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THE IPTS REPORT

Edited by the Institute for Prospective Technological Studies (IPTS) and issued in cooperation with the European S&T Observatories Network

DECEMBER 1996

- **Solar Thermal Energy Technology: Potential for a Major European Industry**
- **Diffusion of Energy Technologies: The Influence of Increasing Returns**
- **European Craftsmanship and the Multimedia Information Society**
- **Supporting Decision Processes: Data Constraints and the Role of Knowledge-based Tools**
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EUROPEAN COMMISSION
Joint Research Centre

CEE XV/8

he IPTS Report, launched in December 1995 on the request and under the auspices of the Commissioner for Science, Research and Development, Edith Cresson, has now completed its pilot phase. What seemed like a daunting challenge in late 1995, appears now in retrospect as a crucial galvaniser of the IPTS energies and skills.

The Report has published articles in a number of areas, keeping a rough balance among them and exploiting interdisciplinarity as much as possible. Articles are deemed 'prospectively relevant' if they explore issues which are either not yet on the policymaker's agenda (but due to be there sooner or later), or aspects of issues which although on the agenda their importance has not been fully appreciated.

The thorough drafting and redrafting process, based on continuous interactive consultation with our collaborating network of institutes, which will progressively become even more involved in the process, guarantees quality control.

The first, and possibly most significant, indicator of success is that the Report is being read. Issue 00 (December 1995) - of which 2000 copies were printed in what seemed to be an optimistic projection at the time - has become a collector's item. Since then circulation has risen to 6000. Requests for subscriptions have come not only from all over Europe but also from the US, Japan, Australia, Latin America, N. Africa, etc.

The positive comments our efforts have received have been highly gratifying and the constructive and engaging criticism of our readership has formed part of the ongoing process of improvement. The comments we have received range from the informal, formal communications (in paper or electronic form), and take in as well as a Reader Survey commissioned by IPTS.

Readers' direct engagement with the content of the report's articles has led us to include a Letters-to-the-Editor section, which started in the June issue.

The rising esteem in which the publication is held is also making it increasingly attractive for authors from outside the Commission. We have already published contributions by authors from such renowned institutions such as the TNO in Holland, the VDI in Germany, the ENEA in Italy, the Council of Strategic and International Studies in the US, etc.

The Report is produced simultaneously in four languages (English, French, German and Spanish), by IPTS, to these one could add the Italian translation volunteered by ENEA (yet another sign of the Report's increasing visibility). The fact that it is not only available in several languages, but also largely prepared and produced on the Internet's World Wide Web, makes it quite an uncommon undertaking.

We will continue to strive to meet the expectations of our very diverse readership, to avoid the traps of oversimplification, encyclopaedic reviews or the inaccessibility of academic journals. The key is to remind both ourselves and our readers, that we cannot be all things to all people, that it is important to carve out our niche and keep on exploring and exploiting it, hoping to illuminate topics under a new, revealing light, for the benefit of the readers, to prepare them to manage the challenges ahead.

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uropean Research and Technological Development (RTD) policy is about to undergo a reorientation. This fact was expressed in the principles and goals underpinning the new Fifth Framework Programme which were outlined in the last preface to The IPTS report. This rethinking of RTD policy, clearly going beyond the normal updating of preceding programmes, has been triggered by three main developments in recent years.

- First of all, solving several of the most important challenges to society and economy is now regarded to be crucially dependent on successful technological innovation. The competitiveness of European industry, employment creation and what could be called sustainable development in its wider social, economic and environmental sense have been given a prominent position on the political agenda. Research and Technological Development are expected to provide options addressing these problems.

- Secondly, new insight into the processes driving the emergence and diffusion of new technologies has had an impact on our approaches to RTD policy. The research work which has been carried out in the last decade on technological innovation itself has shown that the explanatory and predictive power of very simplistic models and especially of the linear model of technological change is exhausted. We need to consider simultaneously the impact of new scientific findings, of market opportunities, of societal needs and of the contextual conditions for R&D like education, training, regulation, and culture. Only such a multifaceted view on technological innovation can help to achieve an efficient and targeted use of scarce research funds.

- Finally, the application of the principle of subsidiarity should have helped to avoid the duplication of research efforts by putting more emphasis on the co-ordination of European and national research activities. European research programmes are not meant to substitute national ones, but to deal with the European dimension of the issues at stake and to create synergies with the national programmes.

In other words, these three driving forces will first of all affect the content and the focus of the Commission's new RTD programmes. But they also indicate a need for better adjustment mechanisms between the Commission programmes and policies in order to make the overall approach more consistent. And finally, they have implications for the organisation of RTD-policy-making itself because the institutional set-up was created at a time when our thinking about the role and the emergence of technological innovation was much simpler than it is now.

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Some initial steps have already been taken in recent years to address these organizational questions. The task forces have been created as a means of co-ordinating policies horizontally and to achieve a deeper involvement of industry and other societal interest groups in key policy areas like transport or water. And the recent Commission documents, especially the Green Paper on Innovation, have taken several of the new insights on board, preparing the ground for more specific measures.

Related to these institutional issues is the situation of the Commission's own research activities in the institutes of the Joint Research Centre. They are expected to contribute to dealing with these new challenges. The JRC is part of the institutional structure of the European Commission, and it fulfils the role of a neutral body which supports the European institutions - on scientific matters - in the formulation and implementation of their policies. The high complexity of innovation processes and the corresponding need for knowledgeable, independent and competent advice therefore gives the JRC a very important function. It is obvious, that this function can only be fulfilled if the JRC is open to new developments in society and able to adjust its research activities to the needs outlined above. The deeper involvement of the JRC-institutes in competitive and socially driven research has been a first step in this direction. In the coming months the shaping of the Fifth Framework Programme will be an opportunity to carry past lessons further, not only for the JRC but for European RTD policy as a whole.

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The first article in this issue examines the prospects for solar thermal technology (STT), a renewable energy technology which can already provide 80-100 MW power plants at near-competitive costs. With government support for R&D and, critically, for the construction of plants during the early stages, STT will be able to compete with fossil fuels by 2010. This has a number of implications, amongst which the fact that STT could become part of a more sustainability oriented energy supply. Climatic factors mean the benefits of STT are more direct in the southern, less favoured regions of Europe. Moreover, the European industry's early lead can be consolidated and export markets can be exploited in sun-belt regions worldwide.

The second article argues that recent academic studies and policy reports have (again) underlined the importance of increasing returns, as well as factors often overlooked by analysts, such as technology lock-in, irreversibility, etc. The presence of such phenomena (along with other market failures and/or deviations from perfect competition) may cause markets to pass over the most desirable technology, as witnessed in the cases of the energy technology examples presented in the article. In such instances, the article argues, proactive technology watch and preservation of technological diversity may be the most appropriate response.

The third article argues that software development could become the bottleneck for the emergence of the information society, as well as an area which Europe in particular may well need to emphasise. Software production still remains a craft-like, labour-intensive process, often crucial for the success of industrial products. The article advocates emphasising training aimed at improving software skills, as well as collecting appropriate statistics on the demand and supply of the requisite skills in order to fine tune skills supply to market demand.

The penultimate article does not deal with an individual problem, but with the problem-solving, decision-making process itself. It suggests that the ever-increasing amounts of information decision-makers have to consider are not best dealt with by most standard decision support system (DSS) tools. More emphasis may be needed on analysis and knowledge extraction, rather than information collection. The article argues that artificial intelligence techniques/tools (e.g. neural networks, fuzzy logic, etc.) could enrich DSS tools in order to enhance knowledge acquisition, extraction and representation, especially in those all too common cases in which information is expressed in non-quantifiable, natural language form.

The final article projects a bright future for biodegradable plastics thanks to their energy-saving and positive environmental impact characteristics, made possible by recent technological developments. The article suggests this positive profile, and the interest expressed worldwide in this potentially very important market, may call for a review of waste management policies in Europe and the adoption of appropriate standards.

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Solar Thermal Energy Technology: Potential for a Major European Industry

Irving Spiewak

Issue: Solar thermal technology can be utilized now to provide 80-100 MW scale power plants at close to competitive costs. There are improved technologies on the horizon that would fully compete with fossil fuels by 2010 with the help of government support for research, development and the construction of early plants.

Relevance: Solar energy could be a key part of a global sustainable energy supply. European industry is in excellent position to build solar thermal plants, creating manufacturing jobs, and construction and operations jobs in some depressed regions of southern Europe. Going beyond Europe, the EU industry could assume a world leadership role and develop major export markets to North Africa and other sun-belt regions if it is given favourable policy treatment.

The European Parliament resolution on renewable energies has called for a large increase in the European use of renewable energies, with a target of 15% of the primary energy mix by 2010 (European Parliament, 1996). This represents a formidable challenge to the national governments of the EU, since the current use of renewables amounts only to 6%. The resolution argues that such an increase is justified to conserve the limited resources of fossil fuels, to reduce dependence on imports, and to begin a serious effort to reduce the build-up of greenhouse gases in the atmosphere. Of the renewables, only wind has been positioned to contribute a significant share of any increase in the use of renewables. Solar-thermal technology has also progressed to the point of readiness to use on a large scale, and could reach commercial competitiveness by 2010 given appropriate government support

Solar thermal has an anticipated economic potential for about 23000 megawatts of electricity in the Mediterranean region by 2025 (DG XVII Expert Group, 1996). About 2/3 of this economic potential is in the northern Mediterranean countries (H. Klaiss et. al., 1991), while the bulk of the physical potential resides in Africa. If the EU countries introduce a "CO2 reduction" scenario, the solar capacity in the Mediterranean region could reach 13500 MW by 2005 and 63000 MW by 2025. This might include substantial transport of solar power from North Africa to Europe.

The European Parliament has called for an increase of renewable energy's share from 6% to 15% Solar-thermal technology could give vital support to wind energy in the effort to meet this target

There are 350 MW of operating parabolic trough solar plants that have demonstrated high reliability and outstanding ability to meet peak load demands in California for a decade. Power from these plants is available on demand by means of hybridization with natural gas. European-owned industry controls this technology and could undertake at least 80 MW per year of new projects with the present manufacturing plant capacity.

In California solar thermal energy has demonstrated its reliability and ability to meet demand for over a decade

The present costs of electricity from solar thermal power plants are about twice the costs of the best fossil fuel technology. It is anticipated that a

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As well as forming part of a mixed technology generation scenario, solar thermal energy could be used to generate clean fuel for transportation to where it is needed

properly focused development strategy could cut the solar plant costs in half by 2010. Such a strategy would include the construction of plants with the best available technology to build utility capabilities, and sustained technology improvement and demonstration. The present European lead in this area could be maintained and strengthened. This would, however, require that the European industry intensify its technology development and actually build commercial plants.

Beyond 2010, solar-thermal, together with wind and hydropower, could provide the bulk of central-station renewable electricity. This would be supplemented by distributed power generation by photovoltaic cells and biomass. There are also excellent prospects for the penetration of solar thermal technology into the production of clean fuels for transportation and distributed electricity generation via high temperature thermo-chemistry, using technology based materials processing in a high-temperature solar furnace. Initially, natural gas, biomass or coal could be converted to methanol or hydrogen in such solar furnaces operating at 800-900 degrees Celsius. Eventually, we could anticipate water-splitting processes operating at 1300-1500 degrees to produce hydrogen as a major energy supply vector.

European Solar-thermal Experience

Many solar-thermal projects were undertaken in response to the oil price crises of the 1970's. These included the construction of four solar tower prototypes in France, Italy and Spain, and a parabolic trough prototype in Spain. These early solar power plants failed to reach the desired performance levels and currently only those built at Almeria, Spain are operated, as research facilities. They constitute the main European solar research centre (the 'Plataforma Solar de Almeria'). No solar -thermal power plants have been built in Europe since the early 1980s because of the low price of fossil fuels. The unsuitability of the northern European climate for this technology has been a factor in discouraging investment by some national governments. However, current trends to the globalization of energy markets implies that the potential of this industry should not be underestimated.

