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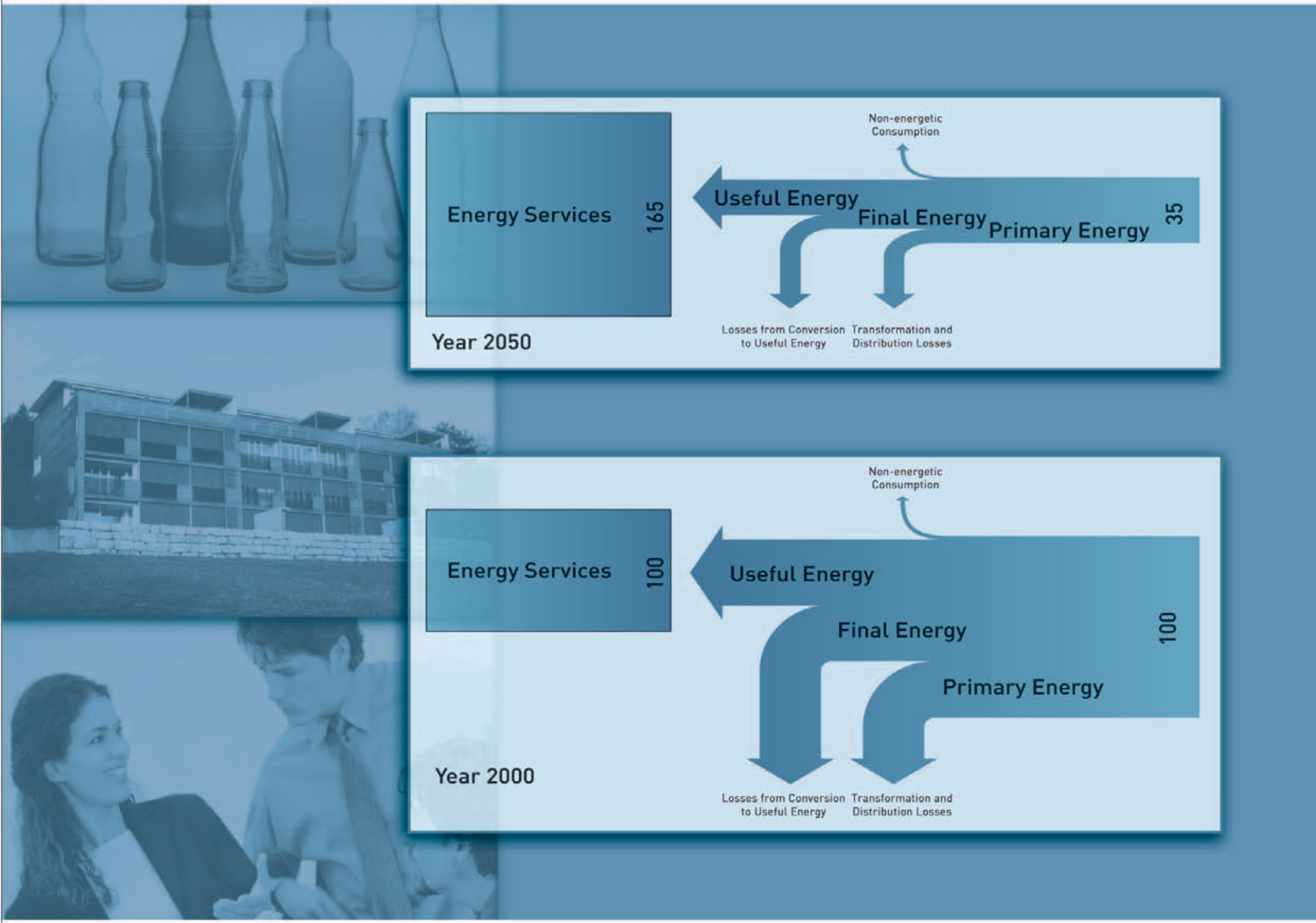
Steps towards a sustainable development

A White Book for R&D of energy-efficient technologies

novatlantis
Sustainability at the ETH domain

Eberhard Jochem (Editor)



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Steps towards a sustainable development

A White Book for R&D of energy-efficient technologies

Eberhard Jochem (Editor)
March, 2004

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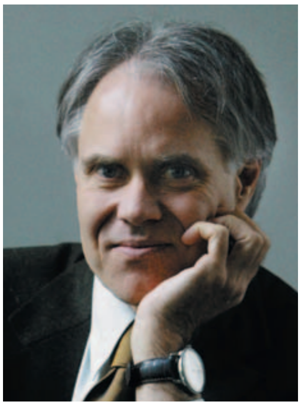
Preface



Swiss Federal Councillor Moritz Leuenberger
Head of the Federal Department of Environment, Transport, Energy and Communications (DETEC)

“In 1998, the Board of the Swiss Federal Institutes of Technology promoted the vision of a “2000 Watt society” to be achieved within five decades. The energy use of 2000 Watt per capita is one third of today’s per capita energy demand in Europe. Energy can be regarded as the “blood” of industrialised countries; their inhabitants still expect further economic growth and higher income during the next five decades.

Although this vision of reducing present energy-related greenhouse gas emissions of industrialised countries by at least a factor three is supported by the recommendations of the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), one may question whether these objectives are technically feasible, leaving aside economic feasibility or political acceptability.

Avoiding unsustainable climate changes and their related economic and social impacts represents just one challenge for the more efficient use of energy and materials. Other reasons are the production maximum of oil in the next few decades and the unavoidable re-concentration of oil production in the Middle East, where two thirds of world oil resources remain.

Within a first analysis, the authors concluded that the vision of a 2000 Watt per capita society would be technically feasible without reducing the levels of comfort. This is an important message as the possible contributions of energy and material efficiency to a sustainable development are very often underestimated. This first analysis focused on efficiency issues of energy and material use; it did not consider any changes in primary energy as another option for reducing greenhouse gas emissions in this century.

In the last few years, economists have started asking which technology would be the major driver for the next Kondratieff cycle. In view of the challenges a 2000 Watt per capita society would have to shoulder, the next Kondratieff cycle may not be technology-driven, but entirely problem-driven and supported by many new technologies such as nano-bio-gene, membrane technology, power electronics, and new materials, but also by new entrepreneurial concepts.

As the sponsor of this brochure, novatlantis has recognised that such a vision needs wide spread distribution and consideration among researchers in academia and industry as well as in research administrations and foundations as a precondition to any further steps to be taken.”

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Elements of solutions – R&D hot spots

Executive Summary

> If you want to build a ship,
> don't drum up the men to gather wood,
> divide the work and give orders.
> Instead, teach them to yearn for the vast and endless sea.
> *Antoine de Saint Exupéry*

The forthcoming challenges and a resulting vision

In the coming decades, the probable stagnation of oil production between 2020 and 2030, the re-concentration of crude oil production in the Near East, and the threat and consequences of climate change will compel industrialised nations to use energy much more efficiently and to employ materials that are less energy-intensive. Research and development in this decade that contributes to realising energy efficiency potentials is likely to be regarded as important in scientific, entrepreneurial, and political realms.

In 1998, *the Board of the Swiss Federal Institutes of Technology* promoted the vision of a "2000 Watt per capita society by the middle of the 21st century". A yearly 2000 Watt per capita energy demand corresponds to 65 GJ per capita and year, which is one third of today's per capita primary energy use in Europe. Assuming a growth of GDP (gross domestic production) per capita by two thirds within the next 50 years, the 2000 Watt per capita society implies improving primary energy use by a factor of 4 to 5, admitting some influence of structural change in less energy-intensive industries and consumption patterns (see Figure 0-1).

The objectives and relevant R&D policies

This vision poses a tremendous challenge for R&D to improve energy and material efficiency. It is obvious that completely new technologies and supporting organisational and entrepreneurial innovations are needed to achieve this goal. Hence, the questions have to be asked:

- are the necessary efficiency goals achievable in principle by the middle of this century, i.e. by applying the theoretical and empirical knowledge of natural, engineering, and social sciences?
- What are the central technologies, entrepreneurial innovations, and boundary conditions needed to arrive at the 2000 Watt per capita vision in 2050? And which technologies can wait to be developed?
- When do these need to be available and introduced into the market in order to achieve their desired impact by 2050?
- Which kinds of R&D and other policies (e.g. building codes, financial incentives) have to be implemented today or within this decade?

In a first consideration of these questions, the technological and behavioural areas and the necessary research were screened in a pre-study during 2002. A brief report of the basic results is presented in this brochure.

The pre-study examined efficiency potentials in the transformation from primary energy to useful energy and, more importantly, from useful energy to energy determining factors and finally to energy or material services. The examination of these potentials must consider the lifetimes of manufactured artefacts: buildings and infrastructure that will save or waste energy in 2050 are being built or refurbished today; 2050's computers will be designed in 2040. It is easy to envisage technologies that would make a 2000 Watt per capita society possible by the year 2050. However, without exploiting the opportunities that re-investment cycles offer, a 2000 Watt society will not emerge and will not even be technologically feasible. The pre-study emphasised the enormous size of energy conservation potentials achievable, not only by reducing energy losses, but also by decreasing the specific demand for different energy services through improved material efficiency, material recycling and substitution, and intensification of product use.

Preliminary results and first conclusions – the cornerstones of technical feasibility

The following results were derived from screening all technological areas and behavioural aspects. Contributions will have to come from all sectors and technical systems, but also from changes in the behaviour of a multitude of actors in society (energy saving potentials for Switzerland in brackets).

- *Buildings,* which use about one third of final energy for heating, have a very large technical energy efficiency potential compared to the present building stock (about 80%). Recent technological advances in building construction and operation, although considerable, have by no means exhausted the technological and cost reduction possibilities. Key technological developments include new types of insulation and window systems, highly efficient low temperature heating and heat recovery systems, decentralised combined heat, cold and power production, integrated photovoltaic and solar thermal systems as well as ground-coupling systems for seasonal heat storage.
- Similarly, the efficiency of *large equipment and industrial plants* like paper machines, petrochemical plants and industrial kilns

will continue to be improved greatly (by 20 to more than 50%). Here, however, the re-investment cycles are long. Energy-intensive manufacturing equipment will undergo substantial changes through loss reduction and total process substitution (e.g. new physical, chemical and biotechnological processes instead of conventional thermal separation and synthesis processes leading to energy savings up to even 80% or 90%).

- Regarding thermal power generation, large efficiency potentials exist due to new high temperature materials, combined cycles, co-generation or substitution/combination with fuel cell technology (40 to 60%) as advanced systems; within this context, the development of holistic system design methodologies is of importance.
- One of the areas with the largest savings potential for 2050 is road transport, especially passenger cars (more than 50%). Further advances in internal combustion engines and fuel cell technology, braking energy recuperation systems, lightweight frames and new tyre materials are very promising. The aviation sector is also of high importance and can be considerably ameliorated by improved turbines, improved structural and aerodynamic efficiency as well as air traffic management techniques. New high-speed train systems with highly efficient magnetic levitation technology are an interesting alternative. Telematics offer helpful solutions to implement traffic and modal split management as well as freight logistics. New transshipment and container technology is important to make multi-modal freight traffic more efficient and attractive.
- Systematic innovations through the use of *information technologies and power electronics* will be very important, allowing better control, improved product quality, logistics and decentralised energy conversion at high efficiency levels (30% to 80%). Applying control technologies to the more efficient use of energy, other resources, and rental services is a large, rewarding technological challenge.
- The present efficiency indicators are often inadequate. Important methodological advances in life cycle exergy analyses require additional efforts to raise the awareness of scientists, engineers and experts in research administrations.
- *More efficient material use,* additional recycling of energy-intensive materials or substitution by less energy-intensive materials, greater re-use of products, and improved material efficiency will all contribute to reducing the quantity of materials produced and, hence, the energy demanded (30% to 90%). Entrepreneurial innovations will support these options and pooling will intensify the use of machinery, plants, and vehicles.
- The brochure also reports on *techno-economic bottlenecks and existing obstacles* to the development, acceptance, and market diffusion of innovative technologies; it may be important to consider these even at the R&D stage.
- Finally, necessary research has been identified on *group-specific behaviour in investment decisions* and everyday operation relevant to resource efficiency. This is often neglected but remains an essential element of innovation and technology diffusion.

Wherever possible, the brochure specifies the research areas and topics that would contribute the most to realising the identified energy and material conservation potentials. However, the timely implementation of high-efficiency technologies and solutions in areas with long re-investment cycles will be crucial.

The prerequisites of the vision's technical feasibility

Synthesising the findings of all technological areas (i.e. converting primary energies to final and useful energies, reducing the losses of useful energies, increasing material efficiency, recycling and material substitution), it can be safely concluded that the vision of the 2000 Watt per capita society is technically feasible within some five decades. This conclusion is based on the following observations and prerequisites:

- the time horizon of half a century to achieve this goal seems to be the absolute minimum, as the total capital stock of an industrialised economy has to be replaced at least once by investing in highly efficient technologies or has to be refurbished (buildings, settlements, transport infrastructure) and the energy and material efficiency greatly improved.
- It is fortunate that the sector with the longest re-investment cycle, the buildings sector, does not require as many additional successes of research and development as other sectors and technical areas (except for further cost reductions). However, the political acceptance in this field is presently far from sufficient to meet the targets.
- Taking the backcasting approach of re-investment cycles of long lasting capital goods, the major focus of R&D has to be given to more efficient power generation (including co- and tri-generation), highly efficient aircraft and trains, long lasting production equipment of basic industries (e.g. steel, cement, paper as far as these materials are not substituted by less energy-intensive solutions).
- Another major focus of R&D has to be the development of generic new technologies with low operating temperatures (e.g. membranes, absorption, biotechnology) and substantially im-

proved efficiencies of energy and material use (e.g. changed properties of surfaces due to nanotechnology, feeding back brake energy by power electronics).

- Structural changes to less energy-intensive production and saturation processes of energy-using appliances and infrastructure will support the necessary efficiency gains. On the other hand, ever increasing mobility, particularly by aircraft, hedonistic lifestyles, or even climate changes which result in higher summer temperatures inducing additional air conditioning demand are (or may be) compensating trends.
- Finally, research in academia and industry needs more resources and changed incentives and the innovation system needs a greater focus on resource efficiency issues and more long-term perspectives in its decisions and activities.

The 2000 Watt per capita society – technically feasible, but politically?

Politically, the feasibility may be at stake due to European societies' short-term decision horizons in the economy and the political system, a similar orientation and behaviour of many private households and voters and the hesitant attitudes of many actors and responsible organisations despite the lip service paid to the concept at political and company level. Many interest groups such as manufacturers, planners, product accompanying services, or the banking sector may not be aware of the opportunities offered by the shift towards greater resource efficiency (greater turnover, better competitiveness on world markets, higher product quality as a co-benefit for companies in industry and services, new jobs, less external costs, eventually increased economic growth and fewer adaptation investments to climate change in the long term from a public point of view).

The transition to a 2000 Watt per capita society requires a fundamental change in the innovation system (e.g. research policy, education, standards, incentives, intermediates and entrepreneurial innovations). This system must be continuously extended, evaluated, and improved over the coming decades with the perspective that it will be integrated into the country's policy on innovation and sustainable development.

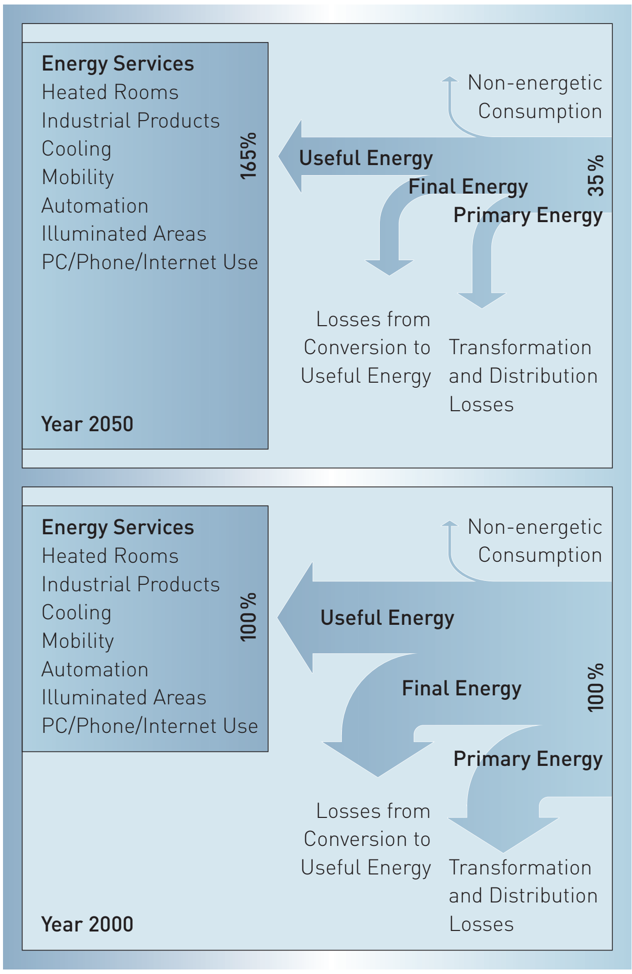


Fig. 0-1: **Energy flows and energy services of Switzerland in 2000 and 2050 – reducing energy per capita demand by two thirds while increasing energy services by two thirds**

R&D needs, opportunities and recommendations

The authors strongly recommend the design of a research programme and process that would have a decisive impact and help the European industry become a leader in those technologies and services contributing to a 2000 Watt society. The 10 million CHF research programme on buildings and settlements planned by the Swiss National Science Foundation in 2004 or the energy research programme launched by the National Energy Research Council in the United Kingdom are good examples.

The idea of the 2000 Watt per capita society and its benefits have to be communicated and further discussed among scientists in academia and industry, in public administrations for research and innovation, environmental protection and energy policy. A *consciousness of the opportunities* presented by new resource-efficient technologies and services with regard to their co-benefits still has to be developed.

Similarly, the *consciousness of potential cost decreases* of new technologies in the long term by learning and economies of scale has to be developed as well as the *intention to stimulate the* *technical competition* between new and traditional technical solutions (e.g. heat pumps and boiler/burner systems, material substitution).

In the light of the requirements, energy research must be understood to encompass all technical systems that use energy during their operation and production phases, not solely energy conversion technologies. Moreover, energy and material efficiency research and related behavioural research has to be understood as:

- *an important contribution to sustainable development in industrialised countries,*
- *a timely investment to support developing countries* on their paths of sustainable development. Instead of embarking on the same course of wasteful energy use as the old industrialised countries, developing countries have a chance to "tunnel through" to a highly resource-efficient capital stock within the next few decades. This option is not an altruistic notion, but an efficient investment because it reduces the greenhouse gas emissions from developing countries and, hence, avoids adaptation investments in industrialised countries which would otherwise have to be made.

Finally, the *research and innovation system of a country or the European Union* has to be the objective of research given the fact that energy-related research is predominantly focused on energy conversion and energy supply and that non energy-related research for new technologies generally does not consider implications of energy use or the efficient use of natural resources. The demand for research of this kind begins with the development of an assessment methodology that allows R&D funds to be allocated to the various fields of energy and material use, including behavioural aspects, in a transparent and meaningful manner. The research should also address the differences in the lobbying intensity of manufacturers and users of energy conversion technologies on the one hand and of manufacturers of energy- and material-efficient products and services on the other. An understanding of this difference may be extremely important for allocating R&D budgets in the near future.

There are many different steps that could be taken at present: R&D initiatives in selected technical and behavioural fields at the national or the European level, a research programme in selected fields which could be co-ordinated between several European countries and/or the European Commission. Depending on the status of research, the complexity of the technical field, the necessary research institutions involved, the constellation of the research partners, or the risk taking capability of companies to be involved in the R&D activities, one may consider specific R&D supporting instruments such as:

- seed money for locating project partners with common interests and competence in leapfrogging using new technologies or materials to progress towards a much higher energy efficiency (which is now the accepted practice of some first scientific networks), or
- additional incentives for additional energy or material efficiency in ongoing research for new processes or products where this aspect of resource efficiency is not particularly considered (e.g. in cases, when publicly funded and well suited innovations get additional R&D support by the Ministry of Energy (or Environment) in order to reduce simultaneously the specific energy demand of that particular new technology);
- in cases where new technologies have a large cost decrease potential, a government may consider an incentive which decreases annually (such as the feed-in tariff for wind power in Germany) to bring down the initial perhaps higher cost of these non-conventional technologies, taking into account that improved energy or material efficiency also decreases the external cost for society which is currently not reflected in the market prices.

In view of the huge number of potentially successful R&D areas, this brochure cannot hope to cover or describe all the instruments that might be very effective in contributing to the overall vision of a 2000 Watt per capita society. The intention of this brochure is limited to starting a process of thinking and action, bearing in mind the extremely challenging objective.

Although this White Book cannot be more than a starting document, the authors will try to communicate the results and recommendations to governments, industry, and national science foundations in the hope of launching broad European R&D initiatives based on the vision of a 2000 Watt per capita industrial society.

If a national programme for sending man to the moon or a joint international R&D effort for nuclear energy were feasible in the 1960s, why should the vision of a 2000 Watt per capita society not be possible in the future?

1: Introduction and the challenges of the coming decades

Energy plays a central role in the economy of both industrialised and less-developed countries. Every country faces three major energy-related challenges in this century and over the next decades in particular:

- the share of fossil fuels in current primary energy use, amounting to 80% globally and 58% in Switzerland, is likely to remain high during the next decades, given the economics and limited acceptance of nuclear power and the small economic potentials and market shares for renewable energies. This situation conflicts with the pressing need to reduce energy-related CO_2 emissions which are driving global climate change. These emissions cannot be sufficiently absorbed by the geosphere and have thus increased the atmospheric CO_2 concentration by more than 100 ppm or 35% since 1880. The *impacts of climate change are a major threat* to mankind in this century according to the Intergovernmental Panel on Climate Change (IPCC 2001 a).
- Recognising the role of crude oil as an energy price setter on world markets, energy policy will have to pay more attention to the peaking of oil production within the next two to three decades. With declining oil production, *energy price levels are likely to increase substantially.*
- Energy policy will also have to give *greater consideration to diversity and security aspects* given that global road, air and ship transportation is currently almost 100% dependent on oil and that two thirds of the remaining oil resources are concentrated in the Near East, a region of considerable political instability.

To meet these challenges, energy and technology policy must pursue improved efficiency in energy production and use as well as improved material efficiency and an increased use of renewable energies as a substitute for fossil fuels, especially oil.

Today, more than 400,000 PJ per year of global primary energy demand deliver almost 300,000 PJ of final energy to customers, resulting in an estimated 150,000 PJ of useful energy after conversion in end-use devices. Thus, 250,000 PJ or two thirds of primary energy demand are presently lost in energy conversion, mostly as low- and medium-temperature heat (UNDP/WEC/UNDESA, 2000). The Swiss conversion efficiencies of the transformation sector are somewhat better due to high shares of hydropower, but the large conversion losses in road vehicles offset most of this advantage; the total energy conversion losses at the final energy efficiency level, therefore, amount to about 37% on average (see Figure 1-1).

Considerations of future improvements in *energy efficiency* often *focus on energy-converting technologies and the distribution of grid-based energies, where the energy losses amount to some 60% of primary energy in most economies.* But there are two addition-

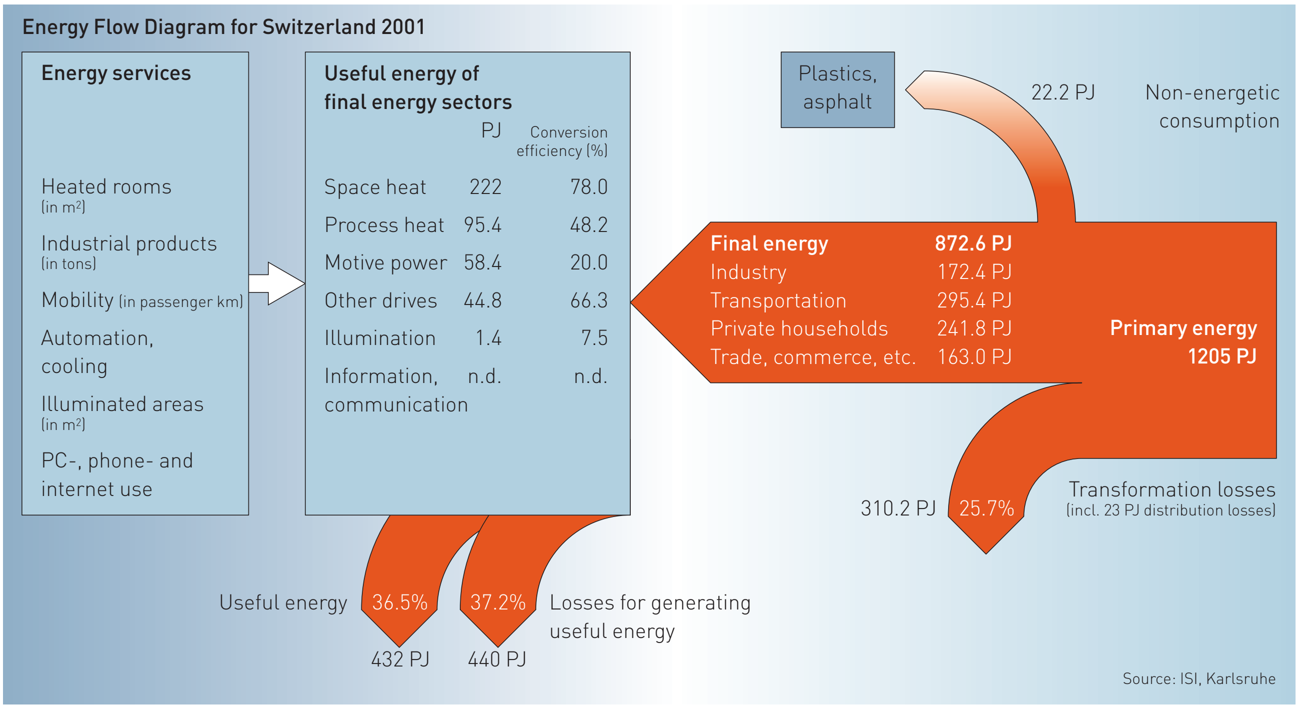


Fig. 1-1: The energy system from services to useful, final and primary energy, Switzerland 2001

al areas for reducing future energy demand which are presently given little attention (see Figure 1-1):

- *energy losses at the level of useful energy* (currently almost 39% of the Swiss primary energy demand) could be substantially reduced or even avoided through such technologies as low-energy buildings, membrane techniques or biotechnology processes instead of thermal processes, and lighter vehicles or the re-use of waste heat.
- *The demand for energy-intensive materials could be reduced* by recycling or substitution of those materials, by improving their design or material properties, and by intensifying the use of products, plants, and vehicles by pooling (e.g. car-sharing, leasing of machines).

