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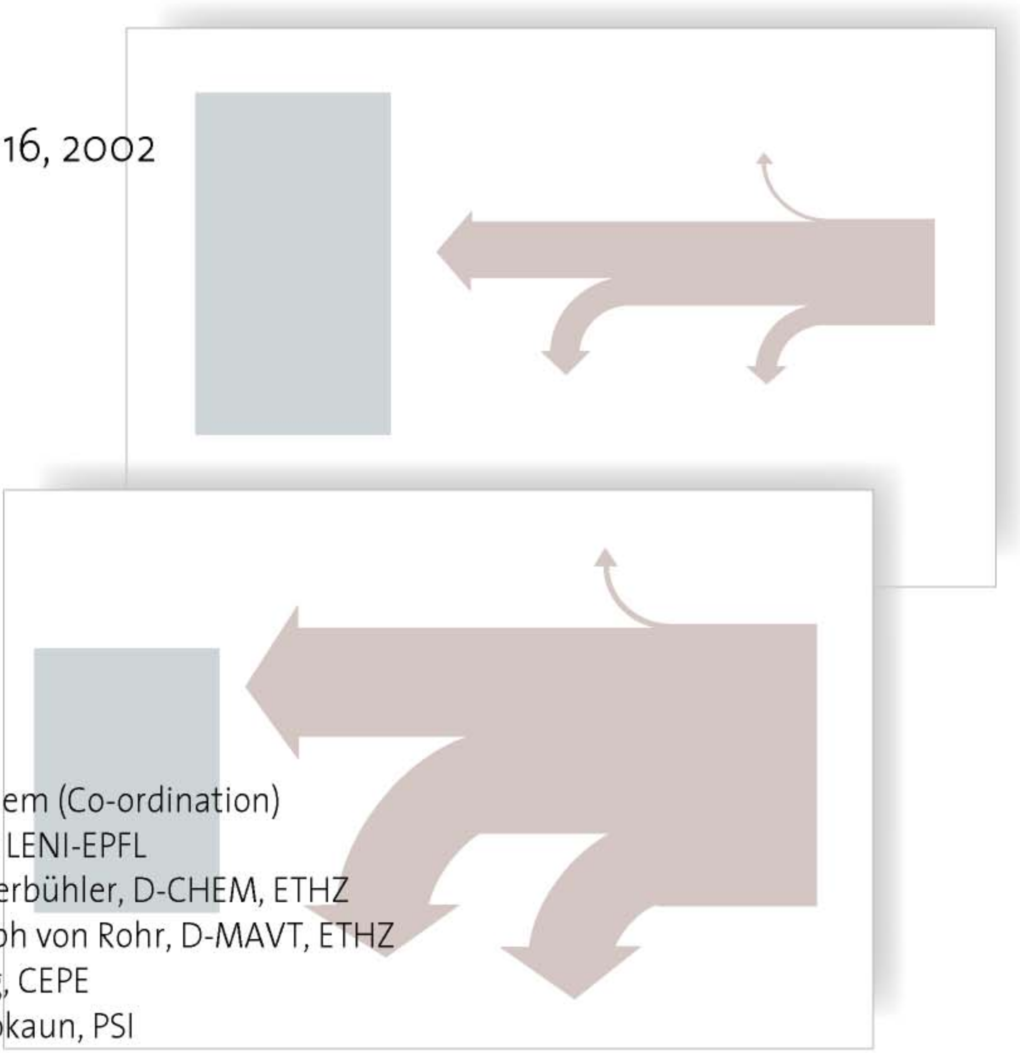
Steps towards a 2000 Watt-Society

Developing a White Paper on Research & Development of Energy-Efficient Technologies

Pre-study
December 16, 2002



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Preface

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/capita per year, which is one third of today's per capita primary energy use in Europe. Assuming a doubling of GDP (gross domestic production) per capita within the next 50 years, the 2000 Watt society implies a factor 4 to 5 improvement in primary energy use, admitting some influence of structural change on less energy-intensive industries and consumption patterns.

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 measures are needed to meet this goal.

