supplier of dryers), Amsterdam; July 1, 1999
- CEN commission on paint standards, Dublin, July 1999.
- VVVF (Dutch paint manufacturer’s association), Leiden; July 9, 1999
- CEFIC/ESIG, Amsterdam; July 15, 1999
- Decopaint team meeting, Dublin; July 19-21, 1999
- CEPE, Dublin; July 20, 1999
- Ster paint (waterborne paint supplier), Amsterdam, September 14, 1999
- VVVF, Leiden; October 4, 1999.
- IIASA, Laxenburg, October 6, 1999
- Austrian Ministry of Environment, Vienna; October 7, 1999.
- Goodyear, Amsterdam, November 4, 1999.
- DG Environment, Amsterdam; November 4, 1999.
- Rohm&Haas, Amsterdam; November 5, 1999.
- UNIEP, Amsterdam; November 5, 1999.
- Sigma Coatings, Amsterdam, January 12, 2000.
- Goodyear, Amsterdam, February 4, 2000.
- FNV B&H, Dutch construction trade union, Woerden (NL), February 10, 2000.
- CEPE, Brussels, February 18, 2000.
- UNIEP, Brussels, February 18, 2000.
- Decopaint team meeting, Dublin, March 9 & 10, 2000.
- CEFIC/ESIG, Amsterdam, March 31, 2000.
- COT, Centre for Research & Technical Advice, Haarlem (NL), April 5, 2000.
- ERMA, Dublin, April 2000.
- ERMA, Amsterdam, April 17, 2000.
- British Petroleum, Amsterdam, April 18, 2000.
- DG Environment, Amsterdam, May 19, 2000.
- DG Environment & member states’ representatives, Brussels, May 22, 2000.
- UNIEP & CEPE, Paris, June 2, 2000.

Symposia

- European Coatings Show and Symposium, Nuremberg; April 12-14, 1999
- SPHERE+ Conference, Amsterdam; April 22-23, 1999
- Master Painters and Decorators Centenary Meeting, Dublin; May 12, 1999.
- “Philosophy on VOC in coatings”, symposium NVVT (Dutch association of paint technologists), Nieuwegein; September 21, 1999.
- Symposium of the Dutch Society of Occupational Hygiene (NVvA), Workshop on health hazards from paints, Rotterdam, March 30, 2000.

Additional Technical meetings – Enterprise Ireland

Date	Contact	Subject
3/5/99	Union-Chemie, J. Hoogendonk	Information by mail
3/5/99	Wacker, Peter Hirschmann	Information by mail
5/5/99	Rohm & Haas, David Malley	Information by mail
12/5/99	NAMPDI Hugh Peacocke, Chris McLoughlin, Fleetwood/Sherwin-Williams-Conor Doyle, US Paint Contractor-Les Honeycut, Mitch Clarke	Discussions with Irish Professional Painters Association
18/5/99	Rohm & Haas, D Malley	Technical discussion
21/5/99	ICI Paints, Slough, UK P Taylor	Technical discussion
21/5/99	Interchem-Hellas SA, Toprakcioglu	Technical discussion
27/5/99	H Marcel Guest (Manchester England), Arthur Ingham	Technical discussion
27/5/99	HSH Aerospace Finishes, Johan Leuridan	Decopaint presentation.
27/5/99	Peintures Dothee S.A.,Nathalie Adam	Decopaint presentation
27/5/99	Aalterpaint N.V.Goert Uvin	Decopaint presentation
27/5/99	General Paints Ltd, Pat Healy	Decopaint presentation
27/5/99	International Coatings and Adhesives, Howard McConnell	Decopaint presentation
27/5/99	Firwood Paint & Varnish Co Ltd., Derek Finch	Decopaint presentation
27/5/99	Spraylat International Ltd, Elizabeth Clegg	Decopaint presentation
27/5/99	Sterling Technology Ltd, David Waring	Decopaint presentation
27/5/99	Rhopoint Ltd, Eric Tan	Decopaint presentation
27/5/99	Paint Research Association, Roger Brown	Decopaint presentation
1/7/99	Peter Svane Coatings Consultancy Denmark	CEN Wood Committee Technical Discussions.
1/7/99	Katharina F. Bosschaart-Thurich Sigma Coatings	CEN Wood Committee Technical Discussions
1/7/99	Peter Kirkham Coatings Consultant	CEN Wood Committee Technical Discussions
1/7/99	Roy Miller Consultant in Wood Protection	CEN Wood Committee Technical Discussions
1/7/99	Pirjo Ahola VTT Building Technology, Finland	CEN Wood Committee Technical Discussions
1/7/99	Franco Bulian	CEN Wood Committee