First empirical and theoretical considerations suggest that the overall energy efficiency of today's industrial economies could be improved by some 80 to 90% within this century (e.g. Jochem et al. 2002). Given the above-mentioned challenges connected with energy use and the high potentials for efficiency improvements, the Swiss Board of the Federal Institutes of Technology (1998) promoted the vision of a 2000 Watt per capita society by the middle of the 21st century. This represents a reduction of present Swiss per capita primary energy use by two thirds.

The challenges energy-related research is facing at the beginning of this century should not only be seen as threats. The technical and entrepreneurial solutions offer *large opportunities for industries and service sectors,* as the present intensive use of energy and materials will be substituted by capital goods and know-how. Furthermore, the new technologies may induce high export potentials for highly industrialised regions which obviously include Switzerland and Europe.

Within this context, the brochure tries to identify substantial technological advances resulting in highly efficient energy use as these are likely to be promising investments in sustainable development in the long term. One crucial prerequisite is R&D that furthers these technologies. The brochure also tries to give examples of research groups promoting the relevant technologies and innovations in Switzerland.

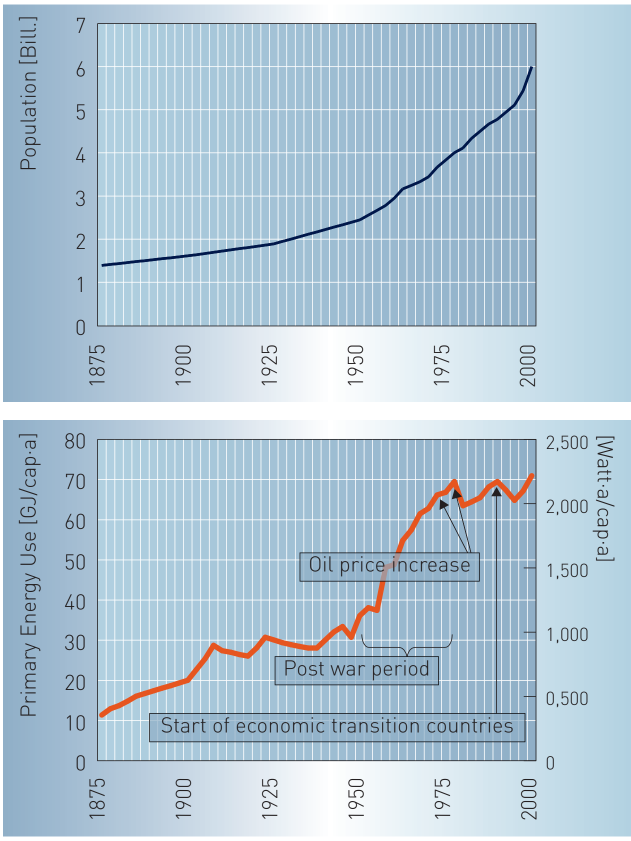
Countries and firms that invest in these technologies and the related R&D will boost their economies and make a significant contribution to the pressing problems of climate change and the imminent peaking of world oil production.

2: The objective – is a 2000 Watt per capita society feasible?

In order to identify promising research areas, the analysis begins by pointing out relevant technologies, important actors, and favourable boundary conditions for their timely market penetration. The overall objectives of the pre-study (Jochem et al. 2002), the results of which are presented in brief in this brochure, were as follows:

- *identify key technology fields* likely to contribute significantly to a 2000 Watt per capita society based on present energy use losses and conceivable major direct or indirect improvements in efficient energy and material use. It was essential to limit the focus to the most promising technologies and, wherever possible, to related R&D in order to give the envisaged short-term research programme a manageable scope.
- *Develop a preliminary methodological approach for the ex-ante evaluation* of resource efficiency and related R&D in these fields. The prospective evaluation has to consider technological maturity and market contiguity, long-lived commodities or investments as well as consumer goods with life-cycles of less than 10 years, i.e. goods with several investment cycles until mid-century.
- *Design a preliminary research agenda for the main study planned for the period 2004 to 2006* based on the insights and results of the pre-study, with particular focus on R&D opportunities for the Swiss scientific community and on Swiss technology manufacturers' competitive advantages.
- *Synthesise the findings of all technological areas* by answering the question of whether a two thirds reduction in per capita energy use is technically feasible in spite of an assumed economic growth of some 75% within the next 50 years.

These objectives were pursued in a short pre-study in 2002. The reader should therefore be aware that this brochure represents the first attempt of the authors to identify possibilities of reducing the present average energy demand of industrialised countries to a 2000 Watt per capita society as the present average primary energy demand of mankind (see Figure 2-1). Since 1875, global per capita energy use grew constantly for a 100 years and has only stagnated in the last two decades at around 70 GJ per capita and year, i.e. slightly above 2000 Watt per capita, a level that Switzerland passed in the early 1960s (see Figure 2-2). It



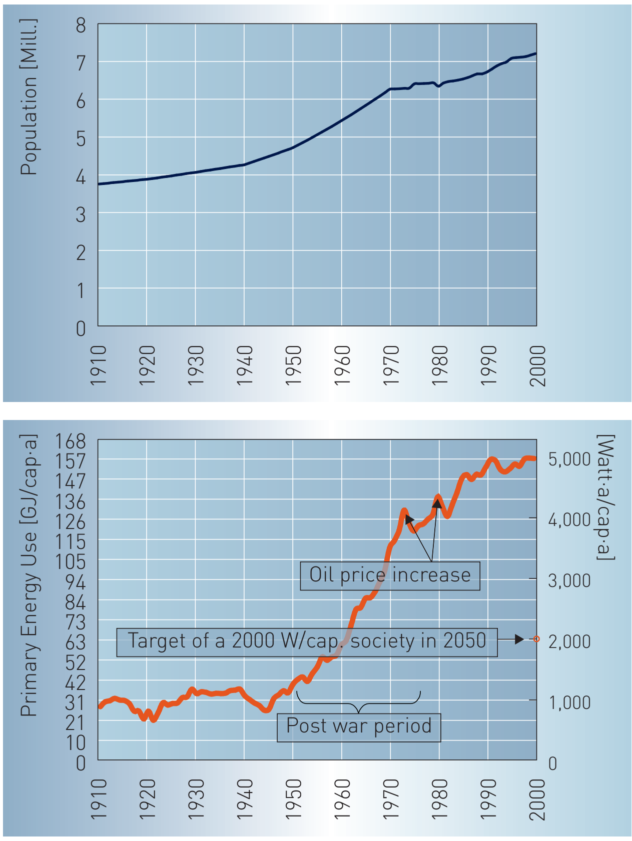
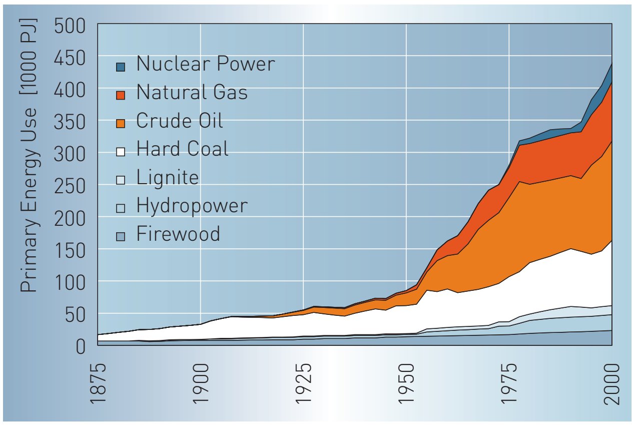


Fig. 2-1: **World primary energy demand and energy per capita use, 1875 to 2000**

Fig. 2-2: **Swiss primary energy demand and energy per capita use, 1910 to 2002**



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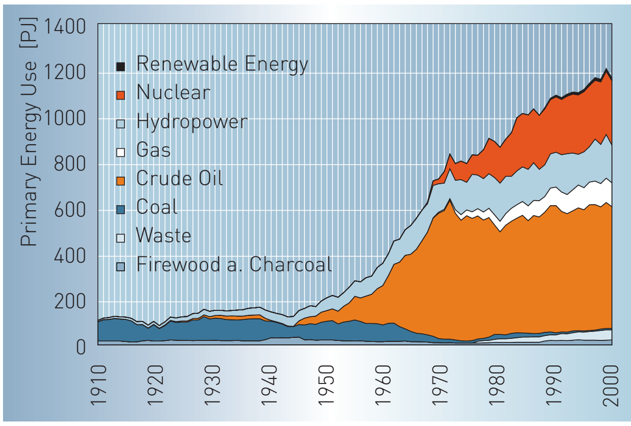

Fig. 2-2: **Swiss primary energy demand and energy per capita use, 1910 to 2002**

might therefore be possible to keep global primary energy use at this per capita level despite the substantial economic growth expected in the developing countries which presently represent more than 85 % of the global population.

3: The methodological approach – checking the feasibility

This section briefly describes the methodological approach (see Figure 3-1) and the criteria used to identify, select, and evaluate the various technological fields, and also relevant actors. As an aid to prioritising innovations on the basis of their timely introduction, the technique of backcasting was used, which examines re-investment cycles and necessary R&D periods. To help generate ideas about new technologies and their implementation, possible boundary conditions for technological development in the energy field over the next decades were described in a short scenario. Energy flow analyses applied to batch process-oriented industries as well as a heuristic concept for identifying actors and institutions for innovation are described as useful tools.

Setting the agenda for research and development

The identification of *potentially relevant technologies* is structured along the lines of the traditional energy economics sectors, the national energy balance (see Figure 1-1), and extended by examining materials' and systems' efficiency as well as behavioural and entrepreneurial aspects. However, the analysis starts by looking for improvements and efficiency at the energy service level first as this determines the rest of the energy chain:

- *intensification of the utilisation* of plants, durable and consumer goods through increased leasing of machines and equipment, car-sharing and other product-dependent services.
- *Enhanced recycling and re-use of energy-intensive materials* and increased *material efficiency* by improved design, construction, or material properties which result in significantly reduced primary material demand per material service unit.
- Improved *spatial configuration of new industrial and residential areas* according to exergy-relevant aspects, and improved merging of residential services in order to reduce the need for motorised mobility. These changes would require modifications in the regulatory framework of local authorities and countries.
- Significantly *reduced demand for useful energy per energy service* (e.g. passive solar or low energy buildings, substitution of thermal production processes by physico-chemical or biotechnology-based processes, lightweight architecture of mobile parts and vehicles, recuperation and storage of kinetic energy).
- Significantly *improved degrees of efficiency at both conversion steps* – primary to final energy and final to useful energy; achievable by applying new technologies (e.g. fuel-cell technologies, substitution of burners by gas turbines or heat pumps (including heat transformers), ORC turbine systems).

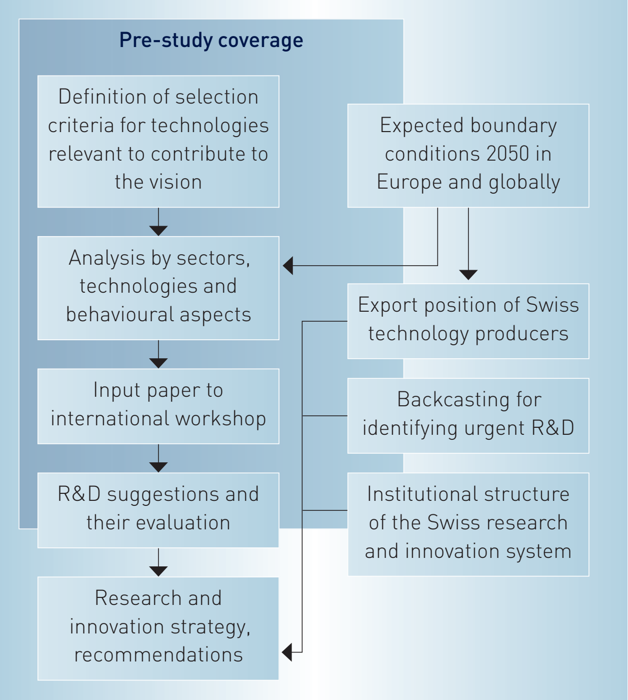

Fig. 3-1: **Methodological approach and working steps for identifying major technologies and R&D to realise a 2000 Watt per capita industrial society**

Identifying substantial and promising energy efficiency potentials

In general, in order to be selected for further consideration, a technological field had to meet the following *selection criteria:*

1) A minimum current energy demand of at least 2 to 3 PJ in Switzerland, i.e. a minimum of 0.2 to 0.3 % of current total Swiss primary energy demand, or a similar percentage that is likely to be realised by the new technology in 2050.
2) An envisaged energy-saving potential of at least 20 to 25 % in the field of energy conversion technologies and more than 50 % at the level of useful energy and material efficiency.

After a technological field had been identified, the search for interesting technologies was conducted by literature analysis, databank screening, and interviews (by phone or in person). Taking into account the limitations of the pre-study, the results presented here should be considered more as exemplifications of the methodological approach than as the final results of a comprehensive analysis.

Given the multitude of technologies using energy in final energy sectors and the vast number of options to improve the efficient use of energy in all these processes, vehicles or machinery, the identification of promising energy efficiency potentials by additional R&D becomes a major challenge. Sometimes the energy input used by certain technologies is known from official energy statistics as are the achievable energy efficiency potentials already analysed by technologists (e.g. buildings and homes in the residential sector, cars, power stations, boilers). However, in other technological areas, and particularly in industry, the energy use and losses of the various processes are scarcely known, except for some energy-intensive processes in the basic product industries such as cement, primary aluminium, paper, or steel.

The search for energy losses – the first step in the search for efficiency potentials

As energy losses of processes substantially depend on whether they are operated as batch or continuous processes, it is suggested to distinguish these two kinds of operation and to *concentrate on batch processes* for two reasons:

- batch processes in industry, crafts, services and the residential sector are widely used and constitute a substantial share of the final energy use of an industrialised country.
- As the energy losses per output of batch processes are likely to be larger than those of continuous processes (due to start/stop operation), there is a relatively high probability of identifying larger energy efficiency potentials here.

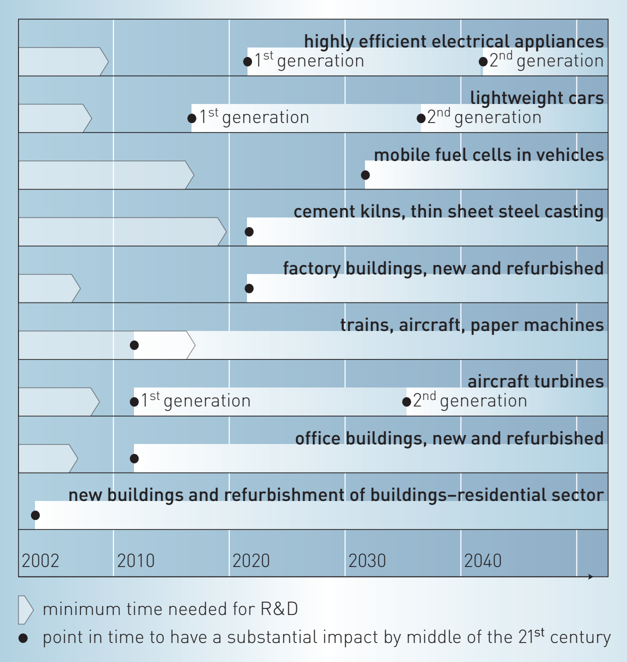

Fig. 3-2: Timing and priority-setting of R&D by backcasting and re-investment cycles

The *method for identifying energy losses* described in the Box below is a stepwise analysis distinguishing between several types of losses:

- the conversion losses to generate the forms of useful energy needed, such as steam, hot water, direct process heat, compressed air, other technical gases, mechanical power etc.,
- distribution losses of the different streams of energy and technical gases,
- the basic heat losses by transmission or ventilation from the machinery or plants in operation,
- the theoretical heat or mechanical power demand for the process under study,
- the various losses of heat, cooling, technical gases and mechanical power within the process itself, in the products, and end-of-pipe technologies (ducts, wastewater, wastes etc).

Each type of energy loss may involve specific technologies and R&D activities that would contribute to reducing them in the future.

Backcasting: feasibility test by re-investment cycles and necessary periods for R&D

If the vision of the 2000 Watt per capita society is to be realised, the re-investment cycles of different technologies in the various sectors must be taken into account. For instance, the re-investment cycle of cars and electrical appliances is 10 to 15 years, allowing three to five new generations from now until 2050 (Figure 3-2). In contrast, the refurbishment of the stock of residential buildings may take more than 50 years, which means that the investments in insulation made (or not made) in this decade will determine the success or failure of the 2000 Watt per capita society in 2050.

Given the long lead times for R&D and long re-investment cycles, e.g. in the case of buildings, trains, aircraft, thermal power plants and certain very long-lasting process technologies, the success of the vision may already be questionable today (see buildings in Figure 3-2).

Considering the dynamics of the necessary R&D periods and the typical re-investment cycles, the backcasting method is very useful to prioritise R&D ideas in related technological fields in a dynamic fashion. These fields include the existing building stock, trains, aircraft, water turbines, and new industrial processes including paper-making plants and planning new long-lived industrial sites and transportation infrastructure.

METHODS FOR IDENTIFYING ENERGY LOSSES OF BATCH PROCESSES IN INDUSTRY, CRAFTS AND SERVICES – AN EXAMPLE: MULTI-PURPOSE CHEMICAL BATCH PRODUCTION

Description of the energy losses along the energy chain

Until recently, there were no models available to investigate the energy use of batch plants in process industries. However, batch production has a substantial share of industrial and commercial final energy demand. Allocation of energy use by means of models or measurements is important for optimisation purposes and to highlight research targets. For mono-product batch plants and multi-product batch plants with low variation between products, a top-down approach for energy modelling is applicable (i.e. energy use can be allocated to total produced amounts of substances). Heating steam consumption is dependent on degree-days and air change rate of the whole production building. For multi-purpose chemical batch plants with highly varying products, models were developed according to equation (1):

$$E = E^{RM} + E^{A} + E^{L} * t \qquad (1)$$

where, E is the use of a specific energy in kWh per batch, E^{RM} is the physical energy use of the reaction mass per batch (e.g. heating up of the substances and evaporation), E^{A} is the physical energy use of the apparatus per batch (e.g. heating up of the metal of the apparatus), E^{L} is the energy loss of the apparatus per hour, and t is the batch time in hours. The loss term was determined by several measurements of single unit operations. The summation of the energy uses of such unit operation models and the base heat and power demand of a factory building (i.e. energy demand at zero production) result in a model of the energy use of the whole facility (see example in Figure 1).

The base energy demand (i.e. the losses throughout the piping system in the building) amounts to about 7 % of the total steam use and has a relatively small energy saving potential. The main part of the steam is used for the apparatus group reactors and nutsche dryers. Further investigations of these main consumers (for the same two days) resulted in the picture presented in Figure 2.

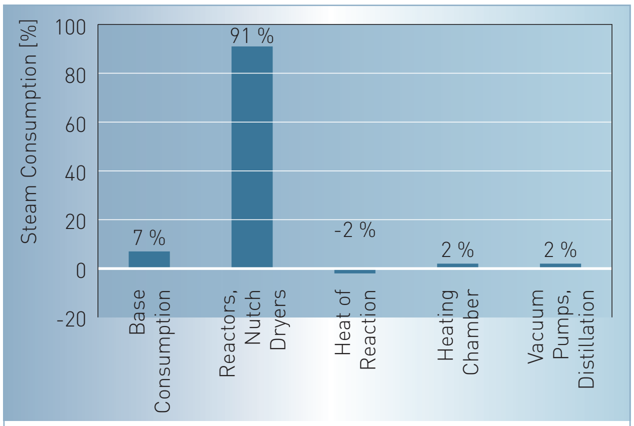

Fig. 1: Modelling results for the allocation of steam and heat use for two days in a multi-purpose batch plant

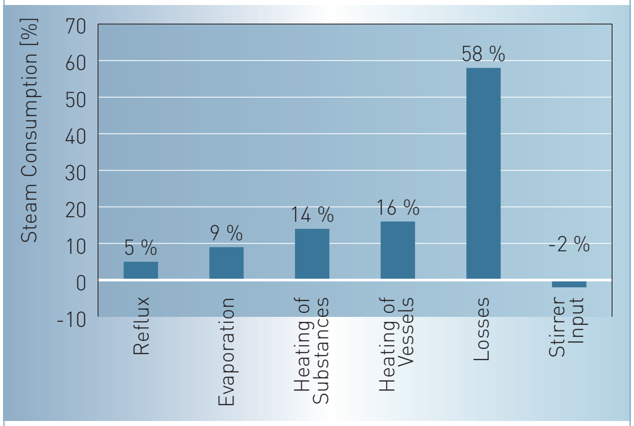

Fig. 2: Steam demand of the reactors and nutsche dryers (see Figure 1) for the investigated two days of production in a multi-purpose batch plant

About 14 % of the steam demand used for the reactors and dryers (about 90 % of the total steam demand of the factory building) is needed for evaporation purposes (either for reflux, distillation or drying). A change in the solvents used or improved temperature control (i.e. no reflux is needed) and shorter reaction times could minimise the steam demand. Performing the reactions in more concentrated solutions could be another way to reduce evaporation energy demand. Lower reaction temperatures (e.g. with the help of more efficient catalysts) would be another possibility for significant savings for this energy use. However, this would result in longer reaction times, which would increase the time dependent losses. The heating of the vessels requires about 16 % of the heating steam demand (for reactors and dryers). Reductions could be achieved through leaner equipment (less metal), lower temperatures or by the switch to a continuous process (i.e. heating-up the apparatus only once per campaign). The losses make up about 60 % of total steam use of the reactors and dryers. The largest saving potentials are thought to be here. Therefore, research should focus on these losses. Much better insulation and different heating systems with better steam traps would yield large savings.

Problems and uncertainties regarding quantification of losses and different practices in companies

The long lifetime of equipment in the process industries and services (about 15 to 25 years for infrastructure and about 8 to 15 years and more for production equipment) represents a major problem as well as the multi-purpose character of factory buildings (no product-specific optimisation of the equipment is possible). In many branches such as the fine chemicals and pharmaceutical industry, energy costs make up only a small share of production costs and are, therefore, not in the focus of optimisation.

R&D options

- **R&D to reduce losses.** Losses could be reduced by optimising the heating/cooling systems using heat integration. Another possibility could be to optimise the design and material choice of reactors, pipes and ducts.
- **Continuous process possible?** Flexible, continuous micro-reactors may be a possible alternative in the future.
- **Substitution of the process possible?** New "minimal-energy" processes have to be investigated for their substitution potential.
- **Substitution of the product possible?** New "minimal-energy" life cycle products have to be investigated for their substitution potential.
- **Bottlenecks /applicability:** the systematic method for the identification of energy losses has to be checked and validated in other batch plants (processing industry).

Recommendations

The energy allocation tool is a useful method for the systematic analysis of batch processes. These processes are rarely energy-optimised and therefore offer significant potentials to realise a 2000 Watt per capita society.

Criteria for evaluating the R&D ideas

Finally, a rough assessment was made by applying the methods of identification and selection mentioned above. The *evaluation criteria* used were:

- cost reduction potentials of the new technologies considered,
- a favourable (at present or achievable in the future) export position of Swiss technology producers,
- perceived favourable acceptance of the new technologies or obstacles which can be overcome in the next decades, and finally,
- the timing of re-investment cycles and the length of R&D necessary before market introduction.

These evaluation criteria were systematically applied to each technological field considered. The results are documented in the Appendices of the report (Jochem et al 2002).

THE SOCIETAL AND ECONOMIC BACKGROUND OF TECHNOLOGY USE IN THE YEAR 2050 – A SCENARIO SKETCH TO FACILITATE TECHNOLOGICAL FORESIGHT

Identifying low energy technologies expected to be in use by the middle of this century was a major challenge of the analysis, since trying to look 50 years ahead is an unusual exercise for R&D in most technological fields. This therefore had to be supported by a description of the relevant techno-economic, demographic, geopolitical and other boundary conditions in 2050.

As a starting point, the authors present a hypothetical description (projection) of the general state of affairs for the year 2050. The following conditions can be expected (here described in the past tense form to give the impression of a viewpoint half a century away in time from today):

- **World population** grew to 8 billion people, less than was projected at the end of the 20th century. Except in Africa, all world regions have a high proportion of elderly people.
- **Global Gross Domestic Product** (GDP) grew more slowly than expected until 2050, because former industrialised countries grew at a linear per capita growth rate of some 400 Euro per capita and year (as already observed between 1950 and 2000).
- **Climate change.** Necessary adaptation investments became substantial in areas with large, highly populated river deltas (e.g. dam construction in Bangladesh, the Netherlands, New Orleans/Mississippi) and in semi-arid zones (e.g. huge irriga-

tion projects in the Mediterranean countries and long-distance water transport systems). All countries have accepted and established greenhouse gas emission reduction targets and strict international control, with UNDP enforcing the obligations through internationally accepted sanctions. Jet fuel use for international flights has been taxed since the 2030s (except hydrogen), whereas regional domestic flights were taxed earlier. The tax income from all jet fuels is used for adaptation investments in poor countries.