The authors have screened the technological areas and necessary research in this first attempt. They are grateful for all the advice and suggestions given by colleagues in Switzerland and abroad, particularly by the participants in the international workshop on September 9 - 10 2002.

In view of the challenges facing humanity this century, the authors are convinced of the need to take action immediately to further research and policy in energy and materials efficiency.

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

Executive summary

In the coming decades, the threat and consequences of climate change and of the re-concentration of crude oil production in the Near East will compel industrialised nations to make much more efficient use of energy. R&D that helps realise energy efficiency potentials is likely to be regarded as important in scientific, entrepreneurial, and political realms. Demand for highly energy-efficient technologies will rise steeply, and firms that can provide them will prosper. The identification of energy-efficient technologies and related energy conservation potentials undertaken in this pre-study is a first step toward designing a R&D strategy that is consistent with the need to evolve towards a 2000 Watt per capita society. Reaching this level by 2050 implies reducing primary energy use from 1200 to 460 PJ per year, despite a projected 65% economic expansion (see Figure 1).

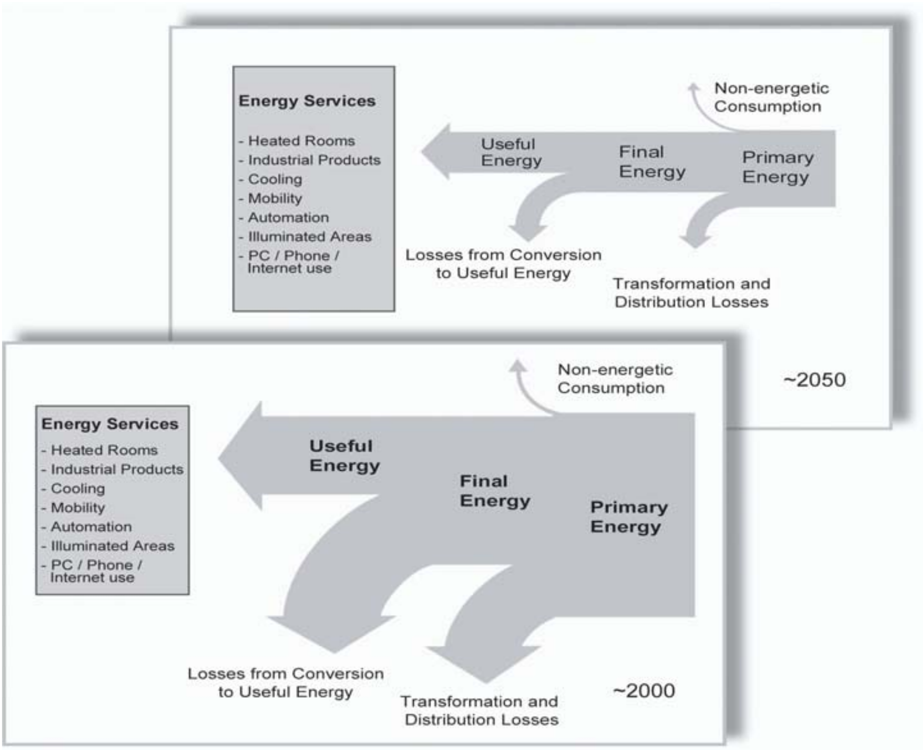

Figure 1: Energy flows and energy services of Switzerland in 2000 and 2050 – reducing energy per capita demand by two thirds while increasing energy services by two thirds

This report examines efficiency potentials in energy's transformation from primary energy to useful energy and, more importantly, from useful energy to energy 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 today; 2050's computers will be designed in 2040. It is easy to envisage technologies that would make a 2000 Watt society possible by the year 2050. However, without exploiting the opportunities re-investment cycles offer, a 2000 Watt society will not emerge and will not even be technologically feasible. This report emphasizes the enormous size of energy conservation potentials achievable not only by reducing energy losses but also by decreasing the specific demand for several different energy services through improved material efficiency and intensification of product use (Figure 1).