The current trend towards globalization of the energy market makes production in sun-belt countries for consumption in the north a possible future option

Active research and development has been supported in the EU at the national level, notably in Germany and Spain, at a rate of about US$23 million per year. EU national programs constituted 43% of the OECD world-wide budget for solar-thermal R&D during 1991-3 (International Energy Agency, 1994) and were approximately the same as the US government expenditures.

Status of Technology and Costs

Solar-thermal technology was commercialized by the Luz Co. (Israel) that built the series of plants in California from 1984 to 1990. Their parabolic trough technology was similar to that demonstrated earlier at Almeria. Luz was forced into bankruptcy in 1991 when previously available government subsidies were terminated and they were unable to get the necessary financing for the next plant. Their technology and manufacturing assets were purchased by a Belgian company, now Solel Solar Systems, Ltd. Pilkington Solar International GmbH (Germany) built the mirrors for the California plants and they, together with Solel, are actively marketing the Luz technology. They are able to supply power plants of up to 80-100 MW at costs of about US$2800/kW.

The competitiveness of these plants depends strongly on the underlying interest rate and other local factors. For a real interest rate of 8%, a subsidy of about 1/3 of the capital cost is needed to compete with fossil fuel-fired plants. Once the plant enters operation, the power sales should substantially exceed the costs of operation and create a positive cash flow to recoup the investment cost.

The plants currently being offered are far superior to the early prototypes in that they incorporate the learning based on many years of operation and offer firm power via fossil fuel backup, including the optional combination with highly efficient and

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economical gas turbine plants. More advanced parabolic trough and tower plants are being developed in Europe, Israel and the USA. With an appropriate program of development and plant construction, solar-thermal electricity costs should be fully competitive by 2010 in the Mediterranean and other sun-belt regions. See Figure 1 for the solar thermal industry learning curve.

Cost reductions of up to 50% are expected, relative to current solar-thermal power costs as a result of a combination of the following factors:

- Development of innovative mirror systems, the solar collectors constituting 30-40% of present plant investment cost.
- Development of simpler and more efficient heat transport schemes such as direct steam generation and superheat in parabolic trough geometry.
- Higher temperature, more efficient receivers and power cycles, including Brayton (gas turbine) cycles.
- Novel optical systems such as beam-down power towers that provide close physical coupling of the receivers and power block
- Improved integration of solar and fossil-fuel inputs to hybrid plants.
- Benefits of learning and scale in larger plants and factory mass production of solar components.

Market for Solar thermal Technology

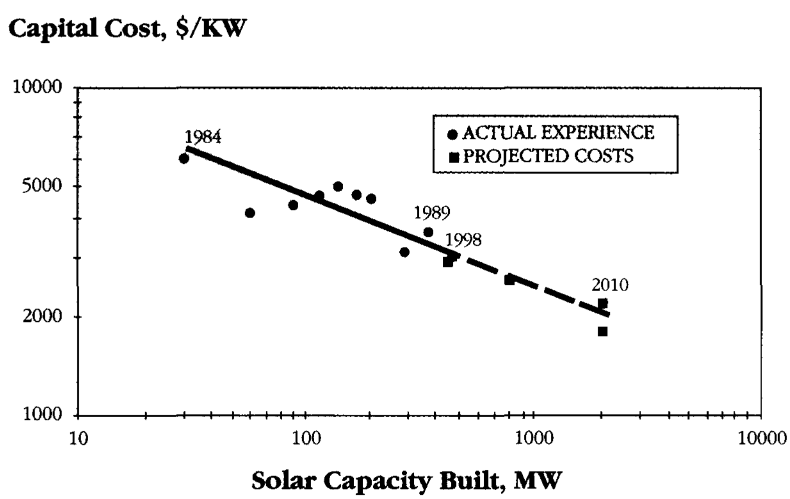
Projections of future demand for electricity indicate world-wide growth of 2.0% to 3.3% per year between 1995 and 2015 (EIA,1996). This requires addition of about 90 GW of capacity per year. Growth is particularly strong in the developing world, including a number of sunbelt countries with large populations. Feasibility studies of solar-thermal power plants have been conducted, under various sponsorship. These indicate potential markets in southern Europe, North Africa, Jordan, Israel, India, the USA, Mexico, and Brazil. We have carried out an analysis of potential market growth following commercial maturity and competitiveness. We estimate a market share of 5 GW per year for solar-thermal in a business-as-usual scenario. A much faster growth would be feasible in response to government stimulation, for example if needed to reduce carbon dioxide emissions.

Solar thermal plants can offer firm output by hybridization with fossil fuel generation technology

Requirements for a Self-sustaining Industry

A significant contribution of solar-thermal power to the European Parliament's 2010 target cannot be achieved without a higher than present rate of investment in R&D and demonstration plants. Any self-sustaining renewables industry cannot develop rapidly based on market forces alone because of

Figure 1: Solar Thermal Industry Learning Curve



Demand exists worldwide and a market share for solar thermal technology of 5 GW per year is estimated. This could rise sharply if governments move to limit carbon dioxide emissions

High R&D costs make it difficult for this sort of technology to be developed rapidly on the basis of market forces alone Moreover, it receives little funding relative to other renewable energy technologies

the high cost of the R&D and demonstration steps, and the long time required to recover these costs. The introduction of renewables is currently supported by OECD national government R&D budgets of about US$700 million annually, of which the EU countries contribute about $300 million (International Energy Agency, 1994) plus some additional incentives for commercial sale of clean energy. The EC Fourth Framework Program allocates an additional 435 million ECU (about US$540 million) over four years 1994-98 Solar-thermal R&D gets about 8% of the national renewables budgets and only 1.2% of the EC Program's renewable energy budget. Renewables in total received only 7.2% of the total OECD budgets for energy R&D in 1991-3.

The European industry enjoys a technological lead and proximity to many consumer countries which could give it an important position on the world market

Manufacturing experience can be gained only by building plants and constitutes one of the essential ingredients to a self-sustaining solar-thermal industry. Similarly, the engineering- construction companies, the utility operators, and government regulators in the technology user countries need to be involved at an early date to develop a demand for, and confidence in, solar energy. This process requires funding by international banks and national governments. The World Bank is considering support to several proposals for solar-thermal power plants. We have estimated that supplementary funding of 400 to 700 million ECU over a 12 year period by a combination of international, national bodies and the EC would lead to a self-sustaining industry. The European industry is well positioned to gain a leadership role because of its existing capabilities and its proximity to the major user countries.

It has been estimated that each solar-thermal project will create 1000 man-years of employment in the host country during the manufacturing/ construction phase and 50 jobs for plant operations during 20-30 years

Special mention must be made of the importance of North African countries in this process. They are already becoming linked to the European electrical grid. Because the peak demand for power in Africa occurs later in the day than in Europe, it is logical to exchange solar power generated in Africa for base-load power generated in Europe during the evening. In Africa the solar resources are superior and labour costs lower, so African countries could supply cheap low-technology components to be integrated into the high-technology European solar products. After 2010, we may expect breakthroughs in superconductor technology (New Technology Week, 1996) that would reduce the costs of long-distance power transmission across the Mediterranean.

Benefits and Impacts

It has been estimated that each solar-thermal project will create 1000 man-years of employment in the host country during the manufacturing/construction phase and 50 jobs for plant operations during 20-30 years. Depending on the capabilities of the local industry, it has been estimated that 40-50% of the initial costs will be spent in the host country (Pilkington, 1996). The host countries would benefit from the electricity production using indigenous resources. Their fossil fuel purchases would be reduced, or in the case of fuel-exporting countries, their exports could be increased. Projects of this kind will create employment for engineering and manufacturing in the European Union. The European industry is poised to assume a world leadership role in this important technology.

If there were a massive increase in the use of renewable energy, it would serve to reduce market pressure on fuel prices at a time when fuel resources might be less abundant, thereby increasing the stability of fuel prices. The operating solar plants would reduce the output of carbon dioxide and other greenhouse gases, compared to alternative electricity generation based solely on fossil fuels. On the negative side, expanded use of renewables, while increasing overall employment, would reduce employment in other energy sectors, principally coal mining.

Beyond Electricity

Research has demonstrated the feasibility of high-temperature (thermochemical) gasification of carbonaceous materials such as biomass, coal or oil-shale at 800-900 degrees Celsius to produce a fuel gas mixture of hydrogen and carbon monoxide. This syngas can be further processed into methanol or pure hydrogen. The expected advantages of such processing carried out in a solar furnace are yields of fuel products with

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calorific values above those of the carbonaceous feedstocks, and the ability to process low-grade and waste materials with essentially no emissions to the atmosphere other than small amounts of CO_2. Exploratory research at higher temperatures of 1300-1500 degrees with metal oxides indicate that eventually it will be possible to separate water into hydrogen and oxygen at reasonable cost.

Solar thermo-chemistry could therefore play a major role in replacing fossil fuels, not only in the production of electricity, but also in transportation and heating fuels. The largest cost component, here again, would be the solar collectors. The innovations in optical systems in solar electricity production could also be utilized in the production of solar fuels.

Conclusions

Solar thermal technology can make a major contribution toward the replacement of fossil fuels with renewables, leading to a sustainable energy system. The European industry is in an excellent position to assume a world leadership role in such a process. There would be significant job creation in such an industry. However, government support for research, development and construction of early plants would be required during the initial phase. It is expected that, with such support, a self sustaining and expanding solar electricity industry would be viable by 2010. Beyond 2010, solar thermal technology could contribute to the production of solar transportation and heating fuels, particularly hydrogen and methanol.

Thermochemical gasification of low-grade fuels to produce higher-grade syngas and the direct splitting of water into hydrogen and oxygen are two further applications of solar thermal energy that may be feasible in the future

Keywords
electricity generation, solar energy, renewables, CO_2 emissions, environmental protection

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Irving Spiewak holds a Master of Science degree in Chem Engineering, from the Massachusetts Institute of Technology. Before joining the IPTS as a Visiting Scientist, specializing in technology watch in solar thermal energy and other renewables he worked as a research scientist and program manager at Oak Ridge National Lab, USA, and a research scientist at the Weizmann Institute of Science, Israel. His research interests include the energy/environment field

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Diffusion of Energy Technologies: The Influence of Increasing Returns

Stéphane Isoard

Issue: The recent publication of the Commission Green Paper on Innovation has brought to the forefront concepts embedded in the mainstream of evolutionary theory thinking. The Joule III program also devotes particular attention to the analysis of energy technology dynamics and its environmental and economic consequences. Recent advances in mathematical and modelling techniques now make the formalization of this approach possible and permit the quantitative assessment of the theory.

Relevance: From the perspective of increasing returns, the most efficient technology is not guaranteed to prevail in the market, nor even to survive in it. Therefore, R&D policy may need to concentrate on encouraging technological watch and on preserving technological diversity. In competing technology systems, institutional organizations may have a role to play in promoting socially and environmentally desirable technologies when alternatives have serious imperfections, thereby securing the most beneficial technology path.

Introduction

Based on Schumpeterian ideas, Evolutionary Economic Theory focuses on the integration of the dynamic components of technological change in the diffusion of technologies

Mainstream economic models often make strong assumptions regarding perfect competition within markets, characterize technology as a free commodity and assume the maximizing behaviour of agents. Some emerging disciplines, such Evolutionary Innovation Economics, Industrial Economics and the Sociology of Technology, have, in recent years, developed alternative paradigms of technological diffusion processes. The Evolutionary Economic Theory, mainly built upon Schumpeterian ideas, has focused in particular on the integration of the dynamic components of technological change in the diffusion of technologies: technological uncertainty, externalities, diversity and market selection mechanisms have been introduced and recently formalized.

