The Global Coatings Report introduces the role of coatings in providing color and protection, explains the technology and innovation behind coatings development and production, and addresses the commitment of the coatings industry to continuous improvement in environmental performance. In addition, The Global Coatings Report gives a comprehensive, independent market overview, analyzing the industry both in terms of region and sector, including analyses of major market trends.
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INTRODUCTION

As Chairman of the world’s biggest coatings company, it gives me great pleasure to present Akzo Nobel’s inaugural Global Coatings Report, which offers a comprehensive overview of the global market and highlights the industry’s pivotal contribution to all aspects of society.

For many people, the word coatings immediately conjures up images of paint. But paint represents just one aspect of the incredibly diverse world of coatings and this Report details the fundamental—and often overlooked—role that coatings play in our everyday lives. It also attempts to explode the popular misconception that coatings are boring—we’ve all heard the saying “it’s like watching paint dry”—by providing fascinating insights into an industry which is constantly innovating and has a very exciting future in store.

While the chemicals industry as a whole is continuing to evolve by focusing on very specific markets, the coatings industry has gone one step further by separating to create its own highly specialized sector. Subsequent developments mean that in contrast to the chemical industry, a substantial percentage of the products manufactured by coatings companies is not sold to industrial customers, but is purchased by consumers and professionals. As a result, a different approach to marketing and sales is required.

Customers and end-users are also driving the increased demand for improvements in areas such as performance, ease of application and removal, sustainability, quality commitment, functionality, environmental properties and related services. All of which has required significant attention from manufacturers in order to ensure that products meet expected standards and the market remains buoyant.

In providing a detailed outline of the industry, this Report not only describes the role of coatings in providing color and protection, but also explains the science and innovation behind their development and production. In addition, it addresses the industry’s commitment to continuous improvement in environmental performance and takes a glimpse at a future in which the functionality of coatings will be transformed.

This Report also gives a comprehensive, independent overview by analyzing the industry both in terms of region and sector. It includes interesting analysis of major market trends and indicates that the coatings industry as a whole can look forward to healthy growth. Although we regard the growth projections given in this overview as being too bullish, we share the positive outlook for the global coatings market, indicating promising growth opportunities for Akzo Nobel and the industry in general.

Hans Wijers
Chairman of the Board of Management
WHAT ARE COATINGS?
WHAT ARE COATINGS?

Coatings are everywhere. They’re all around us. If you are reading this report in an office, then your desk, PC, telephone, the shelving on the walls and even your cabinets will all have been given some form of coating. At home, your television, fridge, furniture and most of your other household items will also rely on coatings for protection and outward appearance. Then there’s the paint used to decorate the walls both at home and at work. Of course, the car (or the train, or the bus) that you use to travel between the two will also have coatings on their exteriors and interiors, as well as on all their moving and non-moving parts. How about the airplane you take to your international meetings, the boat you cruise on during vacations, the bridges you cross, the buildings you pass, the list goes on and on. Coatings are a central part of the world we see around us every day.
BUT WHAT EXACTLY IS A COATING?
Put simply, a coating is a film forming substance which protects a substrate (i.e. a surface or material) against potentially damaging elements in its environment, as well as enhancing its appearance. But this basic definition is only the tip of the iceberg. Because if you delve deeper, you’ll find that there’s a myriad of complexity and invention just waiting to be discovered. Coatings, you see, are inherently different when it comes to their production, application and functionality. What the very general definition of coatings fails to do is acknowledge that the conventional functions of protection and aesthetics are often complemented and enhanced to meet additional, more specific demands.

The coatings market is typically broken down into three major categories: architectural and decorative coatings; industrial coatings and special purpose coatings. Within these groupings there is an enormous range and variety, not only in terms of the properties that the coatings themselves possess, but also the particular purposes they serve, the technology behind them and the methods used to apply them.

ARCHITECTURAL COATINGS OR DECORATIVE COATINGS
When people talk about coatings they are usually referring to architectural or decorative coatings. Principally, this means paints, but it also includes all kinds of lacquers and varnishes that are used to protect and decorate surfaces such as internal and external walls, doors, window frames, and so on.
The market for architectural or decorative coatings includes both the do-it-yourself enthusiast and the professional or trade sector.

INDUSTRIAL COATINGS
Of course, it’s not just houses that get painted. Virtually all consumer durable products, as well as all types of industrial equipment, have to be coated in some way or another. New cars arrive “coated.” Anything made from wood—be it home or office furniture, kitchen and bathroom cabinetry, flooring, windows and doors, or various other factory-finished building products—will be coated to enhance its appearance and provide it with protection. Everything from computers to fridges and freezers, washing machines to DVD players and mobile phones, are coated to extend their lifespan and enhance their aesthetic appeal.

These coating products are applied using different methods, depending on the specific needs of the application. Powder coatings technology involves a material being applied electrostatically, either in a fluidized bed, or it can be sprayed and then subsequently “cured” by applying heat. This is usually done in an industrial oven, or by using infrared irradiation and is sometimes combined with other methods such as UV light irradiation. Alternatively, steel and aluminum sheets used in some manufacturing processes are coated while the metal is still on “coils,” large rolls of flat, unprocessed metal sheets. This is even more demanding because the coating has to withstand being rolled, cut and pressed after application on the metal—it therefore needs to be extremely durable.

You will also find coatings on other plastic products ranging from car dashboards and bumpers to video recorders, computers, mobile phones, skis, tennis rackets and surfboards. Then there are coatings for packaging which are applied to the internal and external surfaces of food and drink cans, caps and closures, and cardboard and plastic packaging.
Coating major structures such as this is crucial, even if it’s a mammoth task. In fact, the expression “Painting the Forth Bridge,” used by the British to mean a job which never ends, is derived from the Scottish bridge of the same name which was actually the world's first major steel bridge when it was finished in 1890. Although the expression is still in use, the reality of contemporary coatings means that the phrase should be redundant—technology has advanced so much that a steel bridge like the Forth Rail Bridge now only needs to be painted once every 20 years.
SPECIAL PURPOSE COATINGS
That coatings are ubiquitous in our society can be seen from the fact that the third category is simply known as special purpose coatings. Research-driven innovation has enabled us to produce coatings that have very special properties to meet entirely specific needs.

PROTECTIVE COATINGS
As their name suggests, protective coatings are applied on various steel and concrete structures to preserve long-term strength and integrity. They need to be effective in a variety of situations and must be able to withstand adverse conditions resulting from, for example, atmospheric exposure or contact with corrosive chemicals. The type of coatings used depends on the specific end use, because they can be adapted to suit different environments, such as the demands of the oil and gas industry, the chemical industry, power and water utilities, the food and paper industries, bridges and roads, as well as railways. These coatings have to be particularly robust, because even the slightest weakness in a coating can quickly become the focus for degradation and corrosion of the structure beneath.

CAR REFINISHES
Take the car, for example. Unfortunately, everyday life means that the pristine coating found on a new car or commercial vehicle does not always stay that way. Refinishing, or recoating, of vehicle bodies is vital if vehicles are to be repaired and given a new lease of life. But the coating used to paint your car when it was new is not the same as the one used when you need to have it repaired.

Why? First of all, when coatings are applied to new cars, they are cured (or dried) at temperatures of more than 130 degrees. This is not possible with finished cars because most of the non-metallic parts—added later during original construction—would melt or be badly damaged by the high temperature. One fundamental challenge, therefore, for what is called car “refinishing” is to manufacture coatings which provide the same set of advanced properties as the original coating, without requiring high temperature curing.

Secondly, the color of your car paint does not stay constant. A range of environmental factors such as UV irradiation and other forms of weathering and air pollution can all cause subtle changes to the color of existing coatings. The industry must also ensure that car refinishing professionals have coatings that can exactly match the “new” color of the car, and change in the same way over time as the existing coating.

MARINE COATINGS
The marine environment is very harsh. Salt water is particularly corrosive and a wide range of specialty coatings have been developed to protect the superstructure and hulls of ships from its impact. Organic matter, such as barnacles and seaweed, also builds up quickly on vessels, damaging the hull and undermining speed and energy efficiency. Special products—known as anti-fouling or foul release coatings—have been developed for marine vessels which act as a salt water barrier and also minimize the build-up of this organic matter. These products are used on all marine vessels, including commercial tankers, ferries, and leisure craft ranging from the smallest dingy to the most luxurious superyacht.