	CATAS Italian Centre for testing furniture and wood-based products.	Technical Discussions
1/7/99	Guglielmo Chiapparini Salchi (BASF)	CEN Wood Committee Technical Discussions
1/7/99	Jon Graystone PRA	CEN Wood Committee Technical Discussions
1/7/99	Ernst Häring Akzo Nobel	CEN Wood Committee Technical Discussions
1/7/99	Jan Lindeboom Van Wijhe Verf	CEN Wood Committee Technical Discussions
28/7/99	EI regional offices Dusseldorf, Munich, Warsaw, Prague, Berlin, Brussels, Milan, Stockholm, Vienna, Amsterdam, Budapest, Copenhagen, Madrid, Paris.	Mailing lists and contacts.
9/12/99	Fleetwood Sherwin Williams	Initial contact.
27/1/2000	General Paints Ireland Barry Donoghue	Discussion on alkyd emulsions.
17/2/2000	Team meeting	Meeting prior to CEPE TC Deco presentation.
4/4/2000	Degussa Huls Luc Driessen	Discussion on VOC and APE-free tinters.
12/4/2000	ERMA. Steve Rees, Jim Hemmings.	Technical Discussion.
14/4/2000	Fleetwood Sherwin Williams	Application methods.
2/5/2000	International Coatings and Adhesives, Eamonn Blaire.	Technical Discussions.
3/5/2000	EI-(Timber and Forest Products) Declan Cahill	Factory treatment of joinery.
4/5/2000	Peter Svane. Coatings Consultant	Wood coating issues.
4/5/2000	Piero Ahola. VTT	Results from the Air Project on wood coatings.
8/5/2000	Roy Miller Consultant	Wood coating issues.

Interviewees with respect to economic effects (WIMM)

Organisation	Country	Contact
Akzo Nobel	NL	Dr. B. de Hek, R. Joosten
Akzo Nobel	D	H. Witte
B&Q	UK	Dr. A. Knight, C. Cooper
Boss Paints	B	P Bossuyt
BP Amoco	UK	Dr. I. Kersey
Carrs Paints	UK	J. Midwood
CEPE	B	Dr. J. Warnon
DSM	NL	J. Vriens,G. Dekker,W. vd Hulst
Gem. Dienst Afvalverwerking	NL	E Velthuizen
Hauptverband Farben	D	H. Bartholemy
HEMA	NL	K. van Riel
ICI Paints	UK	R. Leggeter
Intergamma	NL	E. Schipper
Shell Chemicals	NL	G. Fokkema

Appendix 7 (to chapter 9) - Starting point formulating parameters.

Interior matt paint for walls.

Vinyl/acrylic latex

M.S.	V.S.	S.G.	H_20
46.75	25.56	1.34	51.69

Method 1. VOC content as a percent by mass

$$\text{VOC} = 100-46.75-51.69 = 1.56\%$$

Method 2. VOC content in grams per litre, ready to use including water

$$\text{VOC} = (100-46.75-51.69)\times1.34\times10 = 20.9 \text{ g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

$$\text{VOC} = \frac{(100-46.75-51.69)\times1.34\times1000}{100-(51.69\times1.34)} = 68 \text{ g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-46.75-51.69)\times1.34\times10}{25.56} = 0.82 \text{ g/m2}$$

Paint for bathroom/kitchen walls.

Vinyl/acrylic latex

M.S.	V.S.	S.G.	H_20
47.4	32.5	1.239	48.86

Method 1. VOC content as a percent by mass

$$\text{VOC} = 100-47.4-48.86 = 3.74\%$$

Method 2. VOC content in grams per litre, ready to use including water

$$\text{VOC} = (100-47.4-48.86)\times1.239\times10 = 46.3 \text{ g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

$$\text{VOC} = \frac{(100-47.4-48.86)\times1.239\times1000}{100-(48.86\times1.239)} = 117.4 \text{ g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-47.4-48.86)\times1.239\times10}{32.5} = 1.425 \text{ g/m}^2$$