This pre-study reaches the following definitive conclusions:

(1) Achieving 2000 Watt per capita by the middle of this century implies a complete re-investment of the capital stock in industrialised countries (and a complete refurbishment of the building stock to be used in 2050).

(2) In light of these 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.

(3) Reducing current per capita energy demand by two-thirds within five decades requires not only research in natural and technical sciences but also behavioural research on decision making and day-to-day operation and innovation in industry, services, crafts, transportation, and private households.

(4) Moreover, the transition to a 2000 Watt per capita society needs the support of a fundamental change in 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 being part of a Swiss policy on sustainable development.

Contributions to this enormous change will have to come from all sectors and technical systems but also from changed behaviour of many actors:

- *Buildings*, which use a third of final energy for heating, have a very large energy efficiency potential. Past technological advances, although considerable, have by no means exhausted the technological and cost reduction possibilities. Key technological developments include new types of insulation and integrated designs for new buildings and houses such as low-energy and solar passive houses and commercial buildings, combined heat and power, and heat-pump systems.
- Similarly, the efficiency of *large equipment* like power stations, paper machines, and industrial kilns will continue to be improved greatly. 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).
- One of the areas with the largest savings potential for 2050 is road *transport*, especially passenger cars. Further advances in internal combustion engines and fuel cell technology, braking energy recuperation systems, lightweight frames and new tire materials are very promising. The aviation sector is 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 trans-shipment and container technology is important to make multi-modal freight traffic more efficient and attractive.

- Systematic innovations through the use of *information technologies* will be very important despite short re-investment cycles for the single elements of the energy-using systems considered. Putting control technologies at the service of more efficient use of energy and other resources is a large, rewarding technological challenge.
- *More efficient material use*, additional recycling of energy-intensive materials or substitution with 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, energy demanded. Entrepreneurial innovations will support these options and the intensified use of machinery and vehicles by pooling.
- The report identifies techno-economic bottlenecks and existing obstacles to the development, acceptance, and market diffusion of innovative technologies; it may be important to consider them even at the R&D stage. Finally, the report identifies the necessary *research on group-specific behaviour* in investment decisions and everyday operation relevant to resource efficiency.

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

The authors strongly recommend the design of a research programme and process that could have a decisive impact and help Switzerland to become a leader in technologies for a 2000 Watt society.

R&D towards a 2000 Watt society - results of the pre-study: Overview

The overview summarises the assessment of efficiency potentials that might be achievable with new technologies by the middle of this century. The saving potentials, documented in absolute terms for the various sectors, technological fields and behavioural areas, have been synthesised, taking into account mutual interference and sequential efficiency improvements along the energy chain (see Figure 2).