AEROSPACE
Airplanes are a specific and highly technical challenge for coatings manufacturers. Aircraft need to be able to deal with temperatures ranging from -55°C in the air to +50°C on the ground, as well as having to withstand strong UV irradiation at 30,000 feet. On the ground, aircraft coatings also have to cope with various fluids which could act as a solvent, or are otherwise aggressive, such as aviation fuel, de-icing fluids, hydraulic liquids and so on. In addition, the coatings need to be resistant to the impact of dust traveling at 900 km/h, which has an effect similar to sandpaper. But that’s not all. The coatings also need to withstand the vibration effect of incredibly powerful engines, and aircraft hull and wing movements. Then there’s another factor to consider. Airplanes usually have to be colorful and attractive, while developing coatings which are less damaging to the environment is becoming increasingly important. So it’s hardly surprising that the highly regulated and extremely demanding aviation sector has seen the development of technologically advanced coatings that address these very specific needs.
The study incorporated an extensive program of research, surveying published data on the industry and then discussing the market and validating or adapting initial assumptions with a large panel of experts including trade associations, journalists, coatings manufacturers, coatings distributors and end-user industries.

In-country research was carried out in 25 major coatings markets, which allowed for an unusually accurate insight into poorly documented markets through interviews with industry experts. This was checked and verified against a separate program of research studying the market at regional and global level through a programme of desk research, review of company financial data and interviews with global players and other industry experts.

> COATINGS: A GROWING MARKET

In 2005, the global coatings market was worth US$ 85.7 billion, or 26.5 billion liters. The market has shown healthy increase in recent years. Between 2001 and 2005, the average annual growth stood at 2.7% in constant value terms, and 4.2% in volume terms. Between 2005 and 2010, the annual growth rate is forecast to accelerate, to 5.4% in constant value terms, and 5.6% in volume terms. Much of the growth over the past five years has been driven by increasing demand in developing markets, especially in Asia (notably China, but also Thailand, Indonesia, India and Taiwan) and Eastern Europe (especially Russia, Hungary and the Baltic States).

This is due to a combination of critical factors – firstly, increased disposable income has catalyzed higher levels of home ownership and spending on the home, both directly on paint and on items that use industrial coatings, such as cars and electrical appliances.

Secondly, these regions have reaped the benefits of industrial relocation, as coating-buyer industries, such as automotive construction, industrial wood manufacture and shipbuilding, the shift from the traditional manufacturing center of Western Europe and North America to the cheaper markets of Asia and Eastern Europe.

In part, the growth seen in these markets is being offset by a weaker overall performance in the developed markets of Western Europe and North America, which have seen slower growth, as they struggle to plug the gaps left as industry relocates. In these regions, growth in coatings sales is driven by the use and development of more sophisticated products that answer demand for cost-effective, environmentally responsible, effective coatings, notably including powder coatings.

Competition is particularly high in these developed markets, at manufacturer level and, with regards to decorative coatings, at retail level, where DIY chains are pushing down prices and thus threatening margins. With rising raw material prices also a factor, manufacturers face a challenge to maintain profit levels.

A key driver of growth is the shift from solvent-based coatings to environmentally friendly options, including powder coatings, waterborne coatings, high solid coatings and UV curables. This is led largely by a tighter legislative environment, which is particularly marked in the EU and North America, but is also beginning to impact the emerging markets as awareness increases.

It should be noted that this shift towards more environmentally friendly coatings such as high solids means that volume growth when measured in liters appears understated – these coatings require less volume to be used for the same coverage as more traditional options. Product category growth varies widely across countries, but at global level, powder coatings is the star performer, maintaining growth, albeit slowing, in Western Europe and North America, while quickly increasing penetration in developing markets in line with emerging environmental awareness.

Automotive coatings are also recording good growth due to increased car ownership at global level, and especially in Asia Pacific and Eastern Europe. Decorative coatings are also strong, led by construction activity in many developing markets, but also in developed markets where the splintering of the nuclear family and the growth of the second or holiday home is creating demand for a larger number of housing units.

\[ \text{Total Volume Sales in Liters} = \text{Total Volume Sales in Kgs} \times 0.65 \]

1 Note that for the purposes of this study, to allow compilation of total market volume figures, powder coatings, which are typically reported in kilograms, were converted to an equivalent volume in liters using a conversion factor of 0.65 kg per liter.
WESTERN EUROPE AND NORTH AMERICA REMAIN CRITICAL MARKETS

While Asia Pacific holds the position of largest market for coatings by value at 30% of the total in 2005, Western Europe and North America also retain very strong positions within the global picture. In 2005, Western Europe took a share of 27% of the global total (US$23.5 billion), while North America followed closely behind with a share of 25% (US$21.8 billion).

Both regions are largely mature, with the exception of parts of Southern Europe, particularly Turkey, and Mexico. As such, they have a well-established consumer and industry base for coatings, although many industries have shifted to the lower cost regions of Asia and Eastern Europe. High levels of disposable income mean a steady demand for a wide range of end products. Typically, decorative coatings outperformed the other sectors in the mature regions, led by new housing builds in key markets such as USA and Spain, while industrial coatings struggled to adjust to the shift of manufacturing bases to outside these regions.

In North America, USA was the dominant market by far, with total value sales of US$18.8 billion, and it also drove regional growth 2001 to 2005. Over the forecast period however, growth in the large U.S. market is expected to be eclipsed by Mexico. Although Mexico was stagnant during the review period, sales are likely to pick up in the short term, generating growth of 48% between 2005 and 2010 (annual growth of 9.6%), as trade relations with the U.S. and Canada stimulate local industry, especially in automobiles.

In Western Europe, in constant terms value growth was universally low, with the majority of markets recording decline. However, three markets bucked this trend: Turkey, Sweden and Spain. Growth in these countries was primarily fuelled by their relatively strong and growing economies, with Spain buoyed particularly by high levels of construction, and Sweden by keen and growing interest in DIY, and a fairly stable industrial base.

<table>
<thead>
<tr>
<th>Region</th>
<th>2001-2005</th>
<th>2005-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia Pacific</td>
<td>26.3</td>
<td>39.8</td>
</tr>
<tr>
<td>Western Europe</td>
<td>-3.5</td>
<td>13.3</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td>42.8</td>
<td>68.1</td>
</tr>
<tr>
<td>North America</td>
<td>5.6</td>
<td>18.8</td>
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<tr>
<td>Latin America</td>
<td>3.7</td>
<td>17.0</td>
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<tr>
<td>Middle East</td>
<td>19.4</td>
<td>14.9</td>
</tr>
<tr>
<td>Africa</td>
<td>10.8</td>
<td>27.2</td>
</tr>
</tbody>
</table>

In Western Europe, in constant terms value growth was universally low, with the majority of markets recording decline. However, three markets bucked this trend: Turkey, Sweden and Spain. Growth in these countries was primarily fuelled by their relatively strong and growing economies, with Spain buoyed particularly by high levels of construction, and Sweden by keen and growing interest in DIY, and a fairly stable industrial base.
TURKEY – A VOLATILE COATINGS MARKET

Although the performance of the Turkish economy has been volatile and it suffered from an economic downturn early in the review period, it was still one of the few Western European markets to record positive value growth between 2001 and 2005, and as recovery sets in, is expected to be the key driver of growth in the region to 2010, with average annual growth projected to reach 15.8%. Growth is stimulated by demand from the construction, furniture and automotive industries, all of which are developing strongly and are expected to continue to do so. The strength of local coatings manufacturers also plays a role, following consolidation and improvements in the quality of locally produced coatings. The fastest moving sectors here include professional/trade decorative, due to growth in construction, especially in major cities experiencing urbanisation; aerospace, due to a booming tourism and hospitality industry; marine, led by increased numbers of ships and competitive pricing; and coil coatings, due to strong growth in local appliance manufacture, especially by companies such as Beko and Vestel.

USA – THE WORLD’S LARGEST MARKET

In 2005, the USA paints and coatings market was worth US$18.8 billion, making it the largest market in the world. Due to its maturity, the USA faces the challenge of approaching saturation and of key industries relocating to cheaper countries: yet value growth remains positive, at 1.6% per year between 2001 and 2005, and projected to reach 3.4% annually between 2005 and 2010. The market has principally been buoyed by strong sales of decorative coatings, due to new home construction led by low interest rates, as well as good growth in various types of protective coatings, and a stable automotive industry. Although innovation is a strong feature of the market with improvements in aesthetics and efficiency expected across the board, the impact of this on prices and profits has been offset by the rise in production costs due to increasing raw materials prices and stringent environmental regulations.

USA: VALUE SALES OF COATINGS BY SECTOR 2001-2010

TURKEY: VALUE SALES OF COATINGS 2001-2010

> THE POTENTIAL OF DEVELOPING MARKETS

The massive future potential of the developing markets is clear when per household spend on coatings is measured next to mature markets (U.S., Western Europe). While U.S. per household spend stands at US$169, Asian markets such as India, Indonesia and China are still at less than US$20 per household – indicating they may have the potential to grow by more than 8 times before they reach maturity.