Paint for bathroom/kitchen walls. Eggshell

M.S.	V.S.	S.G.
63.5	45.5	1.166

Method 1. VOC content as a percent by mass

$$\text{VOC} = 100-63.5 = 36.5\%$$

Method 2. VOC content in grams per litre, ready to use including water

$$\text{VOC} = (100-63.5)\times 1.166\times 10 = 426 \text{ g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

VOC = N/A

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-63.5)\times 1.166\times 10}{45.5} = 9.36 \text{ g/m}^2$$

Paint for exterior walls.
Vinyl/acrylic latex

M.S.	V.S.	S.G.	H_20
61.4	45	1.43	36.16

Method 1. VOC content as a percent by mass

$$\text{VOC} = 100-61.4-36.16 = 2.44\%$$

Method 2. VOC content in grams per litre, ready to use including water

$$\text{VOC} = (100-61.4-36.16)\times 1.43\times 10 = 34.89 \text{ g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

$$\text{VOC} = \frac{(100-61.4-36.16)\times 1.43\times 1000}{100-(36.16\times 1.43)} = 72.25 \text{ g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-61.4-36.16)\times 1.43\times 10}{45} = 0.775 \text{ g/m2}$$

Paint for exterior walls.
Styrenated/acrylic solution

M.S.	V.S.	S.G.	H_20
N/A	44.9	N/A	

Method 1. VOC content as a percent by mass

VOC = N/A = N/A

Method 2. VOC content in grams per litre, ready to use including water

VOC = quoted value = 450g/L

Method 3. VOC content in grams per litre, ready to use, excluding water

VOC = N/A

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

VOC = g/L/volume solids = 10 g/m^2

Gloss topcoat for interior trim (wood).
Acrylic latex

M.S.	V.S.	S.G.	H_20
44.4	33.1	1.22	47.6

Method 1. VOC content as a percent by mass

VOC = 100-44.4-47.6 = 8.03%

Method 2. VOC content in grams per litre, ready to use including water

$$\text{VOC} = (100-44.4-47.6)\times1.22\times10 = 98 \text{ g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

$$\text{VOC} = \frac{(100-44.4-47.6)\times1.22\times1000}{100-(47.6\text{X}1.22)} = 233.5 \text{ g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-44.4-47.6)\times1.22\times10}{33.1} = 2.96 \text{ g/m}^2$$

Gloss topcoat for interior trim (wood).
<u>Alkyd emulsion</u>

M.S.	V.S.	S.G.	H_20
57.4	44.3	1.304	42

Method 1. VOC content as a percent by mass

$$\text{VOC} = 100-57.4-42 = 0.6\ \%$$

Method 2. VOC content in grams per litre, ready to use including water

$$\text{VOC} = (100-57.4-42)\times1.304\times10 = 7.8\ \text{g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

$$\text{VOC} = \frac{(100-57.4-42)\times1.304\times1000}{100-(42\times1.304)} = 17.2\ \text{g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-57.4-42)\times1.304\times10}{44.3} = 0.176\ \text{g/m}^2$$

Gloss topcoat for interior trim (wood).
<u>Conventional alkyd solution</u>

M.S.	V.S.	S.G.
69.5	54.1	1.176

Method 1. VOC content as a percent by mass

$$\text{VOC} = 100-69.5 = 30.5\ \%$$

Method 2. VOC content in grams per litre, ready to use including water

$$\text{VOC} = (100-69.5)\times1.176\times10 = 358.7\ \text{g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

VOC = N/A

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-69.5)\times1.176\times1000}{54.1} = 6.63\ \text{g/m}^2$$

Gloss topcoat for interior trim (wood).

High-solids Alkyd solution

M.S.	V.S.	S.G.
80.6	68.5	1.269

Method 1. VOC content as a percent by mass

VOC = 100-80.6 = 19.4 %

Method 2. VOC content in grams per litre, ready to use including water

VOC = $(100-80.6)\times1.269\times10$ = 246.18 g/L

Method 3. VOC content in grams per litre, ready to use, excluding water

VOC = N/A

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$VOC = \frac{(100-80.6)\times1.269\times10}{68.5} = 3.59 \text{ g/m}^2$$

Sealers/undercoats trim (wood).

