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# Growth in action

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"Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs."

COMPETITIVE AND SUSTAINABLE GROWTH

*This issue of Growth in Action focuses on the progress in sustainable development achieved through improvements in materials and in products, processes and organisation across a broad spectrum of manufacturing industries.*

*Growth in Action* is the magazine of the Competitive and Sustainable Growth Programme, one of the thematic programmes of the EU Fifth Framework Programme for Research and Technological Development.

The articles and information featured in this magazine are based on material already published on the GROWTH Programme's internet website, which can be found at http://europa.eu.int/comm/research/growth/index.html. Readers are invited to consult the website for more extensive coverage of the issues addressed in this magazine and to discover many more themes and articles added and updated on a regular basis.

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# Foreword

## A development that lasts

*Sustainable competitiveness* is key to the long-term future of Europe's economy. Wealth and job creation, enhancement of the quality of life, preservation of the environment and natural resources are all inextricably linked. More than ever, they depend on the capacity of society as a whole to generate and use knowledge and technology but above all to change social attitudes towards consumption of goods, disposal of waste and use of transport and energy.

### Profitable sustainability and sustainable profit

Industry, with its 40 million workers, is the engine of the EU economy; without it neither growth nor sustainable development can exist. Industry can achieve sustainability by improving products, processes and services – enabling more efficient use of resources and minimising environmental and social impacts.

Research must help improve the competitive position of EU industry in the world market. Sustainable firms are those that constantly search new goods and services produced through efficient and quality-based systems to satisfy social needs.

Development of commercially viable and sustainable products can create 'first mover' advantages. But real breakthroughs are needed. The Commission can encourage this by bringing key skills together and by shortening development times. Financial support for projects reduces risk and makes things happen faster.

### Measurable achievements within industrial research

Since its launch in the early 1980s, the principal objective of the EU industrial and materials technologies research programme has been to develop and disseminate high-quality technologies, materials and production systems that take account of environmental and social impacts of products and processes. With a budget of over €1 100 million, the GROWTH programme has funded some 1 000 industrial technologies and materials projects.

In an independent analysis of a selection of completed projects, around 80% of respondents pointed to a measurable positive impact on the environment and sustainable development. This included reduction of material and energy intensity in goods and services, reduction of waste and toxic dispersion, enhancement of product recyclability and reuse, increase in performance, and higher materials efficiency.

More than 80% of partners also consider that their project was an important factor for their R&D strategy and facilitated an improvement in their competitive position.

### The goal of sustainability in years to come

Sustainable development espouses a broad agenda, underscoring the importance of identifying key priorities for action, particularly where the risks of non-sustainability are highest and where international co-operation is essential to ensure sustainable approaches to manufacturing and processing.

Sustainability knows no frontiers and industry is becoming increasingly global. Sustainable development is a main topic driving the Sixth Framework Programme (FP6) for 2002 to 2006. FP6 has been conceived to meet the needs for structuring and strengthening the European Research Area with new instruments to allow concentration and integration of research on priorities chosen for their relevance in economic and social terms.

Three topics are envisaged for industrial research under Priority 3 of FP6:
- Nanotechnologies and nanosciences;
- Multifunctional materials; and
- New production processes and devices.

Research for sustainable industrial production will have to pay particular consideration to human resources and social acceptance of new technologies.

The path towards sustainable products and processes is not just a challenge for the scientific and industrial community but, above all, a major opportunity for our society and our environment.

**Ezio Andreta**
***Director***
***European Commission – Research Directorate General – GROWTH Programme***

# Towards a sustainable



**Sustainability was one of the main topics discussed at the European Council in Gothenburg on 15 and 16 June 2001. The conclusions of the summit reinforced European Union (EU) commitment to the concept of sustainable development – defined as 'meeting the needs of the present generation without compromising those of future generations'. This has long been a principle underlying European Commission funded research, and is a key element in the GROWTH programme.**

United Nations (UN) summits held in Rio de Janeiro in 1992 and Kyoto in 1997 put sustainable development firmly on the global political map, while the 1999 Amsterdam Treaty made its implementation one of the core tasks for the EU. The need to link sustainability and research was reiterated at the Lisbon Council of March 2000, following the approval of the concept of a European Research Area (ERA) in January 2000 that helped stimulate the debate on sustainability.

New proposals were defined in detail at the Stockholm summit in March 2001 – and, on 14 and 15 May, the Industry Council formulated conclusions on *'A Strategy for integration of sustainable development into the enterprise policy of the EU'*. Subsequently endorsed at Gothenburg, this adds an environmental dimension to the Lisbon objective – which was to make the EU 'the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion'.

## Economic opportunities

'Failure to reverse trends that threaten future quality of life will steeply increase the costs to society or make those trends irreversible,' the Gothenburg communication warns. At the same time, it states that setting clear and stable objectives for sustainable development will present significant economic opportunities, offering the potential to unleash a new wave of technological innovation and investment, as well as generating growth and employment. In fact, sustainability has been a central consideration in the approach to collaborative research since the earliest days of the EU RTD (research and technological development) framework programmes. Successive programmes, addressing the overall objective 'to strengthen the science

# future

The Council therefore invited industry to take part in the development and wider use of new environment-friendly technologies, and stressed the importance of decoupling economic growth from resource use.

and technology basis of EU industry and to encourage it to become more competitive' as defined in the EC Treaty, have always taken into account socio-economic dimensions.

The Maastricht Treaty put more emphasis on the integration of industrial competitiveness with concerns for economic growth, the environment and safety. GROWTH, together with the other EU research programmes, has pursued this orientation; its problem-solving approach has focused research efforts on important socio-economic needs by combining sustainable industrial growth with employment; quality of life and respect for the environment. This is also the reason why projects of critical size and involving more co-ordination were stimulated under FP5 to achieve common strategic objectives.

In some sectors, significant advances have already been made – as illustrated by the successful outcomes of initiatives in industries such as pulp and paper, chemicals, electrical/electronics and automotive manufacture.

Here, production is progressively becoming more resource-efficient, and an increasing number of counter measures are being employed to avoid noxious emissions and polluting effluents. Increased attention is also being paid to full life-cycle management, which considers the environmental impact of a product at every stage, from raw materials and manufacture, through in-service use and maintenance, to recycling or eventual disposal. Eliminating risk in the workplace is yet another area being addressed.

## More research needed

A great deal more nevertheless remains to be done to attain the goal of a sustainable Europe. A recent report by the ETAN-STRATA (European Technical Assessment Network-Strategic Analysis) expert group states that, 'competitive and sustainable production can only be achieved if innovation arises out of a more integrated arena. This reorientation of research, technology and innovation reflects the fact that technologies do not exist in isolation.'