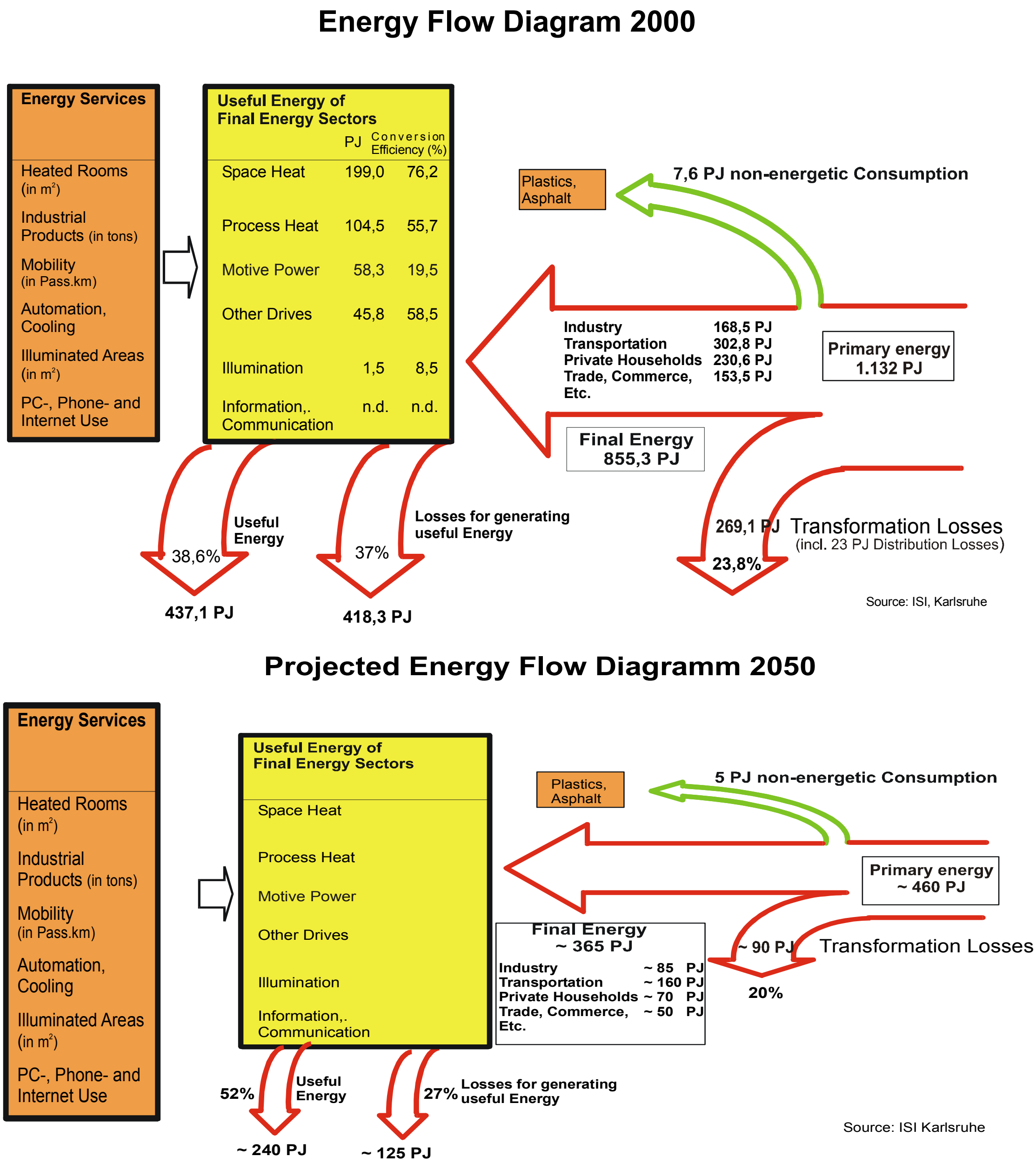

Figure 2: Swiss energy use in 2000 and estimated energy use summarising the energy/material efficiency potentials (including behavioural changes and entrepreneurial innovations) in 2050 by sectors and three levels of energy conversion and use.

Major savings of more than 200 PJ can be expected from the residential building sector from new insulation techniques for walls, roofs, windows and basements and tighter building envelopes and solar gains through adapted construction techniques for houses and buildings. However, this potential is only feasible by the mid of this century if substantial insulation measures are made by almost all building owners within the re-investment cycle starting this decade! A similar reduction in final energy use may be achievable in the transportation sector, particularly from the car subsector, through lighter vehicles and substantially improved propulsion systems, better logistics, and transferability between the different modes. Increasing air transport, however, may diminish the saving potentials in this sector.

Smaller and less certain potentials are possible in industry (100 to 130 PJ); in the commercial and agricultural sector (150-200 PJ); for cross cutting technologies such as information and communication technology, variable speed drives and power electronics; and through improved material efficiency and substitution, recycling, and intensification of product use (80-100 PJ). The latter area also demonstrates that energy services involving vehicles, machines or appliances can be differently organised and will thereby change the demand for energy services. Finally, organisational changes and entrepreneurial innovations or policies influencing behaviour and even lifestyles have substantial energy-saving potentials that are often economically favourable but rarely perceived (60-120 PJ).