- Real prices of **fossil fuels** grew substantially (crude oil prices on the world market doubled from some 25 $/barrel in 2000 to 50 $/barrel), as the mid-depletion point of oil resources was passed and oil production has been decreasing since 2030. Coal is still used, but very often gasified, and the separated CO_2 is sequestrated in exhausted oil and gas fields and in suitable aquifers.
- **Renewable energies** experienced a fascinating take-off in the last decades, starting with wind power after the turn of the 21st century, later in the 2020s with biomass use and geothermal energy and since the 2030s with other renewables accumulating to almost 40 % of global primary energy supply.
- **Nuclear power** was phased out in some European countries because of negative popular sentiment there. In other countries, the use of nuclear energy has remained acceptable over the five decades, with no major accident having occurred since Chernobyl in 1987.
- Europe is a federation of the former European countries. The federation follows some **major policies** at the European level, including general energy and economic policy, climate change policy, trade and foreign policy as well as military policy. The European **population** has been constant for several decades: the decline in the population born in Europe has been compensated by controlled immigration of young and middle-aged people from Asia, Africa and Latin America. The population has a high proportion of elderly people (around 40 % are over 65).
- European **climate change** policy enforced a reduction target of 70 % of energy-related CO_2 emissions between 1990 and 2050 within the context of the Frame Convention on Climate Change (FCCC). The 2050 target was almost met.
- **Income distribution** among individuals is more pronounced in 2050 than it was in 2000.

4: R&D suggestions for new technologies for a 2000 Watt per capita society

This section gives a short summary of the findings on promising energy-efficient technologies by sector and technological field. Each chapter illustrates in a Box one R&D idea and its assessment in more detail.

4.1: Low energy buildings and houses – the central role of refurbishment

The building sector currently demands more than 40% of EU total energy use. Considerable savings could be achieved here by a future-oriented refurbishment of the existing building stock. This has the potential to make a major contribution to the goals stated in the EU Green Paper on the European strategy for the security of energy supply and the White Paper on energy for the future. Both the technology and proven concepts are available for new low energy housing and the European countries have adopted a progressive Energy Performance Directive for new buildings.

Internationally, passive house technology can be considered the state-of-the-art in energy-efficient buildings. Over the past five years, more than 3,000 apartments and single-family homes were built in Germany, Austria and Switzerland utilising this technology until the end of 2003. The energy demand for heating is about 10 kWh/m^2 heated gross floor area. These are "1-litre houses". The total primary energy demand including household electricity (weighted) is less than 100 kWh/m^2 (120 per net floor area). For the first time, new buildings which also meet modern comfort standards come very close to what may be considered "sustainable" housing. Demonstrating this housing technology for new buildings has already proved a successful means of stimulating innovation in the building sector (e.g. EC project "CEPHEUS", completed; IEA activity "Sustainable Solar Housing", ongoing).

The challenge – the refurbishment of the building stock

However, in the next decades, the energy demand of buildings will be dominated by the existing building stock, not by the relatively small share of new buildings. The fossil fuel use of existing buildings will play a key role in global warming and environmental degradation for decades to come. The existing building stock represents an important legacy, but also a challenge to society. Existing buildings have been largely ignored in the past as there are difficulties and objections to incorporating them into building regulations and codes. Most ongoing renovation fails to take

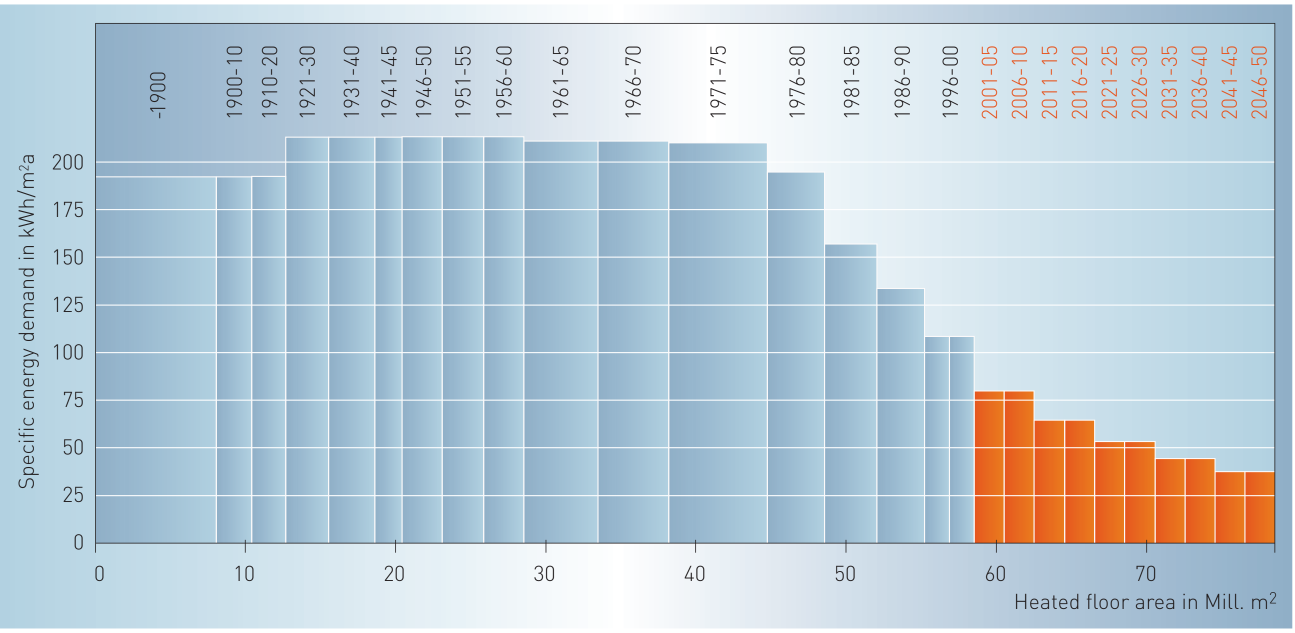

Fig. 4.1-1: Increase in heated floor area and development of specific energy demand for heating and hot water of domestic buildings by periods of contruction, data from the Canton of Zurich. The size of the bars represents the energy used. It is obvious that the future energy demand will be dominated by the existing building stock (blue bars). Future constructions (red bars) will have a relatively small impact on total residential energy use (Energieplanungsbericht Kanton Zürich, 2002)

advantage of the opportunities for a sustainable improvement of the building stock. But without major improvements to the existing stock, no real advances in efficiency are possible within the decades to come. Any low key improvements to the building stock are likely to be offset by the energy demand of additional floor area (see Figure 4.1-1).

Existing buildings can often no longer compete with new and modern buildings. Many old properties cannot offer the comfort and qualities of new buildings. Whether to renovate a building or demolish and reconstruct it becomes a crucial decision (see Figure 4.1-2). This does not solely depend on technical aspects. Financial aspects have to be considered as well as social implications. Estimating what will give the best return on investments often constitutes the dominant part of the building owner's decision plus the social and environmental implications of the various options. Advanced planning tools have to be developed which allow the evaluation of the environmental, social and economic impact of the retrofit concepts and provide decision-support on the issue of refurbishment versus demolition of existing buildings.

Refurbishment alone is hardly cost-effective in energy terms. Energy-saving measures have to be optimally combined with and economically evaluated as a general upgrading of the building's features, with comfort improvement (excellent thermal comfort, better noise control, improved air quality) and with added value such as optimised floor plans or additional space use (attics, enlarged balconies etc.) and improved renting possibilities.

R&D needs, opportunities and recommendations

From the technical point of view, building refurbishment still struggles with three major challenges:

- high performance thermal insulation systems which are less space consuming than conventional insulation materials. Special vacuum-insulated retrofit components should be developed, tested and demonstrated. The focus of the proposed technologies should be on cost efficiency and robustness. Due to the substantially lower space requirement, the newly developed solutions will not only be cost-competitive but also provide added value. The aim is to develop and measure the performance of suitable, low-risk solutions for existing buildings. Easy-to-apply vacuum-insulated sandwich panels and combinations with traditional insulation materials are to be developed in collaboration with industrial partners (see Box). The specific problems of thermal bridges have to be investigated.

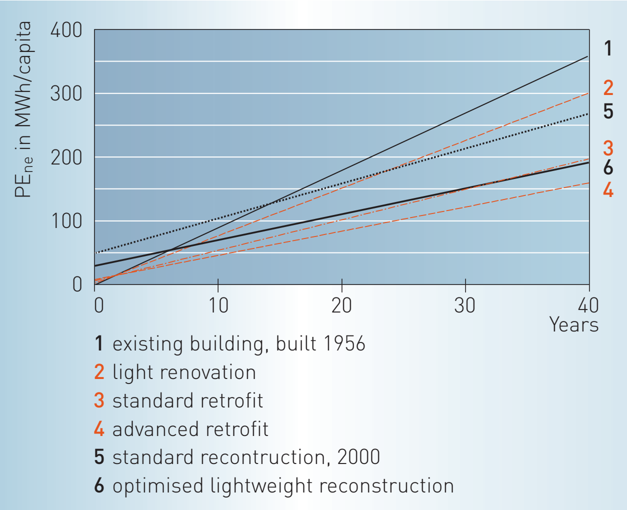

Fig. 4.1-2: Long-term impact of refurbishment versus new-buildings. The diagram shows the cumulated primary energy demand of an existing 24 apartment house (1), three retrofit alternatives (2 + 3 + 4) and two reconstruction options (5 + 6)

Fig. 4.1-3: Retrofit Demonstration Building Therwil (CH): after renovation and added penthouse, 1/4 of original energy demand for heating and hot water (~ 50 kWh/m²)

- Cost-effective and easy to install mechanical ventilation systems. Ventilation systems are a key element for good air quality and efficient heat recovery. The existing ventilation systems have to be improved in relation to their space requirement, installation costs, effectiveness and noise control. Additional features have to be integrated such as highly efficient heat recovery and heat and cold production and distribution. Research and industrial development is required to optimise the design of such ventilation systems.
- Optimised integration of renewable energy technologies such as thermal collectors for hot water production and PV-panels for electricity. Collectors are still difficult to integrate in existing building envelopes. New roof constructions in particular often represent a value added to existing buildings. Solar panels integrated into roof tops have to be further developed which also provide thermal and/or water insulation as additional functions.

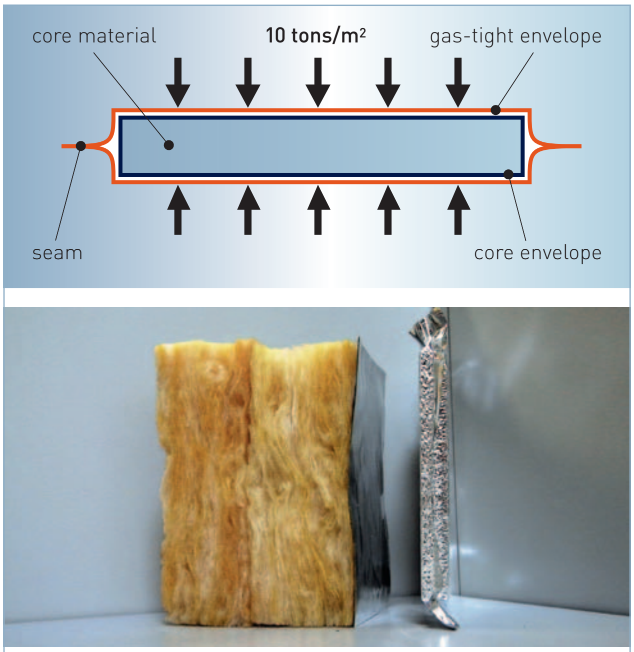

Fig. 1: Schematic cross section through a VIP (above), comparison of the thickness of a conventional mineral wool insulation board and a VIP (below) of equal thermal resistance

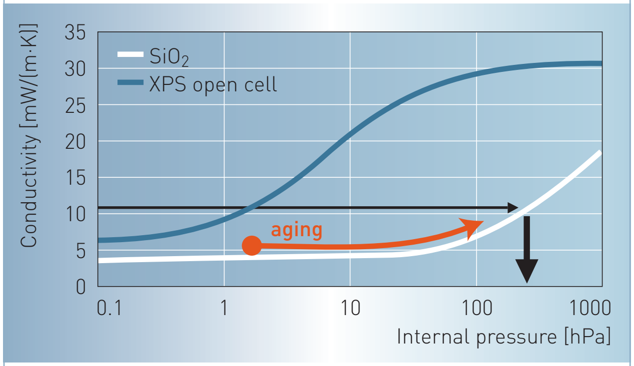

Fig. 2: Pressure dependence of thermal conductivity. Nanoporous core materials such as fumed silica (SiO_2) achieve a much lower thermal conductivity at higher gas pressures than conventional insulation materials such as extruded polystyrene (XPS). The aging effect due to gas leaking is therefore much slower.

REDUCTION OF THERMAL LOSSES USING HIGH-PERFORMANCE INSULATION TECHNOLOGIES

The maximum heating load of renovated houses should be reduced to 10–20 W/m² (today's average is about 50 W/m²). To achieve this, thermal insulation layers of 20 to 30 cm are applied to new buildings. In existing buildings, the available space is often limited and usually precious. Therefore new systems should apply high-performance vacuum-insulation technology in combination with traditional insulation materials where appropriate.

Present status of the technology

In the last few years, vacuum-insulated panels (VIP) have been developed for building envelope applications. At present they are typically made of a microporous core structure which is evacuated and sealed in a thin gas-tight envelope (Figure 1).

In most products appearing at present on the market, fumed silica (SiO_2 agglomerates) is the main component of the core material. Compressed to about 200 kg/m³, the pore size between the SiO_2 grains is well below the mean free path of gas molecules at an internal pressure below 1 mbar. Since the molecular collision rate is strongly reduced in this case, gaseous heat transfer becomes virtually negligible. Heat transfer is thus limited to solid conduction (about 3 mW/(m·K)), and thermal radiation (less than 1 mW/(m·K) by admixture of opacifier. Hence the total thermal conductivity of the evacuated SiO_2 core is about 4 mW/(m·K). This is roughly 8 times lower than conventional thermal insulation boards.

First results from the application of vacuum-insulated panels are available from demonstration projects in Switzerland, Germany and Austria. Excellent insulation performance is achievable with vacuum-insulated panels of only 2 cm thickness. But it is obvious that building-related applications and quality assurance programmes have to be developed for this promising new insulation concept.

R&D aspects

The gas-tightness of the envelope is a key issue for the proper functioning of a VIP, especially for a long-term building application. Lowest permeation rates can be expected for "massive" metal layers with a thickness of several micrometers. However, thermal measurements and numerical calculations at EMPA show that the edge heat flow through a metal foil envelope can be much larger than the heat flow through the VIP core itself. In order to combat the thermal bridge problem, metallised polymer films are now widely used in combination with VIP products for building applications. To overcome the gas permeability problem, newly developed laminated high barrier films include up to three metallic layers each with a thickness in the range of 30–100 nm. Although better performance compared to a standard metallised film can be expected, it is still an unresolved question whether these barriers really achieve the stringent requirements needed to ensure the targeted VIP service life in the order of 30 to 50 years (see Figure 2).

While VIP application is growing rapidly, neither testing procedures nor any service life predictions for VIP have been established so far. A second focus has to be put on the calculation and experimental validation of the thermal properties of building components with built-in VIP. And efforts have to be made to develop semi-products and practical applications which are suitable for the rough conditions on construction sites and during their long service life.

Recommendations for R&D

- Support generic research on understanding the barrier properties of inorganic barrier layers and the chemical and physical processes that cause degradation and corrosion,
- develop innovative detection techniques for low-level gas permeation rates,
- study and develop alternative high-performance insulation technologies that avoid vacuum requirements by applying nanostructured materials and rare gases,
- develop robust vacuum insulation systems and super insulated components that have a long service life,
- prove the applicability and effectiveness of such systems and components in demonstration projects.

4.2: Transportation – low energy mobility, impossible for democracies?

Worldwide transportation is expected to increase from today's 35 trillion person kilometres to 53 trillion in 2020 and to triple to about 103 trillion in 2050. At the same time, the share of high-speed transport (mostly air traffic) is anticipated to grow from today's 16% to about 41% at the expense of all other transport sectors. In Switzerland, transportation has increased its share of end energy use to 33% during the last two decades. The present Swiss energy demand of all relevant traffic modes can be allocated in decreasing order to passenger cars (137 PJ), aviation (66 PJ), trucks (44 PJ), trains (10 PJ), and buses (4 PJ). The five options to reduce the energy demand covered in this sector are:

- *more efficient passenger cars and new city cars* due to better design and construction, reduced weight, more efficient drive trains and the introduction of renewable fuels.
- *More efficient aircraft* due to improved engine technology, structural and aerodynamic efficiency, and new designs for hydrogen use.
- *More efficient trains and high-speed trains* through improved vehicle components, whole-train design, and optimised technical operation.
- *More efficient buses and light-duty trucks* by improved drive train efficiency.
- *Traffic and modal split management* via extensive use of telematics applications and also human-powered mobility.

Heavy-duty trucks show a limited savings potential of about 15%, mainly because of their already optimised drive train efficiency and because they are operated primarily at full engine-load.

More efficient passenger cars and new city cars

Passenger cars show a large potential for efficiency improvements of up to 70%. This maximum potential for a car *with the present or improved driving and load capabilities, safety and comfort* can be achieved by lowering the aerodynamic drag coefficient by 30% thanks to better car body design, the rolling resistance by almost 50% due to better tyre materials, and the car body weight by more than 20% as a result of using aluminum or other lightweight materials. Together with the most efficient drive train system and the capability of recuperating braking energy, these measures can lead to energy savings of about 50% for internal combustion engines and up to 70% for fuel cell-powered

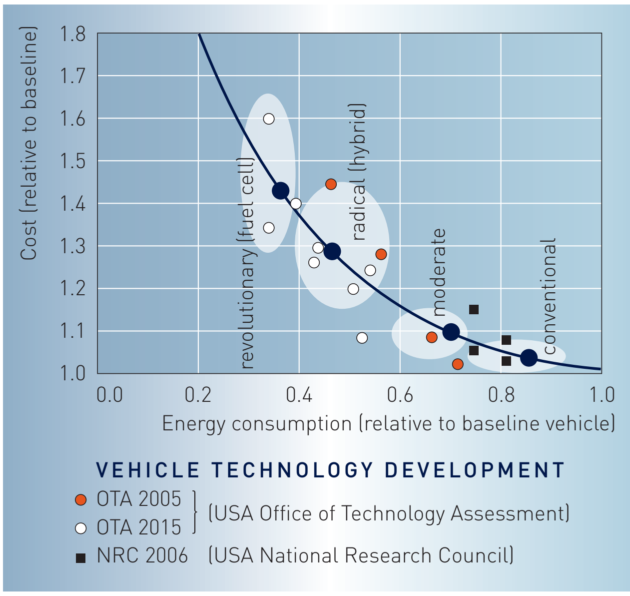

Fig. 4.2-1: Technological options for CO_2 mitigation in motorised individual transportation. Conventional and moderate efficiency improvements include reduction of weight, air drag and rolling resistance. Together with the most efficient drive train system and the capability of recuperating braking energy, these measures can lead to energy savings of about 50% for internal combustion engines (radical, hybrid) and up to 70% for fuel cell-powered cars with supercapacitors as power boosters and energy recuperators (revolutionary, fuel cell).

Fig. 4.2-2: PSI tests the experimental car Hy.Power, a modified VW Bora equipped with hydrogen fuel cells and supercapacitors to recover braking energy. The photo shows Hy.Power arriving at the 2005 m high Simplon pass on January 16, 2002 during harsh weather conditions.

cars with supercapacitors as power boosters and energy recuperators (see Box and Figure 4.2-1). In order to achieve these potentials, the following R&D areas have been identified as important:

- R&D on new car body concepts to integrate new drive trains and reduce air drag and rolling resistance.
- R&D on fuel cells to lower the production costs and find efficient solutions for hydrogen storage to permit a sufficient driving range with renewable fuels.
- R&D on the production and distribution of renewable fuels, especially hydrogen from biomass and solar energy.

Some Swiss companies and Universities of Applied Sciences (FH) as well as the ETH domain have been involved in the development of special city cars. By 2050, this car type might be important for short-distance and low-speed travel, with reduced passenger and load capacity, and a weight below 500 kg. City cars could improve the efficiency of inner-city car traffic by up to 85%. However, city cars would fulfil a new function compared to passenger cars, which are also suitable for long-distance travel. Thus, city car contributions to reducing energy demand are strictly dependent on behavioural, marketing, and policy changes and seem most useful in multi-modal traffic concepts.

More efficient aircraft

Of all the traffic modes, aviation has shown the largest growth over the last decades and will be of the greatest importance in the future. Technical improvements aiming at turbine technology as well as structural and aerodynamic efficiency could result in efficiency improvements for aircraft of up to 45% until 2050. Alternatives to kerosene-based fuels are promising but long-term. Hydrogen fuel, which would dramatically reduce direct CO_2 emissions, requires new approaches to aircraft design and supply infrastructure. The climate forcing effect of water released into the lower stratosphere from the combustion of either conventional or alternative fuels must be taken into consideration. Long reinvestment cycles imply that the best technology of 2025 to 2030 will represent the fleet average by around 2050. Thus, it can be expected that new fuels and completely new aircraft design may only have a partial impact until 2050. The effect of Swiss R&D contributions may be restricted to turbine efficiency and advances in material science due to the dominance of a few large global producers and related research institutes.

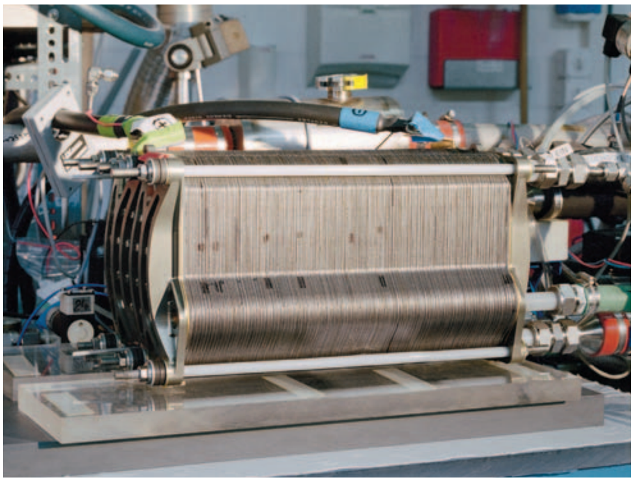

Fig. 4.2-3: One of six fuel cell stacks with 125 cells for the Hy.Power experimental car during a test run at PSI. It produces up to 8 kW electricity from pressurised hydrogen and normal air oxygen, of which about 20% are used for the compression of air and other aggregates.

More efficient trains and high-speed trains

The presently dominating steel-wheel-on-steel technology will have to be developed in the direction of faster and more comfortable passenger trains as well as freight trains with improved freight handling and efficiency. To reduce the energy use of trains, it will be necessary to improve train components or single vehicles, to optimise whole-train design, and to realise improved technical operation of trains and vehicles. The estimated savings potential is up to 60%, resulting from new propulsion concepts (up to 30%), new light construction materials (up to 20%), reduced air and mechanical resistance (up to 10%), and the combination of these measures together with optimised technical operation. The Swiss rail industry is traditionally quite active in this field where substantial R&D is being undertaken.

The high-speed trains currently available (TGV, ICE) are compatible with the existing track system but need special high-speed tracks with reduced curvature in order to reach top speeds higher than 200 km/h in regular service. Their potential for further increases in speed, and thus for competition with flights up to 1000 km, is limited. Several concepts of new high-speed railway systems based on magnetic levitation or jet-powered trains are under development, e.g. the MLU (Japan), Transrapid (Germany), and the SwissMetro/EuroMetro (Switzerland). With top-speeds over 500 km/h, they enable fast and energy-efficient passenger and freight transport and have the potential to replace short-distance air traffic. In Switzerland, EPFL, several Universities of Applied Sciences (FH), and some companies are developing the SwissMetro/EuroMetro which would operate below ground in partially evacuated tunnels running by levitation, magnetic propulsion and guiding systems. However, it is open to question whether substituting non-efficient air traffic by comfortable high-speed trains would perhaps lead to an increase in overall traffic-related energy consumption as an unintended rebound effect.

More efficient buses and light-duty trucks

Buses and light-duty trucks have a much lower direct impact on total energy consumption than passenger cars, but they play an important part as front-runners for new drive-train systems. Their use in inner-city traffic, their larger space capacities for fuel storage and other components, the possibility of central refuelling, and their high visibility make them especially attractive for alternative and efficient propulsion systems, in particular for fuel cell systems. Overall savings potentials of up to 33% for buses and 60% for light-duty trucks can be envisaged. The reduced relative potential compared to passenger cars largely results from stricter boundary conditions in vehicle design.

Traffic and modal split management

Traffic management can support the implementation of legal, political and economic measures to improve safety, traffic flow, and capacity. Thus, a *system view* focusing on a bundle of measures that support one another and incorporate low energy demand as one of the decisive criteria is fundamental. The analysis has focused mainly on technical measures up to now without assessing quantitative efficiency potentials. Air traffic management systems are used for the guidance, separation, and control of aircraft movements and lead to an additional 5% efficiency gain. For car traffic, telematics applications in various forms include planning and control instruments to ensure better traffic flow on motorways and in inner cities, efficient navigation, and better control of driving behaviour. For truck traffic, load management is the critical factor. The average load factor is presently only around 50%, which results from a decentralized distribution and "just-in-time" delivery. Telematics applications can help to improve freight and terminal management and therefore lead to higher load factors.

Technical measures for modal split management (as for traffic management) can only aid other measures, in order to substitute less efficient traffic modes by more efficient ones or by

Fig. 4.2-4: Supercapacitors reach an unprecedented high capacitance of thousands of Farad by increasing the electrode surface of traditional electrolyte capacitors (with about 0.01-0.1 Farad) by factors of up to 100 000. This is achieved by using coal particles with surface properties that can be described by applying the concept of fractal geometry (surface dimension of the electrodes is about 2.6). 100 elements with 2700 Farad and a maximum of 2.6 Volts are sufficient to provide 30 kW for 20 s, and to accelerate, e.g. a 1000 kg car to 120 km per hour. If combined with fuel cells producing continuous power of only 30 kW, a car with good dynamical properties results without the fuel cell stack being oversized (for the sake of acceleration, today's car engines are oversized by a factor of 2 to 8).

new forms of multi-modal traffic. In Switzerland, there are leading R&D contributions to new forms of human-powered mobility for short-distance driving, e.g. hybrid solutions for bicycles. Multi-modal passenger travel, combining public transport and car-sharing, could be made more attractive by providing information on intermodal route planning and by setting up interactive systems to reduce waiting times. Intermodal freight traffic, combining trains and trucks, could be improved by better transshipment technology, freight handling, and faster routing using telematics applications.