Innovations, the report observes, may fit one of two archetypes:

1. Traditional **efficiency strategies** involve a linear methodology seeking lower inputs for a given activity. Environmental gains are derived from waste reduction, the elimination of pollution, and conservation of energy and natural resources.

2. **Sufficiency strategies,** on the other hand, are concerned with the search for, and implementation of, new ways to meet human needs. They employ loop processes whereby producers concentrate on the sale of performance and the optimisation of use value – for example providing cold food or photocopied documents, rather than selling refrigerators or photocopiers. This creates a demand for competence in managing the value of the assets retained in material products. It shifts the focus from 'production' to **'production and consumption'.**

In addition, it encourages a preventative engineering approach in which technical systems are designed with resilience and redundancy, to permit continued operation in the event of component failure.

The expert group advocates that future EU RTD policies and action should foster context-breaking solutions based on sufficiency. It also emphasises the need for collaborative processes as a means of developing vision, thinking in a 'total systems' manner, identifying and solving problems, and overcoming barriers to change and joint action.

## ERA forms ideal environment

Because the world and the needs of its citizens have evolved significantly over the past ten years, such new thinking is essential if Europe is to combine sustainability with the maintenance of a competitive and dynamic socio-economic system. In short, EU industry must embrace the need to accept some radical changes from:

- An approach based on material resources to a knowledge-based approach;
- Quantity to quality, delivering products and services more adapted to the needs of its customers and of society;
- A monosectoral to a networked mode of working.

Strengthening the research community has to be based on strong links between RTD institutions and industry, especially as Europe suffers a deficit in the number of in-company researchers when compared with its international competitors. For the EU, the figure is 2.5 per 1 000, whereas in the USA and Japan, it exceeds 6 per 1 000.

In addition, Community policy must exert a leverage effect, especially as Commission funding accounts for only 4% of Europe's total research appropriations. It should therefore enable projects to reach a critical mass in fields where the efforts of individual Member States alone cannot suffice. Co-ordination of the actions should also help to improve complementarity between programmes on a national and Community scale. Synergy between the various tools available at the European level is a necessary condition to avoid the dissipation of effort.

In his opening address to the 'Bridging the Gap between research and policy' conference in Stockholm from 9 to 11 May 2001, Research Commissioner Philippe Busquin pointed out that ERA would provide an ideal environment within which to meet these demands, since it is designed to bring together the strengths of the Member States in order to resolve problems faced by the EU as a whole. He emphasised the obvious links between sustainability and policy and that science and research enable significant progress to be made in the area of sustainable development.

The principal mechanism for this will be the new Sixth Framework Programme (FP6) – which with a total budget of €17 500 million ranks 'sustainable development and global change' as one of the seven major priorities, most of which contain some reference to sustainability.

Activities of FP6 will be channelled into three broad avenues: 'Focusing and integrating Community research', 'Structuring the ERA' and 'Strengthening the foundations of the ERA'. The first of these will absorb the bulk of the effort deployed under the framework programme, and is of

## focusing and integrating european research (total budget €12 055 million)

The following priority thematic areas have been defined on the basis of European added value:

1. Genomics and biotechnology for health (€ 2200 million);
2. Information society technologies (€3600 million);
3. Nanotechnologies and nanosciences, knowledge-based multifunctional materials, and new production processes and devices (€1300 million);
4. Aeronautics and space (€1075 million);
5. Food quality and safety (€685 million);
6. Sustainable development, global change and ecosystems (€2120 million);
7. Citizens and governance in a knowledge-based society (€225 million).

In addition to the seven thematic areas, the last heading will cover:

8. Specific activities covering a wider field of research – i.e. supporting policies and anticipating scientific and technological needs; horizontal research involving SMEs; international co-operation (€1320 million).



particular relevance to the follow-up to the GROWTH programme. The research themes covered by GROWTH – Key Action 1 on innovative products, processes and organisation, and the Generic Action on materials – will be covered by the priority thematic area dealing with nanotechnologies, intelligent materials and new production processes.

### Human element

Primary instruments used to achieve the objective of pan-European research collaboration will be integrated projects, networks of excellence and EU participation in joint research programmes of Member States.

The operators – and the ways in which they learn, develop and share their competences – are equally crucial in the processes of life-cycle optimisation and the practical application of scientific discovery and technological innovation.

As a natural evolution from today's research, the framework programme will bring a socio-economic focus to future RTD, encourage multi-disciplinarity, and include provision for the development of methods to measure sustainability. It will also ensure that ongoing dialogue with Europe's citizens and enterprises will maximise understanding of, and support for, the vision of sustainable development.

> By highlighting **sustainability,** FP6 will direct attention not only upon **technologies,** but also on knowledge and the importance of **human resources.** It recognises that hardware and software alone will not solve **the problems.**

# Goals changing for production

**The advent of the ERA could have a quantum effect on the future conduct of research. Hervé Pero, Head of Unit, Products, processes and organisations, comments on the past, present and future impact of sustainability issues on industrial RTD in the EU.**



**GIA: How importantly has sustainability figured to date in your part of the GROWTH programme?**

**Hervé Pero:** While the phrase 'sustainable development' has come to political prominence over the past year, it has always been an integral part of the rationale for GROWTH – indeed, the full name of the programme is 'Competitive and Sustainable Growth'. Under Key Action 1, the objective has been to improve European competitiveness, while at the same time seeking to add economic value and employment, preserve the environment and maintain human values. Sustainability issues also imply developing a holistic view of research activities, through multidisciplinary and multisectoral approaches.

**GIA: What particular provisions for sustainability were made under the Fifth Framework Programme (FP5)?**

**HP:** The research undertaken has sought to modernise industry by developing breakthrough technologies that minimise the use of materials and resources, strive to reduce waste, improve workers' safety and avoid adverse effluent emissions.