PER HOUSEHOLD SPEND ON PAINTS AND COATINGS IN SELECTED MARKETS 2005
CHINA – THE ENGINE OF ASIA PACIFIC

The Chinese market was worth US$7.3 billion in 2005, or 30% of the Asia Pacific region. The market shows enormous potential. At present, it is the second largest market in the world after the USA: yet while per household spend on coatings in the USA stands at US$169, in China this is only US$19.1. Growth has proved swift: between 2001 and 2005, value sales of coatings increased by 92%, and are projected to grow by a further 63% between 2005 and 2010. Fifty percent of the market is accounted for by decorative coatings, with growth driven by extensive property development. The fastest growing sector is industrial coatings, where demand from the appliances, automotive and electronics industries has stimulated sales. However, the market is troubled by the large numbers of small local competitors operating on a value platform, and also by manufacturers producing fake branded paints of low quality. This is being addressed by government initiatives.

CHINA: VALUE SALES OF PAINTS AND COATINGS 2001-2010

The fastest growing markets for coatings between 2001 and 2005 were Asia Pacific and Eastern Europe. The value growth of 26% between 2001 and 2005, or 6.5% per year overall in Asia, was slowed by the sluggish performance of some of the larger, more developed markets, such as Japan, Australia and South Korea, and masks the extremely positive growth of markets such as China, Indonesia and Vietnam.

Much of the growth in Asia can be attributed directly to the massive Chinese market, which accounted for 50% of total regional sales by value in 2005. Although much less significant in terms of market size and potential, Thailand outperformed China between 2001 and 2005, with annual growth rates of 24% against China’s 23%. India and Indonesia also recorded swift growth, both of 9% per year.

Eastern Europe recorded dynamic growth of over 40% by value between 2001 and 2005, which equates to an average annual growth rate of 10.7%. A similar rate of growth (13.6% per year) is predicted for the period from 2005 to 2010. Although no specific country in Eastern Europe is performing as strongly as China, there is still solid growth in the region—which is much smaller than Asia Pacific—and no developed markets are holding back overall growth. Eastern Europe is also benefiting from the relocation of industries such as wooden furniture, automobiles and packaging. Poland, Czech Republic and the Baltic States are all developing quickly as industrial centers. The region is also benefitting from the emergence of the Russian economy. While this has yet to show any real development as an international manufacturing base, thus limiting growth in industrial coatings to date, economic growth is stimulating a strong increase in decorative coatings and DIY.

LATIN AMERICA STRUGGLES TO MAINTAIN MOMENTUM

The Latin American market has been troubled over the past five years by economic and political instability. While Argentina has recorded very swift overall growth as recovery takes hold, (annual growth since 2001 stands at 29%) Brazil, the most important market in Latin America, has been slower to respond, with an average annual decline of 0.6% over the same period. Investment in industry has been limited in recent years as international manufacturers opt to hedge their risks, and much of the growth seen in the region has stemmed from decorative coatings.

Lack of regulation has also proved an obstacle to growth in parts of the region, with poor quality control and a market flooded with low quality products, especially in Brazil. This issue should be addressed by government initiatives in the medium term.
Globally, the decorative sector dominates the market, accounting for 45.1% of sales – US$38.6 billion – in 2005. Furthermore, it has shown impressive growth, increasing from 43.3% of the total in 2001, and is set to increase further to 45.3% by 2010. This translates to an average annual growth of 3.8% between 2001 and 2005, and a slightly higher rate of 5.5% forecast to 2010. Critically, decorative coatings growth has been driven by new construction, particularly in emerging markets where housing ownership and commercial developments are showing strong growth. Decorative coatings are also performing well in a number of developed markets where the housing market, particularly new builds, are strong, notably in the U.S. and Spain.

This is not the only factor responsible for driving up sales of decorative coatings. Trends towards DIY and home decorating boosted sales in a number of markets, led by media attention and by the expansion of DIY retail networks, such as Home Depot’s extension into Mexico, and Praktiker and Castorama into Eastern Europe.

Nonetheless, this challenging environment does not preclude pockets of growth. Powder coatings and automotive coatings have performed quite well – powder coatings showed annual growth of 6% across the region as a whole, while metal automotive coatings recorded growth of 3% per year, and plastic automotive coatings 1.7% per year. The shift to powder coatings has occurred mainly among the international players, with few local players taking up these products to date. Over the next five to ten years, this picture could change: as the region heads towards a more stable economic and political base, investment in industry may well pick up, and spur growth in the coatings industry. Average annual growth across the region is expected to speed up from 0.9% over the review period to 3.4%, led by investment in industry and infrastructure, notably refinery plants in Argentina, and the automotive industry in Brazil.

> DECORATIVE COATINGS RIDE ON HOUSING DEVELOPMENTS AND BUSINESS CONSTRUCTION

Globally, the decorative sector dominates the market, accounting for 45.1% of sales — US$38.6 billion — in 2005. Furthermore, it has shown impressive growth, increasing from 43.3% of the total in 2001, and is set to increase further to 45.3% by 2010. This translates to an average annual growth of 3.8% between 2001 and 2005, and a slightly higher rate of 5.5% forecast to 2010. Critically, decorative coatings growth has been driven by new construction, particularly in emerging markets where housing ownership and commercial developments are showing strong growth. Decorative coatings are also performing well in a number of developed markets where the housing market, particularly new builds, are strong, notably in the U.S. and Spain.

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INTERNATIONAL CONSTRUCTION BOOM

BRAZIL: New construction began to pick up post-2003, and is expected to accelerate. In 2004, the government introduced the National Housing System to bring additional housing to a country with a shortfall of more than seven million units.

TURKEY: Urbanization has resulted in housing and office building in major cities; economic recovery driving investment in company premises and delayed building maintenance; rebuilding of Marmara region following 1999 earthquake, in five and 10-year government funded development program.

UNITED STATES: Housing construction encouraged by low interest rates and changes in demographics, as empty nesters resize and relocate, and double income households purchase new homes and remodel existing ones.

UK: In 2004, the government announced a £3.5 billion program to build over 70,000 affordable homes in three years. This follows a period of slow housing construction, which has led to under-supply.

CHINA: World’s largest construction boom. 2008 Beijing Olympics, plus 2010 World Expo (Shanghai) and Asia Games (Guangzhou) leading to massive investment in urban infrastructure. Home ownership has seen explosive growth since the closure of the government backed welfare housing scheme in 1998, and the real estate market is officially estimated to maintain its current rate of 10% over the next five years.

SPAIN: A strong economy, high second home/tourism demand, and increased immigrant demand has kept Spain one of the leading European countries in terms of new building starts.
Decorative coatings is a highly competitive area, especially in developed markets, characterized by rising raw material prices and the erosion of profit margins due to the low price policies of the major DIY chains. In response, manufacturers have focused on innovative and higher value coatings, a factor which has helped keep value sales buoyant. Specialist coatings and unusual finishes and colors are of particularly note.

Industrial coatings determined by relocation of industry

At global level, industrial coatings are seeing the beginnings of a growth spurt – from 2001 they increased by an annual average of 2.3%, and this is expected to accelerate to 5.9% to 2010. Industrial coatings accounted for 36.1% of the total market in 2005, stable on 2001, but the figure is expected to rise to 36.9% by 2010. This growth has been almost entirely focused on the developing markets – especially Asia and Eastern Europe – as key industries have shifted from the traditional manufacturing nations in North America and Western Europe to these lower cost markets that are also showing fast paced growth in terms of local demand.

Automotive coatings are significant here, with metal coatings worth US$6.6 billion in 2005, and plastic coatings a further US$2.4 billion. Growth in these sectors has been healthy, fed primarily by the increase in car ownership in developing markets – demand in developed markets is fairly flat. Between 2001 and 2005, plastic coatings outperformed metal coatings (albeit from a much lower base), with average annual growth of 1.5% compared with 1.4%. This reflects the accelerating use of plastic parts in car manufacture, and also the increased use of powder coatings, which is serving to erode sales of metal OEM coatings. Indeed, powder coatings is the key driver in the industrial coatings sector. Between 2001 and 2005 it registered average annual growth of 10.3% and is still expected to maintain double digit growth at 11.5% a year to 2010. Powder coatings has benefited enormously from the shift to environmentally friendly coatings options, with regulation and voluntary industry change driving growth in this important and dynamic category. While the explosive growth seen in the 1990s is now slowing in North America and Western Europe, interest in powder coatings continues apace in Asia and other developed markets as environmental awareness takes a greater hold.