R&D needs, opportunities and recommendations

There is no doubt that the energy savings potential will very much depend on future progress in efficiency, material technology and telematics applications. To summarise the preliminary findings of the relationship between the various options of sustainable transport and energy demand, the following conclusions can be made:

- a dedicated R&D effort is necessary to move towards the realisation of the aforementioned potentials in different transport categories. Although there is no major car or aircraft company located in Switzerland, the Swiss automotive supply industry is substantial, with a turnover of more than 6.3 billion CHF.
- R&D in the important passenger and light-duty car sector has to focus on providing precisely controlled and downsized internal combustion engines (ICE) with improved fuel injection, variable valve timing, improved compression ratios and temperature control, less friction, and engine shutdown during idling. In addition, new lightweight car-body materials and new tyre materials with less rolling resistance, intelligent control and continuously variable transmission (CVT) constitute important aims.
- In parallel to the improvement of traditional ICE, radically new concepts also have to be developed, based e.g. on fuel cell propulsion systems. In this context, R&D has to aim for the low-cost production of high-performance polymer electrolyte fuel cells (see Figure 4.2-3), fuel cell membranes, optimisation of the fuel cell stack and system components and in particular technology to recover braking energy such as, e.g. supercapacitors (see Figure 4.2-4).
- As the rapid growth in the aviation sector will outperform the (although important) savings potential, Swiss R&D has to focus mainly on alternatives to reduce short-distance air traffic. In this context, high-speed trains might turn out to be a valuable contribution.
- Traffic and modal split management based on new telematics applications offers new options for passenger and freight transport, and might contribute to inducing behavioural changes of customer preferences in a more sustainable direction.

The close relationship between transport systems and energy demand opens up an entirely new area of *energy systems analysis.* It will be important to imbed all the above-mentioned measures into a larger societal framework to ensure their full energy savings potential. Without considering the system as a whole, including changing customer preferences (e.g. the trend towards heavy off-road cars, longer distances between home and workplace, longer-distance holidays by airplane, etc.), many measures might result in a net *increase* of energy use due to important rebound effects overcompensating the savings potentials. One major challenge will be to gain enough influence over customer behaviour in a democratic system, relying on convincing technology, modern and appealing designs, intelligent publicity and, first of all, an educational system which integrates the concept of sustainable development.

FUEL CELLS AND SUPERCAPACITORS: A POWERFUL COMBINATION FOR THE EMISSION-FREE CAR

Powered with biomass-produced or solar hydrogen, fuel cells produce electric energy and emit only clean water vapour. Combined with supercapacitors for storing braking energy and for boosting, such a car would have the same (or even better) dynamical performance as today's petrol cars and would use around four times less energy.

Present status of the technology

- Fuel cells have been used in space technology and submarines since the 1960s, but have only been intensively discussed for road traffic, decentralised stationary electricity production and portable electronics for about 15 years.
- Supercapacitors were developed in the last decade and combine the advantages of batteries (high energy density) and normal capacitors (large currents, no degradation due to absence of chemical reactions).
- The European Community began funding CITARO-buses operating in 10 European cities in 2003 (see www.fuel-cell-bus-club.com), and leading car manufacturers have developed prototypes for passenger cars (e.g. DaimlerChrysler launched the necar5 and Honda the FCX in 2003, see www.hyweb.de). Because they are only produced in small numbers, they are very expensive.
- The roughly 500 g hydrogen needed to power a medium-sized fuel cell car over 100 km could be produced from biomass with today's technology for about CHF 2.80. By comparison, the costs for a conventional gasoline car using 8 litres per 100 km are CHF 2.40 without taxes and around CHF 10.00 including taxes.

R&D aspects

- Swiss research at the PSI concentrates on the development of better performing and less expensive components for fuel cells and supercapacitors. The development and integration of the technology into a VW Bora (with ETH Zurich and industrial partners) was demonstrated by driving the resulting "Hy.Power" over the Simplon pass in January 2002.
- Important international R&D on fuel cells is, e.g. at Ballard Power Systems, General Motors, Intl. Fuel Cells (USA), Toyota, Honda (J), Nuvera (I) as well as at the Los Alamos Natl. Lab. (USA) and the FZ Jülich (D). Universities making important contributions include the Universities of South Carolina, Connecticut and Case Western (USA), and several European universities.
- Important international R&D on supercapacitors is concentrated at Maxwell Technologies (USA, one company is located in Rossens near Fribourg, Switzerland), EPCOS (D) and Panasonic (J). The group of B.E. Conway (Univ. Ottawa, Canada) contributes with important basic research.
- Present R&D bottlenecks for fuel cell technology are its reliability under extreme conditions (e.g. low temperatures), a drastic cost reduction resulting from better and less expensive materials and mass production, and inherently safe hydrogen storage devices. System integration (aggregates for the fuel cells, supercapacitors) also holds large potentials for optimisation.
- Present R&D bottlenecks for supercapacitors are increasing power density and a major cost reduction (a 2700 F, 2.6 V supercapacitor today costs around 120 CHF; about 100 supercapacitors would be necessary for a car).
- Research on certification, distribution, and acceptability for the public is connected with the production, transportation and storage of hydrogen. The most critical problem is the storage of hydrogen in passenger cars which might be overcome, e.g. using lightweight compounds to store hydrogen without significant overpressure.

Recommendations

- Support generic research on understanding the technical limits of supercapacitors, fuel cells and the possibilities for their integration into one system.
- Support generic research on inherently safe hydrogen storage and on systems analysis identifying technical, political and social opportunities to enhance the fleet share of novel car types.
- Support applied research to optimise the production of fuel cells and supercapacitors and to combine them together with other components in novel car designs.
- Support systems research to analyse possible options of transition or co-evolution of fuel cell and combustion engine driven motorvehicles under aspects of cost, infrastructure, acceptence, employment and economic impacts.

4.3: Electronics and electric power systems

Due to the invention and development of electronics, electric systems have changed rapidly in recent years. Two new groups of technologies have emerged,

- information technology (IT) as an integral part of business processes, goods (e.g. smart objects), control systems, information and telecommunication systems, and
- power electronics as an integral part of transformers, switches, motors and generators (including control devices and sensors).

Both are termed cross-cutting technologies in this study as they can be implemented in all sectors and almost any application. Both groups of electronics open up new potentials of energy and material efficiency that are only partially known at present given fast increasing applications in many energy-related fields and products.

R&D in both areas is driven by the desire for increased speeds, voltages, currents and for miniaturisation. Because of heat dissipation problems, energy efficiency at the level of single devices is a prerequisite for these improvements. Energy efficiency at the level of equipment, production systems or products and services to the final customer is a different matter. IT and power electronics hold, at the same time, potentials for dramatic efficiency improvements and for tremendous increases in waste, in particular for an accurate matching of production to individual requirements and for automated mass production with no connection to needs and wants.

Information Technology – inducing high energy and material efficiency potentials, but also further needs and energy demand

Information processing, as such, does not require much energy. IT systems including power transformation and cooling systems do, however, account for about 5% of Swiss electricity demand, and microelectronics in all sorts of appliances account for about another 5%. As IT is an integral part of almost any technological advance, it is difficult to give any quantitative estimates of the associated energy conservation potentials[1]. Most studies find mixed effects of IT on energy use as a whole. The principal effect is often an indirectly caused increase of energy use due to IT's contribution to economic growth. In many cases, energy efficiency potentials due to improved remote control can be achieved in all the final energy sectors described in Chapter 4.

As some examples illustrate, *IT's* use in practice determines its energy effect:

- an on-board navigation system for road vehicles can be used to avoid traffic jams and detours and thus reduce driving, or it may enhance the automobile's general attractiveness and result in increased driving time.
- In the textile industry, IT's time-saving acceleration of manufacturing processes has contributed to shorter fashion cycles, greater output, and therefore higher overall energy use, even while the specific energy use (per ton or monetary unit) of produced goods has decreased.
- One principle function of IT is the translation of sensor signals into control signals. For example, measurements of humidity in textile drying, the brightness of daylight, or the exact millisecond condition in an internal combustion engine cylinder can be translated to provide the greatest precision and energy-saving control for the respective processes. IT applications in colour metrics, for instance, provide about 30% energy savings in textile dying and about 20% in potato chip roasting.
- IT equipment is rapidly becoming smaller and cheaper. It is also becoming an integral part of many goods (pervasive computing). Computers and telecommunication systems are increasingly inseparable systems (computers talk and transmit messages, telephones are smart devices). The economics of "ubiquitous computing" is rapidly improving. Intelligent machinery, software and IT integrated in other products will, unlike stand-alone IT, be very important in the future.

Power electronics – making the silent revolution of electricity systems feasible

The introduction of power electronics has been called the "silent electrical revolution". For many end users, this introduction can be seen in higher efficiency, improved flexibility, and added features in many electrical appliances. Almost all the electrical appliances used in modern homes contain some power electronics. For energy savings, or management, controllability is an important prerequisite, and this is offered by power electronics circuits to a very large extent.

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1) The influence of Information Technology (IT) is so large that a study of it cannot be undertaken in a purely scientific way; there is no reference system. The lack of a reference system for comparison was noted by de Sola Pool in his seminal study on the telephone (Ithiel de Sola Pool, Ed. 1977. The Social Impact of the Telephone. Cambridge MA: MIT Press).

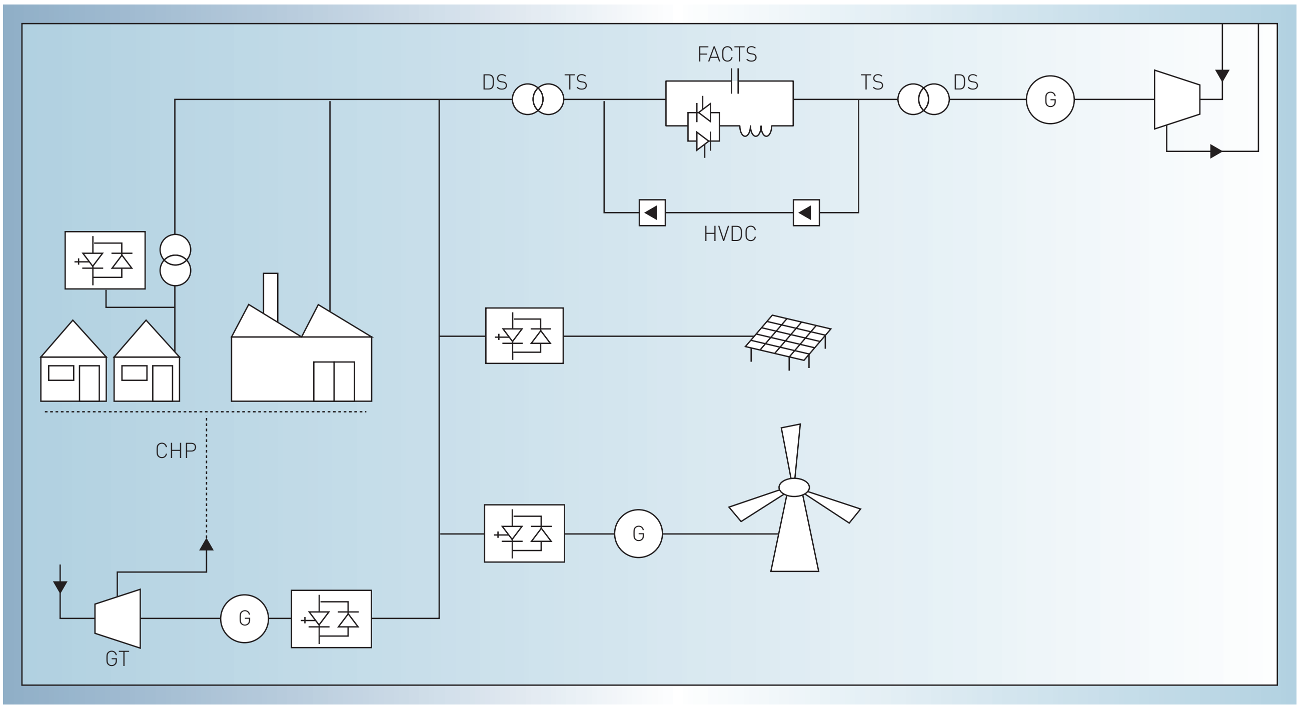

Fig. 4.3-1: A power system with integrated power electronics solutions (GT = gas turbine, CHP = combined heat and power generation, G = Generator, HVDC = high voltage direct current, FACTS = Flexible AC Transmission Systems)

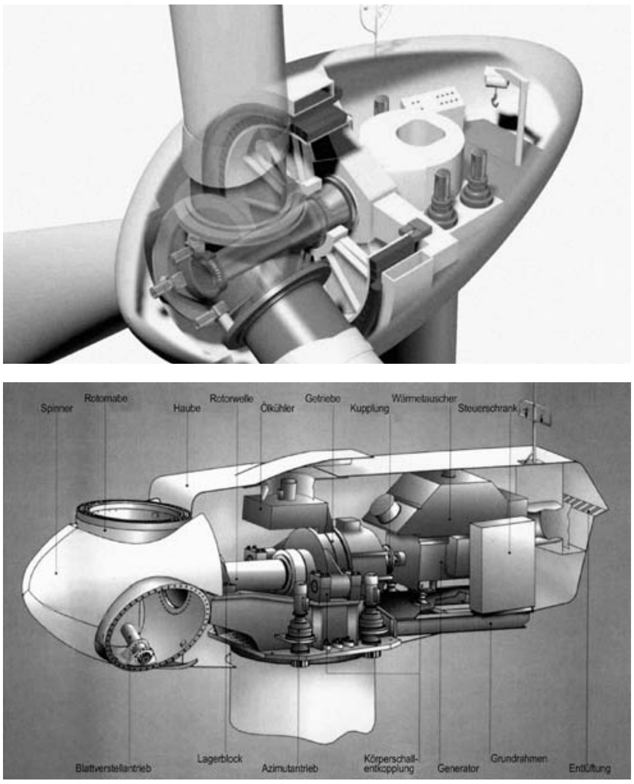

Fig. 4.3-2: New wind converter systems with power electronics (above) substituting traditional gear boxes (below)

The energy efficiency potential of power electronics in drives alone can be conservatively estimated at 30 PJ [2]. This not only includes an efficiency improvement in producing mechanical drive from electricity, but refers primarily to avoiding unnecessarily produced mechanical drive (air blown when there is no need for air movement, idly turning shafts etc.), as well as the possibility of recuperating mechanical drive in traction to produce electricity while braking.

A large efficiency potential is also found in smart decentralisation. Let us look at this in more detail. Today, one can see a clear trend developing away from electric power systems, where all the electric power is generated in relatively few large power plants connected to the transmission or sub-transmission system, to systems where a substantial fraction of the power is generated by a large number of small power plants. The best examples are Denmark and northern Germany. In the western part of Denmark during some loading conditions, generation from non-dispatchable power sources may even exceed the

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2) 60% of all electricity consumption is said to be used in motors of all kinds. As power electronics becomes cheaper and cheaper, it pays to utilise this not only in large motors, but also in smaller and smaller ones. Assuming that the saving potential is 50% for large motors and zero for small ones, the average for the whole motor stock can be estimated very crudely at 25%.

Fig. 4.3-3: High integration of information and communication electronics with power electronics contributing to mixtribution in the future. Decentralized electricity generation (e.g. photovoltaics, fuel cells, wind power, small co-generation units) combined with larger generation capacities will be managed as virtual power plants including real time electricity prices for small consumers operating automised electrical appliances

load in the system. This massive expansion of distributed generation is to a large extent a consequence of political decisions and initiatives and agreements in the European Union. Similar developments can be expected, to a greater or lesser extent, in other member states. In other countries, similar political initiatives have also been introduced in order to stimulate small-scale regenerative electric power production.

In these new systems, the traditional power flow direction from large centralised power plants through the transmission system to sub-transmission and distribution systems to the end-users will no longer persist. Instead, more mixed load flow patterns will occur, these are sometimes referred to as a “mixtribution” system (see Figure 4.3-1). This picture shows some of the features of the “mixtribution” system, especially the power electronic interfaces. In this figure, only the power electronic based devices at the generation, transmission, and distribution levels are shown. The different forms of power electronics devices play a very important role in the loads, as will be shown below, but these devices are not explicitly drawn in Figure 4.3-1. We retain the old terminology even if the transmission and distribution systems are to play very different roles than their traditional one. In practice, the terms will denote systems at different voltage levels.

A completely new function of power electronics is needed by the interfaces between various new electricity sources and the grid, illustrated by interfaces to wind and solar power, but not restricted to these (see Figure 4.3-1). These power sources provide DC voltage and current, e.g. solar and fuel cells, or AC power at varying frequencies, e.g. wind and hydropower, and an inverter or frequency converter is required to transform the power to the fundamental frequency.

The development in power electronics has been very rapid and has had a significant influence on power system development over the last few years. Many achievements can be seen as spin-offs from communication and IT applications, but some are driven by requirements within the energy sector. Particularly the control of power electronics has benefited a lot from the revolutionary development in microprocessors and integrated circuits, which has decreased the costs for these functions drastically. The development concerning power handling components, i.e. traditional thyristors, GTOs, IGBTs, IGCTs etc., has also been significant, but the market for these devices is still smaller, so the same developments have not been seen. Recently, the automobile industry has shown an increased interest in power electronics, and this huge market might increase the interest of semiconductor manufacturers in higher power rating devices (see Chapter 4.2).

Future applications of power electronics may substitute many traditional mechanical power converters such as gear boxes in cars (when fuel cells will be applied; see Box) or in wind converters (see Figure 4.3-2).

Long-term perspectives of an energy-efficient society applying micro and power electronics in highly integrated technical systems

A future energy system with a mix between central and distributed electric power generation would require a different control scheme than the one used today in electric power systems. It is anticipated that more control functions will be local, incorporating load management and control of local power supplies and storage devices. These local controllers need to communicate with each other to achieve overall optimisation and ensure system stability. Local controllability requires power electronics and the controllers and communication calls for IT and microelectronics (see Figure 4.3-3). It is also anticipated that an optimisation between different energy forms, i.e. between electrical, chemical, mechanical etc., would be required. A project aiming at analysing and designing such a system has started at ETH (Vision 2020).

R&D needs, opportunities and recommendations

In order to utilise the efficiency improvements offered by power electronics, further R&D work is needed. Salient areas to be researched are:

- integration of power electronics based solutions in flexible network configurations, including energy storage devices and load managemement.
- Development of control, protection, and communication schemes to ensure system stability and reliability.
- Development of low-cost energy efficient converter topologies.
- Development of low-cost semiconductor devices.

The research items above are further elaborated in Andersson (2004), DeDoncker (2003) and ETH Zurich, vision2020@ech.ee.ethz.ch

POWER ELECTRONICS APPLIED IN TRANSFORMERS AND SWITCHES, MOTORS AND GENERATORS

Power electronics are distinguished as providing three separate functions in power supply systems:

- supplying the conversion between AC and DC currents and voltages, and vice versa, and together with transformers, changing voltage and current amplitudes.
- Giving increased controllability in AC systems via so-called FACTS devices (FACTS = Flexible AC Transmission Systems).
- Controlling the power output as a part of motors and drives according to the needs of the application, e.g. pumps or ventilators.

The energy saving possibilities and system benefits due to these functions are discussed below:

- all electric energy flows through power converters and transformers many times before being dissipated. Total loss in inefficient electricity transport and distribution is presently about 6 % of the total electricity supply and could be halved (about 10 PJ in Switzerland) for example by:
  - reducing the weight of transportation converters and transformers as central parts of train drives,
  - optimising small transformers for applications with long low or no-load periods. For example, house bells are only intermittently used and have loss currents of 3 W in the worst case, 1.6 W for average models and 0.6 W for the best models. For 3 million Swiss households, an average of 28 TJ could be saved per year by exclusive use of the best house bell technology already available today!
- FACTS devices could be used to control the flows to transmission corridors that are not heavily loaded. An increased use of non-dispatchable power sources, such as wind and solar power, will introduce strongly fluctuating load patterns. A greater degree of control will then be needed to ensure system stability.
- It is estimated that about 60 % of electricity is used in electrical motors. Currently, still only a small fraction of mechanical work is recuperated in motors, except in new trains, trams, and elevators. Improving the steady-state efficiency of motors and drives is of secondary importance. The overall technical energy saving potential is estimated to be about 30 PJ. The two most important factors are:
  - motors can be configured to provide mechanical drive according to momentary needs (e.g. a ventilator can be controlled by real-time air quality monitors). In many applications, motors provide at least twice as much mechanical drive as necessary.
  - Variable speed motors can be used as breaks and can recuperate mechanical drive. About one third of the electricity can be recuperated in many traction applications.

4.4.: New industrial processes – from micro-organism design to product design

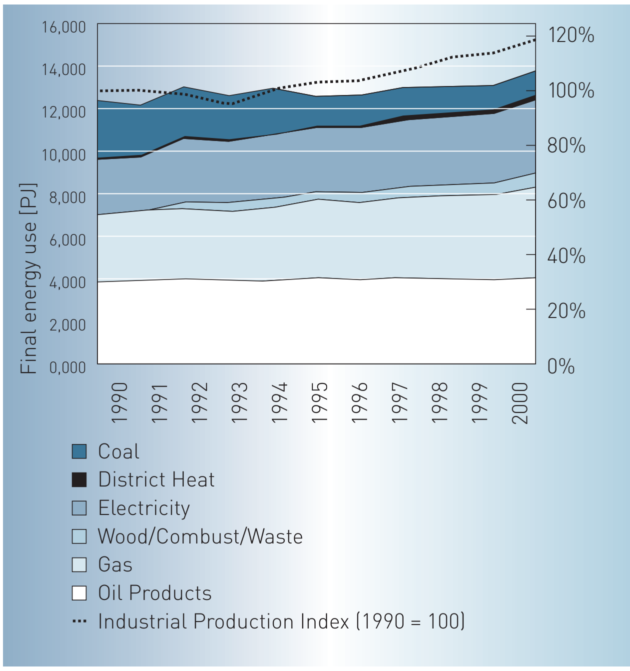


Fig. 4.4.-1: Industrial energy use (+11 %) and production (+20 %) of the European industry (EU-15 and Switzerland), 1990 to 2000

Industry has succeeded in stabilising final energy demand in many European countries during the last decade and is now using between 20 and 25 % of total final energy demand (the Swiss industry with below average share of basic goods production: about 170 PJ per year or 20 % of total final energy demand). The reasons for this success – relative to the other sectors of energy use, particularly to transport – are not only due to increased energy efficiency, but also to structural changes of industrial production in favour of low energy-intensive sectors with higher value added and high growth (e.g. investment goods industries) and by the saturation or closing down of energy-intensive branches. In total, industrial final energy increased by 11% and industrial production by 20 % respectively between 1990 and 2000 (see Figure 4.4-1). Electricity and natural gas increased their shares at the expense of carbon-intensive coal and heating oil.

Substitution of products and processes is a promising strategy

Identifying industrial processes with high efficiency potentials is the most difficult task in the attempt to establish a 2000 Watt per capita society, because thousands of technologies are operated in this sector. Very often their energy relevance is unknown due to the variety and heterogeneity of the production processes involved. In many cases, better operation and slight technical improvements may reduce specific energy use by more than 30 to 40 % (e.g. compressed air, lighting, co- and tri-generation).

But in many cases substituting an existing production process by a new one is the long-term option to substantially reduce industrial energy demand which is necessary to reach the goal of a 2000 Watt society. In many sectors, research and development have been working on improving the existing processes and their energy efficiencies for decades and no further substantial progress can be expected here. But new technologies open up new opportunities for process substitution, such as:

- substitution of presently used thermal separation processes (evaporation, distillation, rectification) by new processes such as membrane technologies, crystallisation, or other mechanical separation processes.
- Substitution of thermal drying by mechanical drying (e.g. impulse drying), infra-red drying, or substitution of the solvent with lower evaporation heat demand.
- Substitution of chemical synthesis processes (at high temperatures and/or high pressures) by improved catalysts, enzymes, or biotechnology-based processes at temperatures between 25 and 50 °C. For example, the biotechnological production of Riboflavin (Vitamin B2) needs 50 % more raw material in total than conventional processes but reduces the non-renewable feedstock consumption by 75 %. It also reduces the emissions of volatile organic components by 50 % and has 67 % less wastewater. Further examples, together with an extensive analysis of the substitution possibilities of biotechnological processes, are given by Gaisser (2002). Another example, namely the replacement of fossil feedstock by biomass for plastic production is treated in detail in the following section.

The example of process substitution: sustainable plastic production

Over the last century, plastics have found their way into every area of our lives. Plastic is mostly used for packaging (38 %) and construction (18 %), but also in household, electrical and electronic devices, in the automotive industry, in agriculture, and many more. Plastics made their appearance at the beginning of the 20th century and since then the production and consumption of plastic have grown rapidly and are continuing to grow by an estimated 4 to 5% per year at the global level. Plastics cover a vast range of different materials with different properties depending on their applications. The main advantages of plastics are their low weight, their good manufacturability and their low price.

The consumption figures for plastic materials are impressive: in 2002, 0.6 million tons were consumed in Switzerland, 57 million tons in the EU-15 and approximately 150 million tons worldwide. For the EU-15, this is equivalent to 94 kg of plastic being presently used per person in 2002 (APME/CEFIC 2003).

Plastic is produced mainly from crude oil, natural gas and coal. Approximately 1.5 kg of fossil fuel is needed to make 1 kg of plastic. Three-quarters of this are used as feedstock and one quarter as process energy. With the predicted gradual drying up of the world's oil reserves within this century, the inexpensive supply of plastic's main raw material is no longer ensured. In addition, they use about 5% of global yearly fossil fuel use contributing to emissions of greenhouse gases. Therefore new ways to create plastic have to be found, which actually returns research to its starting point in the 1980's when, under the influence of the oil crises, the first projects tried to substitute oil by biomass as the primary feedstock for plastics production.

Bioplastics

Driven by the need to substitute the fossil fuel feedstock for plastics production, bioplastics are being developed and slowly entering the market. They represent a new generation of plastics, the components of which are derived entirely, or almost entirely, from renewable raw materials such as wood, corn, potato, wheat, natural oil, proteins etc. So far, it has been shown that plastics can be created from biomass with no shortcomings in their mechanical properties compared with conventional plastics. Most of the bioplastics projects are still at an experimental stage and only a few have made it to full scale production so far.