What is most important now is to study the interaction between production and consumption – and, where possible, to stimulate changes in patterns in order to optimise the global value chain. As emphasised at the Gothenburg Council in June 2001, that means achieving the **best compromise between manufacture and the use of products and services, taking into account factors such as end-of-life technology, reuse and recovery, and internalisation of external costs.**

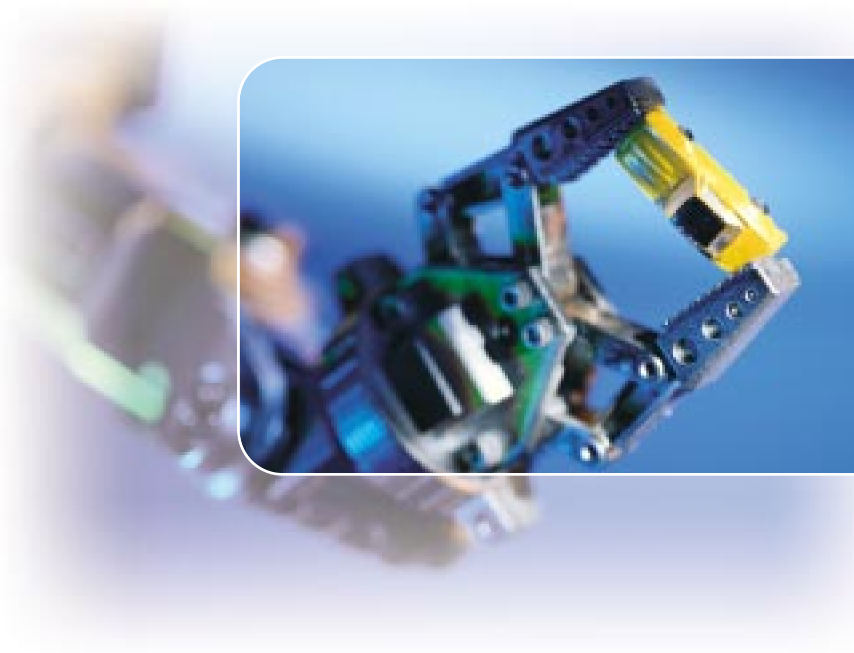
This concept has been addressed under FP5, in which the key technical elements are embodied in a series of Targeted Research Actions. These are intended to stimulate integrated and co-ordinated RTD in key areas that relate to the use of advanced technologies delivering customer-oriented product-services, including machines, that bring value both to industry and to society as a whole. Objectives include the development of resource-saving miniaturised products and processes; more efficient new-generation manufacturing machinery and equipment; and eco-efficient modern factories that couple high productivity with zero-waste and zero-accident levels. Some of this could seem like a Utopian dream, but it is certainly a legitimate goal for research. A nice example is the SUPERPOL(1) project, aiming at substituting solvents by supercritical $CO_2$ in chemical processes – a totally different, but much cleaner way of processing.

Promotion of the extended enterprise, in which people can work together more effectively in networks, was seen as a further means of improving the overall value chain. And in the context of the construction industry, we also looked at ways of making structures safer and more long-lived – which is yet another aspect of sustainability. Several examples can be found through the 'environmentally friendly construction technologies' network(2).

*(1) SUPERPOL: Polymerisation and polymer modification in supercritical fluids – a novel way for cleaner manufacturing of plastics (BRPR970503)*

*(2) http://www.tra-efct.com*

# technology



**GIA: What proportion of projects to date has had a sustainability content?**

**HP:** To qualify for support, all projects have to meet five selection criteria, one of which concerns their environmental and societal impact. This can be more or less important, according to individual cases, but our evaluation of finished projects shows that more than 80% pointed the way to significant improvements in sustainability. These could be measured in terms of reduced consumption of materials or resources, lower waste, less pollution, more effective use of products-services and infrastructure, or less hazardous processes and materials.

Various thematic networks have also been created that contribute to the minimisation of resource consumption and waste. A good example is AWARENET(3), which seeks both to reduce effluents and residues, and to promote new forms of production that make rational use of currently wasted components with nutritional value or other useful properties.

**GIA: What changes do you envisage under FP6 and the European Research Area?**

**HP:** Sustainable development, as a major societal objective of the new framework programme, will be a central pillar of future research in Europe: an essential part of the problem-solving approach.

However, FP6 adds the dimension of the European Research Area (ERA), with its broader vision of co-operation. This could lead to two significant differences.

Today, we typically undertake research and then stimulate industry to exploit the results. Within tomorrow's larger-scale integrated projects we would normally have all necessary activities of a concurrent 'research and innovation' approach, including for example provision for dealing with the relevant standardisation bodies, so pre-normative research could become much more important than it is today.

*(3) AWARENET: Agro-food wastes minimisation and reduction network (G1RT-2000-05008)*

Modules covering training and the dissemination of knowledge to SMEs (small and medium-sized enterprises) will also be incorporated. The overall impact should therefore be greater in stimulating para-research areas, such as education and technology transfer.

Through its proposed networks of excellence, FP6 could also encourage the extension of teaching curricula to include sustainability and quality-of-life aspects, including risk assessment, waste prevention and the wider perception of industrial responsibility. This is likely to have a significant medium- to long-term effect on the coming generation.

**GIA: How will this affect the future of the GROWTH programme?**

**HP:** In fact, we are in a continuum. When we combined the BRITE and EURAM industrial research programmes in the early 1990s, we were already following sustainable development principles, although they were not described as such at the time. Since then, our understanding has progressively improved – and, in FP5, the approach was spread across every programme, in particular through harmonised selection criteria.

ERA brings an opportunity to build an EU-wide RTD community, whose activities are not limited by regional or sectoral interests. If the instruments work well, they could have a quantum effect on the future conduct of research in the EU and on its impacts. Participants in future European research activities should largely be aware of this strategic political objective.

# Materials science on the move

***'Sustainable competitiveness'* is the way ahead. Luisa Prista, Head of Unit, Materials, explains how new priorities will shape the approach to materials research in the years to come.**



**GIA: In the context of materials research, how are attitudes changing towards considerations of sustainable development?**

**Luisa Prista:** The world has seen spectacular scientific and technological advances arising directly from materials research. New semiconductors, ceramics, polymers, metal alloys, biomaterials and other hybrid materials have drastically improved and changed our daily life. These advances have provided new products, generated wealth and created new jobs. Most of them have also made an enormous contribution to sustainability. Until recently, however, we have tended to think about sustainability mainly in terms of environmental impact.

The Gothenburg Council pushed sustainable development to the forefront of political awareness and, by adding the environmental dimension to the conclusions of the Lisbon Council, expanded the general perception of the meaning of 'sustainability'.

> A link between environment, prosperity, employment, social cohesion and economic reform is now established.

The challenge for industry today and in the future is not to face environmental sustainability alone, but to face what can better be described as 'sustainable competitiveness'. This new concept is wider and embraces all goals set by the two councils. Based on qualitative – rather than quantitative – growth, it tackles environmental, prosperity and social issues, as well as public acceptance, culture and human dignity.

Consequently, the development of new materials cannot be seen in isolation and must be considered within this broad context. It is essential to take account of the new materials, their means and ways of production and transformation, their applications, and their life-cycle implications for environment and society. This requires a 'system approach' and an overall integration of actors and activities.