It can be safely assumed that the partial substitution of nuclear power plants after 2020 by decentralised integrated systems will substantially improve the efficiency of the Swiss conversion sector. There is thus a chance that the total necessary efficiency gains in the final energy sectors required by the 2000 Watt per capita society may be realised under very optimistic assumptions of further technological progress in all sectors of the economy and the residential sector. Of course, as a first result, this estimate is highly hypothetical, but it indicates that the 2000 Watt society vision is not out of the range of theoretical possibility.

Conclusions, recommendations and further steps of the analysis

Within the limitations of a pre-study, this chapter draws first conclusions for R&D policy in Switzerland and offers some recommendations at the sectoral level (section 1). As the recommended R&D efforts have to be evaluated within the context of relevant research boundary conditions, actors and institutions, some first remarks are presented for further discussion (section 2). Finally, steps for further analysis and the communication of achieved and expected future results are suggested (section 3).

1. Promising R&D areas of analysis – conclusions and recommendations

(1) The existence of a technology's energy-saving potential alone does not further the 2000 Watt society. Only when a technology's (behavioural) potential is realised and the technology is broadly marketed and used is energy actually saved.

(2) The goal of a 2000 watt per capita society by the middle of this century cannot be achieved if energy-related R&D is exclusively focused on efficiency improvements of energy conversion technologies in the transformation and final energy sector (total energy conversion losses in both sectors amount to two thirds or about 700 PJ in Switzerland today). R&D must also be extended to cover several other technological fields as well as behavioural and entrepreneurial aspects:

- Transformation of useful energy to energy services presently loses 400 PJ. Major improvements in and substitution for existing technologies are possible in this area (e.g. passive solar houses and buildings, substitution of traditional energy-intensive processes by new low-energy processes in industry, lighter vehicles).
- *More efficient use of energy-intensive materials and their substitution with less energy-intensive materials* (e.g. foamed plastics or non-ferrous metals) will not only reduce the energy demand required to produce them but also the final energy required by the lighter moving parts and vehicles during their operating lifetime. Increased R&D is recommended to facilitate the recycling of energy-intensive materials (such as paper, steel, glass, plastics, aluminium, asphalt) and the partial re-use of long-lasting investment and consumer products, contributing to lower material demand.
- *More efficient organisation of individual and societal needs* by offering services instead of owned but rarely used products, vehicles or unwanted floor space in dwellings, office buildings and factories (e.g. instead of owning, short-term renting or leasing of vehicles, harvest and production machines). In addition, more professional planning, construction, and operation of energy-converting plants may help reduce energy losses (e.g. contracting of heat generation, cogeneration, compressed air, or cooling). The savings potential of this organisational and entrepreneurial field is at least 50 to 100 PJ by 2050.
- A final point is the explicit consideration of *systems aspects with regard to wasteful and unproductive exergy losses or unproductive mobility* in urban areas or freight transport. The design of industrial parks could integrate aspects of cascaded heat use along its tempera-

ture level; non-polluting production and low-noise crafts could be re-integrated into residential areas, thus reducing local mobility between home and workplace. This strategy would contribute to a low-energy society with reduced demand for short-distance motorised mobility in the long-term.

(3) However, *long re-investment cycles in some applications* (particularly in the building, train, aircraft, and infrastructure sectors) necessitate forward-thinking policy that applies the *new low-energy solutions as early as possible*.

(4) The crucial R&D areas outlined above will have to be taken up by researchers in many countries. Therefore, *periodic, thorough evaluations* will be needed to identify the most supportive technological and social science-related research areas. These should be best suited to advance future Swiss energy efficiency, and they should sustain and improve the competitiveness of Swiss producers of sustainable technologies in future world markets. This *selection of the most promising areas for Swiss research, development and innovation* has to be seen as a *continuous ongoing process of evaluation* of the opportunities and the comparative advantages of the Swiss research and innovation system.

(5) For private households and passenger transport, however, it is somewhat doubtful that improving the energy efficiency of a technology with a high energy-saving potential will actually lower energy use. In the past decade, for example, the increasing use of lightweight components in car construction has not lead to lighter cars. The gains have been mostly counterbalanced by the addition of new technical features such as air-conditioning, GPS-navigation, motor-driven windows, and safety components. Good research support may be able to compensate for these trends and preserve the energy savings.