Acrylic latex

M.S.	V.S.	S.G.	H_20
50.4	34.6	1.32	48.8

Method 1. VOC content as a percent by mass

VOC = 100-50.4-48.4 = 0.8 %

Method 2. VOC content in grams per litre, ready to use including water

VOC = $(100-50.4-48.8)\times1.32\times10$ = 10.56 g/L

Method 3. VOC content in grams per litre, ready to use, excluding water

$$VOC = \frac{(100-50.4-48.8)\times1.32\times1000}{100-(48.8\times1.32)} = 29.68 \text{ g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$VOC = \frac{(100-50.4-48.8)\times1.32\times10}{34.6} = 0.305 \text{ g/m}^2$$

Sealers/undercoats trim (wood).

Alkyd emulsion

M.S.	V.S.	S.G.	H_20
55.8	42.2	1.310	44.1

Method 1. VOC content as a percent by mass

$$\text{VOC} = 100-55.8-44.1 = 0.1\ \%$$

Method 2. VOC content in grams per litre, ready to use including water

$$\text{VOC} = (100-55.8-44.1)\times1.310\times10 = 1.31\ \text{g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

$$\text{VOC} = \frac{(100-55.8-44.1)\times1.310\times1000}{100-(44.1\times1.310)} = 3.10\ \text{g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-55.8-44.1)\times1.310\times10}{42.2} = 0.031\ \text{g/m}^2$$

Sealers/undercoats trim (wood).

Conventional alkyd solution

M.S.	V.S.	S.G.	H_20
82.7	60.4	1.805	

Method 1. VOC content as a percent by mass

$$\text{VOC} = 100-82.7 = 17.3\ \%$$

Method 2. VOC content in grams per litre, ready to use including water

$$\text{VOC} = (100-82.7)\times1.805\times10 = 312\ \text{g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

VOC = N/A

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-82.7)\times1.805\times10}{60.4} = 5.16\ \text{g/m}^2$$

Exterior Gloss trim paints(wood).

Acrylic latex

M.S.	V.S.	S.G.	H_20
45	33	1.22	47.89

Method 1. VOC content as a percent by mass

VOC = 100-45-47.89 = 7.11 %

Method 2. VOC content in grams per litre, ready to use including water

VOC = (100-45-47.89)×1.22×10 = 86.7 g/L

Method 3. VOC content in grams per litre, ready to use, excluding water

$$\text{VOC} = \frac{(100-45-47.89)\times1.22\times1000}{100-(47.89\times1.22)} = 208.5 \text{ g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-45-47.89)\times1.22\times10}{33} = 2.6 \text{ g/m}^2$$

Exterior Gloss trim paints(wood).

Alkyd emulsion

M.S.	V.S.	S.G.	H_20
59.4	47.6	1.288	39.7

Method 1. VOC content as a percent by mass

VOC = 100-59.4-39.7 = 0.9 %

Method 2. VOC content in grams per litre, ready to use including water

VOC = (100-59.4-39.7)×1.288×10 = 11.6 g/L

Method 3. VOC content in grams per litre, ready to use, excluding water

$$\text{VOC} = \frac{(100-59.4-39.7)\times1.288\times1000}{100-(39.7\times1.288)} = 23.7 \text{ g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-59.4-39.7)\times1.288\times10}{47.6} = 0.243 \text{ g/m}^2$$

Exterior Gloss trim paints(wood).

Conventional alkyd solution

M.S.	V.S.	S.G.
69.5	54.1	1.176

Method 1. VOC content as a percent by mass

VOC = 100-69.5 = 30.5 %

Method 2. VOC content in grams per litre, ready to use including water

VOC = (100-69.5)×1.176×10 = 358.7 g/L

Method 3. VOC content in grams per litre, ready to use, excluding water

VOC = N/A

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-69.5)\times 1.176\times 10}{54.1} = 6.6 \quad \text{g/m}^2$$

Lacquers for interiors/exteriors (wood).