In the developed markets, further growth will be driven by a shift towards higher value powders (offsetting encroaching commoditization) such as higher value-added acrylic or polyurethane systems, which also opens up more application areas, especially in automobiles. Innovations which improve function and process efficiencies will also ensure continued growth – these include those offering low energy usage, thinner/more uniform films, higher yields, lower temperature curing, a wider range of colors and superior durability. Plastic coatings recorded moderate growth of 3.1% between 2001 and 2005, the result of decline in Western Europe and North America, and increase in Eastern Europe and Asia. Asia Pacific is now the centre for plastics manufacturing, and has benefited not only from demand from export markets but also growth in local demand for products such as computers, mobile phones, electronics and toys.

Special purpose coatings boosted by growing car ownership in developing markets

Value sales of special purpose coatings stood at US$16.1 billion in 2005, up by an average of 1.1% per year since 2001. Average annual growth to 2010 is expected to be higher, at around 4.1%. Special purpose coatings is the smallest sector of the market, taking a share of 18.8% in 2005, down from 20% in 2001, and predicted to continue on this path to 2010, when it is forecast to account for 17.8% of the total. The dominant subsector here is that of auto refinish, largely due to the high unit prices on this category. Auto refinish registered sales of US$6.2 billion in 2005, outperforming the sector as a whole with annual growth of 3.4% per year to 2010. The key factor behind growth here is the increasing size of car fleets in developing markets, while more mature markets have seen a less sparkling performance. Protective coatings is also a significant area, with sales of US$5 billion in 2005, and annual growth of a relatively swift 2.8% since 2001, expected to accelerate to 4.3% per year to 2010. Investment in road/rail infrastructures in developing countries (notably China in preparation for the Beijing Olympics) has been critical here, as has investment in manufacturing and power plants.
While auto refinish struggles in developed markets due to lower collision rates and improved coatings, the growth in car ownership in developing markets in Asia, Eastern Europe, and Latin America keeps the sector buoyant at global level. Given the low levels of ownership in markets such as China and India, this growth is expected to continue here for many years.

Aerospace and marine coatings are comparatively minor areas in volume terms, but high in value. Marine coatings are proving buoyant, led by healthy orders for fuel tankers in Asia, a shift towards environmentally friendly coatings, and boosted demand for yachts and pleasure boats in markets where a wealthy upper class is emerging, notably in China. Aerospace went through a difficult period between 2001 and 2002 as the commercial airline business suffered following the events of 9/11. Recovery, however, has been evident here since 2003.

CAR OWNERSHIP IN DEVELOPING MARKETS

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VALUE SALES OF SPECIAL PURPOSE PAINTS AND COATINGS BY SECTOR 2001/2005/2010

FACTS AND FIGURES
APPLICATIONS FOR POWDER COATINGS

CHINA – US$1.5 BILLION Mostly used for appliances, metal furniture and piping, as well as decorative aluminum profiles. Low use for automotives. Biggest growth area – clear coats for automotive market.

U.S. – US$840 MILLION Reaching critical point following explosive growth. Good growth still evident in metal furniture and metal auto OEM, although the latter offset by relocation of auto manufacturing to China.

GERMANY – US$221 MILLION Automotives and appliance are important here – while end user markets are stagnant, conversion to powder is ongoing. Metal furniture stagnant due to the relocation of industry. Piping is potential growth area.

UK – US$214 MILLION Appliances is the leading application, followed by metal furniture, automotives and finally, piping. Automotive use expected to grow in line with environmental legislation. Metal furniture will suffer from the relocation of the industry.

> STRONG POTENTIAL FOR THE WELL-PREPARED COMPANY
The coatings market is undergoing a period of change. The traditional markets, Western Europe and North America are fast changing shape as long established manufacturing bases fade and move to new regions, as new legislation imposes a new set of rules upon the coatings manufacturer, as manufacturers, distributors and end customers alike consolidate, creating an environment of tough competition. New markets are opening up which offer their own challenges, due to idiosyncratic consumer demand patterns, local regulations (or lack of regulation) and competition from established local players. This is a challenging market, but one which offers good growth potential for manufacturers who are able to understand and confront its challenges. The coatings market is forecast to show healthy annual growth to 2010 (5.4% by value, 6% by volume), with pockets of extremely fast growth in Eastern Europe, in parts of Asia and in product categories which answer changing demand patterns, notably those which offer environmental benefits combined with effectiveness and cost efficiency.
Packaged powder coatings
ADDING COLOR TO OUR LIVES
The Physical Nature of Color

Electromagnetic radiation is characterized by its wavelength and the intensity at each different wavelength. Color perception is caused by stimulation of the eye by the visible range of electromagnetic radiation. The visible electromagnetic radiation ranges from dark violet, (around 400 nm wave length) to dark red (wave length around 700 nm).

> So what is color?

For us in the 21st century, the answer to this question seems obvious. It should be remembered, however, that before the great color scientists such as Sir Isaac Newton, people did not realize that white light was made up of constituent colors. We did not know that electromagnetic waves of different wavelengths had different properties, and that certain wavelengths are perceived as visible color by the human eye.

> Psychology of Color

Similarly, for many years, people did not really understand that there is a clear “psychological” response to color. We are genetically programmed to respond to colors in certain ways, without even realizing that we are doing so. If asked to select a color to paint the outside of their house, for instance, most people will select one which includes yellow. This is because our ancestors once lived in the wild and there is no naturally occurring color which does not include yellow. Few people will make such a conscious decision, but it will happen nonetheless, regardless of where the people are from or their background.

The genetic response to colors is compounded, and often complicated, by social conditioning. The colors that you grow up with influence your choices so that, at the age of two, a person will see and register the dominant or main colors around them. By the age of 12, we have stopped noticing the colors and simply accept them as being natural. By the time we reach our 20s, we are actively (but again unconsciously) choosing the main colors we saw when we were two years old.

The relationship between people and color is not static. This is because our color associations and preferences are influenced by a range of diverse and varying factors and continue to change during our lifetimes. Economic decline and uncertainty, for instance, impacts on people’s attitudes towards life and is reflected in the colors we choose. People tend to decorate in secure and comforting colors, such as mushroom and latte. By contrast, during boom times, people are more likely to choose colors that both reflect their feelings of confidence and communicate success. This was seen during the stock market and real estate boom of the 1980s, when people’s sense of wealth and security was reflected in their use of more demanding and bold colors such as purple.

The way in which people think, behave, and use color therefore results from a complex and fluid interaction of genetics, social conditioning and individual choice.

> Color and the Coatings Industry

What has all this to do with coatings?

While the raison d’être of most modern coatings is to provide protection, coatings have always been used for decorative purposes, helping to create different moods and to communicate different cultural messages. These range from the use of homely colors in homes, to flamboyant car finishes, to the ostentatious use of gold paint in the palaces and homes of the wealthy. Nowhere is the decorative function of coatings more important than in the home. People are very particular about choosing the internal colors in a home because they “own” this space—it provides an environment in which they can “show off” their possessions, lifestyle and personality, and in which they are comfortable. This contrasts with the exterior structure which is not “owned” by the residents in the same way—it is identified more with the building itself—and consequently provokes a very different emotional response. Color is, of course, fundamental to a whole range of additional products including yachts, cars, packaging, furniture, airplanes, and so on. Consequently, color is the key driver for both the decorative coatings market and the innovation upon which it relies, just as much, if not more than, technological advances.

> Adding Color to our Lives

We cannot imagine a world without color. Yet we would have no choice in many aspects of our day-to-day lives were it not for coatings. Quite simply, when it comes to a whole host of objects, surfaces and structures, the way we add color is by using a coating. From the time of our earliest ancestors to the present day, color has been a fundamental part of human existence. We orientate ourselves in the world by color and our daily life is defined by it. Yet color is totally abstract—it cannot be touched, tasted or heard, it can only be seen—and its importance is largely taken for granted.
COLOR AND EMOTIONS

Specific colors are thought to be associated with particular emotions and behaviors including:

- **Red:** urgency, passion, heat, love, blood, excitement, strength, sex, passion, speed, danger
- **Yellow:** warmth, happiness, vibrancy, cowardice, brightness
- **Blue:** truth, dignity, power, coolness, calmness, tranquility, trust, reliability, belonging, melancholy
- **Orange:** playfulness, warmth, vibrant
- **Green:** health, growth, vitality, abundance
- **Purple:** wealth, sophistication, intelligence, royal, spirituality, dignity
- **Pink:** soft, sweet, nurture, security
- **Black:** sophistication, elegant, seductive, mystery, death, rebellion, evil
- **White:** purity, cleanliness, emptiness, clean, youthful, mild
- **Gold:** prestige, expensive
TREND-SPOTTING

The colors identified by the Akzo Nobel trend-spotting process for 2006-2007 in Europe reflect the changing and uncertain world in which we live, where re-use is seen as a better option than invention, and where there is a desire to improve the quality of life by shifting down a gear. Against this background, people are looking to take comfort from the past, from old furniture made new and from a return to drama and a degree of surrealism. These emerging trends are manifesting themselves in a rejection of simple colors such as reds, blues and greens, in favor of more complex and personal colors such as grey-greens with a touch of blue.