Recommendations

On this basis of the conclusions and the results of the Final Report Chapter 4, the authors make the following recommendations:

(1) Policy on R&D in energy and materials efficiency should be increasingly accepted as part of an innovation policy towards sustainable development, not only for Switzerland but globally, by mutual international exchange of new knowledge on technology and organisation and through foreign trade in new energy-efficient technologies.

(2) In order to make progress towards a 2000 Watt per capita society, research has to cover all technological, economic, and behavioural aspects related to energy and materials use. This poses an enormous challenge for interdisciplinary research in the future.

(3) A larger study should analyse in greater detail the potentials of a 2000 watt per capita society, promising technologies, and the most advanced research groups and institutions in these fields. It should be carried out soon. The study should cover the technological and organisational areas identified in this pre-study and be conducted by a broad team of scientists from the Swiss scientific community, taking advantage of the many types of formal and informal co-operation with researchers and research institutions in other countries (see section 3).

(4) The following *specific recommendations* for individual research areas in the various *energy-using sectors* focus on priority aspects:

- *Buildings*: The largest expected savings will come about from substantially improved insulation and air tightness, demand-controlled energy systems (including heat recovery in ventilation systems), heat pumps, and fuel cells. Installation of new high-performance thermal insulation materials at low cost on existing buildings is crucial.
- *Industry*: The recommendations cover the substitution of energy-intensive processes such as thermal separation by processes based on membrane techniques, improved mechanical separation instead of thermal drying, and the substitution of traditional grinding techniques by new ones. This strategy will require basic but applied research. The other strategy focuses on improving existing industrial processes by improving process design and control (e.g. reducing or combining process steps)
- *Transportation:* Given the passenger car sector's significance for energy use and potential savings (30% of final energy use; potential savings of up to 70%), car design measures, light-weight models, the optimisation of the internal combustion engine, and fuel-cells as well as specially designed city cars are of major importance. It also seems prudent to consider the substitution of short-range air traffic by a completely new high-speed train system using magnetic levitation technology, given long lead times for R&D and implementation.
- *Conversion Sector*: Sustained R&D in high-temperature, energy-converting techniques including advanced co-generation systems and gas turbines, fuel cells and related components such as ceramics and long-lasting, selective membranes promises further improvements in energy and exergy efficiency. Particular attention should be paid to integrated and inexpensive systems composed of several elements (e.g. heat pumps, micro gas turbines, cooling, or district heating, all of which contribute as a system to improved exergy efficiencies). Remote control may be important for operating the decentralised units.
- The widespread availability of biomass in Switzerland suggests that some R&D resources should focus on highly efficient *biomass-converting* technologies in different applications, while considering the possible impact on rural areas and the agricultural sector.
- Adequate R&D should be conducted in integrated systems: zero-emission plants, energetic autonomous systems (with an emphasis on process integration and optimisation), and CO_2 capture and storage.
- Behavioural sciences and innovation research is equally important as to improve the decision process, motivation and knowledge of operators, professional training and to support new services supplying professionally generated useful energy.

2. Widening the view from energy-related research to innovation systems

Scientists as well as society have to develop a vision to deal with the energy problem as a challenge. The 2000 Watt society may serve as such a vision. Research support can stimulate and invigorate it, but 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 3) that are

- engaged in scientific research and the accumulation and diffusion of knowledge (i.e. research institutions, universities, schools),

- engaged in education and professional training as well as the dissemination of new knowledge to a broader audience (i.e. educational institutions, media),
- developing and producing new technologies, processes, and products; and commercialising and distributing them (e.g. intermediates, infrastructure, technology producers).

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 appropriate infrastructure. Every innovation system is unique and develops its profiles and strengths only over decades. Each is based on stable exchange relationships among the institutions of science and technology, industry, commerce, and the political system.

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

- a high degree of compartmentalisation (e.g. buildings, road transportation, industrial branches, energy companies) and corresponding sectorisation 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) neglecting then opportunities at the useful energy and energy service level in most cases.