The issue of *returns* perhaps deserves special attention. Within conventional economic theory, decreasing returns to factors of production and constant returns to scale are assumed in order to ensure the unity, stability and predictability of the economic equilibrium, obtained as a solution of an optimisation problem. This, however, means it is often impossible to explain the technology lock-in phenomena related to competing technology systems. The integration of the dynamics of technological change with evolutionary economic theory can provide new insight into these technology diffusion processes. The presence of increasing returns (to scale, to adoption, etc.) may be interpreted as the consequence of learning *effects* which endogenize technological change and lead to irreversibility and path-dependent phenomena. This approach may be adequate for describing the *diffusion* of some energy technologies and the corresponding energy *technology trajectories.* We will point out several examples, among them the competition between engine technologies as a power source for automobiles and competition between different nuclear reactor technologies.

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This analysis should provide new thinking which may be relevant for the implementation of energy R&D policy.

Increasing Returns Framework

Individual technologies may present *increasing returns* to scale and to adoption. The former is related to decreasing unit costs related to production increase (learning by doing), whereas the latter reflects the fact that, the more technologies are adopted, the more is learned about them (learning by using) and the more incentive there is for further adoptions. Increasing returns lead to self-reinforcing processes: which means that a technology that gets ahead, tends not only to stay ahead, but consolidate its position as leader Whereas the competing technologies have progressively greater difficulty in entering or surviving in the market. Positive and negative self-reinforcing processes characterize the presence of increasing returns. When technologies exhibiting increasing returns compete, small events may possibly give one of them an initial advantage, favouring its adoption. Then, thanks to these early events that induce more improvements in this technology than in the others, it may attract a broader proportion of potential adopters, and, finally, lock-in the market. These 'small events' that might affect technological choices may be the strategies of individual entrepreneurs, prior experience of technology developers, political circumstances or simply the timing of contracts. They are typically unknown to the adopters before the outset of competition, and so are not endogenized in their strategic choices

This positive feedback can be a *source of instability in the economy.* It magnifies the random events which historically could accumulate and over time determine which competing technology will emerge and eventually lock-in the market. Thus, systems of competing technologies are characterized by the multiplicity of potential outcomes.

Evolutionary economic theory, which takes into account the impact of increasing returns, provides a model of the economy as a complex system. From this perspective it is not deterministic, not predictable, but instead, process-dependent and constantly evolving. Therefore, the economy we are looking at is, in part, the result of its own historical path. It creates and imposes path-dependent processes such that, in the end, the market structure is selected by a process that is at least partly random.

Moreover, the technology that comes to dominate is *not necessarily the most efficient.* Early events can lock the market into an inferior technological path. Technologies which improve slowly at first but have huge long-term potential, may be locked-out. Finally, once a technological and organizational structure has prevailed and benefits from its increasing returns, it is difficult to change it (the required subsidy to shift from a technological path to an other increases with the degree to which the process is locked-in). Then, for a firm which has made the wrong choice between technologies, the strategy shifts to one in which they try to anticipate the next technological trajectory, the next innovation wave, and to position technologically and co-operatively (ie by establishing partnerships with other actors) in order to exploit it.

We have by now outlined the three theoretical concepts characterizing competing technology systems with increasing returns: *non-predictability* of the outcome, *possible sub-optimal efficiency* of the selected path, and *structural inertia* to shift to an other (perhaps more efficient) path. A model that integrates the lock-in phenomena caused by random historical events, induced by learning effects and increasing returns, leading to path-dependency and irreversibility, may be well-suited to describing the diffusion of competing technologies.

Modelling of Path-Dependent Diffusion Processes

We will present here a simplified example of the way in which the competing technology systems can be modelled in order to explain the long run adoption shares in such a dynamic process. Particular attention should be paid to the two following concepts:

(1) the fact that the choice between alternative technologies may be affected by the rate of adoption prior to the time of choice, and

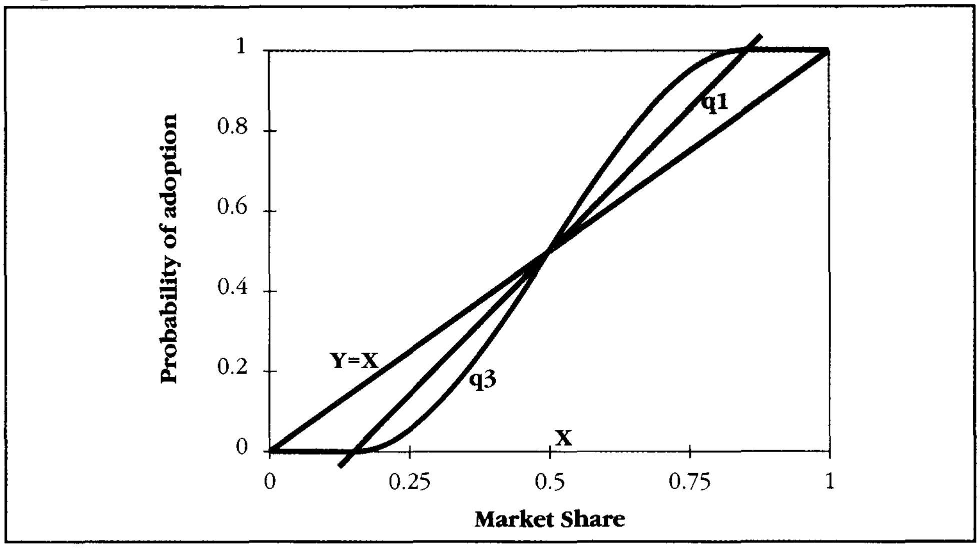
Traditional economics is often unable to explain the technology lock-in phenomenon in which one technology effectively excludes even superior competitors from the market

The more a technology is adopted, the more is learned about it, and the more incentive there is for further adoptions

The present economy is the result of its own historical path; once a technology has prevailed under increasing returns it is difficult to change the situation

Small, apparently unimportant, events may shape ultimate outcomes in a way that influence or constrain choices about which technology to adopt

Figure 1: Adoption Function

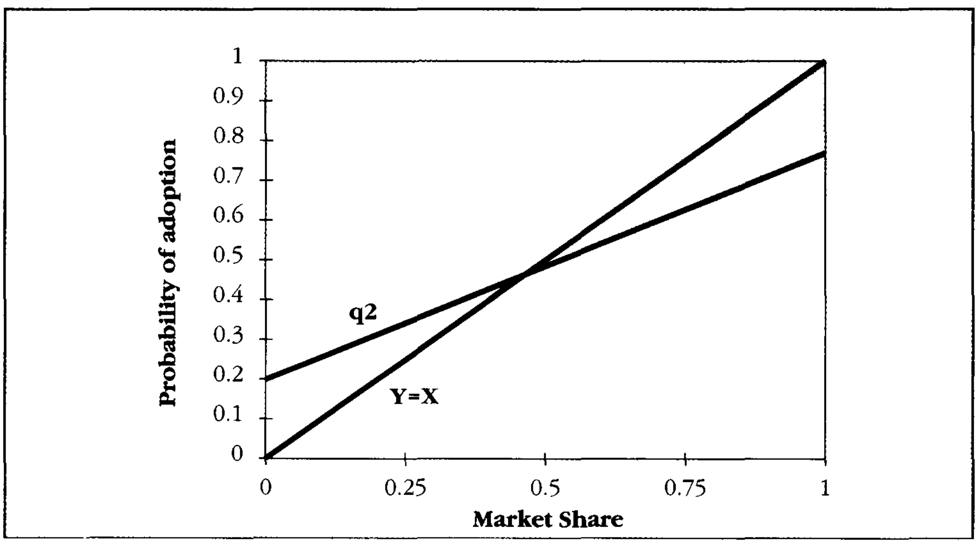


(2) the fact that small events - possibly random ones - may influence adoptions.

Let us take the case of a market where a typical investor has to choose among K possible technologies at a given time. An individual adoption is made of a given technology with a probability that is a function of the present market-shares of technologies. *Increasing returns to adoption* of a particular technology are then characterized by a *more than proportional* effect of its market-share increase on its probability of being chosen and adopted. The probability of a particular technology being adopted at any moment is not necessarily equal to its market-share. It depends rather on an *adoption function* which maps the market-shares into selection probabilities. The characteristics of this adoption function entirely determine the different outcomes (the technologies which may lock-in the market, or the ones which will survive on it) which are supposed to emerge. For this simple discrete sequential-choice problem, we will demonstrate how different events at the outset of the path can dynamically select completely different final structures.

The function q1 in Figure 1 plots an adoption function when there are two competing energy technologies (for instance, renewable 1 and 2). When the probability of adoption is higher than the

Figure 2: Adoption Function



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market-share, there are *increasing returns to adoption*, the technology tends to lock-in the market, and vice versa. The overall outcome depends on the accumulation of the random events that occur in the launching phase of the process. On the other hand, some functions may have, in the long run, a unique stable equilibrium. The function q2 in Figure 2 will lead the two competing energy technologies to share the market equally, with 50% each. Therefore, it appears that the technology will either lock-in or be locked out of the market if and only if, (1) up to a certain market-share x, there are increasing returns (cf. function q1), or at least positive feedback (cf. function q3) and that (2) by x, there are decreasing returns (cf. function q1) or at least negative feedback (cf. function q3). Therefore, the diffusion process will be path-dependent since the probability of adoption of technologies does not equal their market-shares.

Figure 3 plots the results obtained with this model, with an adoption function of type q3. It shows the path-dependency of the different simulated technological trajectories. The studied technology locks-in or is locked out of the market on the basis of the random historical events which select the path of diffusion This emphasizes the dynamic and realistic properties of such models. The obvious non-linearity of competing technology diffusion processes makes this model integrating and simulating realistic patterns look particularly interesting.

The Diffusion of Energy Technologies

We will now examine four historical examples of lock-in phenomena concerning energy technologies. They highlight the relevance of such a model with path-dependent dynamics and a multiplicity of possible outcomes for describing the emergence of technological structure in competing technology systems.

The first example concerns the competition of engine technologies as power source for automobiles. In the 1890's, there were several potential alternative technologies: the steam engine, gasoline engine and electric motor The gasoline engine was thought to be an inferior option because it was noisy, dirty and unsafe. Moreover, it required complicated technical developments in a new technological area But a series of early small events influencing some key developers gave the gasoline engine the opportunity to lead and eventually to lock-in the market by 1920. Both increasing returns to scale and to adoption may have been operating and may be invoked to explain the way in which gasoline engine achieved its dominant position The example shows the non-predictability of the winning technology and the non-superiority of the selected path. It has been widely argued that if the steam engine had been developed to the same extent as gasoline, it might have been superior on technical and environmental points of view Obviously, structural rigidity keeps the 'inferior' choice dominant, in part due to the worldwide diffusion of the gasoline engine. This technological, organizational and infrastructural lock-in makes a huge effort necessary in order to initiate another technological path today, for instance, one including electric cars. It also reinforces the difficulties facing centralised authorities and the need to promote the diffusion of technologies.