Identifying new color trends is no use if manufacturers cannot produce the new colors. So Akzo Nobel makes sure it stays one step ahead by being the only coatings company to have dedicated Research & Development color facilities (in the Netherlands, Sweden and Belgium) for architectural, car refinishing and plastic applications. By using these facilities, the company is able to look 18 months to two years into the future to predict which colors will be in demand and why. Akzo Nobel can then provide appropriate advice to its customers and ensure that it can deliver these colors to the marketplace.
> TREND-SPOTTING
Coatings companies know that consumers will not spend money unless the colors are right. They also know that if they do not provide the exact color a customer wants, someone else will. Therefore, the central challenge for coatings companies is to identify and anticipate people’s changing expectations about color.
To do so, successful coatings companies rely on trend-watchers who examine a wide range of social variables, ranging from underground and emerging street fashion, to architectural innovation and textile popularity and trends that will influence our color choices. They also look at key economic and political events which may impact on people’s color preferences. The range and complexity of factors that impact on taste and human behavior make trend-spotting a very difficult exercise. To be successful, trend-spotters need to think like a social scientist and have an instinctive, visceral understanding of the cultures they are examining.

> COLOR AND RELIGION
The color red was associated with Ra, the sun god, in ancient Egypt. In ancient Greek and Roman times, red symbolized Mars, the god of war, while blue was the color of the sky gods, Jupiter, Juno, and Mercury.
In Islamic tradition, the color green is sacred because it represents Allah—Allah cannot be represented in human form—and it is said in the Koran that the inhabitants of paradise will wear green garments of fine silk.
Hindus associate different gods with different colors. Shiva for example, the Hindu god of simplicity, humility and austerity, is typically represented in white, except for his neck, which is dark blue. His neck became dark blue after he swallowed poison to protect the cosmos from destruction.
In the Indian sub-continent, holy men wear saffron colored clothing and it is also used in religious sites because it represents the harmony of the mind with knowledge, wisdom and the environment. Buddhist monks wear orange because it represents humility.
Color plays a key role in Christianity. The Virgin Mary is typically shown in blue, and God the Father is represented by deep blue in the Old Testament. Different branches of Christianity have used color in their own particular ways. The Puritans’ austere interpretation of the Christian faith was reflected in the black and white clothing they were.
Color continues to play a key role in the emergence of contemporary religions. For Rastafarians, red, gold and green symbolize respectively the blood shed by martyrs, the wealth of the homeland, and the beauty of the Promised Land, Ethiopia.
In Imperial Rome, and today in China and India, white is the color of death and mourning, whereas in most Western societies, the color of mourning is black—it did not, however, become so until the 11th century. Syrians use brown for funerals as it symbolizes falling leaves.
COLOR IN POWER AND POLITICS

In China, the imperial color is yellow, representing absolute power and supreme sovereignty, and is the dominant color within the Forbidden City in Beijing. The roof of the palace is even made up of yellow tiles. The only exception is the roof of Wenyuanhe, the royal library, which is black, as black represents water. It was hoped that it would help to protect the library from fire.

Purple has long been the color of the powerful, being worn by emperors, kings, queens, and religious leaders. The importance of the color stems from its economic cost—it took more than 1,200 murex shellfish to make one gram of the dye in Roman times—and it was so important that Julius Caesar decreed only the emperor could wear it, while the Emperor Nero made the sale of purple dye punishable by death.

Color has also been used to encourage and symbolize political change. With the Russian Revolution, red became established as the color of revolution and socialism. Less forceful and aggressive colors have been used recently to represent less violent political change such as the Orange Revolution in Ukraine. Modern political parties and movements continue to associate themselves with different colors. You only have to look at sports tournaments to see the role that color plays in establishing and communicating national identity.
NATURAL COLOR AND THE ENVIRONMENT

Our physical environment has had a profound impact on our understanding of color. To many early humans, the red earth and the yellow sun came to symbolize life, while the blue-black of night related to passivity and quiet, but also fear and danger. The ancient Egyptians associated the black earth of the Nile with the goddess Isis and also considered black cats to be sacred, a tradition which was later extended to Europe.

To the ancient Greeks, green was the color of Venus, the Goddess of Love and Fertility. This association is echoed today in Europe and China where green is linked to spring and new growth. Natural scientists, such as Empedocles and the Renaissance physician Paracelsus, also considered color to be the soul of life and the root of all existence; the four elements of Earth, Air, Fire, and Water were given the colors of yellow, black, red, and white respectively. According to Maori mythology, when the primeval parents, Papa-tu-a-nuku (earth) and Rangi-nui (heaven), became separated, much blood was shed. Maoris see this blood in red clay and as a glow in the sky and look to it for signs and omens. This is why the Maoris associate red with nobility and divinity and consider it to be sacred.

COLOR IN THE WORKPLACE

As the nature of work has changed, and as the world has become more competitive, so the attitudes towards color in the workplace have been transformed. Businesses now recognize that color has a crucial role to play in the workplace, not just in communicating instructions, ordering and organizing the area and so on, but also in creating an environment within which employees are as efficient and motivated as possible. Practicality led to the use of color in hospitals in the 1920s to reduce glare and thus improve the clarity of vision of surgeons. But color is now used to achieve a range of behavioral—as well as practical—objectives, ranging from assisting clear thinking to reducing the stress levels of employees. Our understanding of the impact of color on the workplace continues to evolve. Recent research has, for instance, challenged the conventional understanding that bland colors such as pale greens and off-whites help workers to concentrate on their tasks by creating a more soothing environment. Although such colors may have a positive impact on concentration levels, without the presence of more dominant colors, this effect is temporary. In addition, certain bland colors may have a negative impact on the workplace—light green has, for instance, been found to unsettle people because of its association with hospitals.

THE WORLD NEEDS COLOR!

Color allows us to communicate different messages, stimulate different moods and is absolutely central to art and entertainment. Can you imagine a carnival in black and white? A multi-colored chess game? The Mona Lisa in a polka dot dress? An Andy Warhol pictures in black and white? A green steak coming with dark grey potatoes and purple red spinach?
THE SCIENCE OF COATINGS

Color has always played a fundamental role in human existence. It is not surprising, therefore, that the original function of coatings—as demonstrated by cave paintings from more than 30,000 years ago—was to provide color. As much as “science” played a part in the early days of coatings it was, therefore, focused on the challenges of producing, applying and maintaining colored coatings. It was towards the end of the second millennium that coatings science turned from empirical craftsmanship to an interdisciplinary science. This development was largely driven by the need to protect the great machines, buildings and products that resulted from the industrial revolution. The science of coatings that emerged enabled manufacturers to begin mass producing coatings with both color and protective functions.

> HOW COATINGS WORK

Even the first coatings produced in the Stone Age were made up of three basic components: pigment, solvent and binder. The function of these basic components is straightforward. The pigment is the source of the color. The binder, which forms a film after drying, allows the pigment to adhere to and protect the painted surface. The solvent allows for even and smooth application of the mixture. With a few exceptions (for example, powder coatings) these components are still the basis for each coating produced today, although they are now accompanied by a whole array of additives which are used to improve and stabilize the formulation and add increased and additional functionality to the coating.
Driven by a range of fundamental pressures and trends, and facilitated by dramatic technological advances, we are now at the beginning of the next great development in the science of coatings. The focus on color and protection has now been complemented by a concern with additional functionalities. Coatings must now serve a wider range of purposes than ever before, and they are changing from passive materials to ones that interact with their environment in an “intelligent” way.

> COLOR

In the early days, the primary objective of applying paint was either to paint pictures or to change or improve an object’s appearance by adding color to it. That’s why “paint research” was, for a long time, primarily driven by the desire to find new types of more colorful pigments. Initially, paint pigments had been derived from natural sources, such as mineral pigments from different types of soils, soot and charcoal, ground semi-precious stones, and extracts from plants and animals.