**GIA: To what extent has materials research within GROWTH already succeeded in achieving sustainability goals?**

**LP:** Within the GROWTH programme, the Materials Generic Activity is dealing with the development of new and advanced materials and their production technologies for industrial sustainability and competitiveness. Considering environmental sustainability, research carried out by our programme has led to a series of innovative 'clean' materials and processes. Spectacular results exist in different disciplines and sectors. For example, new catalysts and synthesis routes are providing clean(er) solutions for process industries, transport and energy production, contributing directly to significant energy savings, and to air, water and soil pollution reduction. All this is accompanied by improved safety and working conditions. Other funded projects have produced new multifunctional composites for structural applications, not only increasing the functionalities but also decreasing significantly the amount of raw materials used – in certain cases a ten-times reduction has been achieved. New light materials have resulted in a huge impact in the transport sector, contributing significantly to sustainability.

We called this aspect the 'dematerialisation' process – the aim is to reduce as much as possible the material content of finished products – producing real environmental benefits. Dematerialisation of products can be obtained in different ways: by reducing size – i.e. miniaturisation; by extending product lifetimes – for example with better selection of material or the incorporation of self-repair mechanisms; by building-in multifunctionality; and by elimination of waste through reuse and recycling. To this goal of dematerialisation, nanotechnologies offer a promising approach by enabling the build-up of new tailored-made materials.

Moreover, during the last calls, we have witnessed a trend towards more knowledge-based materials and systems leading to breakthroughs and emerging markets: this is the case in biomaterials and new smart materials – materials that are able to react to stimulus and to respond to changes – for new applications. These developments are already increasing the scope of sustainability.

**GIA: What will be the focus of future materials RTD?**

**LP:** The focus will be exactly on these more knowledge-based 'intelligent' materials. Up to now we have been able to develop functional smart materials for intelligent systems. Now the challenge is to create new materials that integrate intelligence, functionalities and autonomy – i.e. capability of auto-diagnosis, self-repair, etc. Such materials will not only provide innovative answers to existing needs, but also accelerate the transition from traditional industry to high-technology products and processes. In this sense, we are moving from a 'problem-solving' to a 'problem-finding' model, bringing a more proactive stance with regard to both environmental and socio-economic sustainability.

To make this transition, research will have to pursue several different avenues:

- **Smaller scales:** the need to understand, control and master phenomena and the matter at smaller scales, i.e. the need to give emphasis to nanoscience and nanotechnology as a new approach to materials science and production. This will entail broad multi-disciplinary collaboration, and will necessitate the integration of the top-down approaches (miniaturisation) with the bottom-up approach (nanotechnology);

- **Learning from nature:** comprehending the complex physico-chemical and biological behaviour of the natural world is key to mastering and processing novel materials. The use of biomimetic materials and methodologies holds particular promise;

- **Hybrid materials and technologies:** on average, achieving a given function or performance level using composites or hybrids cuts consumption by 90% compared with conventional single materials. Organic-inorganic combinations, as well as the whole field of surface interactions and surface engineering, merit detailed study – and here again nanotechnologies have a key role to play;

- **New RTD approaches:** future long-term RTD on materials will require two types of approach: one based on openness and curiosity leading to new frontiers of knowledge, and the other more problem-solving application driven, anticipating future industrial applications. Both represent a new challenge for materials researchers requiring interdisciplinary teams; and, finally,

- We must encourage the **integration of materials into manufacturing.** A wide range of new materials is not on the market yet due to difficulties in the manufacturing process. This integration will not only accelerate innovation but also contribute to the development of new sustainable industries, products and services.

**GIA: Will the Sixth Framework Programme (FP6) encourage such advanced thinking?**

**LP:** All these concepts are addressed in FP6 – in particular in the 'nanotechnologies, materials and production' priority area. The new Integrated projects and Networks of excellence will address materials research in a global manner, enabling technological issues to be treated together with scientific, socio-economic, educational, cultural and ethical considerations. The new framework programme offers an excellent opportunity to young scientists to develop their knowledge, creativity and enthusiasm in materials science. New SMEs will also find a favourable ground for starting up. The full involvement of all stakeholders should encourage openness and responsibility, making the ERA an ideal environment for positive change and progress.

# Working for sustainability

*"... It is no longer acceptable either to avoid faci*
*to allow problems to emerge or to create proble*

*In this respect, research on new industrial techno*
*well as on material technologies aiming at susta*

**Growth Programme – External Advisory Group for the Key Action In**



Commission funding has supported collaborative industrial research at EU level for well over a decade. The BRITE (basic research in industrial technologies for Europe) and EURAM (European advanced materials) programmes were launched in 1985 and 1986 respectively, under the Commission's First Framework Programme (FP1). Under FP2, they were merged in 1989 to create the BRITE-EURAM 1 industrial and materials technologies activity. The following year, the raw materials and recycling programme was introduced to address the concern for the environment, at the same time as aeronautic research.

BRITE-EURAM quickly reflected the priorities introduced by the Maastricht Treaty in 1992, integrating objectives such as industrial competitiveness, economic growth, quality of life, respect for the environment and industrial safety. Consistent with the overall approach of FP5, defined to respond to EU economic and social needs, the GROWTH programme supported the concept of 'sustainable industrial growth', integrating competitiveness, employment and environmental aspects and quality of life in general.

GROWTH projects highlighted on the following pages illustrate advances in sustainability in its widest context – environmental, economic, sociological and humanitarian. They reflect the synergy generated by co-operation within multinational consortia involving large enterprises and SMEs, research institutes and universities, established EU organisations and partners from the applicant countries.... They show how industry can save finite resources, employ renewable materials, cut energy inputs, change the patterns of production and consumption, eliminate waste, maximise recycling, and minimise the undesirable effects of end-of-life disposal.

# in Europe

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**novative Products, Processes and Organisation**

# Reducing *materials content and energy* saving

Savings in materials and resources can be achieved by making things smaller or longer-lasting, eliminating waste and improving process efficiency. While nanotechnology is seen as a great hope for the future, successes are already being achieved through simpler measures applicable today.

## Manufacturing on the nanoscale

Carbon has been used for many years to form electrodes in battery systems. However, over 90% of the surface of conventional electrodes does not support electrochemical reactions, and is thus ineffective. The CARBEN(1) project is developing an industrial-scale system for the manufacture of carbon nanostructures that have a more controllable porosity and can give a fully active surface area 10 to 100 times greater than that of the current graphite-like material. These will find application in super-capacitors with high energy and power densities for use in trains and other electric vehicles. Nanostructured carbon will also be used in a unique regenerative fuel cell (RFC) technology for bulk electricity storage – making generating plants cleaner and more efficient.

Nanocomposites with tailor-made electrical, magnetic or chemical properties are being produced in NANOPTT(2) by filling nanosized holes in polymer membranes with various combinations of metals or with other polymers. Such materials can be used as screening to shield microwave ovens and mobile phones, or as the active sensors in 'artificial noses' and miniaturised 'lab-on-a-chip' devices for the detection of biochemical reactions. They could thus have a significant role in protecting human health and safety.