During the early years of the motor car a choice existed between three propulsion technologies. The petrol engine was arguably not the ideal choice, but structural rigidity has kept it dominant

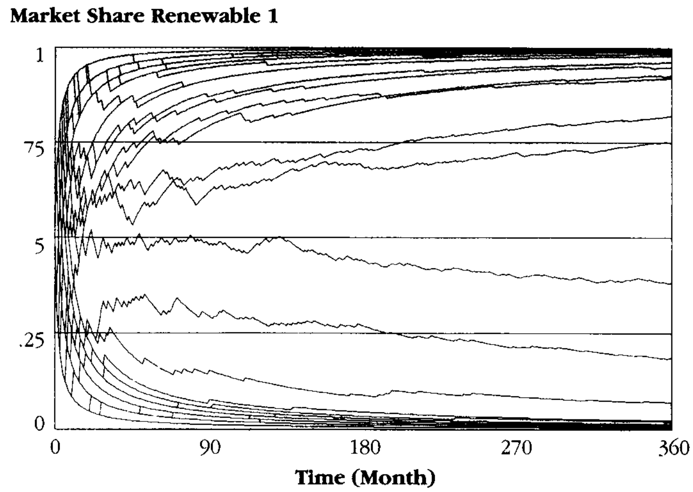
Another example that may show lock-in through increasing returns and learning effects, is that of the competition between nuclear reactor technologies in the 1950's and 1960's. At the outset of competition four options were inventoried: light-water, heavy-water, gas and liquid sodium cooled reactors. In fact, the US nuclear industry locked-in to light-water very quickly. Among the factors which can be invoked, the role of the US Navy in first reactor construction contracts, the desire of the National Security Council to get a reactor at any price, the Euratom program and political considerations all acted early on to favour light-water reactor Construction experience induced learning effects which in turn gave a lead to this technology and finally initiated the lock-in phenomena. The selected path was unpredictable and increasing returns to adoption

The nuclear industry provides an example of how, once a choice has been made about which technology to develop, construction experience gained with this technology can give it the lead

In the technology-based sectors of the economy the free competition mechanism does not guarantee the survival of the best technology

Environmentally and socially desirable technologies may require encouragement from institutional organizations

Figure 3



and to scale as well as structural inertia of this type of production reinforced the leadership of the light-water technology. Whether an other technological trajectory would have been superior in the long run, is still under debate.

The third example concerns the competition between photovoltaic electricity technologies: the crystalline-silicon and amorphous-silicon panels. Early developments for providing electric system to NASA satellites and the interest of the electronic industry to supply the crystalline-silicon component acted in favour of the former technology. Increasing returns to scale induced learning effects which maintained its advance and launched the lock-in. The selected path is still unpredictable We may argue that, due to the still limited contribution of solar energy to electricity production, the emerged structure remains more flexible than the others pointed out before. Intensive research in alternative semi-conductors may be able to moderate this lead.

Finally, the analysis of the institutional behaviour may also be relevant for describing lock-in and path-dependent phenomena. For instance, different views among policy-makers on electricity have resulted in completely different final technological structures. While in France electricity was viewed as a public service, which lead to a public electricity sector devoted to nuclear technology, it was viewed in other countries as a commodity, inducing diversified market structures and learning effects. In France, early public decisions locked-in the market to nuclear technology and initiated path-dependency. Structural-inertia again characterizes this technological trajectory. The same situation arose in the case of the decision process surrounding liquefied natural gas (LNG) projects. Cultural specificities of countries and the different risk-aversion behaviours of the actors induced highly contrasted institutionalized decisions.

Policy Implications

In the increasing returns cases, there are arguments both for and against allowing a product or a firm to dominate a market. A locked-in product may provide advantages to consumers, but, at the same time may obstruct technological progress by diminishing incentives for other companies to develop alternatives. Letting the most efficient technology win the market by itself, on the basis of 'markets forces' alone, may be invoked in the case of constant and decreasing returns. In the technology-based sectors of the economy where increasing returns dominate, the

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free competition mechanism does not guarantee that the best technology successfully gains a market share, nor even survives. Under these circumstances, encouraging and preserving incentives to product and process innovation by R&D seems crucial. Special attention may be dedicated to high-tech sectors. Incentives to firms for joint-ventures, for sharing the huge costs of R&D, for exchanging on networks technical and experience knowledge might be relevant. Therefore, *technological diversity* provides the opportunity for selecting the socially desirable technological path.

Increasing returns models suggest also that policy may pay particular attention to timing when initiating new research: markets which are already locked-in, or close to being so, are of less interest for policy support programs. Effective policy may concentrate on encouraging the development of promising but less attractive technologies that might turn out to be, in the long run, the superior technological path.

Early adopters act and impose externalities on later ones by contributing to the selection of the final technological structure. Special attention to such events is required in order to maximize the social benefits (producers' plus consumers' surpluses) of these different technological trajectories. In competing technology systems, environmentally and socially desirable technologies may require encouragement from institutional organizations when alternatives have strong imperfections in terms of negative externalities. For instance, renewable energies might not be already competitive and attractive for producers at micro-economic level, but in promoting these technologies, public policies tend to maximize social welfare. It leads them, in the long run, to be competitive, and in addition, it helps to avoid running up against a environmental constraint. These externalities, related to CO_2 emissions, are managed and the environmental objective is partly achieved by initiating a *socially more beneficial technology path*. *Technology watch* is then strongly recommended in order to be attentive to the signs at the outset of new technological trajectories. In order to avoid having to face structural inertia if a inferior path has been already taken, it is necessary to integrate long term views, externalities, etc. and act early.

On the other hand, subsidized and sponsored technologies are priced and strategically manipulated. R&D public funds can be used for other purposes by opportunist firms ('Free Rider' behaviour). Private and public R&D results can also fail to be introduced on the market if they compete against an already commercialized product of the company which performed the research. In addition, the arguments against a wait-and-see policy (initiating technological trajectories) assume that institutional organizations know a priori which type of returns (increasing, decreasing, constant) occur in sectors and technologies. Institutions face several technologies on which they have to bet. Moreover, it may be hard to initiate a path in a market before it is even fully defined. Therefore, the possibility of lock-in on an inferior technological path remains, *even in a regulated market*.

Keywords
Increasing Returns, diffusion of new technologies, Evolutionary Economic Theory, R&D policy, technological change

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European Craftsmanship and the Multimedia Information Society

Juan Stamm'ler Jaliff

Issue: Statistics on information technology infrastructure tend to focus on hardware e.g. stationary or mobile phones per capita, bandwidth of the information highways, home computers per family, Internet users or nodes by country. However, these indicators do not reflect constraints on software infrastructure development brought about by insufficient personnel skills. Europe-wide statistics showing the fine structure of supply and demand for new IT skills are not available.

Relevance: In spite of recent developments in the underlying technology, production of software continues to be labour-intensive, more of a craft than a manufacturing process. The pervasive application of programmed software to all kinds of goods and services is turning the availability of such craftsmanship into a determinant of industrial success. Recent European surveys show that personnel with skills in new technologies are necessary for successful software development. Education and training initiatives could be fine-tuned to match the structure of labour supply and demand, with the help of appropriate statistics.

Software applications are rapidly finding their way into all consumer and industrial products. Among the main contributing factors are access to inexpensive computing power and the rise in communications network connectivity. The latter is further enhanced by ongoing convergence in network-wide protocols for distributed client-server applications and so-called Intranet applications, which use Internet standards for corporate solutions. Even industrial I&C (Instrumentation & Control) systems, e.g. for process control, have switched from hardwired analogue controllers to distributed digital ones with programmed applications.

Whole new software-based industries are in the making, such as multimedia entertainment and educational software. There are plenty of opportunities for new businesses and virtual enterprises. But even traditional European industries (manufacturing, finance, insurance, process, etc.) are becoming more and more dependent on software, and have to modernise their software development organizations. In both cases, a critical factor is the access to personnel with new software technology skills. It is estimated that the half-life of skills in software is two years. Recruitment of recent university graduates does not solve the problem on its own, for several reasons. Firstly, the bulk of existing personnel must also be extensively retrained. Secondly, university degree curricula often do not reflect the critical technical skills required for application development in time. Thirdly, software development is still much of a craft: programs are mostly custom-made by individuals who produce and interpret specifications. Very little of the software production process has yet been automated. The individual level of craftsmanship is still very important. A software engineer is an apprentice until he learns to master his craft. Europe could develop a competitive advantage by

Increased network connectivity and convergence in network-wide protocols are intensifying the penetration of software applications into all consumer and industrial products

Software skills have an estimated half-life of only two years. Moreover, little of the programming process has yet been automated

leveraging on its population's relatively high educational level and ability to learn new skills. Furthermore, European product developers could benefit from their multilingual and cross-cultural proficiency, specifically regarding the multimedia entertainment industry.

Technology

The advent of widespread applications was necessarily accompanied by a software technology shift with two main characteristics.

- 32-bit programming
- Object-oriented systems development

Both trends converge in one great change in software production. The first is industry jargon for the software architecture required to handle multimedia: 3-D graphics, video, sound, animation, etc It takes its name from the 32-bit desktop hardware architecture which has made it possible.

The second denominates a shift in paradigm to support more efficient software production and reuse. It has become a necessity for the implementation of graphical user interfaces, but has gone on to permeate all realms of industrial software development. Industry-standard analysis and design methods and programming languages have all had to change to support object-orientation. The ultimate goal for the future is to create 'software factories', which would make large-scale reuse of previously programmed objects. The framework for reuse would start even earlier, at the analysis and design stages. However, the current state of practice is far from this goal, and the software development process continues to be highly labour-intensive.

Markets

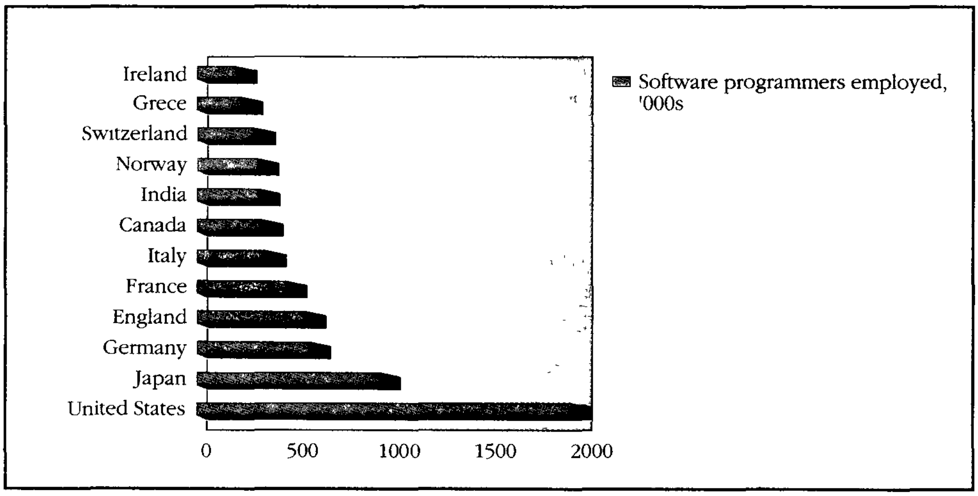
Already in 1993, the global software market reached the size of the hardware market. IBM's software revenues were $13 billion in 1995. Microsoft, with $7 5 billion in revenues for 1995, tops the list of packaged software vendors. Germany's SAP AG, at $1.9 billion, and Software AG, at $0.5 billion, also made the top-20 software vendor list. However, European prospects do not look as promising today in high-growth sectors like multimedia. In 1995, 56% of the world production of CD-ROM titles came from the USA, and only 38% from Europe.

Official US relative employment growth forecasts for 2005 placed computer programmers (56% up on 1990 level), systems analysts and computer scientists (79%) at the top, only surpassed by home-health aides.

As seen in Figure 1, this is still not particularly significant in terms of total employment. Nevertheless, indirect effects of high growth IT

Widely available 32-bit architectures and object-oriented programming imply important changes in industrial software development, bringing the goal of 'software factories' closer

Figure 1: Labour market for software programmers broken down by country



Source Howard Rubin, Hunter College, quoted in The Economist

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(Information Technology) sectors must be taken into account. For example, each and every multimedia production team involves more non-IT people than software analysts and programmers. The latter must be competent in the latest software development techniques in order for the end product to be competitive.

The explosive growth of the Internet and the World Wide Web in the last years is also opening up new market opportunities for start-up Web application developers by expanding the size of the potential market and reducing distribution costs. New software technologies for the Web, like the Java net-based programming language, along with 'pay-per-use' revenue collection (in which revenues can also be 'passed on' to sub-suppliers) can reduce market entry costs.

European software companies have hitherto succeeded mostly in niche markets. A good example is that of French object-oriented development tool vendors. But the factors mentioned above increase the probability of European start-ups that lock-in large-volume global markets, thanks to increasing returns (see 'Diffusion of Energy Technologies: The Influence of Increasing Returns' in this issue of *The IPTS Report*).