Acrylic latex

M.S.	V.S.	S.G.	H_20
29.6	28.4	1.027	64.3

Method 1. VOC content as a percent by mass

VOC = 100-29.6-64.3 = 6.1 %

Method 2. VOC content in grams per litre, ready to use including water

VOC = (100-29.6-64.3)×1.027×10 = 62.7 g/L

Method 3. VOC content in grams per litre, ready to use, excluding water

$$\text{VOC} = \frac{(100-29.6-64.3)\times 1.027\times 1000}{100-(64.3\times 1.027)} = 184.6 \quad \text{g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-29.6-64.3)\times 1.027\times 10}{28.4} = 2.2 \quad \text{g/m}^2$$

Lacquers for interiors/exteriors (wood)*.
Alkyd emulsion

M.S.	V.S.	S.G.	H_20
59.4	47.6	1.288	39.7

Method 1. VOC content as a percent by mass

$$VOC = 100-59.4-39.7 = 0.9\ \%$$

Method 2. VOC content in grams per litre, ready to use including water

$$VOC = (100-59.4-39.7)\times1.288\times10 = 11.6\ g/L$$

Method 3. VOC content in grams per litre, ready to use, excluding water

$$VOC = \frac{(100-59.4-39.7)\times1.288\times1000}{100-(39.7\times1.288)} = 23.7\ g/L$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$VOC = \frac{(100-59.4-39.7)\times1.288\times10}{47.6} = 0.243\ g/m^2$$

**Starting point formulations were not readily available for alkyd lacquers or wood stains.*

Lacquers for interiors/exteriors (wood)*.
Conventional alkyd solution

M.S.	V.S.	S.G.
69.5	54.1	1.176

Method 1. VOC content as a percent by mass

$$VOC = 100-69.5 = 30.5\ \%$$

Method 2. VOC content in grams per litre, ready to use including water

$$VOC = (100-69.5)\times1.176\times10 = 358.7\ g/L$$

Method 3. VOC content in grams per litre, ready to use, excluding water

VOC = N/A

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$VOC = \frac{(100-69.5)\times1.176\times10}{54.1} = 6.6\ g/m^2$$

**Starting point formulations were not readily available for alkyd lacquers or wood stains*

Woodstains for interiors/exteriors (wood).
Acrylic latex

M.S.	V.S.	S.G.	$H_2 0$
22.8	21.7	1.02	69.23

Method 1. VOC content as a percent by mass

$$VOC = 100-22.8-69.23 = 8 \%$$

Method 2. VOC content in grams per litre, ready to use including water

$$VOC = (100-22.8-69.23)\times 1.02\times 10 = 81.3 \text{ g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

$$VOC = \frac{(100-22.8-69.23)\times 1.02\times 1000}{100-(69.23\times 1.02)} = 276.7 \text{ g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$VOC = \frac{(100-22.8-69.23)\times 1.02\times 10}{21.7} = 3.75 \text{ g/m}^2$$

Alkyd woodstains not available, therefore comparison with alkyd emulsion sealer.

Woodstains for interiors/exteriors (wood)*.
Alkyd emulsion for wood priming/sealing.

M.S.	V.S.	S.G.	$H_2 0$
55.8	42.2	1.310	44.1

Method 1. VOC content as a percent by mass

$$VOC = 100-55.8-44.1 = 0.1 \%$$

Method 2. VOC content in grams per litre, ready to use including water

$$VOC = (100-55.8-44.1)\times 1.310\times 10 = 1.31 \text{ g/L}$$

Method 3. VOC content in grams per litre, ready to use, excluding water

$$VOC = \frac{(100-55.8-44.1)\times 1.310\times 1000}{100-(44.1\times 1.310)} = 3.10 \text{ g/L}$$

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$VOC = \frac{(100-55.8-44.1)\times 1.310\times 10}{42.2} = 0.031 \text{ g/m}^2$$

**Starting point formulations were not readily available for alkyd lacquers or wood stains*

Woodstains for interiors/exteriors (wood)*.

Conventional alkyd solution for wood(Satin wood topcoat).

M.S.	V.S.	S.G.	H_20
63.5	45.5	1.166	

Method 1. VOC content as a percent by mass

VOC = 100-63.5 = 36.5 %

Method 2. VOC content in grams per litre, ready to use including water

VOC = $(100-63.5)\times1.166\times10$ = 425.6 g/L

Method 3. VOC content in grams per litre, ready to use, excluding water

VOC = N/A g/L

Method 4. VOC content in grams per litre, ready to use, based on theoretical spreading rate at 10µm dry film thickness (or volume solids)

$$\text{VOC} = \frac{(100-63.5)\times1.166\times10}{45.5} = 9.4 \text{ g/m}^2$$

**Starting point formulations were not readily available for alkyd lacquers or wood stains*

Appendix 8

Discussion on the classification scheme proposed by CEPE in 1996.