## Diamonds cut marble quarry waste

Many open-cast quarries excavating Portuguese pink marble are now as deep as 60 metres; close to the limits of cost-effective exploitation. Beyond such depths, problems may arise due to poorer material quality, safety risks and environmental penalties – inner stresses may cause waste to reach 80 to 85%.

*(1) CARBEN: Carbon nanostructures and nanotubes for energy storage, electrochemistry and field emission applications (G5RD-1999-00027)*

*(2) NANOPTT: Conductive nanowires for applications in microwave, magnetic and chemical sensing devices based on polymer track-etched templates (G5RD-1999-00135)*

In a BRITE-EURAM III project[3], a group of SMEs devised a practical solution whereby horizontal gallery quarrying could be carried out at the existing open-cast sites. This entailed the construction of a specially designed saw, using diamond belt technology to permit rapid cutting of hard and abrasive types of marble.

Productivity improves, as diamond belts require less maintenance than the serrated chains used by conventional gallery saws. Moreover, the new technology permits economical recovery of usable portions of misshapen or fractured waste blocks, while the ability to employ water cooling eliminates the need for environment-polluting lubricants.

## Water at the cutting edge

Two CRAFT projects[4] will encourage the wider use of water jet cutting as an energy-saving, environment-friendly alternative to other technologies. SME partnerships in these projects involved pump, nozzle and cutting-machine manufacturers, additive suppliers and end-users representing applications ranging from hydro-demolition of civil structures (e.g. nuclear installations) to defusing and dismantling of unexploded munitions, and from ceramics to thin metal sheet.

The first project concentrated on optimising the efficiency of abrasive water suspension jets by selection of the most effective soluble additives to improve the coherence and stability of the jet. This produced efficiency increases of 60% to 140% in the cutting of various materials.

In the second case, the focus was on miniaturising the abrasive water injection jets, in order to extend their potential to specialist applications such as those involving ceramics and magnetic materials. Developing a smaller cutting head made it possible to halve the attainable width of cut, bringing a corresponding improvement in cut face quality. At the same time, improvements in cutting efficiency resulted in substantial water savings and a reduction in abrasive consumption.

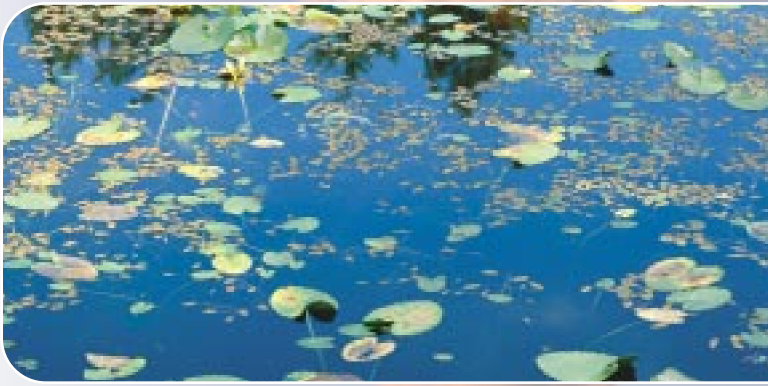
*(3) Development of equipment for hard stone underground exploitation (BRST985466)*

*(4) AWSJs: Improvement of efficiency, availability and quality of abrasive water suspension jets (BRST985261); and AWIJs: Small abrasive water injection jets open new applications (BRST985492)*



# Reducing *effluents* *and* emissions

Liquid and gaseous outputs emanating from industrial production can pollute the environment, create health hazards in the workplace and disperse potentially recuperable raw materials. Solutions are being found in more effective process control and the adoption of alternative technologies.



## Making paper without waste water

PAPER KIDNEY[5] is investigating the use of anaerobic and aerobic biotechnological treatments based on bacteria able to function at the elevated temperatures reached by recirculating water flows in the paper industry. The success of this technique has already been proven in long-term trials, and is now undergoing industrial-scale testing.

The method offers strategic advantages for paper and board mills that may be limited in their absolute effluent load by discharge legislation – which can put a brake on production. The kidney approach could make it possible to increase production while simultaneously keeping effluent discharge at former levels, or even reducing them. It also has important benefits beyond that of facilitating optimal water reuse. Bacterial decontamination converts the carbon from any organic compounds present into methane, which can be burned as a cost-saving fuel for the plant. The ability to function at a constant higher temperature also shortens paper and board drying times, potentially increasing productivity by around 5%.

SLIMEZYMES[6] is researching use of new enzymes as full or partial replacements for the biocides currently employed to combat slime build-up in pulp and paper processing. Potential candidates will be produced on a pilot scale for further laboratory evaluation and application experiments. Parameters giving best slime degradation in circulation water systems will also be identified, and these optimised methods verified under real paper-machine conditions.

Enzymes represent a clean and sustainable technology: they are non-toxic, readily biodegradable and produced using renewable raw materials. New 'green' slime control products will bring the advantage of more eco-efficient processes for industry, while benefiting consumers as a whole – especially in the elimination of undesirable substances from food packaging materials.

The overall objective of the ECOTISSUE[7] project is to minimise the environmental impact of manufacturing absorbent tissue, while also improving properties such as wettability, absorbency, storage life and user comfort for hygiene products like skin wipes, toilet paper, disposable handkerchiefs and nappies. Novel treatment of the lignocellulose fibre raw material by electrical plasma discharges in a gaseous atmosphere is being investigated to achieve these ends, while also greatly reducing the water requirement.

Based on existing experience, the team is confident that the new research will deliver the basis for a commercially viable solution, whereby the reduction or elimination of wet strength chemical additives will facilitate water recycling. The quantities of chemicals used in this process will be extremely low. In most cases, they will react totally in the discharge area, giving rise to zero emissions – and any excesses due to imbalance can easily be extracted by gas purifier systems. Derivative technologies can also be expected to find application in other product sectors – from packaging film and board to medical materials and textiles.

Without the introduction of new treatment methodology, the build-up of suspended solids, colloidal matter and dissolved contaminants makes it increasingly problematic to raise the levels of process water recycling in paper and board mills. To permit a further closure of the water loop, all such ‘accumulants’ must either be controlled or eliminated.

*(5) PAPER KIDNEY: Advanced water treatment technologies for kidney operating of zero effluent water systems for paper and board production (BRPR988002)*

*(6) SLIMEZYMES: Eco efficient novel enzymatic concepts for slime control in pulp and paper processing (G1RD-2000-00387)*

*(7) ECOTISSUE: Ecotissue by gas phase surface modification of lignocellulosic fibres (G5RD-1999-00136)*

SME partners from four European countries pooled their expertise in a CRAFT project[8] on eliminating liquid effluent by combining complementary technologies into a chained process offering an optimal balance of paper production economics and environmental benefit. The collaborative effort targeted a 50% reduction in water usage, plus energy savings of 35% and a similar decrease in the volume of chemical inputs.