European surveys

Two recent surveys confirm the importance of skills development, education and training for the software industry. The first one is an ongoing international benchmark. It is recognized that there is a large spread in the performance of software development organisations, that is in their ability to deliver products that work right, on time and in budget. This makes it particularly useful to carry out a benchmarking effort (see 'Benchmarking of Best Practices: A Perspective for Policy' *The IPTS Report* Issue 9 for more on the subject).

The Application Development Benchmark was started in late 1994 by IBM. It is based on an analysis of both performances and practices within software development organisations across Europe. A structured questionnaire with 66 questions is used to generate the database. To date, 421 organisations in 12 industry sectors from 15 countries have been assessed or have turned in a self-assessment. Results show a wide spread in performance. Leaders outperform laggers by a factor of 5 in development productivity, 10 in maintenance productivity, 30 in delivery quality, and 5 in delivery on-time and within budget. The IT-sector has the highest performance level, but all sectors show a wide variance.

Medium-sized organizations (50-500 people) have the highest average levels of both performances and practices. Small ones (less than 50 people) have the lowest average level of practices. Statistical analysis shows that the key practice areas which affect performance the most are all human-centred: skills, quality and culture. Furthermore, the skills practice shows weak relative strength, which means that it has a high improvement potential.

The second one is a hearing on the prospects of the national software industry organised by the Swedish IT-commission on December 13th, 1995. The general theme was "How can Sweden develop a successful software industry by the year 2000?" Questions were put forth to some 70 representatives from the software industry, customer organisations, higher education, research and the financial sector. Responses were summarized into eight areas for proposed government activities, of which two are related to education and training:

- To undertake initiatives to enter the software engineering area in depth and stimulate research in software development and better technology transfer from university to industry
- To undertake initiatives which facilitate for industry and university to find synergy to create a national Media Lab.

One of the main obstacles to reaching the proposed vision is that universities provide just a quarter of the graduate engineers needed by Sweden in the software field. Both surveys' findings reinforce recent educational concerns at the national level elsewhere in Europe. For

Europe still lags behind the US in the multimedia market

Multimedia development calls for mixed teams with a variety of IT and non-IT skills

The World Wide Web is also opening up new potential markets

IBM's benchmark study has shown that medium-sized organizations are the best performers

Some countries are experiencing a shortage of appropriately trained graduates in the IT field

The evolution of the market means that IT needs have changed a great deal; a wider range of skills are now needed Training can be a slow process sometimes yielding only limited success rates

There is a particular need to bridge the gap between the universities and industry and prepare graduates better for the 'real-life' project environment

Experience shows that improving the skills base generates businesses and jobs

Training is costly and better statistical information is needed Europe-wide in order to fine-tune skills training to real needs

example, the Netherlands' SWAP 2000 (Software Action Plan 1996-2000) reports that the number of Dutch first-year computer science students has fallen from 1200 in 1988 to 463 in 1994 The Info 2000 (Germany's Way to the Information Society) action plan reports about insufficient audio-visual technology skills.

Education and Training

The skills set needed for the development of IT applications for today's and tomorrow's markets is significantly different from that of yesterday. Three key attributes in this context are multimedia, client-server and object-oriented architectures. All three are interrelated, and it is important to take two points into account. The first one relates to learning difficulties. Long learning curves are reported by industry in making the transition from old to new technology. Software staff have to be retrained, and up to a third do not make it to multimedia projects, by some industry accounts

The second one is that the skills set is becoming larger, not smaller. Whereas a software project in the past usually involved just one programming language, it now requires several, plus a number of third-party libraries and development tools. The trend is towards specialization at the implementation stage. This means that the previous stage, analysis and design, becomes more and more important, as it provides the common working platform for a number of specialists.

This is confirmed by another recent industry survey developed by IBM to obtain accurate descriptions of the critical tasks in software development. It was adopted and administered in numerous industry sectors by the Open User Recommended Solutions forum. In the object-oriented area, the ten most crucial tasks are all but one in analysis and design. This means that a more engineering-like approach to software development should be taken, with a reorientation of training priorities so that analysis and design are included along with language syntax.

Several of these issues were also addressed at INSPIRE '96, the first International Conference on Software Process Improvement - Research into Education and Training. It was held in Bilbao, September 26-28, organised by ESI, the European Software Institute, and the British Computer Society There was a consensus among participants as to the necessity of bridging the gap between university and industry, and the importance of the role which government can play to this end. It was refreshing to see that suggestions from industry regarding the emulation of a real-life project environment with project teams, as part of the coursework, were met by examples from European universities. At the Politecnico di Torino, for instance, industry representatives are invited to play the role of customers.

Discussion

The IT market of the next century requires a highly skilled work force. The multimedia industry needs professionals from various disciplines, including software specialists Access to the latter must be ensured if Europe wants to be competitive in this sector, which offers a great potential for the start-up of new SME's. For example, the promotion of software curriculum development at local universities in Karlskrona/Ronneby, Sweden, has had the effect of multiplying the number of local SME's Access to up-to-date skills is also necessary for the competitiveness of traditional industries, which become more and more dependent on software in their production lines.

Some government initiatives aimed specifically at promoting long-term software education and training have been launched. An example at the national level is the Netherlands' SWAP 2000 programme mentioned above. At the European level, some Community programs like ESPRIT's ESPITI address specific software training components.

Given the long learning periods involved, it would be beneficial to tune education and training carefully to take into account the structure of labour supply and demand. In order to assign

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priority to skills related to new technologies in high demand, it would be very useful to collect statistics about skills inventories and industry demand Doing so across Europe, this would not only help to train new software professionals efficiently, it would also help in the effort to retrain the existing work force and give a hint about Europe's competitiveness in the IT sector.

A survey methodology could be deployed, for example, through the governmental employment services. It would be important to repeatedly update the skills categories in order to reflect labour market dynamics. For example, today there is a large demand for skills in Java, a Web programming language developed by Sun corporation, which was launched as recently as spring 1995.

Keywords
labour statistics, education and training, software, multimedia, information society

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Supporting Decision Processes: Data Constraints and the Role of Knowledge-based Tools

H. Hernández and P. Canarelli

Issue: Decision makers are having to deal with ever larger volumes of information generated by the rapidly increasing capacity to collect data from a wide variety of sources. This trend goes in parallel with the growing need for a better understanding of the complex relationships between all the elements of human activity, especially in policy and decision making. In this context, there is scope for enhancing the methodology used for knowledge extraction and so benefit from its full potential to support decision processes.

Relevance: Modern knowledge extraction tools can play an important role in analysing complex systems and supporting sensitivity and risk analysis, forecasting, and scenario studies. This is especially relevant when dealing with information expressed in a *human way* (ie. non-mathematical way) such as expert opinion and public perceptions of risk and acceptance (eg. of new products, technologies, etc.). Yet, since there is no *best method* for general effective application, the suitability of which depends on the system characteristics, the choice of one or other knowledge extraction tool may bias or undermine the analysis and strongly influence the decision process.

1. Decision processes and support systems

In the past decision-process models were solved using linear programming and graphical techniques, but the limited practical application of this approach has made it necessary to reformulate procedures to take into account the limitations both of information and the human capacity to process it

Decision theory is an essential branch of operations research and resource management and its methodology has been developed at the intersection between applied mathematics and computer engineering. In the past, decision processes were considered to be simple rational mathematical optimisations, based on linear programming and graphical techniques. However, this oversimplification resulted in system representations which were far from real conditions and consequently of limited practical application. Since the end of the 1950s, the Nobel prize-winner H. Simon introduced the need to reformulate decision procedures in order to take into account the limitations both of information and the human capacity to process it (Simon, 1960). Simon suggested the formulation of realistic goals that reflect *satisfactory* solutions instead of optimal ones, and proposed adapting the decision procedure to human heuristic behaviour. He introduced the concept of three interactive and iterative phases: *intelligence phase*, comprising the information and knowledge acquisition and *design* and *choice phases*, for constructing possible alternatives and selecting the best among them. (Figure 1).

Over the last 20 years, together with the introduction of information technologies, decision theory has evolved and brought the construction of integrated Decision Support Systems (DSS). A large number of DSS tools have been developed to cope with the diversity of decision problems and with the needs of different decision makers. Among the main support tools are Management

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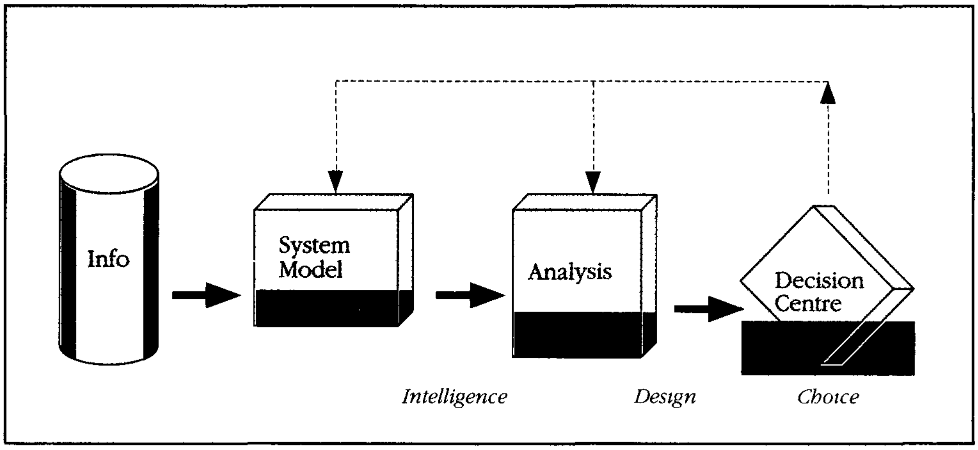
Figure 1: Main components of decision processes



Information Systems (MIS), which are applied to all management tasks; Executive Information Systems (EIS), oriented to top level executives; and Group Decision Support Systems (GDSS), which target the growing needs of group communication and decision processes. These tools are computer-based platforms, based on advanced software engineering techniques and incorporate expertise from human behavioural and cognitive disciplines, so providing, downstream, user-friendly interfaces.

Nevertheless, upstream, in the intelligence phase, the capacity to extract and represent knowledge remains a main bottleneck. An effort in that direction is observed by recent attempts to integrate techniques from Artificial Intelligence (AI) into DSS, in particular the so-called knowledge-based tools. In the next section, the AI contribution is shown to be especially valuable for decision-making processes that involve human knowledge and its associated representation problem.

2. Knowledge discovery

The analytical constraints set by incomplete and complex information are worsening due to the growing capacity to acquire information. This trend is fed by the increasing performance of information technologies, allowing the construction of huge databases and collection of information from diverse sources and in a variety of forms. This exceeds information processing capacity and in particular burdens the methodology to extract useful knowledge. Methods and tools dealing with this problem are being regrouped by emerging fields namely *knowledge discovery and data mining* (Fayyad, 1996).

In the context of decision theory, the procedure of knowledge extraction, (Figure 2), can be seen as a subdivision of the *intelligence phase*, which requires in-depth analysis. *Data mining* targets mainly the algorithms to extract relevant patterns from databases and is commonly used by MIS. Whereas *knowledge discovery* refers to the overall knowledge extraction process and, as it is closer to the field of AI, seems suitable for unstructured decision problems.