The following lists the classes of decorative products agreed within CEPE for their proposal for potential VOC reduction.

Class 1	Interior low gloss paints for walls and ceilings.
Class 2	Interior glossy paints for walls and ceilings.
Class 3	Exterior wall paints (façade coatings).
Class 4	Interior and exterior trim paints and also paints for exterior claddings and anti-corrosive decorative paints (not including heavy-duty and anti-corrosive paints).
Class 5	Transparent coatings, lacquers and varnishes on all substrates, preferably on wood.
Class 6	Woodstains and lasures on wood only. This class also contains 'opaque woodstains'.
Class 7	Primers/sealers, binding primers and primers including primers for exterior wood, e.g. binding primers to stabilise loose substrate particles or rendering or to give hydrophobic properties and paints only for use on difficult surfaces, e.g. water soluble stains, loosely adhering materials.
Class 8	One pack coatings for specific end use (such as floors, radiators and metal work) including physically drying solvent based coatings, oxidative drying coatings and high quality emulsion paints.
Class 9	Solvent based one pack paints for use on exterior walls (facades) painted under adverse drying conditions.
Class 10	Two-pack reactive coatings for specific end use applications (such as floors) chemically reactive e.g. polyisocyanate plus polyol or epoxide plus amine coatings, application, e.g. on floors, stairs, on zinc plated steel, on plastic substrates.
Class11	One pack reactive coatings for specific end use application such as floors, chemically reactive, e.g. moisture-curing polyisocyanate coating application, e.g. on floors, stairs, on zinc plated steel, on plastic substrates.
Class 12	Multi-coloured paints, including physically drying solvent based coatings, oxidative drying coatings and high quality emulsion paints, application normally on walls and on floors.

Table 9.13 CEPE proposal for reduction scheme of VOC for decorative coatings

Class	Substrate (use)	Gloss 60°	Current VOC	S/B W/B	Interior Exterior	3 years limit	6 years limit*
1.1	Low gloss walls and ceilings	<25	20-70	W/B	I	30	30
1.2	"	<10	300-450	S/B	I	400[1**]	-**
2.1	Glossy walls and ceilings	>10	70-170	W/B	I	150	100
2.2	"	>25	300-450	S/B	I	350[1**]	-**
3.1	Wall paints for exteriors	-	40-100	W/B	E	60	40
3.2	"	-	450	S/B	E	450[**]	-**
4.1	Interior and exterior trim.	-	100-200	W/B	E/I	150	130[2]
4.2	"	-	300-500	S/B	E/I	400[1,3]	300[1,3]
5.1	Varnish lacquers for wood	-	160-450	W/B	E/I	150	130
5.2	"	-	550-650	S/B	E/I	550	500
6.1	Woodstains lasures	-	20-300	W/B	E/I	170	140
6.2	"	-	550-650	S/B	E/I	550	500
7.1	Wood Plaster Friable surfaces	-	30-70	W/B	E/I	50	30
7.2	"	-	700-800	S/B	E/I	750	750
8.1	Floors Radiators Metal work	-	60-140	W/B	E/I	140	140
8.2	"	-	500-650	S/B	E/I	600	600
9	Masonry adverse conditions	-	300-450	S/B	E	450	450
10.1	Floors Metal Plastic Two-pack	-	60-140	W/B	E/I	140	140
10.2	"	-	500-650	S/B	E/I	550[4]	500[4]
11	Floors Metal Plastic One-pack	-	550-700	S/B	E/I	600	600
12.1	Walls Floors	-	50-75	W/B	E/I	75	50
12.2	"	-	300-350	S/B	E/I	350	-[5]

Defined limits are proposed for 3 and 6 years after proposal becoming effective.

* Includes point-of-sale (POS) tinting systems.
(The 3 year limit excludes POS tinting systems)

** To be phased out over time. Industry plans to be put in place.

1. Formulation based on low (≤5%) aromatic solvents.

2. Limit of 130 necessary for open (wet edge) time.

3. In cases where solvents of higher density than white spirits are used, multiply by the actual solvent density/0.75.

4. Only allowed in situations where class 10.1 is not suitable for application.

5. To be phased out within 6 years of the proposal becoming effective.

VOC any compound having, at normal conditions of pressure (1013.25 KPa) a boiling point of lower or equal to 250°C (523.15°K) and containing at least the elements carbon and hydrogen or in which the hydrogen is partially or completely replaced by halogen, oxygen, sulphur, phosphorus or nitrogen, with the exception of carbon oxides and inorganic carbonates.