A four-component regime comprising pretreatment, membrane bioreaction, electrodialysis and electrochemical activation proved capable of removing more than 97% of suspended solids from the process water, while also cutting chemical nitrogen demand by 90 to 95% and eliminating a high proportion of chemical oxygen demand. The extraction of dissolved salts was also highly effective, with removal rates exceeding 70%.

Overall, the long-term performance of the technology combination confirmed that this is a valid concept for industrial exploitation; some redesign has already been implemented in participating mills.

Reduced water consumption, together with energy savings, a 10% productivity rise from improved runnability and the

*(8) A competitive concept for the paper industry towards zero liquid effluent (BRST 985399)*

## progress in pulp and paper

The pulp and paper industry generates an annual turnover in excess of € 400 billion. Comprising more than 1 300 mills and some 1 000 pulp, paper and board producers, it provides direct employment for over 260 000 people. Indirect employment through the whole paper and forest sector brings this total to around 4 million.

Europe has long been a technological leader in this field, with a strong commitment to sustainable production. The end products themselves are based on a sustainable resource: wood fibres are both renewable and recyclable for reuse or energy generation. Currently, recycled fibre meets about 40% of the total raw material requirement, but the industry aims to increase this to at least 56% by 2005.

The sector has been successful over the past 20 years in transforming itself from a heavy polluter into a low waste, low emission producer. Innovative research solutions – such as process control electronics, process modelling and automation, biotechnological treatment of effluents, membrane separation and chlorine-free bleaching – have contributed to substantial reductions in environmental impact.

Use of advanced combined heat and power (CHP) plants to generate one-third of the industry's total electricity requirements has resulted in a 35% energy saving. Extensive adaptation of plants to switch from fuel oil to natural gas – as well as using biofuels such as non-recyclable paper to meet 50% of thermal energy requirements – has led to $CO_2$ emission reductions of 17% over the past decade, while $SO_2$ output has been cut by 55% and NOx by more than 85% in the same period.

A generally high dependence on fresh water remains a major concern, although polluting effects such as biological oxygen demand in effluents and the discharge of organic chlorine compounds have been greatly reduced. As described on these pages, moves towards the adoption of closed-loop processes wherever possible will further decrease water consumption and effluents.

possibility to recover and reuse process chemicals, could cut the partners' production costs by more than € 10/tonne. The results will also be applicable in sectors such as textiles and foodstuffs, where water plays an essential role in the primary production processes.

## New composite sets sail

Thanks to ENVIROCOMP(9), thousands of small boat builders could enjoy safer, more agreeable working conditions. This award-winning GROWTH project has produced a new composite that offers an alternative to classical glass-reinforced polyester structures,

In the EU alone, over 300 000 tonnes of polyester marine products are made each year. Their manufacture involves manual lay-down of layers of glass-fibre matting impregnated with a liquid resin in an open mould. Such products contain high levels of styrene monomer, a harmful solvent both for the environment and for health, and require strict measures for ventilation and removing emissions from the workplace.

The ENVIROCOMP solution is to impregnate co-mingled glass and thermoplastic polypropylene (PP) fibres under heat and vacuum. This not only eliminates the solvent pollution problems, but is also a cleaner, cheaper and labour-saving process – from which offcuts, and even complete mouldings, can be recycled.

*(9) ENVIROCOMP: Low pressure moulding of environmentally friendly thermoplastic composites for the Manufacture of large surface area structures (BRPR960228)*

## Leading the way to lead-free crystal

Lead crystal glass is a quality European export, but the very fact that it contains lead means workers may be at risk from metal-laden fumes, and makes waste disposal difficult. A CRAFT project(10) examining the manufacture of unleaded crystal glass showed that other metals with lower toxicity could be used to make crystal that even experienced experts find difficult to tell apart from the lead-based product. Moreover, this would also allow for safe disposal in ordinary landfill sites

The European definition of lead crystal as glass that contains a minimum of 24% lead oxide is a feature that once contributed to its reputation for quality. Today, however, it is causing consumer disquiet. Denmark wants to ban all imports containing lead, while some states in the USA require lead crystal glass to carry a health warning.

In fact, there is minimal risk to consumers, as virtually no lead leaches from glass during normal use. However, lead is an extremely toxic metal that is retained for a long time in the body. For glass workers, exposure to high levels of lead is a potential occupational hazard and the toxicity of glass waste also poses long-term waste disposal problems.

There is now pressure from some sectors of the industry to review the definition, thus allowing safe and environment-friendly crystal to be made using the alternative materials.

*(10) Evaluation of the biosafety of lead substitutes in the manufacture of unleaded crystal glass (BRST975122)*

# Towards cleaner chemicals

Chemicals form the EU's second largest manufacturing sector. Moreover, Europe is the world's most important producer of chemicals, accounting for 32% of the total global output. The EU industry directly employs more than 1.7 million people and has a turnover of € 400 billion, some 30% of which is generated by SMEs. Another 3 million employees work in sectors using the products of the chemical industry as direct inputs.

Overall, this diverse sector has demonstrated good progress in moving towards sustainability. Despite a 26% increase in production volume over the past few years, carbon dioxide emissions have remained stable – representing a cut of 21% per unit of production since 1990. Furthermore, the industry has reduced its energy consumption by 8% over the same period.

Successes to date in achieving cleaner production result both from technology developments and from strong co-operation between industry, authorities and stakeholders at European and national levels. Through the industry's voluntary Responsible Care initiative, member companies are also committed to supporting a continuing effort to improve their health, safety and environmental performance.

The OECD predicts that the future industry will look very different to that of today, with production 85% higher in 2020 than in 1995. At that time, non-OECD countries will lead in the supply of high volume basic commodity chemicals, while the EU and other OECD nations will concentrate primarily on technologically advanced markets. The ongoing drive towards sustainable technologies and the elimination of waste will thus require still higher levels of innovation.

# Changing *production* and consumption *patterns*

Adopting the total life-cycle approach to resource management requires new strategies for product manufacture and usage, with sustainability factored in from the earliest stages. Project results show that this mode of thinking can actually bring significant economic benefits.

## Electronic design for life

Consumer electronics and electrical industries are at the cutting edge of change: manufacturers are constantly redesigning and placing new models on the market to stay ahead of rivals. Technological advances in computer technology, for example, render designs redundant after only a few months. But now, proposed laws are forcing European producers to look for the first time at the lifetime costs of their products – taking responsibility for the collection and recycling of wastes, as well as for finding replacements for banned materials.