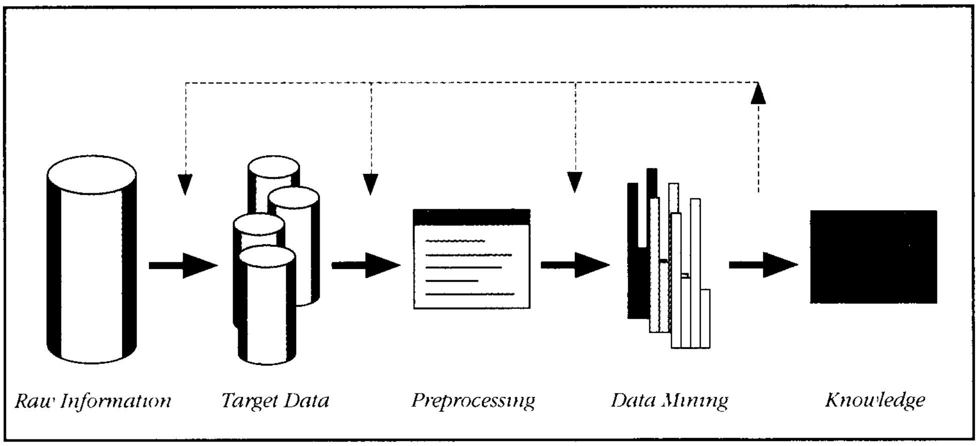
These fields encompass a large number of techniques that attempt to cover the wide scope of systems and applications. However, there is no technique or recipe to apply to solve any system in general. In fact, contrary to the automation of procedures in other areas, in this field, the analyst's contribution is required to develop or adapt available techniques for the specific problem. There are two main overlapping characteristics determining the type of technique to be used. First, the type of information relevant for the system, ie. the quantity and quality of available data. Second, the number of variables involved in the system and their interdependencies These two characteristics define the degree of representability of the system, which is the central issue of knowledge discovery.

The evolution of decision theory has brought about the construction of integrated Decision Support Systems (DSS), computer-based tools incorporating expertise from human behavioural and cognitive disciplines

Information acquisition capacity is expanding beyond the capability of traditional techniques to process it, promoting the growth of the fields of knowledge discovery and data mining

No technique is applicable to all systems. The choice will depend upon the quantity and quality of information, the number of variables and their available data

Figure 2: Knowledge extraction procedure



Source Adapted from Fayyad, 1996

There is a necessarily large difference between the tools which deal with numerical information and those that handle linguistic description

Model building techniques

Building models is at the heart of the scientific method. Indeed, a model is nothing other than an aggregation of existing knowledge which is structured in order to be used in a systematic way. Over the last century, a large number of model building techniques have been developed. They can be broadly classified in two groups depending on whether they deal with quantitative or qualitative information.

Statistical analysis underlies most of the techniques for extracting knowledge from noisy data

Raw information is usually expressed either through a set of numerical data or through a linguistic description. While the former medium is relevant when information is relatively accurate and when uncertainty is low, the latter is clearly adapted to the case of vague, fuzzy or imprecise information, and concerns exclusively human expertise.

Given the large difference between these two information representations, it is no wonder that the respective processing tools present large differences.

Neural networks are able to learn from representative sets of data, to find non-linear global functions representative of the specific problem

Extracting knowledge from data

As far as noisy data are concerned, knowledge extraction is essentially based on statistical analysis, which covers a vast set of specific techniques. While older techniques, e.g. from simple probabilities to more complex principal component analysis- have a clear descriptive role, they may be less adapted to model building, let apart their deficiency in taking into account non linearity and effective multidimensional analysis which are two main aspects of today's databases.

Almost as old, linear regression that has largely diffused over the last decades thanks to the availability of computers, leads, on the other hand, to complete models linking input descriptive variables and output dependent variables. Yet, the issue of modelling non linearity present in the relationships between variables is not more considered Neural networks permit to go beyond this point. A neural network architecture mimics that of the brain with synapses and neurones. Provided with a representative set of data, it is able to *learn* (possibly non linear) relationships between variables and, eventually, to lead to a non-linear global function representative of the specified problem.

Apart from function-based mathematical description, other types of models are also possible, using in particular conditional rules, thus offering greater transparency of the knowledge format. Several methods are known for extracting rule-based knowledge from data. For instance, decision trees, fuzzy neural networks or the natural selection-based genetic algorithms. The latter having shown the great advantage of highlighting only the coherent and highly structured part (in other words, the useful part) of the information leaving aside its noisy component.

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A further line of analysis aims at understanding complex non-linear dynamic systems, e.g. those exhibiting self-organizing properties, chaotic regimes or strong sensitivity to initial conditions. These systems are widespread in nature and underlie the mechanisms of many human activities. Conventional techniques are limited in their capacity to analyse such systems, thus the interest of recent disciplines, chaos theory and synergetics in particular, which present rather a descriptive character but may, in some cases, help improve the understanding of such systems.

Extracting knowledge from human expertise

Human knowledge is far less easy to represent. Among the main difficulties are the large share of implicit knowledge, the low underlying accuracy and the variety of linguistic descriptions which are used. A first step necessary for dealing with human knowledge is thus to structure it, i.e. to select a limited number of items and, possibly, to group them in categories. Historically, structural analysis has been one of the simplest approaches for processing this knowledge. Making use of a highly simplified structure of relationships - similar to a binary format - between items, structural analysis authorises that way to extract higher order interdependencies.

Going beyond this simple analysis implies to get closer to Artificial Intelligence. Artificial Intelligence is probably one of humankind's oldest quests. Two approaches, two philosophies, have historically been associated to it. A hard approach consisting of mimicking all aspects of human mind, which is still a very long way to go, and a soft - and pragmatic - version aiming at capturing only its simplest and roughest aspects. Clearly, the latter has already largely reached its objectives with the diffusion of expert systems in almost every field of activity during the last two decades.

Even if expert systems have shown important drawbacks - for instance, a very limited knowledge domain and low flexibility -, they have however met their objectives as some aspects of human reasoning could be mimicked in a functional way.

Today, fuzzy expert systems make it possible to get closer to mimicking human deductive reasoning. Like their more traditional counterparts, fuzzy experts systems rely on conditional rules for storing knowledge issuing from expertise. Yet, the fuzzy approach authorises a higher flexibility of the reasoning with the possibility of assessing the degree of applicability of each rule as a function of a particular context. The whole set of rules is then combined in a framework leading to a conclusion that truest rules will have the strongest influence (Canarelli, 1996).

This human-like deductive reasoning also offers the possibility of adjusting the accuracy of the description to that of existing expertise, leading to a family of models covering the full range from qualitative to quantitative description.

3. A typical decision problem on urban transport

Some of the issues discussed above can be illustrated with a common decision problem. Consider a hypothetical case of an average European city facing congestion problems (and associated pollution). The commercial zone is partially, on its southern side, surrounded by a river on one side and connected to the other northern areas by two main roads. The main accesses to this zone are completely clogged during rush hours. Among the alternative solutions to the problem are the construction of, say:
i) another bridge,
ii) another northern road access,
iii) a tram-way.

To evaluate these alternatives, one can rely on the large amount of historical data collected during the city's development. The data can help to assess the extent of congestion lessening as a function of each alternative. However, these *first order* estimations, based only on past traffic activity and population patterns assuming that 'nothing

Decision trees, fuzzy neural networks and the natural selection-based genetic algorithms are just some of the methods for extracting rule-based knowledge from data

Human knowledge is made difficult to represent by the large share of implicit knowledge and the complexity of linguistic descriptions

Artificial Intelligence is divided into a hard approach, which seeks to mimic all aspects of the human mind, and a more pragmatic, soft, approach capturing only its simplest aspects

Fuzzy expert systems make it possible to get closer to mimicking human deductive reasoning. These use conditional rules storing knowledge issuing from expertise

The urban environment is a complex system depending on both endogenous aspects and exogenous factors

changes elsewhere', will hardly reflect the mid to long term evolution of the city, because important future shaping factors are not included in this restricted framework. Indeed, urban areas are highly complex dynamic systems whose evolution is very difficult to predict. Transport is only one of the many variables strongly coupled in the urban system, which depends on endogenous aspects but also on exogenous factors (Forrester, 1969). Examples of such exogenous factors are future social patterns, (e.g. lifestyle or the acceptance of information technologies), economic evolution (e.g. city unemployment and growth rate), and technological evolution (e.g. the effectiveness of road telematics). The analysis of these exogenous factors is rather difficult because the available information is usually uncertain, vague and imprecise. Actually, its main source is often human knowledge, therefore, more appropriate modelling is necessary to evaluate these alternatives.

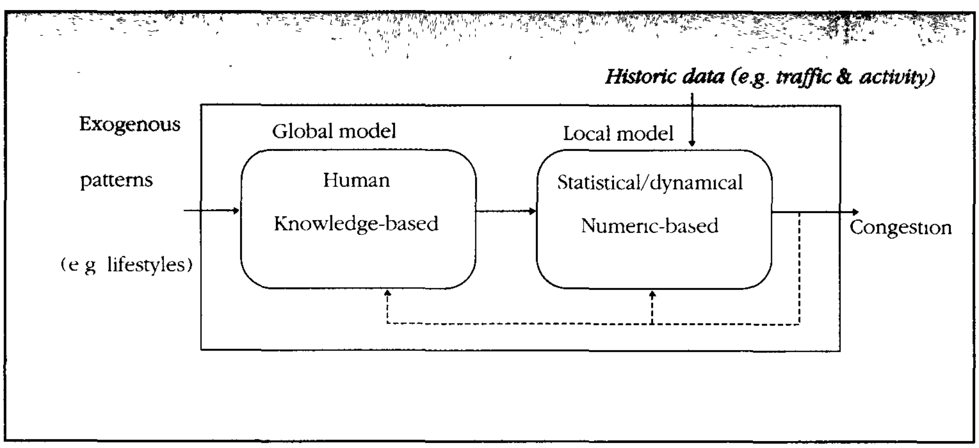
One interesting possibility is to construct a *hybrid model*, made of local, historical, and well defined information which is itself contained in a more general, but fuzzier and more uncertain, framework. This model would allow the decision makers to simulate the evolution of each alternative -and eventually score according to some specific criteria- in the context of the assumed evolution of some highly uncertain exogenous factors. While the historical data-based component could rely on more or less conventional statistical modelling, knowledge-based techniques would cover the more uncertain part. For instance, a rule-based fuzzy model could be used for, first, storing existing human expertise and assumptions, and, eventually, combining this knowledge (Figure 3).

One possibility is to construct a hybrid model, comprising a variety of information which is itself contained in a more general, but fuzzier and more uncertain, framework

The results from both approaches can lead to largely different conclusions. Trends extracted from city historical data only can, for example, show that housing and working patterns quickly displace toward the southern zone and that experience with road building have shown a quick adaptation of road users, leading in the past, to a rapidly decreasing congestion in former accesses. The conclusion which arises immediately from this analysis is, of course, the benefit provided by building another bridge, which logically should then be the choice of the decision maker.

On the other hand, the overall *hybrid model* could extend the analysis by integrating wide expertise outside the specific transport issues. For instance, roughly expressed expertise could represent the slowly decreasing size of household or the quickly increasing concern about personal safety in urban areas. The *hybrid model* could thus take into account further aspects such as the growing car ownership or the increasing reluctance to use public transport. While the conclusion offered by the reduced model would still be valid (in terms of congestion only) for the

Figure 3: Example of hybrid model. The system is decomposed in two according to its characteristics and available information: exogenous/endogenous variables, uncertainty, time constants, etc.



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short term, the *hybrid model*, would go beyond, through looking at the resulting scenarios of evolution. For example, it could show the mid to long-term extra benefits of the tramway option (provided that the insecurity issue is dealt with in an effective manner) and the increasing drawbacks of the bridge option, arising from the induced building expansion around the bridge and its subsequent traffic consequences.

The interest of the extended *hybrid model* is thus to enlarge the comprehensibility of the context and to offer to the decision maker other criteria (e.g. the important time horizon aspect) on which her/his decision can rely.