Conventional plastics are non-biodegradable, which causes a problem for plastics waste disposal: the volumes involved are too large for simple dumping on landfills, combustion emits greenhouse gases and recycling still has problems due to the need to separate the various types of plastics. Plastics made from biomass can avoid these problems because they are biodegradable. For certain applications, bioplastics never even enter the waste stream; in other applications when they have to be burned after use, they do not increase the greenhouse gas concentrations in the atmosphere.

Production of bioplastics

There are two principle ways to produce bioplastics: one is fermentation of starch or sugar derived from corn, potato etc., to create a polymer that is made into resins in a few more process steps, which can then be used in traditional plastic manufacturing processes such as hot-extrusion. Another principle is to mix starch, fibres and natural binders together to create resins with high fibre content that can be manufactured using injection moulding and look and behave like conventional plastic, except that they are biodegradable.

The same technique is also being performed with wood in the form of sawdust instead of starch. Using this feedstock, complicated shapes can be moulded that look like wood. The Swiss company, Napac, produces such resins from Chinese reed. This process won the Swiss Technology Award in 2003.

Market pioneers

Biopolymers produced by a few companies are already visible in the first applications. The crucial point will be whether they can be produced cost-competitively with conventional plastics made using today's low priced fossil fuel. The development and growth of bioplastics will only pick up speed if they succeed on the market. A few companies already produce biopolymers on an industrial scale:

- Cargill Dow, USA, began producing polylactic acid (PLA) polymers at the world's first full-scale plant that now produces 140 000 tons/year (see Figure 4.4-2). The facility ferments sugars from corn into lactic acid, which is converted into a lactide and polymerised into PLA. Their products are marketed under the "NatureWorks" label and are used for packaging and textiles, see *www.cargilldow.com*.
- Metabolix, USA, launched their first 50 000 litre PHA (polyhydroxyalkoanates) polymer production site in 2002. The company has been working on fermentation routes to PHAs since 1993. They use sugars from corn wet-milling as feedstock for the fermentation. Since the costs of the current process are high, they are looking into growing aliphatic polyesters directly in plants which should halve the price of today's PHAs, see *www.metabolix.com*.
- Novamont, Italy, is producing starch-based polyester co-polymers with a capacity of 20 000 tons/year at the moment. They produce shopping and waste bags and new also foamed prod-

ucts for protecting wine-bottles or the food packaging used by the McDonalds chain of restaurants, see *www.novamont.com.*

- Rodenburg Biopolymers, the Netherlands, has a 40 000 tons per year plant to produce a polymer made from potato peelings. The starch is not purified and undergoes partial hydrolysis in a fermentation step. Current applications are plant pots and sticks containing controlled-release fertilisers, see *www.biopolymers.nl.*
- R&D is being conducted in many areas – from growing renewable feedstocks, identifying better enzymes for fermentation, through to new applications profiting from the specific properties of bioplastics.

Energy savings from making plastics biodegradable

Bioplastics replace or compete with PET, polyesters, polystyrenes, and other polymers. Depending on the plastic replaced, fossil energy use can already be reduced by 20 to 50 % today, with a forecast of up to 80 % for new projects (Cargill Dow). Bioplastics are CO_2 neutral. The biodegradability of bioplastics is being utilised in several applications where it economises processes:

- waste bags made of bioplastics: no need to slice the bags open before dumping on landfills.
- Flower pots from bioplastics: containers used during transportation become too small as the plant grows. By using biodegradable material for the pots, there is no need to remove the pot before replanting in the ground, since it will disintegrate slowly. Furthermore, fertilisers could even be added to the plastic that will be released slowly to the ground around the plant as the pot degrades.
- Agricultural covers used to protect the plants from the weather or birds needed to be recollected when no longer required and were then usually burnt. Made with biodegradable plastics they could simply be left on the fields, saving labour and transportation costs.
- The biodegradability of bioplastics can also be used for special medical applications, like envelopes for drugs that dissolve slowly over time. By controlling the biodegradability speed of the plastic, the rate of release of the drug can be accurately managed.

The amount of fossil fuel that could be substituted by biomass is huge, considering the fact that per kilogram plastic, almost one kilogram of fossil fuel feedstock could be saved. The whole of the globally installed bioplastic production capacity today could only cover about half of the plastic consumption of Switzerland. This illustrates how far bioplastics still have to go, despite the successes in operating the first full-scale production facilities.

Fig. 4.4-2: Production plant for polyactide from starch (Blai, Nebraska, USA), 140 000 t/a, 10 years development

It is possible to substitute conventional plastics with plastics made from renewable resources. Over the past 10 years, intensive research has brought forth first industrial scale production plants together with the first applications for bioplastics on the market. Until now, the cost of bioplastic is still about four times higher than conventional plastic and hence most applications are found in niches, where they benefit from certain special characteristics like biodegradability.

R&D needs, opportunities and recommendations

Research activities focusing on reducing the costs are looking into different areas, from production plant optimisation to genetic changes within the renewable feedstocks used that could increase their starch content or even grow polyester directly within the plants.

In order to make substantial progress in this field, R&D efforts need to be co-ordinated and combined. EU-R&D programmes could provide a good platform for such combined research activities. Polymers with very different properties exist in many different applications. The same applies to the new bioplastics, their chemical composition depends on their intended use, so many different production possibilities can be conceived. In the box below, a project is described that investigates the possibility of producing base chemicals for polymers from the lignin found in wood instead of corn-based sugar.

The plastic industry has had 50 years to develop and reach its current know-how, diversity and capacity. Production prices of conventional plastics are low and no major investments are needed. In contrast, the bioplastic industry is just starting up and very large and risky investments are required in production plants, infrastructure, R&D etc. That is why companies need to invest in bioplastics today, like Dow, Cargill or DuPont have done already. Eventually, when oil prices begin to rise, mankind will benefit from the efforts undertaken today.

FROM WOOD TO PRIME CHEMICALS: A SWISS RESEARCH PROJECT

ETH Zurich and PSI are planning a research project together with Dow Chemicals that investigates a new technology to produce high value chemicals from biomass. Some of the obtained chemicals are essential building blocks for plastic production. Within this project, wood is investigated for its suitability as the main bio-feedstock. Switzerland has a potential of five million m^3 of wood per year that could be used as feedstock. This can be obtained from various sources like sawmills, wood processing industries or as waste wood from old furniture or building demolitions.

A commonly proposed approach for the synthesis of chemicals from biomass is the complete decomposition (gasification) of the biomass at high temperatures (800–1000°C) to a synthesis gas containing CO, H_2, CO_2 and CH_4. This "decomposition and recombination" approach uses a lot of energy and produces undesirable by-product streams. Furthermore, only relatively simple, low-value molecules with low functionality can be produced using this approach.

The approach taken in this project, however, consists of decomposing the biomass only partially in an aqueous phase (hydrothermal processing) to a range of intermediates including phenolics, carboxylic acids, aldehydes, alcohols, and sugars. These intermediates can then be separated and further processed to valuable chemicals such as vanillin, levulinic acid, and polyols. Working in an aqueous state (200–400°C, 150–300 bar) has the advantage that no energy is required for drying the biomass, making hydrothermal processing very energy efficient (see Figure 1). A modular plant design allows flexibility in the production volume.

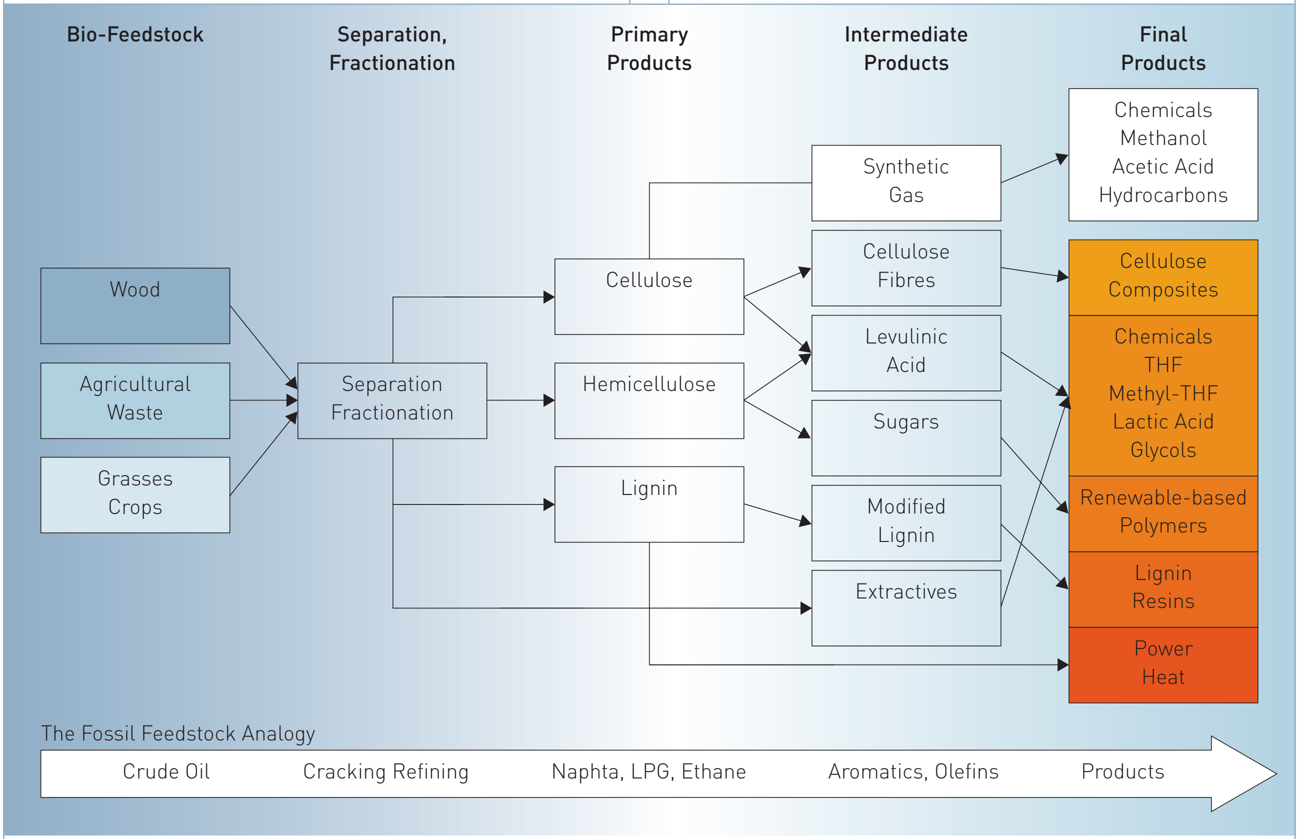


Fig. 1: **Possible routes for the production of base chemicals and intermediates from biomass**

Future benefits for industry and the economy in Switzerland

- The organic residues from forestry and agriculture amount to approx. 6.6 million t dry matter per year. Assuming a 50 % yield of phenolics from the lignin fraction, about 500 000 t of phenolics could be produced from surplus biomass in Switzerland. The cellulosic part could be converted into chemicals using thermo-chemical as well as biotechnological processes. Minerals could be recovered and recycled as fertilisers in agriculture.
- As Switzerland does not possess fossil fuel resources such as coal, oil, or natural gas, the production of chemicals from biomass in a biorefinery would open up a completely new field of industrial activity. Many new jobs would be created in the areas of biomass harvesting, transport, storage, distribution, processing, sales and marketing. Small and medium-sized engineering and construction companies would be involved in the design and the construction of the biorefineries.

Website links to industrial and university research groups:

- Specifically about biopolymers: www.biopolymer.net
- Online European research gateway www.cordis.lu/ergo/home.html
- A report by the OECD (Organisation for Economic Co-operation and Development) on the application of biotechnology to industrial sustainability www1.oecd.org/publications/e-book/9301061e.pdf

4.5: Material efficiency and substitution – the additional energy source

The close relationship between the efficient use of energy-intensive materials and energy demand has not received very much attention from energy analysts and policy makers in the past, even though about one-third of total industrial energy demand is required for material production and everyone knows that moving parts and vehicles would need less energy during their lifetime if they weighed less. In most energy demand projections up to now, the more efficient use of materials, products, vehicles, and production plants or the substitution of materials was not seen as being flexible and policy-relevant, but as a “given” level of activity. The four strategic options to reduce energy demand by reducing material intensity covered in this section are:

- *more efficient use of materials* through better design and construction, improved properties of materials, oils or solvents, or even foamed plastics or metals, or reduced use of energy-intensive products such as nitrogen fertilisers. This strategy is particularly important in the case of moving parts or vehicles, as lighter constructions may contribute to a radically lower energy demand over the lifetime of the particular application (e.g. cars).
- *Recycling and re-use* of energy-intensive waste materials or used products (e.g. steel, aluminium, paper, plastics, or glass, as well as re-use of bottles, engines, or tyres from trucks).
- *Substitution of highly energy-intensive materials* by less energy-intensive materials or even by other technologies (e.g. steel and cement/concrete by wood, synthetic fibres by bio-based fibres, newspapers, journals, or books by electronic news and information).
- *Intensified use of products, machinery, and vehicles* through short-term leasing, sharing or renting reduces the demand for materials by diminishing the non-used capital stock which may even include more efficiently used floor areas of residential and office buildings.

All four elements contribute to structural changes within the economy, mostly by lowering the energy intensity of total industrial production, and offer numerous new opportunities in the service sector from selling product-services instead of products.

More efficient use of materials – the future lightweight economy

The strategy of reducing a product's material use while maintaining identical functionality is not a new development. In particular, much attention has been paid to post-consumer wastes by national policies or by the European Union to reduce packaging wastes. The future energy saving potential stemming from improved material efficiency amounts to 0.1% per year (as autonomous technical progress without policy intervention) and to almost 0.25% per year in the policy case (Enquete Commission of the German Parliament, 2002). In order to achieve these potentials, the following R&D has been identified as important:

- R&D on material structures, surfaces, alloys, manufacturing and finishing of metal sheets, paper, plastics, fibres, bottle glass, packages and on the design and construction of products, plants and vehicles (see Figure 4.5-1).
- R&D on polymer catalysts, particularly for polyethylene, polypropylene, polystyrene, polyester and interesting co-polymers to improve their properties and to substitute specialised plastics with higher specific energy use (poly-condensates and poly-addates).
- R&D on foamed plastics and non-ferrous metals for lightweight construction, in particular for moving parts and vehicles.

Recycling energy-intensive waste materials and re-use of products

Recycling energy-intensive waste materials still has some potential, if collection systems became more comfortable and sorting/washing processes more precise, reliable, and less costly. The energy-saving potential stemming from higher shares of recycled secondary materials such as electric steel, recycled paper, glass, plastics, or aluminium ranges from 0.1% per year (autonomous technical progress) to 0.2% (policy case). However, additional efforts will be necessary to realise the upper range:

- R&D on improved separation technologies of post-consumer waste and cars, in particular non-ferrous metals, glass, metal and plastic composites, plastics;
- R&D on improved and less energy-intensive purification processes of metal scrap, plastics and waste paper to reduce the deterioration of the secondary materials produced from recycling materials.
- R&D on improved design for inexpensive dismantling of mass produced appliances and partial re-use of frames and long lasting components, including economic optimisation over the product's and component's lifetime.

Fig. 4.5-1: The weight of glass bottles has been reduced by 45% during the last 40 years. A further reduction by 30% is envisaged by manufacturing ultra light polyethylene coated bottles

Substitution of highly energy-intensive materials

A fundamental connotation of substituting old materials by new ones is the trend from commodities to speciality materials adapted for specific products such as car frames or other car components, ultra light or bio-degradable packaging materials (see Chapter 4.4), specific functions of surfaces (e.g. zero corrosion, improved heat transfer), or specific mechanical properties per weight of material. These advanced materials (for instance produced from nano powder) are becoming more important as they substitute basic traditional metallic materials or plastics. The direct primary energy savings from material substitution are estimated to be less than 0.1% per year at present (autonomous substitution) and up to 0.2% per year or more, if the technical progress by material substitution is supported by relevant policies. Major areas of R&D have been discussed such as:

- R&D on consumer specifications and the traditional material choice of producers given the certain "image" of a specific material in its societal context.
- Applied R&D on reducing the production costs of the less energy-intensive material by exploring the potentials of learning and economy-of-scale effects.
- R&D on the characteristics of light metals or plastics and improving any technical deficiencies relative to the material to be substituted.
- R&D on biomass-based materials and products, including applied gene technology to improve properties and yields (e.g. natural fibres, starch, wood; see also Chapter 4.4).

Intensified use of products, machinery, and vehicles

Using products, machinery, and vehicles more intensively through short-term leasing, sharing or renting and the associated technical dimension of material efficiency – and indirectly of energy efficiency – seems to be a purely entrepreneurial and organisational issue at first sight, but it may also involve new supporting technologies (e.g. clear documentation by electronic devices on the use of the product or vehicle to identify responsibilities during its operation and to develop adequate rental tariffs). The majority of these involve information and communication technologies which in turn require research focused on small, inexpensive, and reliable electronic systems.

Increased renting of products and vehicles may indirectly affect energy use through, for example, a higher energy efficiency of the "younger" capital stock or vehicle fleet, and more reasonable use of the machines or vehicles thanks to the accompanying documentation system. The estimates of known services thus assume annual primary energy savings of less than 0.02% per year (autonomous substitution), but in the longer term and if supported by suitable policies, the intensified use of products, plants and vehicles may contribute to annual energy savings by 0.1 to 0.2% of total primary energy demand. A lot of research is obviously needed in order to identify the potentials in more detail, the changes in the value systems of the relevant actors, and the prerequisites for new services:

- research on customer acceptance; in many cases the various services will be new, e.g. incentives for machinery and car-sharing or improved consciousness about the fixed and capital costs of owning machinery and vehicles with low annual operating hours.
- Research on the willingness of innovative companies to invest in pooling services.
- Techniques for easy and fair pricing, easy scheduling and access, and protection against theft.
- R&D on inexpensive, reliable and parallel I&T-based monitoring and control. New services may require pilot projects with socio-economic evaluations in order to design the necessary policy and financial boundary conditions, to clarify legal questions, and to design professional training and educational programmes.

R&D needs, opportunities and recommendations

There are some indications that recycling seems to play a smaller role compared to material efficiency and to material substitution, mainly due to the potential savings in vehicles and moving parts of machinery and the substitution of primary aluminium. The long-term contribution of the intensified use of products, vehicles, and production plants is certainly being underestimated today, and analytical and empirical work still has to be done in many product areas to produce reliable estimates of energy savings in this area of activity and entrepreneurial innovation.

There is no doubt that the energy saving potentials will depend heavily on future progress in the research and development of improved properties of existing materials such as steel, non-ferrous metals, cement, glass, plastics and fibres as well as the invention, market introduction and diffusion of new materials, e.g. plastics or fibres based on biomass. In addition, the intensified use of products, vehicles, and production plants will be dependent on changes in social values and entrepreneurial innovations which have to be made to realise the expected potentials in the coming decades. To summarise the preliminary findings about the relationship between the various options of sustainable material use and energy demand, the following conclusions can be made:

- if consciously adopted as a policy of sustainable development and by interested companies in industry and the new service sectors, the impact of the four options on energy demand may be significant at about 0.5% reduction of annual primary energy demand. About half the savings are estimated to come from improvements of road vehicles (material efficiency (light vehicles) and car sharing/truck leasing). Other major savings are expected to result from the lighter weight construction of products and plants and the substitution of primary aluminium and petrochemically-based plastics by new materials.
- The obstacles to these potentials are manifold, but the material and energy savings provide opportunities to recover the research and development up-front expenses and additional investments and value added in the new materials and systems.

The close relationship between material use and energy demand opens up an entirely new area of energy systems analysis and, more importantly, offers major entrepreneurial opportunities for a lighter, more efficient and less polluting industrial society. Substituting the use of natural resources by know-how intensive products and services could create new jobs in many service areas.

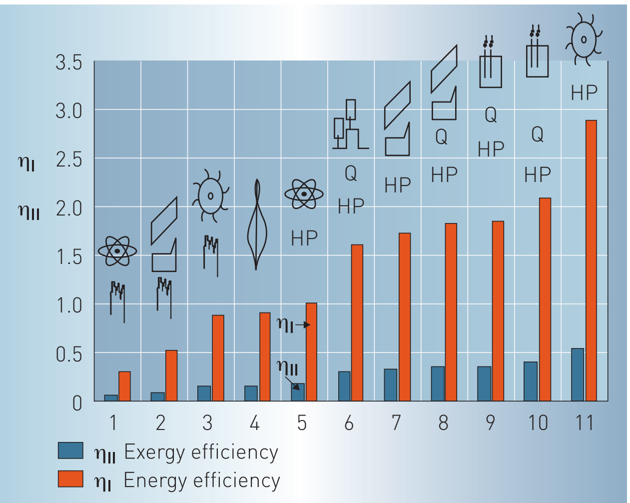
4.6: Converting energy resources into final energies – exploiting the second law of thermodynamics

Energy conversion means converting energy resources into final or useful energy. In the present situation, heat is mainly provided by combustion of fossil fuels (with exergy efficiencies in the case of low temperature heat below 10%), while electricity is primarily produced in centralised power plants (hydropower with efficiencies in the 90% range and nuclear with extremely low efficiencies such as 33%). The last decade has seen fast growth in decentralised electricity production (conversion of wastes and cogeneration) reaching 4.3% (10 $\mathrm{PJ_{el}}$) of total generation in 2002 in Switzerland, which is still small compared to many other countries. The trend towards decentralised production and cogeneration (electricity, heat) or trigeneration (including cold) often combined with heat temperature upgrading using heat pumps is expected to take place in many countries around the world and open up a wider market for Swiss industry. The integration of cogeneration and heat pumps for heating purposes represents a large improvement potential with at least a doubling of the exergy efficiency (see Figure 4.6-1), but also the potential to avoid grid losses due to their closer proximity to the electricity user.

Three scales of energy converting plants have been analysed: (1) centralised plants generally located outside town and producing electricity only, (2) district heat plants usually designed to deliver both electricity and heating and/or cooling services via district networks, (3) domestic plants at the private house or building level primarily delivering thermal services and/or electricity.

Energy resources – potential conflict between security of supply, environmental aspects and efficiency

For energy conversion systems, improving energy efficiency is not the only concern, it is important to consider the different energy resources whose availability will strongly influence the efficiency of the conversion sector. Other factors have been considered in the study like renewability, environmental impacts (greenhouse gases), social acceptance (nuclear waste, safety and dissemination) and the geopolitical context (supply security, primarily for oil). The evolution in resource use will also be affected by the energy distribution infrastructure needed and its efficiency: fossil fuel substitution, increased use of renewables, use of hydrogen as an energy carrier, synthetic fuels production, etc.



1 nuclear + electric heating
2 gas turbine / steam turbine combined cycle + electric heating
3 hydraulic + electric heating
4 boiler
5 nuclear + heat pump
6 cogeneration engine + heat pump
7 gas turbine/steam turbine combined cycle + heat pump
8 gas turbine/steam turbine cogeneration + heat pump
9 fuel cell cogeneration + heat pump
10 fuel cell/gas turbine combined cycle + cogeneration + heat pump
11 hydraulic + heat pump

Grid losses = 4 %, network thermal losses = 5 %, heat pump exergy efficiency = 65 %, network temperature = 65°C, atmosphere temperature = 0°C, cogeneration unit thermal losses =10 %) [Burer et al., 2003]

Fig. 4.6-1: **Different techniques of energy conversion for heat production and their values of energy and exergy efficiency**

In the present situation, the major non-renewable resources in Switzerland are oil, natural gas and nuclear energy. The renewable energy resources (RES) are mainly hydropower (with a very small efficiency increase potential) and biomass (including some wastes and wood) with the potential of at least a doubling of their exergy efficiency using integrated technologies including gasification and/or (bio)methanisation. The other renewable energy resources (wind and solar, which have a significant efficiency progress potential) play only a very limited role in Switzerland (solar electricity totalled only 0.384 PJ in 2002 and wind electricity reached only 0.049 PJ)[3]. All these resources have to be considered not only with respect to their renewability, but also their availability (limit of hydro potential or daily variation for solar)

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3) For example, linear growth in solar electricity in Switzerland in accordance with the present trend would mean a production of less than 2 PJ by 2050. It would take an exponential growth of some 14% per year to reach an annual production in 2050 corresponding to 10% of the Swiss production in 2000.

and ease of conversion, which is not directly reflected in terms of energy efficiency (or of exergy efficiency). The emergence of wind and solar power will increase the need for efficient energy storage, back-up generation and electrical grid management unless hybrid systems are implemented (example: solar-(bio)fuel).

In the field of energy conversion, a global or continental approach should be adopted in terms of exporting technology (e.g. Alstom turbines or Liebherr engines) and in terms of grid interconnection. It is interesting to note that Switzerland is a net exporter of electricity, but the level of current exchanges is such that imports and exports are of the same order of magnitude as the electricity consumption.

Prospects and challenges of fossil fuel converting technologies

Different strategies may be considered with respect to energy conversion: we assumed that hydropower is almost fully exploited in Switzerland, except for a small potential in re-investments of turbines and in mini-hydro (with units smaller than 300 kW), representing only about 0.7 PJ in 2000. The international market is still important for hydropower, but the role of the Swiss manufacturing industry has been declining in the last decades and this trend is unlikely to be reversed. The same applies to nuclear fission, where the involvement of Swiss equipment manufacturers is reduced. Electricity demand is still growing in Europe and this trend may be hard to reverse in view of its growing role in transportation and electricity transport (e.g. between cogeneration and electrically driven heat pump units when not necessarily located on the same site). In Switzerland, as in other industrialised countries like Germany, whether to keep nuclear plants operational or shut them down remains a major issue. Shutting them down could boost the present growth of fossil fuel-based electricity, if electricity efficiency and substitution as well as renewables do not get more attention from energy policy and the electricity users.

Therefore efficiency improvements in fossil fuel-based conversion technologies are both a necessity and a significant industrial opportunity (see Box, Figure 1), particularly when considering the fact that such improvements will also directly benefit biomass conversion. Due to its low cost and huge reserves, coal resources will continue to play an important role worldwide, especially if combined with a successful development of CO_2 capture and disposal strategies.