The first paints either contained no added binder (relying on the inherent binding of the pigments used) or natural occurring “binders” such as animal fat, egg white or blood. These were selected using trial and error and the knowledge about these “ingredients” was transferred from generation to generation. These binders were well suited for applications in a fairly dry environment not exposed to light and weather—many of the renowned Stone Age cave paintings which survived thousands of years perfectly demonstrate the durability of these natural elements.

But these early “paints” were not suited to the external environment—rain and weather would wash them away. Consequently, ancient paint formulators began actively looking for alternative, more resistant binders. As early as 4000 BC, their “trial and error” approach resulted in the introduction of gum arabic, gelatine, or waxes as binders for paints and varnishes in Egypt, Japan and China. By the 6th century, plant oils were being used for the formulation of paints. It was probably by chance that early paint formulators found that these plant oils have the ability to form a resin and to harden when exposed to air, forming a stable and dry film. It took another 400 years for the formulation and preparation of a standard lacquer based on this binder to be described and documented.

> COLOR AND PROTECTION

In the early years of paint development, protection of the underlying surface or object did not really play a role. At this time, research was focused on improving the application process and the appearance of the painted surface, especially with respect to the evenness and the surface gloss. Research found that certain resins can be dissolved in solvents such as turpentine, a naturally occurring solvent derived from pine resin. After application, the solvent rapidly evaporates, leaving the resin as an evenly deposited film on the painted surface. These findings allowed for the introduction of new natural and synthetic resins as binders for new, fast drying paints—right on time to meet the paint needs associated with the onset of industrialization in the mid-19th century, which triggered a huge need for better paint in high volumes. Large amounts of steel used for the construction of trains, bridges and industry installations, buildings and—a few decades later—cars, needed protection against corrosion, dust and weathering.

Up to this point, the definition of the right composition of the paint was very much dependent on the individual skills and experience of the painter and was more an art than a science. There were standardized products, produced by small manufacturers, but they were sold as half-finished products and it was again dependent on the expertise of the painter to make up and apply the finished product.

> “IT’S LIKE WATCHING PAINT DRY…”

The physical drying of a coating based on a polymeric resin dissolved in an organic solvent is different from the film forming mechanism employed in more recent water-based paints. While the first dries through rapid evaporation of the solvent, leaving the hard resin film on the substrate, the latter hardens in a two-step process—water evaporates and leaves the resins and pigments in dispersed particles on the surface. These particles then merge and form the film, followed by a chemical process called “polymerization”—chemical bonds form between small, soluble building blocks to generate a polymeric resin made up of long, non-soluble chain molecules.
Terrible events such as the destruction of the World Trade Center in 2001, and the Piper Alpha oil rig disaster in 1988, highlight the importance of ensuring the best possible fireproofing for buildings and other man-made constructions. Fireproofing methods have been continuously developed to help maintain the structural integrity of steel-based buildings and oil and gas facilities for as long as possible during a fire. This allows time for the complete evacuation of the building and significantly increases the chances of successfully tackling the fire.

Conventional fire-proofing methods typically work by applying thick layers of cement-like material to steel columns and beams. There are some major disadvantages to this approach, such as the weight of the protective material and aesthetic limitations. To overcome these disadvantages, fire protective coatings have been developed which can be applied in thin layers and are more aesthetically pleasing. When heated during a fire, these intumescent coatings do not burn, but undergo a chemical reaction which creates a thick layer of insulation around the steel structure.
The industrial revolution called for coatings produced at an affordable price, in a high and consistent quality, allowing for easy application, with a technically and aesthetically satisfying result. It was then that the rapidly evolving coatings industry involved systematic scientific methods to improve their products and invested in R&D to fulfill the demand of the growing market.

A major breakthrough, in finishing car bodies for example, was the introduction in 1920 of nitrocellulose as a binder for car paints. Nitrocellulose, a man-made resin produced by treating pure cellulose with nitric acid, was chosen because it is soluble in organic solvents and allows for rapidly drying paint formulations, while at the same time providing a hard but elastic coatings film upon drying.

Before that, the mass production of cars was severely hampered by the lengthy process involved in painting of the car bodies. Drying of a linseed oil based coat alone could take up to 14 days, followed by four to eight additional intermediate and topcoats, each requiring another day for application and drying. The use of nitrocellulose not only reduced the time needed to coat a car body from around 20 days to two to three days, but also allowed the use of spraying as a new and more efficient method of paint application. Technology has advanced to such an extent that the coating of a new car body now takes less than four hours!

> APPLICATION METHODS

The development of new coating application methods has played a significant role in reducing both the time needed to apply coatings and their environmental impact.

In 1920, the industry began to use spray guns that were modeled on medical devices used to spray medication into the mouths and throats of patients. It resulted in significant advances in the evenness and gloss of car coatings.

Around 1940, paint rollers became commercially available for the application of wall paints in particular, and other paints and lacquers later on. This technique is fast and efficient and has made life much easier for both professionals and DIY painters.

The roller techniques were the basis for the development of coil coatings, again in the 1940s. This method involves a stationary application roller transferring a very thin coating layer onto an endless sheet of steel or aluminum moving at speeds of up to 200 meters per minute. After application, the coating is dried in an oven at temperatures of up to 250°C, leaving a coated surface which is so tough it can withstand the bending, pressing and cutting that takes place during the manufacturing of metal panels.

In the early 1950s, powder coatings technology was developed in Germany for the coating of metal objects. Since powder coatings by definition contain no solvents and are dry, a special method was required for their application. The technology developed involves an electronic charge being applied to the powder using a specially developed spray gun. The charged powder particles are then attracted to, and settle on, the electrically grounded metal object. The object is then cured at temperatures of between 160-200°C. With no VOCs involved in the production or application of powder coatings, it is one of the most eco-efficient coatings technologies.

> MODERN COATINGS SCIENCE

As coatings are mixtures of pigments, polymeric binders and additives, coatings science encompasses a whole set of different, but inter-related scientific disciplines:

- Organic chemistry—for selection, modification and design of polymeric binder systems and additives.
- Inorganic chemistry—for selection and modification of inorganic pigments and functional additives.
- Analytical chemistry—for characterization of all components of a paint and their chemical interaction.
- Physics—for color analysis and characterization of physical properties and interactions of paint ingredients.
- Biology—for judgment on environmental effects, but also to improve biological stability during storage and application.

Polymer chemistry is one of the most important elements of the science of coatings and plays a central role in the formulation of modern paint coatings. This is because the nature of polymeric binder systems in coatings defines major physical properties of the coated surface. These include hardness, elasticity, resistance to water, weathering or aggressive chemicals; and aesthetic properties such as evenness of the surface and gloss.

> MILESTONES IN THE DEVELOPMENT OF MODERN COATINGS

1867 First ready mixed paint introduced (D.R. Averill)
1879 Spray-gun invented (A. Peel)
1920 Synthetic binders (nitrocellulose) introduced (DuPont)
1923 First method to test lacquer hardness (“Pencil test”, NPCA)
1925 Alkyd resins introduced as binders
1940 Paint roller (N. Breakey)
1940s Coil coatings technology introduced
1953 Powder coatings technology patented (fluidized bed, E. Gemmer)
1965 Anodic electrophoating (automotive, PPG)
1974 Self-polish copolymer antifouling (Courtaulds)
1980s Water based (trim) paint for decorative coatings commercialized
1980s High solid technology introduced
1987 Water based OEM coatings system for cars (BASF)
1992 Waterborne car refinishes
1999 Biocide free foul release system (Akzo Nobel)
**SUPERFINE GRINDING IN AGITATOR MILLS**

The recipe of a modern paint is a complex formulation containing up to more than 20 different components. As well as the basic ingredients of pigment, solvent, and binder, paint may include additional compounds such as thickeners, flow, matting and wetting agents; accelerators or inhibitors; catalysts and plasticizers—to name just a few. Unfortunately, you cannot add and mix these different ingredients like you do with wheat, eggs and sugar to make a cake dough—most of them need to be added in a very specific way, taking into consideration factors such as sequence and speed of addition, temperature, stirring speed and so on.

One of the most delicate tasks is the mixing of pigments. Pigments, being the primary source of paint color, need to be homogeneously distributed in the mixture to allow for excellent gloss, evenness and exact color match, particularly for automotive applications. When mixed into solvent, pigments tend to aggregate and to settle when stopping agitation. Therefore, pigments have to be mixed into the solvent using an elaborate process called dispersion. This employs sophisticated machines such as high speed dispersers or bead mills and well controlled conditions are needed to separate the pigment particles. Furthermore, specific additives are needed to keep the pigment particles apart once they have been separated. The specifications of these machines, as well as the specific conditions employed during the process, are often crucial for the performance of the final coatings product and are part of the intellectual property of a paint manufacturer.