These characteristics of the efficiency innovation system are general and almost independent of the country considered, but they are highly dependent on the ubiquity and heterogeneity of energy and material efficiency itself.

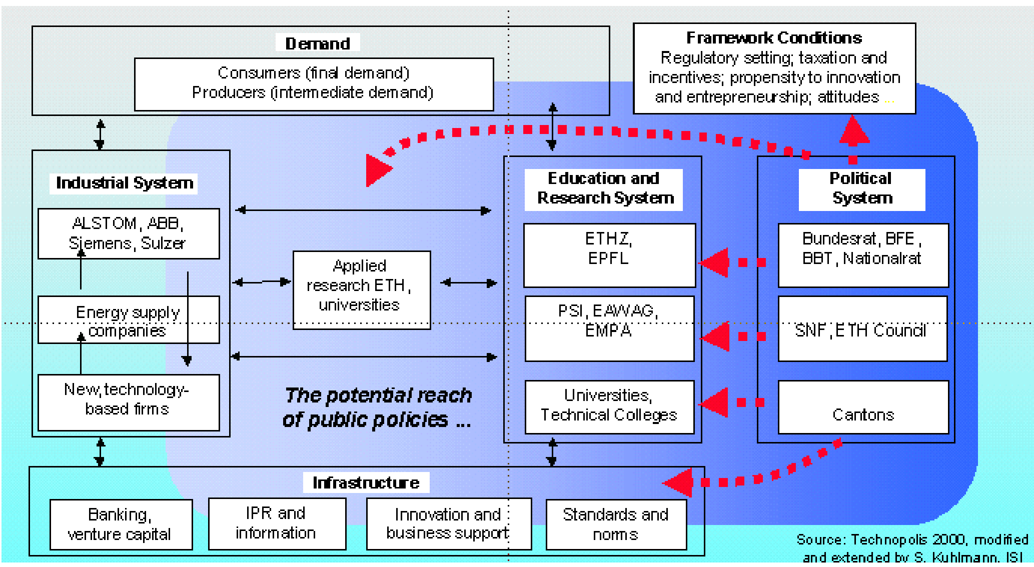

Figure 3: Scheme of the Swiss energy and energy efficiency innovation system

The weaknesses of under-coordinated innovation policy-making, which seem to prevail in the energy and material efficiency field, 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 (focussing 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 innovation-focussed and co-ordinating roles for government, addressing the large portfolio of technologies and innovations, reinforcing user-producer relations, supporting the building 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, sociology of organisation and science, political science, and management science.

3. Further steps of the analysis

The activities that could follow this pre-study are a main study that develops a research and development agenda in greater detail for major technological fields that have been identified. Secondly, the results of this pre-study could be enriched and enlarged to a book publication in order to stimulate and strengthen the discussion on R&D opportunities in the various technological fields.

Proposal for the main study

As described in the methodological approach (see Final Report Chapter 3), this pre-study did not systematically identify and evaluate R&D areas according to criteria like "high competence of the Swiss research community" or "first movers' potential for Swiss manufacturers". The limited effort of the pre-study also did not permit involving a sufficient number of senior researchers for all relevant R&D areas or a broader interview campaign among high-level scientists in Switzerland and abroad.

The *objectives of the main study*, therefore, will focus on the following two topics:

- Identification of the most relevant R&D themes to achieve energy and material efficiency in the technical fields identified as important in the pre-study; to overcome technical as well as cost bottlenecks, and to develop a knowledge base on related entrepreneurial innovations and educational needs.
- In these selected R&D areas, identification of existing or potential strengths of both Swiss research institutions and Swiss technology producers whose contributions towards a sustainable energy technology development could be the largest.
- Recommendations on different research areas, that also consider the dynamics of re-investment cycles in the various fields of energy and material use and R&D periods needed.

The methodology that will be used (and improved) in the main study is described in the Final Report Chapter 3. More detailed analysis would be done on the expected boundary conditions in European and world markets, the present and potential competitive export position of Swiss manufacturers in the different technological areas, and the institutional structure of the Swiss research and innovation systems.