4. Conclusion

The development of decision support tools and in particular their better downstream information processing, widens their scope for management applications, but does not necessarily improve the quality of decisions. More effort is needed upstream in the *intelligence phase*, to develop tools which better represent the system. This is stressed by the needs of decision makers who must deal with increasingly complex systems. Moreover, in recent years, the rapidly increasing capacity for information collection, per se, does not guarantee better knowledge acquisition. On the contrary, this burdens the analysis and does not alleviate the constraints set by uncertain or incomplete data, or the difficulties in representing human knowledge. Therefore, it is necessary to shift priorities from information collection to analysis. Effort should be devoted to developing and promoting knowledge extraction techniques, e.g. knowledge-based techniques from AI, and to enhance the role of scientific analysts in this field.

Trends extracted from city historical data alone favour a purely transport oriented solution (a bridge), whereas the hybrid model could take into account further aspects outside of specific transport issues, such as the growing car ownership or the increasing reluctance to use public transport

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Biodegradable Plastics from Renewable Sources

Mario Demicheli

Issue: Several studies have coincided in predicting an annual growth rate of about 30% over this decade in Europe and the US for biodegradable polymers of natural origin. Market growth is being created by authorities, the green consumer and environmental activist groups. In response, companies around the world are speeding up technological developments while deploying complementary market strategies.

Relevance: Production of biodegradable plastics could offer energy savings and sound environmental benefits, making the examination of integrating these materials into waste management policy in Europe worthwhile. Also, the creation of labels and standards could be a useful way of bringing about the transition from research to innovation, and in developing a European market for biodegradables.

As conventional plastics are persistent in the environment, improperly disposed plastic materials are a significant source of environmental pollution, potentially harming wildlife

Renewable biomass feedstocks (crops) and agro-industrial 'waste' streams emerge as the key alternatives to fossil fuels in chemical manufacturing

Analysis

Plastics and the environment

It is increasingly being realized that the use of long-lasting polymers for short-lived applications is not entirely justified, especially when increased concern exists about the preservation of living systems. The elimination of waste plastics is therefore of interest in surgery, hygiene, catering, packaging, agriculture, fishing, environmental protection, technical and other potential applications [1].

Most of today's plastics and synthetic polymers are produced from petrochemicals. As conventional plastics are persistent in the environment, improperly disposed plastic materials are a significant source of environmental pollution, potentially harming wildlife. In seas, for example, plastic rubbish –from ropes and nets to the plastic bands from beer packs– chokes and entangles marine mammals. One study on cetacean carcasses found that 1 in 30 had choked on plastic debris [2]. Plastics have also a costly impact on waste management, and municipalities are becoming aware of the significant savings that collection of 'wet' organic wastes in so-called 'biobins' to be composted can provide. For these reasons, reaching the conditions for replacement of non-degradable polymers by degradable plastics, particularly for single-use disposables and packaging applications, is of major interest both to decision-makers and the plastic industry [3].

The move to renewable sources

The production of biodegradable plastics can be viewed within the wider context of the 'greening of industry', with most national RTD programmes viewing the use of renewable biomass as an alternative feedstock to fossil fuels in chemical manufacturing. The chief reasons for this are the exploiting the potential of photosynthesis for energy savings, curbing the greenhouse effect, developing eco-compatible processes & products, diversifying agriculture out of food production and, possibly, generating employment [4].

Thus both renewable biomass feedstocks (crops) and agro-industrial 'waste' streams emerge as the key alternatives. Indeed, wastes offer the greatest promise as a feedstock: not only are they cheap,

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but their conversion solves another environmental problem by turning 'waste' into useful products. This means that countries without scope for crop expansion could still benefit from the approach, both economically and ecologically, by reducing the environmental impact associated with the disposal of their industrial wastes. This has led to substantial research, and also very recently resulted in some innovations in two main directions, namely the development of new microbes that can convert cheap substrates, and the cloning and expression of biosynthetic genes in plants.

Extending the recycling loop

Recycling of conventional plastics is a way of reducing the problems associated with plastic waste However, many packaging materials do not lend themselves to recycling owing to contamination with food and ink, and the necessary cleaning prior to recycling is very expensive. Packaging recycling costs Germans about DM3 per kg Furthermore, reprocessing often leads to a downgrading of the polymer use and an increased hold-up in the system. A lack of markets for recycled polymers has led to large stockpiles and the dumping of waste products in other countries. A recent change in German legislation concerning packaging recycling, dropping quotas from the initial 64% to 50%, is largely a response to the lack of market for low quality recycled polymers. Depolymerization technologies are being developed that can return the plastics to its starting material (feed monomer) so that it can then be used to remake the non-degradable polymer. However this approach will increase the cost of the feed monomer and hence the final plastic, and does not solve the degradability problem for the plastic that still ends up into the environment [5].

Even the more efficient recycling loop of non-biodegradable plastic waste in any production process has an associated production cost, to which the disposal cost must be added. Biodegradable plastics are, however, not to be seen as replacement for plastics, but only for specific applications. In fact, their unique physical properties mean that some plastic materials will remain unsubstituted for a long time [6].

Recycling of conventional plastics is a way of reducing the problems associated with plastic waste, but it has the drawbacks that the materials are often contaminated with other wastes and result in poor quality plastics

Biopolymers, conventional plastics and biodegradable plastics

The resins used to make biodegradable plastics fall into two broad categories: natural and synthetic. Natural resins (or biopolymers) are largely based on renewable resources such as starch and cellulose, and polyhydroxyalcanoates (PHA) produced by microbes. Other polymers such as proteins and pectins may also potentially be developed for biodegradable plastics and polymers. Polylactides (PLA), i e. aliphatic polyesters formed by polymerization of lactic acid is usually included in this category since the monomer can be produced by fermentation [7].

Synthetic polymers are made of petroleum-based and other feedstocks and include polyester and polyethylene polymers. An example of a biodegradable, synthetic polymer is polycaprolactone, a thermoplastic polyester resin. Conversely, physical or chemical modification of a natural biopolymer may result in a loss of its biodegradability. Conventional, petrochemical-based plastic materials are not easily degraded in the environment because of their high molecular weight an hydrophobic character. Disposal of plastics, therefore has become a major environmental concern, resulting in programmes to recycle, incinerate or compost these wastes [8].

Both natural and synthetic resins are used to make biodegradable plastics. Natural resins are commonly based on renewable resources like starch and cellulose or polyhydroxyalcanoates (PHA) produced by microbes. Synthetic resins are petroleum-based

The plastics sector

Consumption of plastics material in the EU plastics processing industry was approximately 30 million tonnes in 1994. Germany accounts for nearly one-quarter of total EU demand. Asian economies are becoming more integrated and less dependent on the US and Europe. Japan, Korea, Taiwan, China and Singapore are the main plastic processing countries in Asia with production of more than 25 million tonnes; i.e. one-quarter of world production. China's output of plastic products has been growing at an annual rate of over 20% during the 1990s. In

Cooperative strategies like those in Asia could also be explored in Europe, especially given the feedstock potential of central and eastern Europe

recent years, EU exports to central and eastern Europe countries have increased tremendously [9]. Consequently, waste management problems are expected to worsen in these countries, some of which may possibly join the EU in the near future [10] In highly-industrialized countries plastics represent between 20 and 40% of municipal solid waste by volume. The time has therefore come to think of cooperation in developing strategies for degradables, similarly to what is happening in Asian countries, and especially because eastern and central European countries possess the abundant agricultural resources which are needed to produce the feedstock [11].

Packaging

The production of packaging material is the largest subsector of the plastics processing industry and the food industry constitutes the major end-user followed by the distribution and beverage industries

Accounting for one-third of demand, the production of packaging material is the largest subsector of the plastics processing industry. The food industry constitutes the major end-user followed by the distribution and beverage industries. Despite environmental concerns, the European market for plastic packaging is rising by billions of ECUs every year. Pharmaceuticals, toiletries and cosmetics are large users of packaging. Hence, to keep abreast of future restrictive legislation aimed at reducing packaging weight and volume, these industries are very interested in seeing cheap biodegradable packaging available on the market [9].

The greatest growth rate has been predicted for polyester bottle resins, particularly in the carbonated drinks market, whose annual demand now stands at more than 500 million ECU. In response to this, Japanese companies have recently designed a substitute for polyester bottles with excellent physical properties by modifying 'Bionolle', a biodegradable polyester, using a technique known as stretch-blow moulding [12].

Plastic films

Plastic films are mostly based on polyethylenes with LDPE accounting for one-sixth of total EU plastics consumption. Major end-uses of plastic films are printed films for automatic packaging, shrink and stretch films for overpacking, films for agriculture and horticulture (greenhouses, mulching), films for construction, shoppers, carrier bags, refuse bags, heavy duty sacks, and films for a wide range of technical applications such as magnetic tapes, credit cards, hot foil stamping, cables, motor insulation, furniture films and office films. Agriculture accounts for 3% of total plastic consumption in Europe. Plastic films for covering greenhouses have enjoyed both innovation and spectacular growth over the last twenty years [9].

Structure of the business

Existing polymer production capacity is currently in the hands of the main petrochemical groups, which in turn respond to the demand for raw materials by processors (converters) which are mainly small to medium-sized companies

The plastics industry exists within the broader context of the petrochemical industry. This sector has recently been hard hit by the need to direct significant amounts of capital expenditure and R&D funding in order to comply with ever stricter environmental regulations [13]. Existing capacity for polymer production is currently in the hands of the main petrochemical groups, which in turn respond to the demand for raw materials by processors. The plastics processing industry (converters) is mainly composed of small and medium-sized companies. After procurement of the raw material, the medium-sized plastics processor has to sell plastic products through large scale industries, like car makers, manufacturers of electric and electronic equipment and department store chains [9].

Biodegradable polymer technology can at present only offer a limited range of materials. This is the main reason why US and Japan are now focusing on the technological development of biodegradable polymers, in order to expand the range of these polymers that can fulfil processing and property requirements for many applications in which biodegradability would be an important materials property [14]. The biochemical industry (food, grain, sugar) is therefore in an ideal position to build capacity for biodegradable plastics at the expense of the petrochemical industry or, conversely, the petrochemical industry could adapt its technology for processing renewable feedstocks,

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Table 1: Biodegradable plastics in Europe: business examples [18]

Company	Activities
Biotec (Melitta) Emmerich (Germany)	Commercial business/production of biodegradable starch/polycaprolactone (PCL) compounds for e.g. packaging and waste handling (refuse bags) applications.
BASF Ludwigshafen (Germany)	Development of synthetic, biodegradable co-polyesters and blends with starch e.g. for flexible films applications.
Bayer/Wolf Walsrode Leverkusen (Germany)	Pre-commercial synthetic, biodegradable co-polyester amide for e.g flexible film applications.
Novamont Novara (Italy)	Commercial business/production of starch compounded with polycaprolactone and/or polyvinylalcohol;' Mater-Bi'.

thereby profiting from a long-standing process experience. In the transition, there exists a niche in which SMEs that integrate both polymers production and processing could emerge.

Recent developments

Space does not permit a review of all biodegradable plastics types existing or under-development. In what follows only two recent examples of innovation are mentioned.

Four US DOE (Department of Energy) labs have signed a $7 million agreement with Applied CarboChemicals, a specialty chemicals company, to manufacture chemical feedstocks from renewable farm crops at a significant lower cost than via conventional petroleum-based chemosynthesis. The project follows the recent DOE development of a new microbe as part of a process that converts corn into the key intermediaries used to make a range of industrial and consumer products, including polymers, clothing fibres, paints, inks, food additives, automobile bumpers. Existing domestic markets for such chemicals total more than $1.3 billion a year. A rise in the number of employees is also expected over the next decade as the company builds manufacturing capacity and expands into global markets [15]. This is a typical example of combining chemosynthesis with biosynthesis plants, an approach pursued in America to save energy. The R&D line being followed suggests the possibility that in the near future the process might be extended to use industrial organic wastes (such as from the sugar industry) to replace corn.