Exergy efficiency of energy conversion systems

Exergy measures the thermodynamic value of energy. It defines the maximum work which could ideally be obtained from each energy unit, either hot or cold, being transferred or stored using reversible cycles with the atmosphere as one of the energy sources. The exergy approach is used to represent both the quantity and the quality of the different forms of energy considered in a coherent way. The concept of exergy has the major advantage of efficiency definitions which are compatible with all cases of the conversion of energy resources into useful energy (heat and electricity, heat-cold-electricity, refrigeration).

While energy efficiencies are greater than 100 % for heat pump systems (because ambient energy is not accounted), exergy efficiencies are always lower than 100 %. They provide an indication of how well the potential of an energy resource is exploited in different competing technical concepts. Figure 4.6-1 compares the energy and the exergy efficiencies of energy conversion systems for generating low temperature heat: although the energy efficiency of space heating using electricity is nearly 100 %, its exergy efficiency is in the order of 7 %, a confirmation that the value of energy has been degraded.

FUTURE ADVANCED POWER PLANTS BASED ON NATURAL GAS

An advanced power plant under development combines a gas turbine with a solid oxide fuel cell: at a high temperature, the fuel cell converts natural gas into electricity and syngas that is burned in the combustion chamber of the gas turbine. The fuel conversion

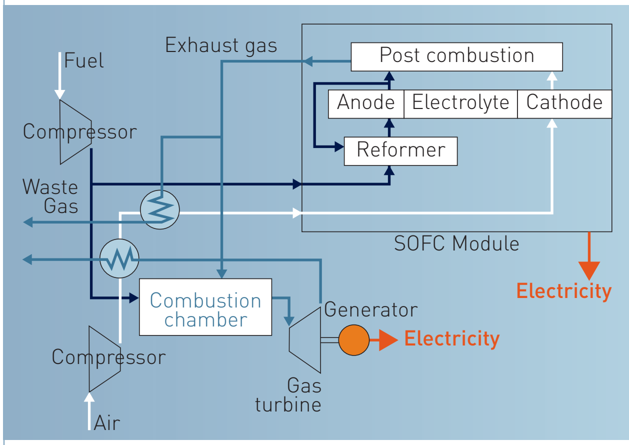


Figure 1: Increasing the conversion efficiency by combining gas turbines and solid oxide fuel cells

efficiency is expected to reach 70 % and produces heat to be used in cogeneration applications (Burer et al. 2003).

The Advanced Zero Emissions Power Plant (AZEP) developed in international cooperation by ALSTOM Power Technology addresses the development of a specific, zero emissions, gas turbine-based, power generation process to reduce local and global emissions in a cost-effective way. In this innovative cycle, it is possible to capture 100 % CO_2, with $NO_X \ll 1$ ppm (see Figure 2, right). The cost of CO_2 separation (compared to tail-end capture) is reduced by 25–35 % in $<$ 6 years, and by 35–50 % in $<$ 10 years. Conventional, air-based, gas turbine equipment is utilised, making retrofitting possible. The loss in power plant efficiency is less than 2 percentage points, compared with an up to 10 point loss of efficiency if conventional tail-end CO_2 capture methods are employed (see Sundkvist et al.; www.azep.org).

Replacing the conventional solution in Figure 3 (below) by an advanced, integrated system incorporating a solid oxide fuel cell, gas turbine combined cycle, compression and absorption heat pumping makes it possible to achieve a high level of energy savings in both heating and cooling modes.

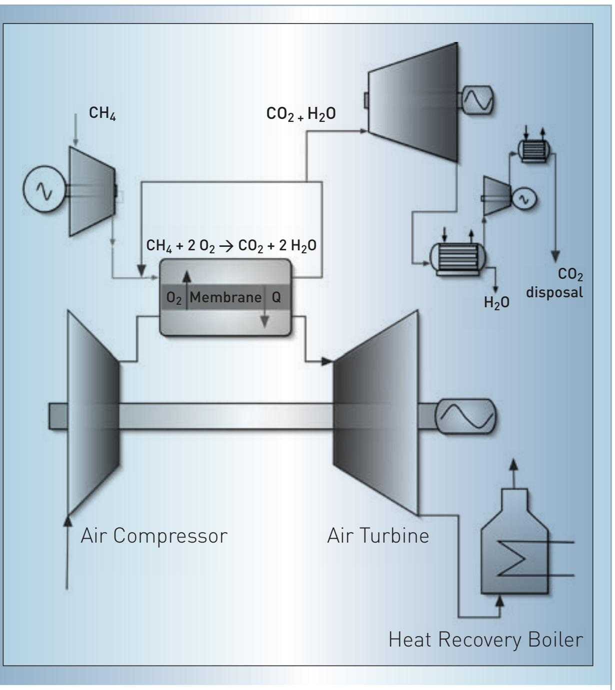
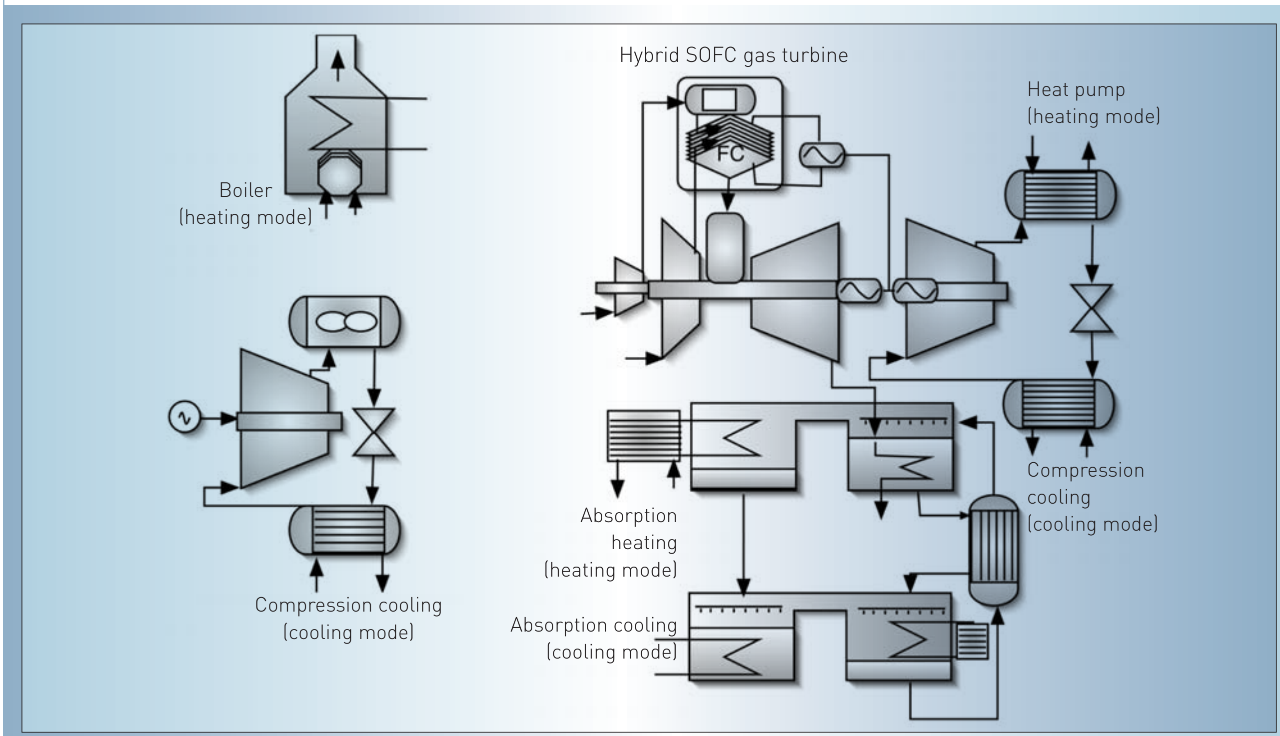


Figure 2: **AZEP – Development of an Integrated Air Separation Membrane – Gas Turbine by Alstom Power Technology**



Conventional solution
Heating mode: 1.05 MW_{LHV}/MW_{th}
Cooling mode^1: 0.59 MW_{LHV}/MW_{frg} (^{1} Mix efficiency: 42%)

Advanced system
Heating mode: 0.41 MW_{LHV}/MW_{th} (38 %)
Cooling mode: 0.20 MW_{LHV}/MW_{frg} (33 %)

Figure 3: **Advanced trigeneration integrated system for a small district heating and cooling system**

Efficiency improvement of renewables – essential for cost reduction

Of the renewable sources, so far biomass has the most significant diversification and energy efficiency potential both in Switzerland and worldwide, especially if we consider its conversion to liquid and gaseous fuels including hydrogen. Solar thermal is significant for heat services with 4.2 PJ per year in Switzerland and a growth rate of 7% per year and its exergy efficiency potential is primarily found in systems based on vacuum and concentrating technologies. Geothermal energy reserves are potentially enormous but the technological challenges involved here are also extensive with major uncertainties. Although geothermal energy is already being exploited in heat pumps' applications for house heating, R&D efforts should also be invested in projects like deep heat mining that allow combined heat and power production and require good integration with district network systems.

Besides most of the conventional energy generation techniques, renewable energy technologies offer significant potentials for future efficiency improvements. Due to the fact that renewable energy sources (RES) by definition do not require fossil or nuclear fuel inputs, energy efficiency is often not perceived as being as crucial for RES as for conventional technologies. However, energy efficiency improvements usually result in better economic as well as environmental performance of RES technologies and therefore have a critical effect on the market diffusion of renewables. For this reason efficiency improvements are of paramount importance, especially for new RES technologies which are often rather costly.

The extent to which further efficiency improvements are possible varies largely between different technologies, and ranges from around 5% for new large hydropower plants to a doubling of efficiency for photovoltaic cells. Potential efficiency gains have been analysed for several renewables by the EU Commission (see Box).

R&D needs, opportunities and recommendations

Some of the research fields concern several energy conversion technologies and are, for example, strongly related to material sciences and other cross-cutting technologies like IT (see also Chapter 4.3):

- *high temperature technologies* are important for gas turbines, fuel cells and CO_2 capture. Research needs concern high resistance and reliability materials, complex fluid flow and jet cooling, advanced electrochemical and sealing materials, microchannel fluid flows and heat transfer in the presence of chemical reactions. Research is also particularly needed in the field of high temperature O_2 separation membranes for nitrogen-free combustion and CO_2 capture for high temperature catalytic combustion in high temperature cogeneration systems and syngas production (see Box, Figure 2).
- *CO_2 capture and sequestration technologies:* research is needed in the field of CO_2 capture technologies including chemisorption, absorption, membranes and compression technologies, but also in the development of new zero emission plants, e.g. syngas and hydrogen-based conversion technologies. For CO_2 sequestration, the research needs will concern the use of solar assisted biological conversion (photo-synthesis), chemisorption (clathrate, hydrate) as well as underground or deep sea storage and must cover the efficiency of such technologies.
- *Integrated systems* have a high potential in terms of energy efficiency. Research here concerns the design methods including life cycle and exergy concepts, optimisation and other computer aided systems (artificial intelligence). The development of reliable (and autonomous) energy systems and enabling technologies like optimal remote control, energy management peak shaving, high power density machines with direct high speed electrical drives also require greater research (see Box, Figure 3).
- *Biomass technologies:* research needs include the development of higher exergy efficiency concepts for the conversion of bio-

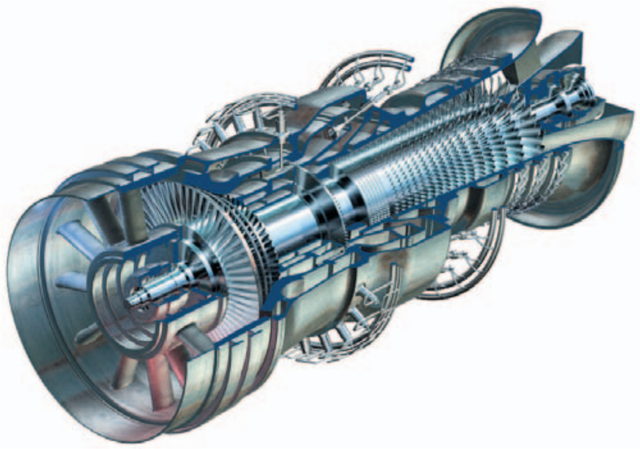


Fig. 4.6-2: Gas turbines have experienced substantial progress in efficiency during the last 20 years; but there are still technical potentials for further improvements by improved materials and design, allowing higher temperatures, improved control and fewer losses

mass considering gasification, pyrolysis and biological conversion. Research is also needed on biomass to fuel conversion (synfuels, hydrogen) and efficient conversion technologies of biomass to heat and electricity.

- *Heat pumps and trigeneration:* in this area, emphasis should be put on efficiency increases and system costs reduction, variable speed oil free compressors, enhanced heat transfer technologies (including absorption) and the use of new fluids (pairs).
- *Hydrogen technologies:* hydrogen is considered to be the future energy vector, efforts should be made in the development of efficient hydrogen production systems (new catalysts, autothermal reactors) as well as reliable distribution and storage schemes.
- *Fuel cells:* the most promising technologies are the SOFC and the PEMFC. Both will play a role in the energy conversion sector with specific application areas. Research is required into materials and system design and operation.
- *Solar thermal:* the main areas of research are advanced concentration with high temperature storage and processes and *solar photovoltaics* (with or without concentration, flexible or not, on transparent support or not etc.).
- *Geothermal:* research is required on efficient low temperature conversion cycles and the development of hot dry rock technologies (crack generation, sealing technologies and anti-deposit technologies).
- *Electricity storage and transport:* supercapacitors, supra conductors, electrolysers should be further developed.

EFFICIENCY POTENTIALS AS A MAJOR CONCERN OF FUTURE R&D ON RENEWABLES – A VISION OF THE EU COMMISSION.

Photovoltaics (PV) is the technology with the best perspectives for future efficiency improvements. Present efficiencies of photovoltaic cells reach up to 25 % for mono-crystalline silicon in the laboratory and up to 17 % in industrially produced cells. For cells based on GaAs, present laboratory efficiencies achieve 30 %. The current laboratory efficiencies for the different mono-crystalline materials no longer differ greatly from the theoretically achievable value, which is about 28 % for silicon for example. The main focus in the short term will therefore be on the efficiency increase in industrially produced cells, for which the target is around 20 % in 2010. In the medium term, R&D will concentrate on new architectures of PV cells, especially with regard to tandem cells and concentrators. Using such advanced devices, efficiencies of more than 40 % in the laboratory and above 25 % in industrial production are targeted for 2010. In the long term, the efficiency of PV cells might also decrease if thin film amorphous silicon becomes economically competitive, as this shows lower efficiencies of about 15 % in the best case. However, tandem architectures might be applied for thin film technologies enabling future efficiencies of up to 50 %. A minor increase in efficiency is also possible from applying new inverters specifically designed for PV applications.

Solar thermal technologies for **electricity** production show annual efficiencies of about 15 % in present installations (parabolic trough collectors), which can be increased to about 20 % by 2010. After 2010, systems based on central receivers are expected to become commercially available alongside the presently used parabolic trough collectors. Progress in efficiency is mainly expected from scaling effects, changes of the heat carrier medium and improvements to the currently used gas turbines.

Active **solar thermal heat** generation has already reached a high level of technical maturity. Therefore major technological breakthroughs should not be expected, but rather continuous improvements of individual system components.

In the case of **wind energy** technology, the highest available efficiency (cp-value) of current turbine designs is about 50 %. This value is quite close to the theoretical optimum of about 59 % (maximum c_p-value according to Betz). Therefore no major breakthroughs with respect to efficiency increases are expected in the future. Due to improved power and revolution control and an aerodynamically enhanced design, minor efficiency improvements can be made in the near future. A much more significant effect with regard to the energy yield of wind converters is expected from the steadily increasing heights of turbine towers.

Hydropower is the most mature RES technology. Therefore there are unlikely to be any major efficiency improvements in new plants. Current turbines have efficiencies of more than 90 %. The major potentials for efficiency improvements here are in the refurbishment of existing plants. By improving the fluid dynamics of the in- and outflow and modifying the turbine design, efficiency improvements of about 15 % can be achieved in older plants compared to present values.

In the case of **biomass** technologies for electricity and for heat production, the majority of those currently used are based on thermo-chemical processes. Here, the main developments will be similar to the evolution of the corresponding conventional technologies; steady but moderate efficiency improvements can be expected. A technology which is currently emerging is the integrated gasification combined cycle, which may offer significant efficiency improvements if it proves successful. Major breakthroughs could also be reached by the application of new bio-chemical processes such as anaerobic digestion technologies.

Geothermal electricity production using new technologies like hot dry rock will need significant technological advancements in order to penetrate the energy market. Among other issues, the efficiency of electricity production has to be increased from the current 7 to 10 % by lowering the self-consumption rate of plants today.

Although **geothermal heat pumps** are already a mature technology, a decrease in the self-consumption rate from the current 25 to 30 % to about 15 % is projected, resulting in major efficiency improvements in the long term.

References: Energy Scientific & Technological Indicators and References (ESTIR) www.cordis.lu/eesd/src/indicators.htm

5: Innovations and soft issues

Fig. 5.1-1: Ordering the harvesting (the energy service) instead of owning the harvesting machinery; using the harvester only two weeks per year or two months per year, if the harvester of a service company starts in the low valleys in early summer and finishes in the mountains in late summer.

Achieving a substantial reduction in per capita energy use requires not only the technical innovations described in the preceding chapter, but also new behavioural patterns in decision making and daily operations, professional energy management, and major entrepreneurial innovations. This relates to several social sciences; their theories and research results have rarely been explicitly applied to a more efficient use of energy in the various target groups. This chapter focuses research on two issues: the intensification in the use of goods and plants (see Chapter 5.1) and the socio-psychological aspects of behaviour and decision making (see Chapter 5.2). The significant contributions of the social sciences may have been underestimated in the past by the producers of energy-efficient technologies and efficiency policy makers.

5.1: Intensification of the use of products, vehicles and plants – using instead of owning

Durables and investment goods are generally purchased, but could often be leased, rented or hired, particularly in cases of small annual usage times (e.g. cars between 200 and 500 hours per year, harvesting machines less than 50 hours, construction machines less than 500 hours, many high temperature industrial processes in small and medium sized companies operating with one shift schedules or less than 2,500 hours per year). From the point of view of material use (and the imbedded energy to produce those durables and investment goods), G. Friend already stated in the mid 1990s that the low annual usage time implies a huge idle capital and material stock of an economy due to the concept of selling and owning products instead of selling and buying product-based services. In the case of high temperature industrial processes, energy losses for the daily start-up and shutdown may be substantial.

The strategy of product-based services of manufacturers or service companies operates on the concept of selling the total service (e.g. harvesting, partial outsourcing of energy-intensive production steps, centralised voice mail instead of answering machines, rented solvents from chemical suppliers), or of pooling durables and investment goods. Oksana Mont describes many cases in great detail, where the intensified use of durables and investment goods reduces their capital costs and compensates for additional service costs for either the total service or contracting, operating, reservation, billing, controlling, and additional insurance. In many cases, ecological or environmental arguments and considerations also contribute to the acceptance of these new services, which are labelled "eco-efficient services" by F. Popov and D. DeSimone. But very seldom are these product-based services looked at from the perspective of material efficiency and indirectly reduced energy use.

At first glance, using products, machinery and vehicles more intensively through short-term leasing, sharing or renting and the associated technical dimension of material efficiency – and indirectly of energy efficiency – seems to be a research area more closely related to the social sciences. In order to successfully realise the "pooling instead of owning" strategy at the commercial level, however, experience strongly suggests the need for supporting technologies in many cases. For example, such technologies provide the user with clear documentation on the use of the product or vehicle, identify responsibilities during its operation, and develop adequate rental tariffs. These predominantly information and communication technologies require research that is focused on small, inexpensive, and reliable electronic systems.

The Swiss industry is very well positioned in this field, given its competence and substantial domestic experience in many areas such as car-sharing and leasing of trucks and construction machinery.

The realisable direct energy efficiency potential of these numerous options of the intensified use of products, vehicles and production plants has not been analysed in any depth and depends very much on the future acceptance and market diffusion of services such as car-sharing, pooling public (municipal) or company vehicle fleets or machinery, and moving elderly people into adequate but appropriately-sized apartments (first analysed by C. Zanger and his colleagues in 1999). Assuming moderate market shares of two of these new services in 2050 (e.g. 10% of car-using households opt for car sharing and two per cent of elderly people move to smaller apartments with an average gain of 20 m² per move and apartment), the energy savings in industrialised countries may be in the order of 3% of current levels of primary energy demand. Increased renting of products and vehicles may indirectly affect energy use through, for example, the higher energy efficiency of "younger" capital stock or vehicle fleets; walking or cycling may displace the car for short trips, and a more sensible use of the machines or vehicles may result thanks to the accompanying documentation system. The indirect effects are estimated to amount to some 10% of the direct effects.

The impact on energy demand of these numerous possibilities to intensify the use of products and production machinery and plants is almost unknown because very few of the existing services have been assessed with regard to energy aspects and many conceivable services to intensify the use of products, vehicles or production facilities have not yet been offered on suitable markets. The estimates of already established services thus assume annual primary energy savings of less than 0.02% *(autonomous substitution)*, but in the longer term and if supported by relevant incentives and suitable policies, the Enquête Commission of the German Parliament (2002) estimated that these may contribute to the annual energy savings by 0.1 to 0.2% of total primary energy demand.

In order to be able to realise the full impact of intensifying the use of products, vehicles, and apartments, *new entrepreneurial forms* are also required which reduce the capital stock for the targeted applications.

Research needs, opportunities and recommendations

Obviously a lot of research still has to be undertaken to arrive at a clearer understanding of the energy saving potentials:

- research on *customer acceptance:* in many cases the services will be innovative, e.g. incentives for machinery and car-sharing or improved consciousness of the fixed and capital costs of owning machinery and vehicles with low annual operating hours.
- Research on the *willingness of innovative companies to invest* in pooling services: R&D on inexpensive I&T-based monitoring and control techniques for easy and fair pricing, easy scheduling and access and protection against theft.
- New services may require *pilot projects* with socio-economic evaluations in order to design the necessary policy and financial boundary conditions, clarify legal questions and design professional training and educational programmes.

In addition, to realise the full impact of intensifying the use of products, vehicles, and apartments, new entrepreneurial forms are needed that reduce the capital stock for those applications where intensified use is desired.

5.2: Socio-psychological aspects – real decisions involve more than economics

In many cases, profitable energy efficiency opportunities are not taken up by private households, companies, or public institutions. There are numerous, not very well known reasons for this fact. But they are important, even at the stage of R&D regarding aspects of design, ability to repair or ease of use. This is illustrated by the fact that evaluations of identical financial incentive programmes offered by different institutions found that participation rates varied by one order of magnitude (Egan, 2001; Stern, et al. 1985). These findings suggest that non-economic aspects such as the type of communication channel, the credibility of and the trust in the communicators and the technology producers are of major importance within the decision making process. The aspect of non-economic motives, therefore, is not only valid when considering sufficiency-oriented energy savings, but at least as important when marketing energy efficiency to all groups of energy users.

Private Households – efficient energy use: invisible and hard to communicate

On the household sector level in general, the progress of energy efficiency has been offset by the large increase in the number of (small) households as well as increasing incomes and leisure time. Social transformations in values and lifestyles have contributed to family dissolution and household dilution, while demographic changes like an increasing elderly population have also reduced household size and correspondingly increased the quantity of goods and energy services demanded. The largest decreases in household size in Western Europe, which involved changes of 20% to 30% over 30 years, occurred in Scandinavia, the Netherlands and Switzerland (-30% or 1% annually; see Figure 5.2-1). Household dilution affects energy and electricity demand not only due to the increase in the number of separate dwellings, but also due to the eliminating of domestic economies-of-scale.

Efficiency gains in one area often stimulate demand for the product or the service by rendering it less expensive, or they lead to the development of new products and new areas of consumer demand. For example, the 75% improvement in the efficiency of washing machines per kilogram of washed laundry achieved since 1960 has been counterbalanced by a fourfold increase in per capita demand. If efficiency gains are chronically inadequate and cannot effect a reduction in total or per capita energy use, or even indirectly fuel an increase as demand co-evolves in step, a socially accepted “sufficiency” development may be needed in addition to an efficiency revolution.