The methodological technique of backcasting will have to be applied in detail to the various system components (e.g. two turbine generations over the lifetime of a single airplane). A broad and in-depth interview campaign will be necessary and will include personal and telephone interviews and critical reviews from workshops and invited scientists from academia and industry.

The authors suggest the following four areas be analysed in detail in the main study:

(1) Applied engineering research with the aim of developing *highly energy-efficient products, components, practices, and systems*. This research could be part of any of the fields mentioned in section 1 but would most likely concentrate on energy-converting technologies. Such research would be partially done through an industry-university collaboration and have explicitly stated energy-efficiency goals, particularly in the case of pure energy-converting technologies. These goals will, obviously, have to be much more ambitious than the usual incremental technological improvements (e.g. ceramic gas turbines, high-capacity heat exchangers with surfaces modulated by nano-technology, super-conductive power lines, high efficiency integrated fuel cell/heat pump/cooling systems). In the long-term, academia will have to play a pioneering role in many of these technical fields.

(2) *Applied engineering research* with significant *implications for energy efficiency* at the level of useful energy, driven primarily by non-energy goals such as higher product quality, increased labour or capital productivity for processes, or a service such as mobility or housing. Improvements in the efficiency of providing energy services from useful energy will be a co-benefit of this category. The main study will have to make specific recommendations for the various research areas covered in the Final Report Chapters 4.1 to 4.2 (e.g. building design, separation by membranes or crystallisation, light vehicles, and foamed plastics).

(3) In R&D areas without direct and obvious links to applications of energy-efficient products, components, practices and systems, *improvements of the strategic properties of materials and devices (sensors, software and communication technologies*) may warrant special attention and support. It is difficult to identify these areas of strategic importance and would require considerable effort in the main study. For example, inexpensive and improved sensors, information, and communication systems are key factors not only for process automation and optimisation and for intermodal transportation, but also for reliable and practical solutions for intensifying product use by developing and supplying information and communication systems-based services.

(4) The development of *systems construction procedures and analytical tools* may be important. Given the large number of design options of buildings, vehicles, industrial process systems, integrated energy systems, and infrastructure, optimisation methods to identify cost reduction potentials of new technologies and systems while accounting for environmental effects may play an important supporting role in engineering efficient components and systems. Such methods would include exergy concepts, life-cycle analysis (LCA), and databases. Pooling data among industries without infringing on proprietary rights would facilitate decision-making about specific R&D paths.

The study will conclude with recommendations on promising fields for R&D in natural sciences, technology, entrepreneurial, behavioural and policy sciences, the latter taking into consideration the Swiss innovation system as well as existing obstacles and market imperfections that hinder the timely implementation of energy- and material-efficient processes and products.

The comprehensive work will be performed within a period of 2,5 years. It will be accompanied by a specially appointed scientific board of representatives from industry, administration, CORE and the national and international scientific community. Interim results will be reported at the end of the first and second year; the interim results will be discussed in an international workshop with parallel sessions on major sectors and organisational and behavioural aspects.

The research effort is estimated to amount to some eight years of scientific manpower. The existing team of six researchers will be increased by five to six senior researchers, with particular emphasis on electric systems, material science, thermodynamic machines, behavioural science and innovation research.

Final Report

Jochem E., Favrat, D., Hungerbühler K., Rudolph von Rohr P., Spreng D., Wokaun A., and Zimmermann, M., co-contributors; Semadeni M., David Goldblatt, D. Kemmler A. Stephan Lienin S., Arthur Janssen A., and Lukas Gutzwiller L., P. Keller P., C. Kölble C., Alexander Primas A., Weber-Marin A. S., Maréchal F., and Richter K., 2002, Steps towards a 2000 Watt–Society: Developing a White Paper on Research & Development of Energy-Efficient Technologies, Pre-study, Final Report, CEPE Zürich, LENI EPF Lausanne, D-CHEM ETH Zürich, D-MAVT ETH Zürich, PSI Villigen, EMPA Dübendorf, submitted to novatlantis, December 2002.