Expression of VOC: Grammes of VOC per litre of paint.

<u>Summary points;</u>

The principal issues associated with the CEPE classification and proposed 3 and 6-year limits are,

- VOC definition excludes one of the most commonly used coalescing solvent, which has a boiling point of 255°C.
- The significant outcome is that after six years there would be no solventborne coatings for interior walls/ceilings.
- Class 9 products reinstates 3.2 S/B for exterior use at 450 g/l.
- Class 8 products could reinstate 2.1 at 140 g/l.
- Sealants or stabilising solutions, as well as water repellents for walls covered by class 7 which allows 750 g/L.
- No differentiation between interior and exterior schemes for wood trim. Exterior requires more demanding in-service performance and application conditions may be adverse e.g. low temperature, high humidity.
- Sealants and primers included in class 7.2 allow 750g/l for wood primers.
- No differentiation between primer and finish for trim and joinery. In some cases, 750g/l could be used for primers.
- 500g/l for interior varnishes after 6 years compared to 300g/l for trim paint.
- The most significant outcome from class 7.2 is that 750g/l allowed for wood primers.

- High quality emulsion paint description used in class 8 could reintroduce class 2.1 at 140g/l.

- Solventborne one pack paints in class 9 reintroduces 3.2 at 450g/l due to the requirement for a product that can be applied during adverse conditions.

- Heavy- duty materials are considered as not belonging in this study, however, these products can be used in some instances, especially by professionals and require definition in terms of their intended use.

- Is there a need for varnishes and lasures to belong in different classes.

Annex 9 – Boiling Points and Vapour Pressures of commonly used solvents in decorative coatings

Table 1 provides a list of commonly occurring solvents indicating their respective boiling points measured at 760mmHg and vapour pressures measured at 20°C. Where known, decorative end-use has been indicated.

Table 1. Solvents listing.

Solvent	**Boiling point B.P.(°C) @760mmHg**	**Vapour pressure (Pascals) @20°C**	**Decorative end-use**
Hydrocarbons aliphatic			
n Hexane	65-70	20000	
n Heptane	94-99	8500	
Cyclohexane	80.5-81.5	10400	√
Methyl cyclohexane	101-103	5100	
White spirits (+ aromatics)	144-165	4000	√
1,1,1-Trichloroethane	73-75	13300	
Terpenes			
Mineral turpentine	150-180	440	√
Hydrocarbons aromatic			
Toluene	110-111	2900	
Xylene	137-142	900	
Styrene	145	710	
Vinyl toluene	164-170	-	
Ketones			
Acetone	56.2	24100	
MEK	79.6	100	√
MIBK	114-117	2150	√
Methyl n-amyl ketone	147-153	500	√
Cyclohexanone	153-156	350	
Esters			
Methyl acetate	55-57	22600	√
Ethyl acetate	78.3	10300	√
Isopropyl acetate	88.4	5800	√
Iso buty acetate	114-118	1800	√
Butyl acetate	124-128	1110	√
Methoxypropyl acetate	143-150	530	√
Alcohols			
DAA	168	100	
Methanol	64-65	12800	√
Ethanol	78.3	5900	√
Propanol	97.2	1900	√
Isopropanol	82.4	4200	√
Isobutanol	107.7	1200	√
Benzyl alcohol	205.2	2	√
n Butyl alcohol	116-119	670	√
sec Butyl alcohol	99.5	1600	√

Table 1. Solvents listing (contd.).

Solvent	Boiling point B.P.(°C) @760mmHg	Vapour pressure (Pascals) @20°C	Decorative end-use
Ethers and ether-alcohols			
Diethyl ether	34.5	58800	
1-Methoxy propan-2-ol	119-122	1120	
1-Ethoxy propan-2-ol	132	-	
Ethyl glycol	134-137	500	
Ethylene glycol	196-198	10.6	√
Methylene glycol	124.5	-	
Diethylene glycol	***245-250***	-	
Ethylene glycol monoethyl ether (Cellosolve) ***toxic***	124	826	√
Ethylene glycol monoethyl ether acetate ***toxic***	145-165	-	√
Propylene glycol	185-190	9	√

The table is a selection of commonly available solvents. A review of solvents used for paints using the Sixth edition of the Ullman's Encyclopedia of Industrial Chemistry (1998) provides the following further list of such solvents and their associated boiling points and vapour pressures that exceed the 250°C/0.01kPa proposed limits.