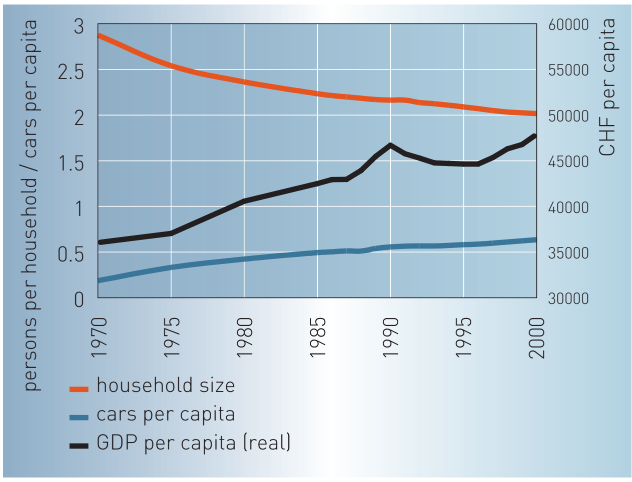
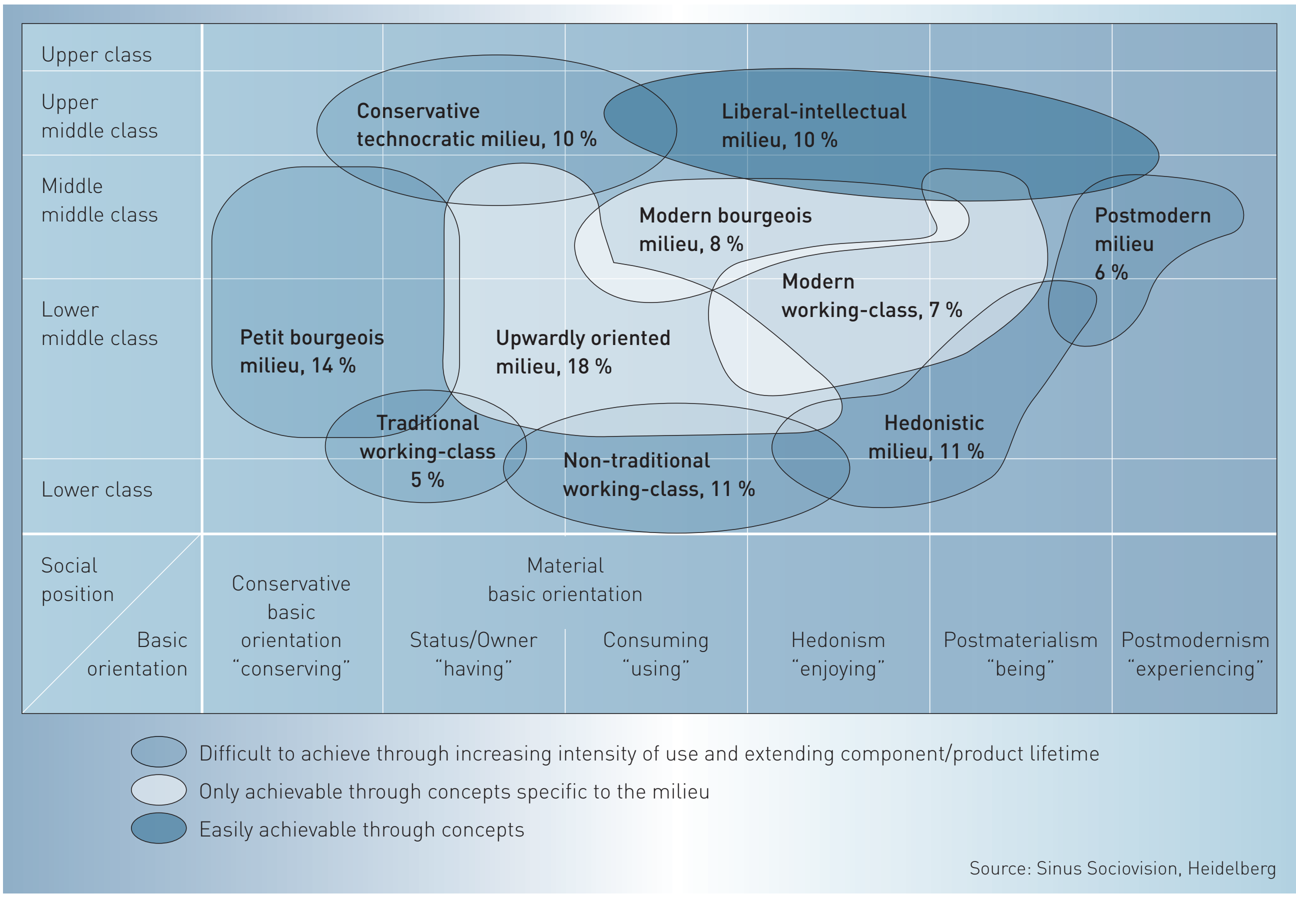


Fig. 5.2-1: **Development of Swiss private household size, cars per capita and GDP per capita, 1970 to 2001**

Income is the primary driver and therefore predictor of household energy use. For several decades now, the Gross Domestic Product per Swiss inhabitant has increased by 400 CHF (or 250 Euro) per year (see Figure 5.2-1). Little research focuses on redirecting household expenditure towards lower material and energy-intensive goods and services in order to lower the corresponding environmental impact per monetary unit spent. This may require policy changes that encourage energy-extensive consumption patterns (e.g. less energy-intensive motorised mobility at the expense of energy-extensive services in leisure time).

Wealthier consumers typically have more luxuries, greater flexibility, and, among certain segments, potentially a greater motivation to trim their energy use, but at a high level. In such cases, direct behavioural changes and related conservation efforts can be more effective for certain activities than better technology choices (e.g. avoiding long-distance weekend trips compared to appliance purchase decisions) where the aim is to cap the energy use of private households. Nevertheless, in a low energy price environment, many people are only concerned about energy, if at all, when making the initial appliance purchase decision, and not when using it from day to day. Even here, householders – lacking knowledge, know-how, or technical skills – typically “under invest” in energy-efficient appliances.



Source: Sinus Sociovision, Heidelberg

Fig. 5.2-2: **Scheme for ten different milieus of an industrialised society**

Human behaviour, especially in a social context, is as important an influence on residential energy use as it is on general household resource and commodity consumption (Lutzenhiser 1997). End-use consumption behaviour is highly patterned, often routinised, and therefore stable over certain ranges within a single household. Unconscious habit plays an important role in energy use, although little research has been done on it. Different patterns of behaviour and the consumption characteristics of various social groups are associated with different lifestyles in social science and marketing research (see Figure 5.2-2). At each income level, the deviation from a group's average household energy consumption is similar (25%), suggesting that a residual "lifestyle" factor is at play. Residential energy use and associated practices vary tremendously with social network, sub-culture, community, and family. Clusters of behaviours, beliefs, and values among householders make for numerous typologies of consumption orientations. For example, analysing household "milieus" (conservative-technocratic, working class, liberal-intellectual, post-modernist, hedonistic etc.) can yield rough estimates of the percentages of the population willing to accept the changes in behaviour or decision patterns required by a given energy policy (see Figure 5.2-2).

However this and other typologies of private households were not specifically designed from the aspects of energy and material use or energy service demand; these unspecific typologies can only make a small contribution to identifying communication needs or effective designs of social marketing.

From a sociological and cultural perspective, with the development of the consumer society, residential energy use has increased along with general consumption. Increased material (goods and services) acquisition has become not just a near universal aspiration, but constitutes a primary marker of status and success. In the consumer society, the consumer's self-respect depends strongly on his level of consumption relative to others ("positional consumption"), a recipe for personal frustration and resource profligacy, especially as the models shift from

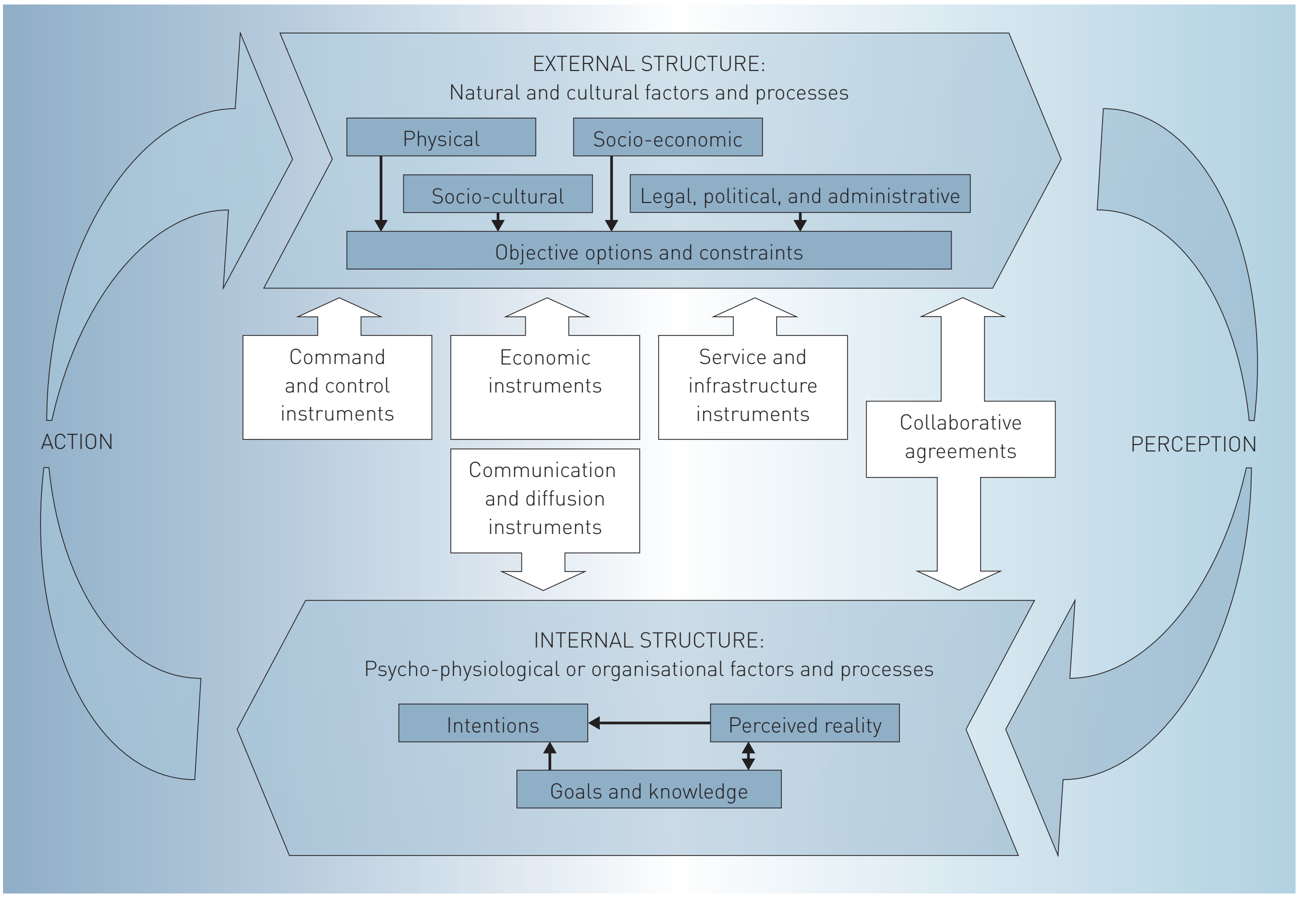


Fig. 5.2-3: **Primary targets of policy instruments in a simplified model of individual/organisational action (Kaufmann et al. 2001, p. 82)**

the next-higher social rung to the super-rich portrayed in films and advertisements. Some research finds that a significant part of growing consumer expenditure stems from attempts to satisfy non-material – social and psychological – needs like identity-forming, even though such increased consumption often fails to meet these needs and may even actively hinder their satisfaction. Arguably, some of the driving forces for energy-relevant household consumption are so deeply rooted in the consumer society that only sea changes in social practices, norms, and/or the political economy could alter them significantly.

Environmental sociology, environmental psychology and anthropology also concern themselves with the *continuous increase in standards of comfort, cleanliness, and convenience and the diffusion and normalisation of ever more energy-intensive lifestyles.* The satisfaction of continuously expanding wants-turned-needs seems to be the object of a significant fraction of Western consumption. It is important to consider that energy use in private households is a co-impact of behaviour and decisions; energy use and the more efficient use of energy is generally invisible and does not attract attention, which makes it difficult to communicate energy issues.

Private companies – lack of knowledge and priority setting – the failure of market theory

Private companies and small and medium-sized enterprises (SMEs) represent the majority of companies in industry and the service sectors. SMEs in particular tend to invest on the basis of payback period considerations instead of profitability calculations (e.g. net present value). The share of energy costs in the total cost is usually below 2 % or even 1 %. Consequently, SMEs lack knowledge and market surveys of energy-efficient solutions. Installing new highly efficient equipment is far more challenging than simply paying for energy use, particularly in “lean firms” or small service companies that suffer from a shortage of technical staff or external advice (Velthuijsen, 1995). Insufficient maintenance of energy-converting systems and related control equip-

Fig. 5.2-4: Decisions on energy-efficient investments are not only based on purely techno-economic facts, but also depend on the company's or private household's value system, preferences and daily routines, on individual motivation, career perspectives and ability to act

ment cause substantial energy losses. External consultants are not always welcome, especially if proprietary production processes are involved. Thus, SMEs are less likely to invest in new, commercially unproven technology. An aversion to perceived risks is an especially powerful barrier to energy and material efficiency (Yakowitz/Hammer 1993).

To broaden horizons, professional training is recommended for technical staff in companies in industry and the service sectors, including consulting companies, architectural firms, skilled labour, and so on. This training should be centred around issues of efficient energy use to improve technical and economic knowledge as well as psychological knowledge (e.g. on group dynamics) for preparing decisions on investments in new technologies, increasing their acceptance, and reducing the perceived risks. Techno-economic potentials seem to be substantial, based on the experience of energy consultants (Energiemodell Schweiz, 2002, Romm 1999). Trust and confidence play a major role when new and more complex technologies are to be adopted and accepted (Siegrist et al 2003).

Public institutions – institutional inertia and lack of incentives: the responsible official in a large institutional setting

The boundary conditions and the decision environments of public institutions are quite similar to small and medium-sized companies: a lack of knowledge, market overview and funds are often severe constraints. In addition, in public budget planning, budgets for operating costs are often separate from budgets for investment. Therefore, possible savings in the operating budget from energy efficiency investments are often not adequately considered in the investment budget. Public procurement is not often carried out on the basis of life cycle cost analysis; instead, the cheapest bidder gets the contract. And as long as the investment meets the project's specification for energy use, it need not be energy-efficient. Municipalities often receive a significant share of their annual budgets through some kind of tax or surcharge for local distribution of electricity and gas from the local energy distributor, lowering the enthusiasm of local politicians for promoting energy conservation and efficient energy use. Politicians often prefer energy projects that are likely to be taken up by the media (e.g. renewable energy projects), but which are economically less attractive than energy efficiency investments.

Supervisors and building managers or department heads do not benefit directly from improving energy efficiency or reducing the energy demand of buildings, the public vehicle fleet or of the water supply or wastewater treatment systems.

Many policy measures and supporting technologies have been developed over the past 20 years to overcome these traditions and obstacles (e.g. specialised energy managers, outsourcing and contracting of energy-conversion plants, external consultants, joint procurement, integration of the energy operating and investment budget, incentive schemes for daily operation), but their use is not yet widespread enough or they have not yet been institutionalised in education, professional training or marketing. Altered budgeting practice, joint procurement, external consultants, professional training, exchanging positive experience in periodic workshops (e.g. EnergieModell Schweiz), and supporting control techniques and software are likely to spur the realisation of present and future energy efficiency potentials in public institutions.

Given the low share of energy costs in the total budgets of private households, most companies and public institutions, two strategies can be considered, reputation management by third parties or goal setting by voluntary action:

- any waste of energy could be stigmatized as showing a lack of responsibility or being ethically unacceptable. Using this social technique, inefficient energy use would become a new threat to the social reputation of private households, companies or public institutions.
- The mechanism of active goal setting by companies, public institutions or groups of private households may be a more positive strategy if monitoring of the target path is possible and accepted. As long as the discrepancy between accepted targets and situational reality is not reduced by changed preferences, actors will try to change the situation as soon as opportunities arise.

Research needs, opportunities and recommendations

The vision of the 2000 Watt per capita society demands knowledge from social sciences about how a sufficiently large number of individuals in private households, companies and public institutions would be willing to undertake sufficiently large steps, particularly in their decisions on energy using equipment, vehicles and buildings. The related research should cover the following issues and questions (see also Figure 5.2-3):

- acceptance of new and more complex technologies and related aspects of trust and confidence in technology producers, energy suppliers, and public authorities,
- research on policies and their optimal mix taking into account obstacles and market imperfections as well as unfavourable value systems;
- problems of combining efficiency and sufficiency strategies to avoid unwanted rebound effects;
- the invisibility, intangibility and delayed billing of energy suggest intensive experiments with new kinds of feedback strategies to overcome these obstacles (Flury/Gutscher 2001);
- diffusion of innovations: search for the most efficient diffusion strategies for individuals, groups and networks;
- typological research to enable a more targeted approach in campaigns;
- mental model research to provide information about lay assumptions with regard to energy-related processes and about differential preferences with regard to financial and social incentives (see Egan, 2001);
- avoidance of reputational risks as a potential motivator.

6: The innovation system supporting the development towards a 2000 Watt per capita society

The subsystems science, economy, and politics are expected to take up the challenging task of developing a vision of a sustainable use of energy. Research support can stimulate and invigorate it, but this vision will only become reality if the system of innovation in place is ready to adopt the new technologies or entrepreneurial innovations. Innovation systems encompass the "biotopes" of all those institutions (see Figure 6-1) that are

- engaged in scientific research and the accumulation and diffusion of knowledge (i.e. research institutions, universities, colleges of technology, schools),
- engaged in education and professional training as well as the dissemination of new knowledge to a wider audience (i.e. educational institutions, media),
- developing and producing new technologies, processes, and products; and commercialising and distributing them (e.g. technology producers, intermediates).

The innovation system of energy-efficient technologies: highly dispersed within the policy institutions

An innovation system also comprises the relevant policy institutions that set the economic, financial, and legal boundary conditions and regulatory bodies (standards, norms) as well as the public and private investments in the appropriate infrastructure. The relevant policy institutions may contribute directly to innovation in energy-efficient technologies by decisions on R&D budgets at various policy levels (EU, Swiss federal government covering the Board of the Swiss Institutes of Technology, the Federal Offices of Energy as well as of Education and Science, the Commission of Technology and Innovation and the budget of the Swiss National Science Foundation, or at the Canton level, responsible for budgeting the Swiss universities and universities of applied science, see Figure 6-2). The data on R&D in Figure 6-2 and Table 6-1 only marginally include research on material science or new physico-chemical or electrical processes which may deliver important technological contributions to achieving a 2000 Watt per capita society. Other policy institutions may contribute indirectly by supporting the development of the educational infrastructure, information and communication networks or the venture capital boundary conditions (see Figure 6-1).

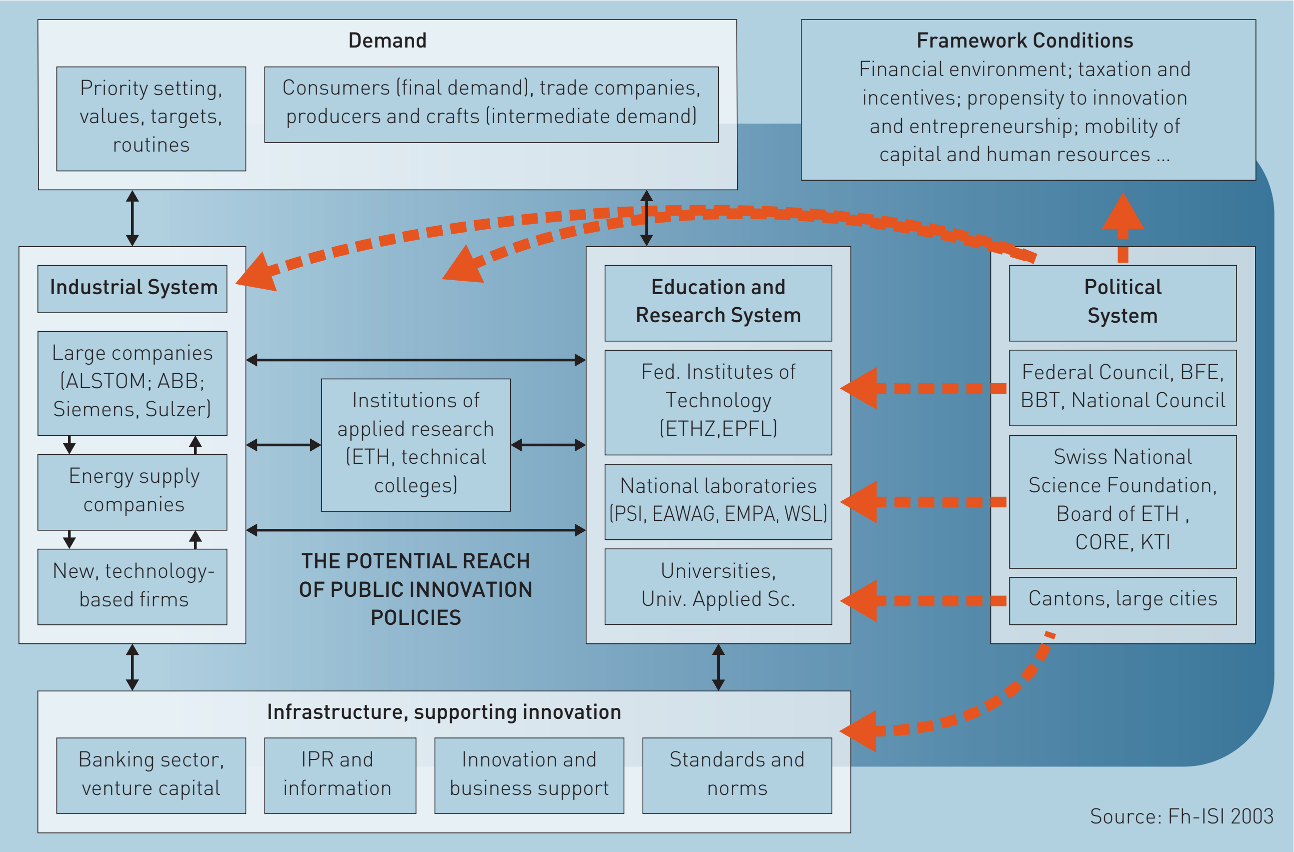
Each innovation system is unique and has developed its profile and strengths over decades. Each is based on stable exchange relationships among the institutions of science and technology, industry, commerce, and the political system. The relationships between the different institutions, however, are often rather weak as each subsystem operates with its own rules and value systems: science with academic merits and reputation, private companies (including the media) with generating (short-term) profits, and political institutions with maintaining the equilibrium of power and interest structures, again mostly with a short-term perspective.

Since energy and material efficiency is widely dispersed over all sectors of the economy and private households, the *efficiency innovation system* is characterised by

- a high degree of compartmentalisation of technologies and energy users (e.g. buildings, road transportation, industrial branches, cross-cutting technologies, energy companies) and corresponding division into various units of the political administration with low inter-departmental exchange and co-operation,
- non-interlinked arenas (corporatist negotiation deadlocks involving sovereignty of Cantons in cases such as building codes; cogeneration using fossil fuels and heat pumps following a systems view), and related failed attempts at restructuring responsibilities in government;
- dominance of a "linear model" of energy supply in political approaches (and among related technologists, energy economics researchers and consultants) which results in neglecting opportunities at the useful energy and energy service levels in most cases.

These characteristics are general and almost independent of the country considered, but they are highly dependent on the ubiquity and heterogeneity of energy and material efficiency. However, the traditional emphasis of R&D on energy supply has changed in the Swiss innovation system: whereas 74% of the total energy budget was spent on nuclear energy (70%) and renewables (4%) in 1977 and only 10% on the efficient use of energy, these shares had changed to 60% for energy supply (29.5% for nuclear energy and 30.5% for renewables) and to 31.6% for the efficient use of energy in 2001. It is particularly interesting to note that the share of energy policy and economics related research increased its share from 6.8% in 1977 to 8.4% in 2001. Total energy research budgets increased (in real terms and in prices of 2001) from 101 million CHF in 1977 to 240 million in 1993. Since then, the R&D budget was reduced to 172.8 million CHF (-28%) in 2001 when the share in energy efficiency remained constant.

The vision of the 2000 Watt per capita society implies the complete re-investment of an economy's capital stock in highly efficient technologies, new services and decision making routines within five decades. This represents a major challenge due to the two characteristics mentioned above:



Source: Fh-ISI 2003

Fig. 6-1: Scheme of the Swiss energy and energy efficiency innovation system

- the limited capacity of the subsystems of the innovation system to communicate and enlarge their mutual understanding and decision making rules in order to work consistently towards the vision as a jointly accepted task (like the Man to the Moon project in the USA in the 1960s),
- the tendency of energy and material efficiency towards compartmentalisation and heterogeneous technologies as their constructive properties.

The compartmentalisation of energy efficiency research is partially avoided in Switzerland by the Federal Energy Research Commission, a consultative body (see Box). The Swiss research and innovation policy on energy efficiency and renewables is further integrated by the evaluation and strategy conference held every four years by the Federal Office of Energy.

Research needs, opportunities and recommendations

The weaknesses of insufficiently coordinated innovation policy-making, which seem to prevail in the energy and material efficiency field in all countries, should be analysed in more detail. Topics here include poorly articulated demand and weak networks which hinder fast knowledge transfer; legislation and market boundary conditions in favour of incumbent technologies (with high external costs), flows in the capital markets (focusing on large-scale technologies and players); and insufficiently organised actors (Johnson, 2000).

Preconditions for success in realising the 2000 Watt per capita society include research on the innovation-focused and co-ordinating role of government, addressing the large portfolio of technologies and innovations, reinforcing user-producer relations, supporting the construction of new networks; stimulating learning and economy-of-scale effects, as well as the articulation of demand and prime movers.

Research on these issues will involve evolutionary economics, the sociology of organisation and science, political science, and management science.