Metabolix (Cambridge, Mass) has recently licensed MIT's patents on the insertion of the genes for the production of the key enzymes in the mechanism of production of PHB (polyhydroxybutyrate - an essential component of biodegradable polyester thermoplastics) into bacteria and transgenic corn. The transgenic bacteria and plants can also co-polyesterify ß-hydroxybutyrate with ß-hydroxyalcanoates up to C12. As so far PHB – the only PHA shown to be produced in plants – has poor physical properties, and attempts to blend it with other polymers and plasticizers have had only limited success, these innovations would seem to be essential for a broader use of PHA in commodity products [16]. The exciting potential of the production of biodegradable plastics in a low cost, renewable production system (using corn, cassava, soybean, etc.) is also apparent from the spate of recent joint-ventures as well as business purchases by big multinational commodity firms, like Monsanto and Cargill [17]. Table 1 refers to some of the pre-commercial and commercial work that is going on in the EU.

Previous false starts in the development of biodegradable materials have foundered on account of high costs, absence of good physical properties (mainly water barrier and heat resistance), lack of an adequate infrastructure for waste management and an adequate means whereby the public can differentiate products.

Four US Department of Energy labs have signed an agreement to manufacture chemical feedstocks from renewable farm crops at a significantly lower cost than via conventional petroleum-based chemosynthesis

Using technology from MIT the Metabolix company is working on the production of components of biodegradable polyester thermoplastics using transgenic bacteria and corn

Composting is an accelerated biological decay process viewed by many to be a potential solution to the solid-waste management crisis existing in many parts of the world

A key issue is whether the residue left by biodegradation is harmful to the environment, ensuring that all organic compounds have been converted into inorganic ones alone is not enough

Tests are made difficult by the fact that environments in which biodegradation takes place differ widely and are not easy to reproduce in the laboratory

Biodegradability and compostability

Certain blends of polyethylene and starch can be degraded by physical agents (such as light). Indeed, a type of polyethylene is being marketed that includes a catalyst prompting the polymerís thermal degradation. Nevertheless, biodegradation is quite another thing.

ASTM standard D-5488-94d defines biodegradable as "capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanisms is the enzymatic action of micro-organisms, that can be measured by standard tests, in a specified period of time, reflecting available disposal conditions".

Composting is an accelerated biological decay process viewed by many to be a potential solution to the solid-waste management crisis existing in many parts of the world. Compostable is defined as "capable of undergoing biological decomposition in a compost site as part of an available program, such that the material is not visually distinguishable and breaks down to carbon dioxide, water, inorganics and biomass, at a rate consistent with known compostable materials." [7]

Management of solid waste should include a critical understanding of the fate of synthetic polymers which may be disposed as solid waste in municipal landfills. Research, marketing and regulatory reviews of degradable polymers should take into account the characteristics of true landfills-not just lab tests of degradation.

To meet the compostability requirement, all of the blend components have to fully biodegrade under composting conditions and within the timeframe of the composting process. Draft national and European test standards for measuring biodegradability under composting conditions are currently under development. The key issue is whether the biodegradation material (ie the residue left by biodegradation) is harmful to the environment [19] Testing the amount of mineralization alone does not take into account the nature of the residue left. Furthermore, biodegradation of blends of non-degradable synthetic polymers and starches, which can actually 'biodisintegrate', is doubtful.

Germany is dealing with the issue of plant health in its biodegradability/composting standards; 'a product must be fully biodegradable under composting conditions and the compost material cannot be phytotoxic or ecotoxic – it will support plant and microbial activity. In fact, the assumption that using natural ingredients always leads to harmless products is not true. Most important is the final destination of the biodegradable material [7].

One issue to be addressed is if current laboratory tests accurately reflect the biodegradability of a material in an real compost pile. The environments in which biodegradation takes place differ widely in terms of microbial composition, pH, temperature and moisture and they are not readily reproduced in the laboratory. Another issue for standards development is balancing the need for shelf life with the demand for rapid degradability. The development of more sophisticated distribution systems so as to avoid products sitting in warehouses, and the creation of more composting facilities directly related to the disposal or these products would be needed. In Japan, the Biodegradable Plastics society (BPS) has proposed a standard for degradability that has been accepted there and is being considered by the International Standards Organization [14].

The OK Compost Conformity Mark is awarded jointly by the international quality inspection bureau A.I.B.-Vinçotte Inter and Organic Waste System, a research institute in the field of biodegradability. Manufacturers can use this label on their material as a proof that it passes the biodegradability test and is appropriate to compost [20]. So far, no internationally adopted standard laboratory method exists for investigating aerobic biodegradability in a composting environment.

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Challenges ahead

Acceptance of biodegradable polymers is likely to depend on four unknowns: (1) customer response to costs that today are generally 2 to 4 times higher than for conventional polymers; (2) possible legislation (particularly concerning water-soluble polymers); (3) the achievement of total biodegradability; and (4) the development of an infrastructure to collect, accept, and process biodegradable polymers as a generally available option for waste disposal [14].

In a social context biodegradable plastics call for a re-examination of life-styles. They will require separate collection, involvement of the general public, greater community responsibility in installing recycling systems, etc. On the question of cost, awareness may often be lacking of the significance of both disposal and the environmental costs which are to be added to the processing cost.

Biodegradability is tied to a specific environment. For instance, the usual biodegradation time requirement for bioplastic to be composted is 1 to 6 months. In Europe, composting is on the increase, and the percentage of population with composting facilities available for their rubbish stands at about 80% in the Netherlands, 40% in Germany, and 30% in Belgium. Adequate regulation is still lacking however, and complaints have already appeared, for example in the Netherlands, where citizens must pay the same tax for plastics that go to composting as for those that go to incineration [21].

The development of starch-based biodegradable plastics looks very promising given the fact that starch is inexpensive, available annually, biodegradable in several environments and incinerable. The main drawbacks the industry is running into are bioplastics' low water-barrier and the migration of hydrophilic plasticizers with consequent ageing phenomena. The first problem together with the cost factor is common to all other biodegradable plastics.

The public will need to be made aware of the need for recycling and to be encouraged to make the necessary changes to their lifestyles

As far as biological polyesters (PHA) are concerned, the recent purchase of Zeneca's Biopol business by Monsanto, who aims to expand it to include plant-derived polymers, does not suggest a bright future for microbial production of these polymers [22]. Nevertheless, research on the production of the polymers by bacteria is worthwhile because it may be useful in helping us understand how to expand the range of polymers made by plants [23].

In summary, the bioplastics of the future will be produced from renewable sources, will have a low energy content and will display in-use properties similar to those of conventional plastics.

Keywords
biodegradable plastics, market, standards, renewable sources, green chemistry, composting

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About the author

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The European Commission is promoting wastewater reclamation and reuse

Laurent Bontoux

In the context of the development of its Euro-Mediterranean policy, the European Union has provided R&D funds for joint projects linking the North and the South of the Mediterranean in the framework of the Avicenne program (now closed).

The IPTS was invited as an observer during the meeting of the Avicenne project "Integrated Management of Reclaimed Wastewater Resources in the Mediterranean Region" (93 AVI 076) which took place on September 27, 1996, in Faro, Portugal. The host was Prof. J. Beltrão, of the Universidade do Algarve.

Worldwide, wastewater reclamation and reuse is estimated to represent an extra water resource amounting to 15% of existing water consumption. Locally, this proportion can be significantly higher (e.g. 30% of agriculture irrigation water and 19% of total water supply in Israel in the future). In view of the increasing pressure on all water resources, in both industrialised and developing countries, supplementing water resources with reclaimed wastewater can no longer be neglected, justifying the IPTS's interest.

As the majority of wastewater reclamation and reuse applications are related to irrigation, this technique and its associated technology are becoming mainstream. As a result, the R&D efforts appear to be broadening their focus to include different application areas such as soil aquifer treatment, groundwater recharge and industrial cooling.

However, while the technology available for wastewater reclamation and reuse is reaching maturity, there is still widespread debate about the need for international water quality standards in this area, including for irrigation. The IPTS is promoting the idea of reflection at the level of the European Union on quality standards for wastewater reclamation and reuse. The Avicenne project is contributing to the exchange of information and determination of the appropriate technologies as well as promoting the expansion of safe wastewater reuse practices in a Euro-Mediterranean perspective.

This project, co-ordinated by Prof. M. Salgot, of the Universitat de Barcelona, started in February 1995 and aims to accomplish four main tasks:

- Investigate wastewater treatment for water and sludge reclamation.
- Investigate the health and environmental effects of wastewater reclamation and reuse.
- Investigate alternative wastewater disposal techniques.
- Investigate new developments in the analytical work needed to monitor the quality of reclaimed wastewater.

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The research teams involved in the project originate from seven countries: France, Germany, Greece, Israel, Portugal, Spain and Tunisia. Prof. T. Asano, of the University of California at Davis, USA, a world renowned expert in the field of wastewater reclamation and reuse, is collaborating with them as an adviser to the project.

In Greece, current efforts aim particularly at promoting the development of wastewater reuse on the islands, where the water resources are more limited. In Tunisia, reclaimed wastewater accounts for approximately 130 million m3 per year and there the discharge standards are more stringent than for reuse. A harmonization of the standards is therefore necessary and experimental work on optimizing ponds for improving water quality is being undertaken. In Germany, the research work focuses on the optimization of the phase separation processes used in wastewater treatment and on the characterization of suspended solids. The French team, in coordination with Prof. Salgot's team, is studying soil filtration as an option for advanced wastewater treatment, biomass production (ie. growing trees) and groundwater recharge. Additionally, Prof. Salgot's team is working on developing good wastewater reuse practices. He is also, along with the Portuguese team, working on the characterization and agricultural application of sludges. The Portuguese team is also looking at the fertilizing properties of treated wastewater. The Israeli team is also mostly concerned with the agricultural use of treated wastewater (impact on crops, on soil salinity, etc.).

The study results are being disseminated by professional papers, conference proceedings and a treatise on wastewater reclamation and reuse.

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The **IPTS** is one of the seven institutes of the Joint Research Centre of the Commission of the European Communities. Its remit is the observation and follow-up of technological change in its broadest sense, in order to understand better its links with economic and social change. The Institute carries out and co-ordinates research to improve our understanding of the impact of new technologies, and their relationship to their socio-economic context.

The purpose of this work is to support the decision-maker in the management of change, pivotally anchored on S/T developments. In this endeavour the IPTS enjoys a dual advantage: being a part of the Commission, the IPTS shares EU goals and priorities; on the other hand it cherishes its research institute neutrality and distance from the intricacies of actual policy-making. This combination allows the IPTS to build bridges across EU undertakings, contributing to and co-ordinating the creation of common knowledge bases at the disposal of all stake-holders. Though the work of the IPTS is mainly addressed to the Commission, it also works with decision-makers in the European parliament, and agencies and institutions in the Member States.

The Institute's main activities, defined in close cooperation with the decision-maker are:

1. Technology Watch. This activity aims to alert European decision-makers to the social, economic and political consequences of major technological issues and trends. This is achieved through the European Science and Technology Observatory (ESTO), a European-wide network of nationally based organisations. The IPTS is the central node of ESTO, co-ordinating technology watch joint ventures with the aim of better understanding technological change.

2. Technology, employment & competitiveness. Given the significance of these issues for Europe and the EU institutions, the technology-employment-competitiveness relationship is the driving force behind all IPTS activities, focusing analysis on the potential of promising technologies for job creation, economic growth and social welfare. Such analyses may be linked to specific technologies, technological sectors, or cross-sectorial issues and themes.

3. Support for policy-making. The IPTS also undertakes work to supports both Commission services and other EU institutions in response to specific requests, usually as a direct contribution to decision-making and/or policy implementation. These tasks are fully integrated with, and take full advantage of, on-going Technology Watch activities.

As well as collaborating directly with policy-makers in order to obtain first-hand understanding of their concerns, the IPTS draws upon sector actors knowledge and promotes dialogue between them, whilst working in close co-operation with the scientific community so as to ensure technical accuracy. In addition to its flagship *The IPTS Report* , the work of the IPTS is also presented in occasional prospective notes, a series of dossiers, synthesis reports and working papers.

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