Table 2. Additional solvents sourced from Ullmans Sixth edition.

Solvent	Boiling point B.P. (°C) @760mmHg	Vapour pressure (Pascals) @20°C
Solvents for paint outside VOC definition.		
Phenyl glycol	***244-250***	**-**
Hexyl diglycol	***240-265***	**-**
Methyl triglycol	***245-255***	***<1***
Ethyl triglycol	***255.4***	***<1***
Butyl triglycol	***255-295***	***<1***
Butyl tetraglycol	***300-340***	***<1***
Phenoxypropanol	***241-246***	***<1***
Methyl tripropylene glycol	***235-251***	***4***
Butyl tripropylene glycol	***274***	***<1***
Tetramethylene sulfone	***285***	**-**
N-Cyclohexylpyrrolidone	***284***	***<5***
N-(2-Hydroxyethyl)pyrrolidone	***295***	**-**
Butyl diglycol acetate	***235-250***	***1.3***
Ethylene carbonate	***246.7***	***1***
Propylene carbonate	***243.4***	***4***

A review of manufacturers starting point formulations provides a list of additional solvents commonly used for decorative paint applications.

Table 3. **Typical solvents for use in acrylic resin binders**

Trade name	Chemical name	Boiling point (°C) @ 760 mmHg	Vapour Pressure (Pascals) @ 20°C
Masonry coatings			
-	Propylene glycol	187.9	9
-	Ethylene glycol	196-198	10.6
Butyl carbitol	Diethylene glycol monobutyl ether	230	2.7
Texanol	2,2,4-trimethyl-1,3-pentanediol mono(2-methylpropanoate)	255-260	1.3
Dowanol DPnB	di-propyleneglycol-n-butyl ether	230	6
Primers and sealers			
-	Ethylene glycol	196-198	10.6
Texanol	2,2,4-trimethyl-1,3-pentanediol mono(2-methylpropanoate)	255-260	1.3
Dowanol DPnB	di-propyleneglycol-n-butyl ether	230	6
Gloss and semi gloss trim paints			
-	Propylene glycol	187.9	9
-	Ethylene glycol	196-198	10.6
-	Methoxybutanol	160	120
Methyl Carbitol	Diethylene glycol monomethyl ether	193	26
Ethyl Carbitol	Diethylene glycol monoethyl ether	196-202	13
Butyl Carbitol	Diethylene glycol monobutyl ether	230	2.7
Texanol	2,2,4-trimethyl-1,3-pentanediol mono(2-methylpropanoate)	255-260	1.3
Dowanol DPnB	di-propyleneglycol-n-butyl ether	230	6
Dowanol TPnB	tri-propyleneglycol-n-butyl ether	274	1
Dalpad A		244	0.6

Table 3. (contd.) Typical solvents for use in acrylic resin binders

Trade name	Chemical name	Boiling point (°C) @ 760 mmHg	Vapour Pressure (Pascals) @ 20°C
Flat and sheen wall paints			
	Ethylene glycol	196-198	10.6
	Propylene glycol	187.9	9
Methyl carbitol	Diethylene glycol monomethyl ether	193	26
Dowanol DPnB	di-propyleneglycol-n-butyl ether	230	6
Texanol	2,2,4-trimethyl-1,3-pentanediol mono(2-methylpropanoate)	255-260	1.3
Exterior wood coatings			
	Propylene glycol	187.9	9
Dalpad A		244	0.6
Texanol	2,2,4-trimethyl-1,3-pentanediol mono(2-methylpropanoate)	255-260	1.3
Butyl Carbitol	Diethylene glycol monobutyl ether	230	2.7

Table 4. Typical solvents for use in alkyd resins.

Technology application	Solvent	Boiling point (°C) @760mmHg	Vapour pressure (Pascals) @ 20°C
Conventional solvent based	White spirits	144-165	4000
High solids	White spirits Ethanol Isobutanol	144-165 78 107	4000 5900 1200
Emulsions	Propylene glycol	185-190	9

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