The GROWTH-funded grEEEn(11) project aims to help gauge when and where they can best adapt designs and processes, so they can improve performance and minimise the economic burden of compliance. By indicating the immediate costs of various actions, and the savings obtainable over a product's lifespan, the grEEEn model will help manufacturers to design environment-friendly equipment. Industrial partners in the project estimate that this could enable companies to cut their costs by up to 5%.

*(11) grEEEn: Cost management system for greening electrical and electronic equipment (G1RD-2000-00355)*

## Multiple use for long-life lenses

In the PLASCOAT(12) CRAFT project, a group of optical sector SMEs and their research partners set out to find a more effective means of applying scratch-resistant coatings to spectacle lenses. In doing so, they also identified a significantly larger potential market in the treatment of display covers for mobile phones and other portable devices.

The challenge was to extend the application of plasma-enhanced chemical vapour deposition (PECVD), a technique usually employed to deposit coatings on to hard substrates, to softer plastic materials used in the production of ophthalmic spectacle and sunglass lenses.

By progressively varying the composition of the coating as deposition proceeded, the team was able to achieve a smooth transition from a polymer-like structure that bonded effectively to the substrate to a tough outer protective surface. The process could therefore replace current lacquering methods, which involve use of environmentally objectionable solvents. It will also reduce manufacturing costs by increasing production speeds and improving reproducibility. Finally, superior protection could double the lifetimes of lenses, while multiple coatings would enhance their multifunctionality.

*(12) PLASCOAT: Plasma enhanced chemical vapour deposition of hard coating on optical polymers*

The outlook for display covers is equally promising. A prototype reactor is now coating substrates with areas of up to more than 1 $m^2$, making it possible to produce 20 000 to 30 000 mobile phone covers a week. Moving towards a targeted 1 million per week would open the door to an industry with a potential annual turnover of € 100 million.

## Making a cleaner cut

Cutting of metals – a key stage in many production processes – requires lubricants to reduce tool wear and dissipate generated heat. Traditional lubricants impose a high cost on manufacturers, as they account for up to 20% of the total operational cost and are largely non-reusable. Their environmental cost is also high, since the effluents are harmful.

LEPOCUT(13) deconstructed the cutting process and looked at each element to make it cheaper, better and less polluting. The main aim was to develop techniques using minimal quantities of lubricant, without risking the quality of the final product.

This wide-ranging study examined cutting tool design and materials, optimised process parameters and tested new, non-polluting synthetic lubricants. The work led to the development of a machining system including all the new elements in a process optimised to use the least amount of cooling lubricant to give a good result. It has the potential to increase the profitability of manufacturing for a key industrial sector, while also improving the quality of the environment in Europe.

*(13) LEPOCUT: Developing less pollutant cutting technologies (BRPR-CT95-0107)*

## Revolution in chemical processing?

In INTINT(14), a consortium consisting of EU and applicant country partners is investigating hybrid processes that combine reaction and separation mechanisms widely used by the chemicals, petrochemicals and pharmaceuticals industries into single, integrated operations known as reactive separation.

For optimal functioning, such processes require appropriately selected reaction column internals, feed locations and catalyst placement. The correct choice of column internals is especially important, but users have hitherto been obliged to rely on a limited choice of commercially available products. Now, however, the project partners are seeking to develop new, intelligent internals that can be tailored precisely to the requirements of specific reactive separations.

The novel methodology could revolutionise chemical plant design. Co-ordinator Prof. Andrzej Górak from the University of Dortmund in Germany predicts that its application will dramatically improve process efficiency, reducing equipment costs and total size by up to 50%. Environmental benefits will derive from increased reaction selectivity, an average saving of 10% in energy consumption and elimination of the solvents used in conventional processes.

*(14) INTINT: Intelligent column internals for reactive separations (G1RD-1999-00048)*

# Recycling materials and end-of-life goods

Legislation is increasingly obliging industry to accept responsibility for the ultimate reuse or disposal of its products or their constituents. Research is uncovering new ways to cut the cost, or even produce a profit from such activities.

## Recycling the technology

It is estimated that Europe produces over 423 million tonnes of waste each year, of which some 22 million tonnes is dangerous or toxic. In many cases, however, little is known about the sources and the extent of waste production by various sectors.

The TRAWMAR(15) thematic network promotes interaction between scientists and technologists working in different EU-funded projects on waste minimisation and recycling. In addition, it aims to generate wider interest in innovative processes and technologies, and to encourage the transfer of best practices. To achieve these objectives, it organises seminars, workshops and conferences to publicise results and identify technological opportunities that may be incorporated into new programmes or projects.

TRAWMAR currently embraces a total of 64 industries, 24 industrial research organisations and 16 universities, working together to:

- Increase the range of treatment options for secondary and tertiary waste from the metals industries;
- Secure additional markets for previously unusable waste;
- Improve the sustainable use of raw materials and reduce the need to increase energy-consuming primary metal production; and
- Define treatment of low-grade waste from the minerals, metals and other manufacturing sectors, using technology with a potential for export to the US, Far East and other market areas.

*(15) TRAWMAR: Targeted Research Action on waste minimisation and recycling (BRRT975002)*

## Green gold from old computers

Each year, the EU produces more than 6 million tonnes of waste electrical and electronic equipment – such as old personal computers, TV sets, washing machines and refrigerators – containing quantities of valuable and reusable materials. But the presence of dangerous halogen-containing compounds and heavy metals makes conventional recycling methods unsuitable. As more than 90% of such waste is deposited in landfill, incinerated or recycled without any pretreatment, its hazardous content is a significant source of pollution in the soil, water and air.

Now, HALOCLEANCONVERSION(16) has developed a novel treatment process that not only extracts the harmful constituents, but also permits the recovery of combustible fuel oils, precious metals and other saleable materials. Scrap circuit boards, for example, can be purchased for around €2 000/tonne, whereas the recovered metals alone could have a value of €7 000 to €8 000. The glass fibre can also be recovered for reprocessing. Recycling of the plastics fraction of domestic refuse was also explored – as was direct reuse of the fuel output as a substitute for electrical energy in steel manufacture.

The results of laboratory tests indicate that, when ramped up to industrial scale, variants of the process may form the core of recycling plants with considerable profit potential. Capable of reclaiming 80 to 85% of the waste from electronic, automotive and packaging products, these will offer a cost-effective way for European enterprises to achieve the clean and energy-saving life-cycle management that is key to a sustainable future.

*(16) HALOCLEANCONVERSION: Process integrated thermal-chemical treatment of halogens containing materials as source of halogens free fuels for steel production and residues for noble metal recovery (G1RD-1999-00082)*

## Metals from motors

Public demand for ever-increasing in-car safety and comfort has already increased the number of electric motors in a typical vehicle to 40, and this number could soon grow to 100 or more. CEMIR[17] set out to solve a basic problem limiting the recycling of these components.