	ETH				UNI	Univ. Appl. Sc.	Federal	Cantons	Private firms	Abroad
	ETHZ	EPFL	EMPA	PSI						
Rational energy use	8 565	6 967	2 165	13 584	5 335	6 388	1 107	1 167	9 750	17
Renewables	4 498	8 314	239	4 652	9 859	5 327	1 172	638	17 265	85
Nuclear	1 571	22 776	320	23 068	878	-	355	264	460	1 353
Socio-economic aspects	1 647	-	579	6 908	469	-	509	35	4 432	58
Total	16 280	38 058	3 302	48 212	16 541	11 715	3 142	2 105	31 906	1 513

Table 6-1: Swiss public expenditure on energy R&D in 2001 (in 1000 CHF). Source: BFE (2002)

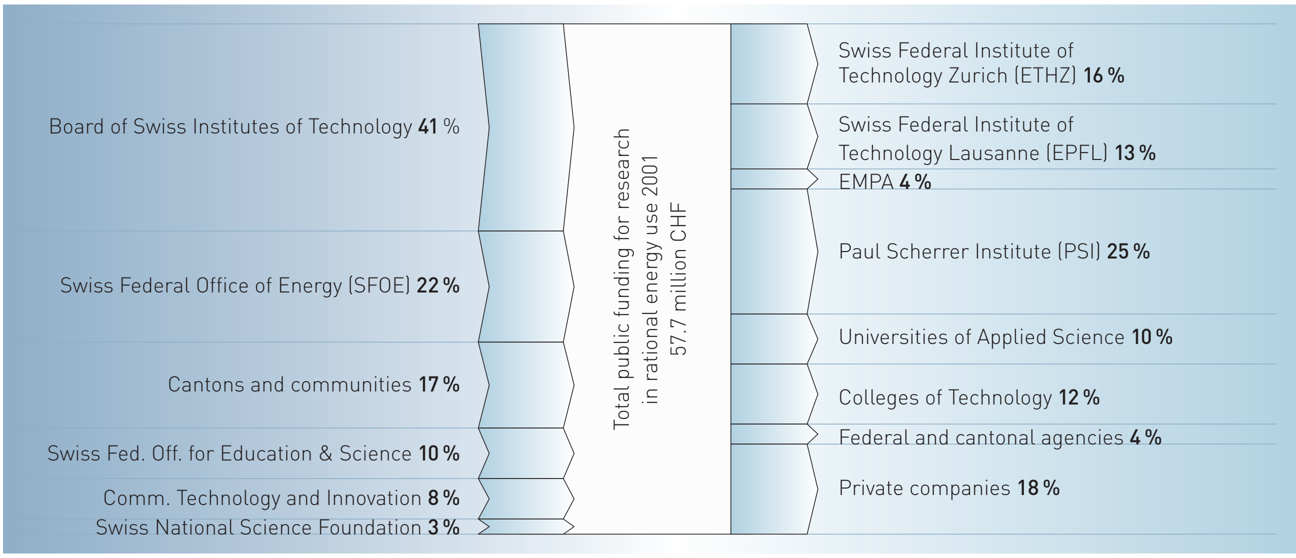


Fig. 6-2: Public research funding on rational use of energy by funding source and research institution; data only marginally include research on material science or new physical or chemical processes

SWISS FEDERAL ENERGY RESEARCH COMMISSION (CORE) – AN INDEPENDENT AND INTEGRATIVE COUNCIL ON ENERGY RESEARCH

The Federal Energy Research Commission (CORE) acts as a consultative body for the Federal Council and the Department of Environment, Transport, Energy and Communications (DETEC). The Commission has 15 members representing the industrial sector, the energy industry, the federal institutes of technology, the National Science Foundation, the Commission for Innovation and Technology, universities, colleges of technology, the Cantons and other promotional bodies. Its secretariat is housed at the Federal Office of Energy. The Commission has the following tasks:

- it defines the Swiss Federal Energy Research Master Plan (including pilot and demonstration plants) and may develop related proposals; this has to be done in co-ordination with interested parties from industry, science, and administration at the federal and Canton levels. The concept of energy-related research has to be regularly adapted to changing boundary conditions and opportunities.
- It regularly reviews and supports Swiss energy research programmes and comments on multi-year energy research programmes launched by offices of the federal government (according to the Swiss Research Law) and on international co-operation in energy research projects.
- It provides information about interesting findings and developments in the area of energy research at the national and international levels.

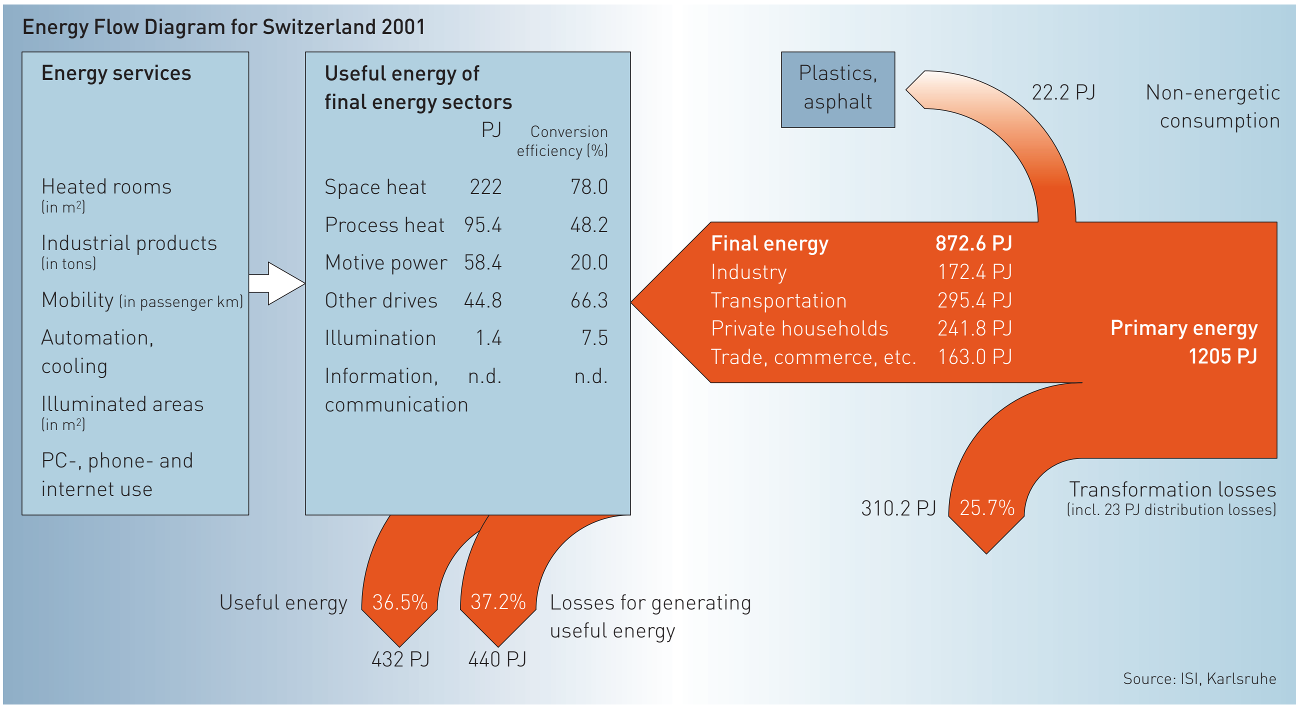
Finally, it recommends measures for teaching and professional training of energy-related education and professions as well as supporting young professionals in energy-related research fields.

In their last report on energy R&D for 2004 – 2007, the Commission recommended reversing the decline in energy funding of the last 10 years and putting a strong emphasis on the efficient use of energy.

Members of the Swiss Federal Energy Research Commission

- **Dr. Tony Kaiser**, President, **Alstom Power Technology Center, Baden-Dättwil.** Industry, large technology producers
- **Prof. Daniel Favrat, EPF Lausanne.** Fed. Institute of Technology (ETH), and Alliance for Global Sustainability (AGS)
- **Pankraz Freitag.** State Councellor and director of public works of **Canton Glarus**
- **Eva Gerber.** Social scientist, School of Art and Design in Lucerne
- **Prof. Dieter Imboden, ETH Zürich.** Fed. Institute of Technology (ETH), Swiss Academy of Technical Sciences
- **Ernst Jakob, Cantonal Office of Water and Energy Economics, Bern.** Energy Management Offices of Swiss Cantons
- **Prof. Christian Kunze, College of Technology EIVD, Yverdon.** Colleges of Technology, Swiss Academy of Technical Sciences
- **Dr. Hansjakob Leutenegger, Municipality of Zug, Zug.** Swiss Energy Council, Parliament (Commission of Environment, Resources and Energy, UREK)
- **Prof. Martha-Christina Lux-Steiner, Hahn-Meitner Institut, Berlin.** Science, international relations
- **Kurt Rohrbach, BKW FMB Energie AG, Bern.** Project and Research Fund of the electricity sector
- **Prof. Louis Schlapbach, EMPA, Dübendorf.** Swiss National Science Foundation, Commission of Technology and Innovation
- **Giuseppina Togni, eTeam GmbH, Zürich.** SMEs, Engineering Consultants
- **Prof. Wavre Nicolas, ETEL SA, Môtiers.** SMEs, Colleges of Technology
- **Dr. Rolf Wüstenhagen,** Institute for Economy and the Environment, **University of St.Gallen**
- **Prof. Peter Zweifel, University of Zürich.** Universities, social sciences

7: Conclusions and recommendations – further action to be taken



Useful energy of final energy sectors

	PJ	Conversion efficiency (%)
Space heat	222	78.0
Process heat	95.4	48.2
Motive power	58.4	20.0
Other drives	44.8	66.3
Illumination	1.4	7.5
Information, communication	n.d.	n.d.

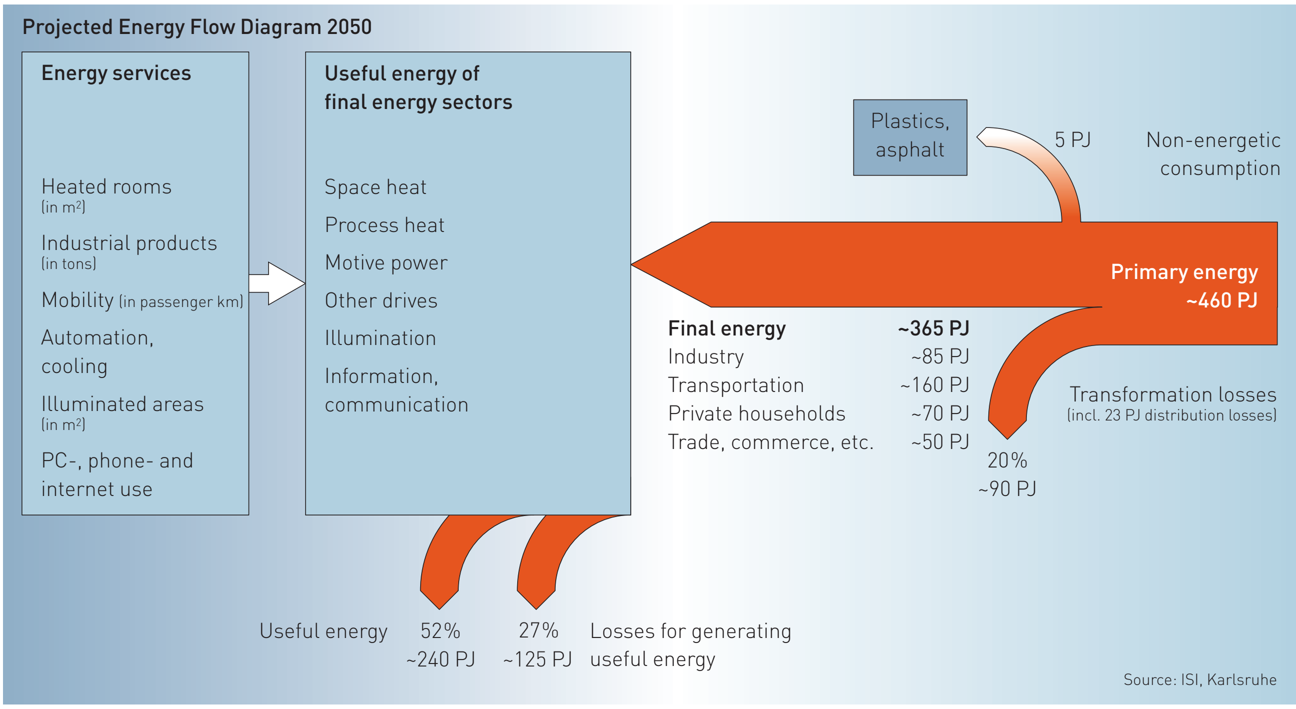
Energy Flow Diagram for Switzerland 2001

Source: ISI, Karlsruhe

A 2000 Watt per capita society – technically feasible?

Synthesising the findings in all technological areas (i.e. converting primary energies to final and useful energies, reducing the losses of useful energies, increasing material efficiency, recycling and material substitution), it can be safely concluded that the vision of the 2000 Watt per capita society is technically feasible within some five decades (see Figure 7-1). The preliminary results emphasise the enormous size of energy efficiency potentials achievable not only by reducing energy losses, but also by decreasing the specific demand for several energy services through improved material efficiency, material substitution and intensification of product use, but also by entrepreneurial innovations such as contracting, different forms of pooling (leasing, renting), and new services. This conclusion is based on the following observations:

- the time horizon of half a century to achieve this goal seems to be the absolute minimum, as the total capital stock of an industrialised economy has to be re-invested at least once in highly efficient technologies or has to be refurbished (buildings, settlements) to result in extremely improved energy and material efficiency.
- The task will require energy savings by at least three quarters of the present average per capita energy use in Europe taking into account a further increase of per capita income in the next five decades. In most cases, this enormous cut in energy demand per capita implies the complete substitution of existing technologies by new ones either already invented or else still to be discovered and developed for market penetration.
- It is interesting to note that whether the sector with the longest reinvestment cycle, the building sector, is successful, does not depend as much on new developments, but rather on cost reductions and quality improvements. New low energy buildings or passive houses can be built today at low additional costs, but retrofitting existing buildings still implies additional costs and additional risks in many cases. The efficiency investments have to pay off over the reinvestment period where the average energy price is not predictable and underinvestment here is probable even at today's energy prices.
- Taking the backcasting approach to reinvestment cycles of long lasting capital goods, R&D has to focus on more efficient power generation (including co- and tri-generation), highly efficient aircraft and trains and long lasting production equipment of basic industries (e.g. steel, cement, paper, as far as they are not substituted by less energy-intensive solutions). Furthermore, the development of generic new technologies with low operating temperatures (e.g. membranes, absorption, biotechnology) and substantially improved efficiencies of energy and material use (e.g. changed properties of surfaces



Source: ISI, Karlsruhe

Fig. 7-1: **Estimated energy use summarising the energy/material efficiency potentials (including behavioural changes and entrepreneurial innovations) in Switzerland in 2050 by sectors and three levels of energy conversion and use**

due to nanotechnology, feeding back brake energy by power electronics) will also be of major importance.

- Structural change to less energy-intensive production and saturation processes of energy-using appliances and infrastructure will support the necessary efficiency gains. On the other hand, compensating trends may include ever increasing mobility, particularly in the air, hedonistic lifestyles and even a changing climate with higher temperatures in summer inducing additional air conditioning demand.

Feasible at which level? European or OECD level?

Except for buildings and the transport infrastructure, many of these capital goods (e.g. plants of basic materials industries, cars, airplanes) are not produced in a small country like Switzerland, but elsewhere in Europe. So it becomes obvious that the vision of a 2000 Watt per capita society cannot be pursued by a single country, but has to be targeted by at least an industrialised continent like Europe, or even better, by all the industrialised countries.

Expanding the regional focus of the vision of a 2000 Watt per capita society is also needed for:

- exploiting the large scientific and technological knowledge of national research centres, universities and industrial research laboratories in Europe and other countries,
- attracting broad political and industrial interest and support and mobilising the necessary financial resources for research and development, and finally for
- realising quick cost reductions of the new technologies by learning and economy-of-scale effects in dynamically evolving large and even global markets.

Expected benefits, suggestions, and recommendations

In order to gain the interest of governments, industry and intermediates, the benefits and advantages stemming from the realisation of a highly resource-efficient society have to be made clear to the various interest groups. The vision of the 2000 Watt society has to be understood and communicated as:

- *an essential part of innovation policy* (not just a task of energy R&D policy) striving for
  - a sustainable development in Switzerland, Europe, and worldwide,
  - improving the competitiveness of the Swiss and EU economy by enlarged opportunities of exporting resource-efficient technologies and their accompanying services,
  - reducing the external cost of energy and material use,

which amounts to more than 100 billion Euro per year in Europe at present, and thus, improving overall economic efficiency in Europe;

- *part of a long-term energy policy* that prepares the necessary lengthy transition period from the fossil to the solar age by reducing the level of total final energy demand;
- *supporting employment,* as increased resource efficiency substitutes the use of natural resources by investment goods and, hence, labour. The additional net labour gain is generally focused on the investment facilitating employment now and is better suited to the high unemployment today and to the ageing population of industrialised countries in the coming decades. The additional employment is also generally more regionally distributed compared to the labour needed to deliver high levels of energies and material use;
- *large opportunities for lead markets and first mover advantages* in industrialised countries and individual innovative companies;
- *a timely investment supporting developing countries* on their paths to sustainable development. Instead of embarking on the same course of wasteful energy use as the old industrialised countries, developing countries have a chance to "tunnel through" to a highly resource-efficient capital stock within the next few decades. This option is not an altruistic notion, but an efficient investment because it reduces the greenhouse gas emissions from developing countries and, hence, avoids adaptation investments in industrialised countries which would otherwise have to be made

The *research and innovation system of a country or the European Union* has to be the object of research given the fact that energy-related research predominantly focuses on energy conversion and energy supply and that non-energy-related research on new technologies generally does not consider energy use and the efficient use of natural resources. The demand for research of this kind begins with the development of an assessment methodology that allows R&D funds to be allocated to the various fields of energy and material use, including behavioural aspects, in a transparent and meaningful manner. The research should also address the differences in the lobbying intensity of manufacturers and users of energy conversion technologies on the one hand and of manufacturers of energy- and material-efficient products and services on the other. An understanding of this difference may be extremely important for allocating R&D budgets in the near future.

There are essential changes in the R&D and innovation system that have to be made.

Fig. 7-2: Passive solar buildings (newly built or refurbished) increase energy efficiency by more than 80 % compared to the present building stock which uses one third of total final energy today

Fig. 7-3: Ultralight, high efficiency cars need 50 % less energy today, although they still use combustion engines and (highly-efficient) gear boxes; road transportation absorbs about 25 to 30 % of total final energy today

- The idea of the 2000 Watt per capita society and its benefits have to be communicated and further discussed among scientists in academia and industry and in public administrations for research and innovation, environmental protection and energy policy. *A consciousness of the opportunities* presented by new technologies and services with regard to energy efficiency as a co-effect and co-benefit has to be developed.
- An awareness *of the potential cost decreases* of new technologies in the long term by learning and economies-of-scale has to be developed, as well as the intention *to stimulate the technical competition* between new and traditional technical solutions (e.g. heat pumps and boiler/burner systems, material substitution).

There are many different steps that could be taken at present: R&D initiatives in selected technical and behavioural fields at the national or the European level, a research programme in selected fields which could be co-ordinated between several European countries and/or the European Commission. Depending on the status of research, the complexity of the technical field, the necessary research institutions involved, the constellation of the research partners, or the risk taking capability of companies to be involved in the R&D activities, one may consider specific R&D supporting instruments such as:

- seed money for locating project partners with common interests and competence in leapfrogging using new technologies or materials to progress towards a much higher energy efficiency (which is now the accepted practice of several research networks such as the Alliance of Global Sustainability, AGS, or 'novatlantis – Sustainability at the ETH domain'), or
- additional incentives for additional energy or material efficiency in ongoing research for new processes or products where this aspect of resource efficiency is not specifically considered (e.g. in cases when publicly funded and well suited innovations receive additional R&D support by the Ministry of Energy (or Environment) in order to simultaneously reduce the specific energy demand of that particular new technology);
- in cases where new technologies have a large cost decrease potential, a government may consider a financial incentive which decreases annually (such as the feed-in tariff for wind power in Germany) to bring down the initial perhaps higher cost of these technologies, taking into account that improved energy or material efficiency also decreases the external cost for society, which is currently not reflected in the market prices.

A 2000 Watt per capita society – politically feasible? Challenges demand visions.

Politically, the feasibility of the 2000 Watt per capita society may be at stake due to European societies' short-term decision horizons in the economy and the political system, a similar orientation and behaviour of many private households and voters and the hesitant attitudes of many actors and responsible organisations despite the lip service paid to the concept at political and company levels. As present energy and material use is relatively inexpensive in Europe and in other industrialised countries, particularly in the USA, efficiency issues do not receive much attention by investors or at the political level. Even worse, the notion is often communicated that resource efficiency beyond that achieved by autonomous technical progress would actually hinder economic growth – a grave misunderstanding of the options of innovation and economic growth.

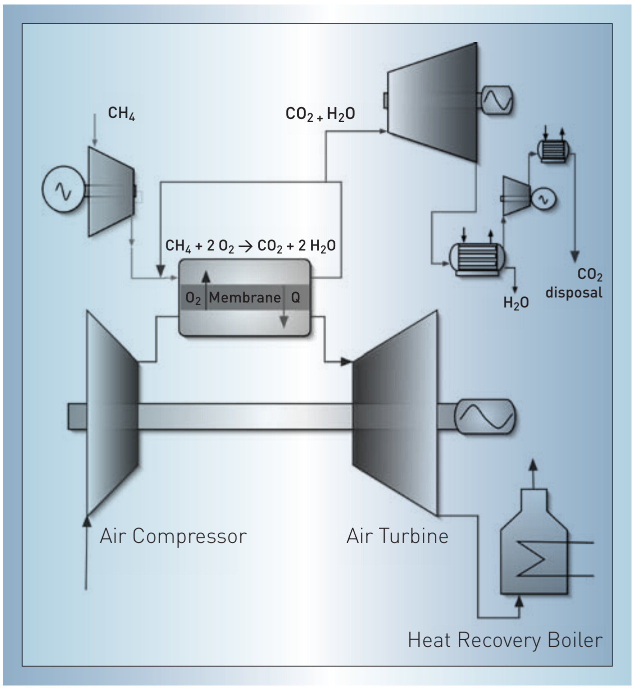


Fig. 7-4: Advanced power plants combining gas turbines with a solid fuel cell may reach 70 % efficiency, i.e. reducing losses of the existing power generation stock by 50 %, and may increase the efficiency by using some of the remaining waste heat (co-generation); electricity generation accounts for about one third of primary energy demand today

To overcome these elements of inertia and misconception, realising the vision of a 2000 Watt per capita society will need convincing arguments (see above for some examples) and a strong coherent policy aiming at a sustainable development on the global level. This notion is not as far-fetched as it might appear at first glance; indeed attempts on a similar scale have been made in the past, e.g. the "man to the moon" project and the joint research conducted on nuclear power generation at an international level in the late 1950s and 1960s. Why should Europe and other industrialised countries not try to develop the political will to strive towards a 2000 Watt per capita society in this decade, to control climate change and achieve a sustainable development on a global scale in the long term?

Glossary

Given the interdisciplinary nature of this pre-study, only a few major terms have been included in this short glossary.

Ancillary benefits: the ancillary, or side effects, of investments and policies aimed exclusively at *climate change mitigation.* Such policies have an impact not only on *greenhouse* gas emissions, but also on the emissions of local and regional air pollutants associated with fossil fuels, and on issues such as transportation, agriculture, employment, and fuel security.

Barrier: any obstacle to reaching an economic potential of resource efficiency that can be overcome by a policy, programme, or measure; not only by government, but also by trade associates or other third parties.

Co-benefits: the benefits of investments and policies that are implemented for various reasons at the same time – including energy or material efficiency – acknowledging that most policies designed to address resource efficiency also have other, often at least equally important, rationale (e.g. related to objectives of improved product quality or capital and labour productivity).

Co-generation: the use of waste heat from electricity generation, such as exhausts from gas turbines, for either industrial purposes or district heating.

Contracting: the outsourcing of an energy converting plant (e.g. heat generation, co-generation, production of compressed air, cold, or technical gases) that is planned, built, financed, operated and maintained by another company (energy service company). This may also cover energy saving services such as efficient lighting, heat recovery and insulation of buildings (the latter facing legal obstacles).

Economic Potential: the share of the *technological potential for energy or material efficiency* improvements that could be achieved cost-effectively through the creation of markets, reduction of market failures or increased financial and technological transfers. The realisation of the economic potential requires additional *policies and measures* to break down *market barriers.*

Energy efficiency: ratio of the energy output of a conversion process or a system to its energy input or of an energy service to its useful energy input.

Energy intensity: the ratio of energy use to economic or physical output. At the national level, energy intensity is the ratio of total domestic *primary energy* consumption in *final energy* consumption to *Gross Domestic Product,* value added, or physical output such as heated floor area or person-km.

Exergy measures the thermodynamic value of energy. It defines the maximum work which could ideally be obtained from each energy unit (either hot or cold) being transferred or stored using reversible cycles with the atmosphere as one of the energy sources.

Energy service: the application of useful energy to tasks desired by the consumer such as the transportation of persons or freight, a warm room, illuminated production facility, or tonnes of electro steel produced.

Final energy: energy supplied that is available to the consumer to be converted into useful energy (e.g. electricity at the wall outlet, heating oil, gasoline, diesel, natural gas, coke, woodchips).

Frozen efficiency: the material or energy efficiency today is projected to remain at the same level in the future.

Material efficiency: the ratio of a desired service to the physical quantity of material necessary to deliver the service (e.g. 0.6 to 2.0 tonnes per car, 30 g per 1 l glass bottle, 60 g per m^2 newspaper).

Mitigation: an anthropogenic intervention to reduce the source or enhance the *sinks of greenhouse gases* (e.g. by energy and material efficiency, renewable energies instead of fossil fuels).

Pooling: machines or vehicles are shared and used by several customers instead of being owned. The renting or leasing is organised by a service organisation that generally owns and maintains the pool.

Primary energy: the energy embodied in natural resources (e.g. coal, crude oil, natural gas, sunlight, wood, wind, bio-mass, uranium) that has not undergone any anthropogenic conversion or transformation.

Recycling: the material of a used product or vehicle is returned to the production step of secondary material after being shredded, selected and eventually purified (e.g. steel scrap used as the feedstock for electric arc furnaces to produce new steel).

Re-use: a used product or vehicle is partially or totally returned to the market after some repairs, amelioration or partial substitution of components (e.g. tires, gear boxes, combustion engines, glass bottles, frames of copy machines).

Structural change: changes over time in the relative shares of energy-intensive and -extensive economic sectors in the industrial, agricultural, or services sector, changes in the share of floor area of one- and two-family houses to the total floor area of residential buildings or of heavy, large cars of the car stock.

Technical potential: the amount by which it is possible to *improve energy and material efficiency* by applying a *technology* or practice that has already been demonstrated.

Useful energy: the energy use related to all energy losses incurred by end-uses (heated rooms, moving vehicles) to dissipate heat at ambient temperature.

Energy unit conversion factors

equals **one**	$\frac{Wa}{cap \cdot a}$	$\frac{MJ}{cap \cdot a}$	$\frac{kWh}{cap \cdot a}$	$\frac{BTU}{cap \cdot a}$
$\frac{Wa}{cap \cdot a}$	1	31.56	8.766	29910
$\frac{MJ}{cap \cdot a}$	3.169×10^{-2}	1	2.778×10^{-1}	948
$\frac{kWh}{cap \cdot a}$	1.141×10^{-1}	3.6	1	3412
$\frac{BTU}{cap \cdot a}$	3.343×10^{-5}	1.055×10^{-3}	2.931×10^{-4}	1

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