**COLOR, PROTECTION AND FUNCTION**

Although color, protection and cost are still key drivers in the development of coatings, the industry and the science of coatings is becoming increasingly focused on the development of additional functionalities. Facilitated by new scientific developments such as nanotechnology, a whole range of new and improved functionalities have been added to those of color and protection, including:

- Dirt-repellent wall paints which use nanotechnology to replicate the effect of a lotus leaf—water runs off a lotus leaf, collecting dirt as it does so.
- Scratch-resistant coatings for cars and other surfaces which make use of nano-particles to create an extremely tough surface capable of withstanding attempts to destroy it.
- Conductive coatings avoiding build-up of electrostatic charges in sensitive areas.
- Anti-graffiti coatings for buildings and vehicles creating a surface which repels spray lacquers and is therefore easy to clean.
The coatings industry is clearly a part of the society in which it operates. Consequently, it is impacted by the pressures and trends driving wider society as much as any other sector. These include increased concerns about safety and security, environmental factors such as energy efficiency, resource scarcity and biodiversity, and the constant process of miniaturization. Advances in the science of coatings are enabling the industry to respond to these pressures and are helping to shape the future direction of the consumer and business markets it serves.

**REDUCTION OF HARMFUL EMISSIONS**

Societal and governmental concerns about the health risks associated with volatile organic compounds (VOCs), hazardous air pollutants (HAPs), as well as other potentially toxic substances contained in coating formulations means the industry is now employing science to reduce and eliminate the environmental impact of coatings.

The results of this movement can be seen in relation to VOCs, which are contained within most liquid-based solvents. The industry now has five different options for reducing the environmental impact of VOCs:

- **High solids technology**—these reduce the VOC content by increasing the solid content (pigments, binders and additives) within the coating.
- **Waterborne systems**—these use water as the primary solvent.
- **Coil coatings**—VOCs containing solvents can be trapped and incinerated to yield energy to run the industrial coating process of steel or aluminum coils.
- **Powder coatings**—binders, pigments and additives are compounded into a dry powder. This is sprayed onto the object, and subjected to heat treatment which melts the powder into a film.
- **Reactive solvent technology**—the solvent is not released, but reacts during the drying process and becomes part of the final film formation.

In addition to the environmental benefits, the non-environmental related performance of many of these new coatings is also significantly improved and just better for the environment.
Panels coated with paints and lacquers in outside weathering test area
There are many things that people can do to minimize their impact on the environment, and there is a constant stream of ideas regarding how we should change our lifestyles to the benefit of the planet, such as flying less frequently and cycling or walking instead of using our cars. Other suggestions go far beyond this and even extend to major political proposals, such as the reduction of economic growth and curbs on industry in order to further reduce environmental damage. The coatings industry has taken its own steps in this regard (see below), but what is undisputed across all approaches to the global environmental challenge is that resources need to be conserved as a matter of priority. The coatings industry is helping to provide a solution to this quest—a role which goes largely unnoticed by the general public—in two main ways:

- Making assets last longer—thereby reducing consumption and aiding the preservation of scarce resources.
- Increasing operational efficiency—reducing fuel use and associated emissions.

### MAKING RESOURCES LAST LONGER

Wood is a natural, renewable raw material, which over the centuries has been used by mankind in many different ways. Despite the plastics explosion of the 20th century, demand for wood remains vast. Global wood consumption is projected to increase by at least 20% by 2010 and by more than 50% by 2050. Despite the rise in managed forestry, issues around deforestation—ozone depletion and biodiversity impact—continue to be highly controversial. It is therefore important that we make the most of our wood resources—and coatings have a major part to play in achieving this.

Quite simply, the longer a product lasts, the less often it needs to be replaced. So if a coating can help a wood product last longer, whether it be flooring, exterior cladding or furniture, then ultimately, less wood will be used and at a slower rate. But there is more to it than this. Traditionally, hardwoods such as oak, cherry and maple are used to make furniture because of the natural beauty of these wood species. However, the slow growth of these trees means that replacing stocks takes a long time. The trick for coatings is to make fast-growing wood more desirable.

Innovation and research in color styling has successfully addressed this issue—faster growing woods and even man-made wood composite products can be coated to look like the more desirable hardwood species, making stock renewal on a regular basis a much more achievable target. As a result, modern coatings allow the sustainable use of fast-growing woods for applications that they were previously unable to fulfill.

As well as increasing the durability of wood, the obvious solution is to use less wood. This has been particularly evident in wood flooring, where the recent boom in demand has been considerable. Until the recent interior design boom, prefinished wood flooring typically carried a five to seven year warranty, after which it would require refnishing or replacement.

Today, due to the development of extreme scratch and wear resistant coatings, prefinished wooden floors carry guarantees ranging from 25 years right up to a lifetime. Moreover, the wear resistant properties that these coatings provide means that thinner wood flooring lasts just as long, reducing overall resource consumption. But the change is also one of habit. Prefinished engineered (plywood type construction) wood flooring has made it possible for do-it-yourselfers to install wood flooring. This has meant that these floors are gaining in popularity and are displacing sales of solid, hardwood flooring, which is good news for sustainability. The surface veneer on prefinished floors tends to be slow-growing

### MAKING CARS DURABLE

The principle of making things last longer to reduce use of raw materials, and the emissions commonly associated with production manufacturing, is equally relevant across a wide range of other fields. For example, only 30 years ago, a newly built car body would have had a life expectancy of eight to ten years, after which it simply would have rusted away. In the meantime, cars have benefited from years of paint and coatings research, protecting them not only from rust, but also from damage caused by rain and sunlight, road chippings, oil, petrol, ice, scratches and even small collisions and from the wear and chemicals in a car wash. Today, ten year warranties for new cars are quite common and there are lots of cars on the road whose bodies still look excellent even after 15-20 years of use.
HELPING AIRLINES CUT COSTS AND REDUCE EMISSIONS

The aviation sector is one area where intense competition, increasing fuel costs and public demand for cheaper air fares are compelling airlines to cut costs wherever possible. In these circumstances, coatings might seem like an unlikely candidate to help with cost savings or bringing about environmental benefits. But that is exactly what they do. Once again, the logic is simple—the heavier an aircraft is, the more fuel is needed to lift it off the ground and keep it there.

A recently developed aircraft coatings system introduced by Akzo Nobel reduces the dry weight of an exterior aircraft coating by 8 to 12%. It achieves this by using changes in the formulation and application scheme. Given that the exterior coating of a large aircraft weighs around 700 kg, this reduction is equivalent to more than 80 kg. This might not seem to be a huge weight reduction, but the annual impact on fuel consumption and the environment is impressive. Depending on the size and type of aircraft, annual fuel savings can be as high as 150 to 250 liters per kg\(^1\), meaning that the weight reduction due to the new coatings system may result in annual fuel savings of more than 20,000 liters per year an aircraft. This is equivalent to a reduction in CO\(_2\) emission of 50,000 kg.

\(^1\) Derived from airline information on annual cost savings through weight reduction
hardwoods, while the core is composed of faster growing wood species. And prefinished wood flooring is usually finished with UV cured coatings that give off little or no emissions, unlike site finished wood flooring which often uses solvent-borne coatings. Decorative coatings likewise have a double function—decoration as well as protection. Decoration follows fashion, trend and taste, which means that decorative coatings will often have shorter lifecycles than other coatings. But innovations in the decorative coatings market have meant that coatings look fresh and new while carrying out their protective duties for longer.

Innovations such as self-cleaning exterior wall paints and façade repair systems have all helped to prolong the life of coatings, meaning that there is much less temptation to paint again. Dust repellent paint, self-healing paints, as well as smell absorbent and odorless paint, have contributed to the increased durability of coated surfaces, and to an improved living environment.

Powder coatings are usually put onto aluminum on the outside of buildings. The powder keeps protecting the metal for a long time after its appearance has faded and the building is more likely to be recoated because it has new owners or is looking tired. Normal powders usually lose their decorative gloss within five years (in Northern Europe) or 18 months (in Florida and Southern Europe). The result is they look poor and would probably be recoated within 20 years. By using a high durability finish, the gloss will last 20 years (in Northern Europe) or five years (in Florida and Southern Europe) and would probably not need recoating for around 40 to 50 years. The main point with powder coating of aluminum is that nobody wants an uncoated building. But the alternatives to powder are anodizing (using sulphuric acid) or liquid paint (solvent), so powder is the green solution.