Traditionally, motor armatures have been made from laminated steel sheets, which bend and distort under the pressure of car crushing machinery, but do not break up and release the copper wire wound around them. By switching to a process based on the moulding of metal powder, the consortium designed an armature that disintegrates when crushed, completely freeing the copper windings for recycling.

The new motors are lighter, smaller and more efficient, bringing enormous commercial potential in an automotive world market worth € 2.1 billion. They can also be used in white goods and other products, further extending the environmental benefits of materials savings and energy conservation.

*(17) CEMIR: Cost-effective electric motors with improved recyclability and less environmental impact (BRPR960249)*

## Recycling car fuel tanks

Fuel tanks made from high-density polyethylene are now the largest plastic components in more than 60% of new European cars. RECAFUTA[18] successfully found ways to remove the tanks and treat them so that the raw material can be used again to produce new tanks.

One of the major problems inhibiting recycling was to find ways of removing fuel residues and other contaminating coatings that accumulate on the fuel tanks during their lifetime. Prototype systems for the removal of external coatings and elimination of residual fuels by solvent extraction were developed and tested.

Work on the physical side of recycling has also advanced a long way. A basic industrial line capable of processing one tonne of plastic an hour is currently under development, and car manufacturers have come up with special tools that can help with the quick removal of tanks at the start of the process. It has also been found that a proportion of up to 40% recycled high-density polyethylene (HDPE) can be used in making new fuel tanks with no problems in the final quality or performance.

*(18) RECAFUTA: Car plastic fuel tanks closed loop recycling process design and life cycle assessment*



## Recycling textiles

EU consumers discard 5.8 million tonnes of textiles a year. Only 1.5 million tonnes (25%) of these are recycled by charities and industrial enterprises. The remainder goes to landfill or is incinerated, representing an enormous unused source of raw materials. Several projects have investigated the production of felts and similar products from textile waste by sorting the clothing collected. The most important research topics concerned the classification of waste and the identification of their fibres and any hazardous components in either the dye or the textile[19].

The main applications of recycled textiles are for wiping rags, fibre production and applications in the paper industry. To enlarge the possibilities, studies on how to widen the use of recycled products have been carried out. But, as in all other industrial sectors, this requires a dual approach: an increased use of products containing recycled content and a more systematic design of recyclable components and materials.

Vehicle makers, for example, are forced to recycle their products after use. At the end of their lives, cars have to be disassembled and the resulting parts used for the same or similar products, to reduce energy consumption and save resources.

Products used for furnishing and upholstery of car seats, composed of laminates of polyurethane foam and polyester or polyamide fabrics, present major disposal problems. Now a new production technology that results in a soft and voluminous product called 'knitted non woven' and based on 100% textile fibres will be developed to substitute for the polyurethane layer[20]. The new approach results in a fully recyclable textile product with enhanced wearing properties. And the recycled fibres can be reused in the new product.

*(19) Recycling of second-hand textile waste (CR1197-BRE21397)*

*IDENTITEX: Innovative technologies for the economically sound identification and sorting of post-consumer textile (BRST985363).*

*(20) Development of recyclable upholstery textiles for automotive industry design and public transport (BRPR960292)*

# making more of automotive scrap

The number of used cars – so-called end-of-life vehicles (ELVs) – in Western Europe is expected to soar from around 7 million a year at present to around 10 million by 2015. While most of the raw materials, ranging from metals and glass to plastics, can be recycled, reused or recovered, a large tonnage still finds its way as waste into landfill sites.

EU legislation is seeking to slash the amount of dumped ELV waste and to increase the proportion of materials recovered. The Directive on End-of-Life Vehicles agreed in May 2000 is the main catalyst for Europe's car makers to improve their performance. This places the responsibility on manufacturers to take back and deal with all new cars put on the market after 1 July 2001, and existing cars from January 2007.

Other environmental legislation, such as the Directive on Integrated Pollution Prevention and Control obliging industrial plants and processing companies to reduce their environmental impact, has focused some research on cleaner, more efficient technology for the smelting of metallic scrap.

Use of plastics by the car industry has increased steadily over the past decade, because such materials offer a lighter, often cheaper, alternative to metals. Although the plastics industry points to rising levels of reuse and recovery, plastics waste still accounts for a high proportion of overall auto waste.

By the end of 2005, the ELV Directive will require automotive manufacturers to reuse and recycle 80% of cars' total weight. The EU has therefore given high priority to co-operative projects and thematic networks that can tackle the industry's problems.



A comparison of the advantages of recycling with other options such as burning plastic and recovering the energy, or simple landfill, should be completed within a few months.

## Tyres turn again

Used tyres represent one of the biggest environmental problems attributable to the car industry, with most of the millions discarded every year finding their way into local dumps. A major obstacle is economic: although recycling tyres is technically possible, it is cheaper to start from scratch with the original raw material.

One way of cutting the pollution problem is to extend the life of existing tyres by retreading. This procedure, which basically involves applying a new patterned rubber surface layer to existing tyres, can be used once for cars and several times for lorries and aircraft. However, only around 12% of European tyres are currently retreaded.

Key problems in the past associated with retreading have focused on checking the steel core of tyres for corrosion, replacing highly polluting chemical solvents used for gluing on the new rubber tread, and allowing better testing of retreaded tyres to predict their future wear. A CRAFT project(21) has provided answers to all three challenges. The research results will make retreading cheaper and more reliable – encouraging wider adoption of the practice, and thus reducing Europe's rubber mountain.

*(21) Improving the control and performance of retreaded tyres (BRST-CT96-5077)*

# Growth agenda

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## Events

As part of its series of press conferences on European research for sustainable production, the GROWTH programme will be organising:

- **End of life technologies** – to be held in May 2002
- **Sustainable work places** – to be held in early 2003.

## Publications

1. **What new industrial technologies for a cleaner environment at the dawn of the 3rd millennium:** Report on European efforts to reduce environmental impact of industry, produced jointly by the GROWTH programme and the National Council of French Engineers and Scientists (CNISF) – 2001
2. **Sustainable production – challenges & objectives for EU research policy:** Expert Group report on competitive & sustainable production and related service industries in Europe to 2020 – July 2001
3. **Outline of a strategy for future industrial RTD activities:** A position paper by the External Advisory Group for the 'Innovative products, processes and organisation' Key Action – January 2001
4. **The path towards sustainable industrial production:** Leaflet on sustainable research in EU – May 2001
5. **Recycling vehicles – giving used cars a new life:** A brief overview of European research in the area of end-of-life vehicle treatment – 2001
6. **Future needs & challenges for materials and nanotechnology research:** Outcome of workshops organised by the GROWTH programme in January and March 2001 – October 2001



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