**INCREASING OPERATIONAL EFFICIENCY**

Where wood is the traditional material and an obvious candidate for protective coatings, areas such as fuel consumption and resultant emissions are key areas in which coatings are playing a positive role in reducing environmental impact. There is also an added complication. Basic science tells us that light colors reflect heat, whereas darker colors absorb heat. But in an ultra-competitive environment, airlines want to stand out and make better use of their brands, which has meant greater use of darker colors for aircraft exteriors. Studies have shown that the difference in interior temperature for a dark grey aircraft versus a white aircraft sitting on a runway on a bright day can differ by more than 30°C. The darker airplane will therefore have to use a higher level of air-conditioning, and therefore an increased level of fuel, to ensure an adequate temperature for passengers than a lighter colored aircraft. To prevent absorption of solar heat in dark colored liveries, work has been ongoing to produce coatings that lessen the heat gain in the aircraft—so reducing fuel usage and consequent emissions. In effect, coatings have changed so that they use solar heat reflecting (SHR) pigmentation, and painting schemes which cause IR/heat reflection within the paint system and prevent the conduction of heat through the aluminum skin of the aircraft.

**REDUCING ENERGY USE ON THE HIGH SEAS**

The environmental impact of the shipping sector has also been lessened as a result of coatings technologies. Shipping is more energy efficient than other forms of transport such as air, rail and cars, and the industry has made significant efforts to reduce its environmental footprint through, for example, improved hull design and the introduction of new engines. Nevertheless, with more than 500 million tons of fuel consumed annually by the world’s non-naval fleet, the shipping industry is still a very significant contributor to global warming and greenhouse gas emissions (primarily nitrogen oxides (NOX), and carbon dioxide (CO2)).

In addition to greenhouse gases, the shipping industry is also under pressure because of its impact on biodiversity. In particular, the industry has been severely criticized for its use of TBT (Tributyltin) in antifouling coatings used on the hulls of ships. Antifouling coatings are used to improve the speed and energy efficiency of ships by removing organic matter, such as barnacles, and seaweed, which builds up on ship hulls and restricts their movement through water.

These types of coatings have already played a very significant role in reducing the operating costs and environmental impact of the shipping sector. It is estimated that fouling on ship hulls can increase fuel use by as much as 40%. Without the use of antifouling coatings, current fuel use would consequently rise by 200 million tons, to a total of 700 millions tons per year. The current use of antifouling coatings is, therefore, providing the shipping industry with an annual fuel saving of US$ 50 billion. The fuel efficiency gains that result from antifouling coatings have also led to a massive reduction in the volumes of greenhouse gases emitted by the shipping industry. Without the use of antifouling coatings, emissions would rise by 640 million tons a year for CO2 and 12 million tons for SO2.
FOUL-RELEASE COATINGS – THE NEXT STEP

Antifouling coatings have already made a considerable contribution to reducing costs and addressing the environmental impact of the shipping industry, but there is still progress to be made. The newer silicon-based “foul-release coatings” do not use biocides to control fouling, but instead use a non-toxic silicon-based compound which provides a slippery, low friction surface onto which fouling organisms find it very difficult to settle. Those that do can be easily removed by simple wiping/washing or by the movement of a vessel through the water. According to Akzo Nobel’s Hull Roughness Penalty Calculator model, the use of such modern coatings instead of a traditional self-polishing antifouling coating (SPC) on, for example, a large container ship over a five-year period can reduce fuel consumption by 6,796 tons. This increase in energy efficiency will deliver shipping owners with a cost saving of US$ 1.7 million, and will reduce CO₂ emissions by 21,747 tons and SO₂ by 408 tons over a five-year period. The fact that such silicon-based coatings do not emit harmful chemicals means that they are effective without having a negative impact on biodiversity.
COATING THE FUTURE
COATING THE FUTURE

Significant advances in the science and technology of coatings, and the increasing demands being made on the sector by industry and consumers, will result in dramatic advances in the performance and protective and aesthetic properties of coatings during the coming years.

The mechanical properties of coatings will continue to be transformed resulting in increased durability, uniformity, hardness, smoothness, scratch and corrosion resistance. The capacity to manufacture new colors and our understanding of the psychology of colors and how they can be utilized will be significantly enhanced and result in a range of new products. The environmental impact of coatings will be further reduced as, for example, they become thinner, a wider range and greater volumes of renewable raw materials are used, and lower curing temperatures are required. Customers will also benefit from the development of coatings which can be applied and dried more accurately, quickly and conveniently. They will do so by using new application methods such as molecular brushes, alternative curing methods (not just infra-red and ultra-violet light), and through the extension of existing curing technologies to new areas, such as floor coatings which are applied on-site and not in specialized factories.

> SMART COATINGS

By far the most striking area of development over the next few decades will take place in relation to the increased functionality of coatings, and the development of so-called smart coatings. What distinguishes these coatings is that they react to external stimuli such as temperature, stress, strain or the environment in an “intelligent” way. The emergence of smart coatings means that the defining functions of a coating—protection and aesthetics—may be supplemented by a wide variety of potential new functionalities, as described below:

• Light and heat sensitive coatings will open up a range of new functions. This might mean, for instance, that as the temperature drops during winter, the colors in our living room may change from brighter summer colors, to something deeper and warmer in the winter.

• Smart coatings may help reduce the need for air conditioning and heating within buildings and cars. By using thermochromic coatings—whose heat reflective properties change according to temperature—a window can switch from heat reflection during warm weather to heat absorption during winter. Coatings could also be used to capture energy during the day, before releasing it as electricity or heat at night.

• Smart coatings can be sensitive to stimuli such as electricity and gas, allowing them to change color on command and warn of electricity malfunctions or gas leaks. Electrical conducting coatings create the possibility for TV screens that can be painted onto walls, and enzyme-based additives might allow coatings to be manufactured that detoxify nerve gases and leaked pesticides.

• Deliberately fading colors could also be used to indicate when a new coating needs to be applied. Easily removable coatings will become increasingly available for the decoration and protection of products ranging from household appliances to winter sport equipment.

• The development of coatings that recognize when they are damaged and are capable of repairing themselves is a real possibility. Once a bump or scratch is detected, for example, such a coating would release repair components from built-in, micro or nano-size “containers” which would release a repair fluid into the damaged area, which then cures and covers the damage.

• The sense-and-respond properties of smart coatings could improve road safety by automatically changing the color of a car into something brighter as darkness descends. Car safety could also be enhanced by the development of luminescent coatings that absorb sunlight during the day and release it during the evening.

• The coatings of the future will also have health and hygiene functions. Antibacterial polymers imbedded into coatings will kill bacteria in hospitals and the home. Coatings with absorption properties could be used to remove cigarette and other unpleasant smells, and dust repellent properties would ensure increased hygiene.

• Coatings already play a significant role in disguising and hiding objects for both military and non-military purposes. Virtually all combat vehicles are coated in camouflage colors and modern stealth bombers are hidden by their radar absorbing coatings. The development of smart coating technologies creates the real possibility of both machine and soldier being made invisible to the naked eye.

Although the future of the coatings sector cannot be predicted with absolute certainty, it is clear that driven by the emergence of smart coatings and developments such as nanotechnology, the diversity of coatings products, and their impact on society, will dramatically increase over the coming decades. They will help us to coat the future.
Nanotechnology refers to technologies that enable material control at the nanometer (nm) level, a billionth of a meter. Nanoparticles are understood to exist between 1 and 100 nm and occupy a realm somewhere between Newtonian and quantum physics. Nanotechnology allows us to build up molecular structures at the nano-level in a controlled and organized way. According to scientists, this capacity will enable us to produce a range of materials with dramatically enhanced and new properties, including for instance, hard materials that are no longer brittle; car finishes that will survive indefinitely; plastic with the same properties as steel; and a space elevator made up of carbon nano-tubes. Although nanotechnology is still in its embryonic phase and the predictions for its future impact may seem fantastic, there are enough nanotechnology products to demonstrate its potential (see Science of Coatings chapter).

The impact of nanotechnology on the coatings sector is, for example, currently being investigated through the EU Advanced Nanostructured Surfaces for the Control of Biofouling (AMBIO) research project. The objective of the project is to use nano-structured coatings that signal to algae and mussels that a particular site is not suitable for them to settle. Akzo Nobel is also, for instance, using nanotechnology to develop very hard materials that are highly wear resistant and very easy to clean, thus extending the lifetime of products.
COATINGS – BRINGING COLOR TO LIFE

Paint has an innate ability to enliven our surroundings, be it with a splash of color in our homes, or by brightening up the exterior of all types of buildings. But coatings often make an invisible contribution that we’re either unaware of, or simply take for granted. Such as when they’re used to help protect major sporting venues, or various forms of transportation.
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