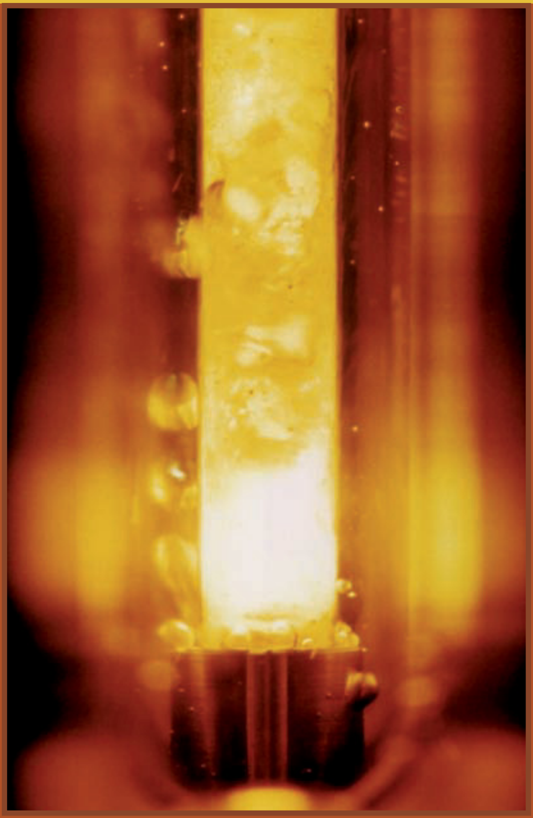
Philipp Rudolf von Rohr, Peter Walde,
Bertram Batlogg (Hrsg.)

Energie



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Coverabbildung:
Flamme, resultierend aus der Reaktion eines Methanol/Wasser-Gemisches mit reinem Sauerstoff in der Umgebung von Wasser, überkritisch bei ca. 250 bar und grösser 370 °Celsius.
Der Einsatz im Energiebereich erfolgt als mögliche «Bohrhilfe» durch Spallation (die lokale Erwärmung des Gesteins ergibt Brüche im Gestein und bewirkt ein Abplatzen). Dadurch wird ein berührungsloses Bohren in grossen Tiefen möglich, etwa für die Erschliessung der Zulauflöcher für Geothermiewärmenutzung für elektrische Energie.

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www.vdf.ethz.ch
verlag@vdf.ethz.ch

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Vorwort

«Energieverknappung», «Rohstoffe zur Energieumwandlung», «Burn-out-Syndrom», «Zellen und deren Energiehaushalt», «Erneuerbare Energie» und «Energie und Krieg» sind Beispiele von Themen zum übergeordneten Begriff «Energie». Diese Themen wurden von ausgewiesenen Fachleuten im Rahmen einer interdisziplinären Veranstaltung der ETH und der Uni Zürich im Herbstsemester 2008 vorgestellt.

Die beobachtete Klimaveränderung und insbesondere die dramatische Zunahme des Kohlendioxidgehaltes in unserer Atmosphäre haben vermehrt dazu geführt, dass Energiefragen nun auch in der breiten Öffentlichkeit diskutiert werden. Energie im physikalischen Sinn kann weder erzeugt noch vernichtet, sondern lediglich umgewandelt werden. Die Umwandlung und der Verbrauch von Energierohstoffen sind beträchtlich mit dem Wohlstand der westlichen Welt verbunden. Zunehmend verbrauchen Nationen wie China und Indien enorme Mengen an Rohstoffen. Um Konflikte zu vermeiden, sind politische und technische Lösungen gefragt.

Die Vortragsreihe war ein Streifzug durch die aktuelle Einschätzung der Energiesituation auf verschiedenen Ebenen, wie die hier abgedruckten Vorträge aufzeigen. Es werden Ansätze zu Lösungen derzeitiger und zukünftiger Energieprobleme präsentiert, die zeigen, wie den Anforderungen in den kommenden Generationen begegnet werden kann. Aufbauend auf fundiertem und gesichertem Datenmaterial, sollen die folgenden Beiträge zu einer konstruktiven Diskussion um Nachhaltigkeit führen. Wir sind überzeugt, dass solche Diskussionen um die Rohstoffversorgung im Zusammenhang mit der allgemeinen Energieproblematik gefördert werden sollen und bedanken uns bei den Vortragenden für ihre herausragende Arbeit, und den zahlreichen Hörern für die engagierten Diskussionen.

Philipp Rudolf von Rohr, Peter Walde und Bertram Batlogg

Eberhard Jochem

Energy flows and losses – the industrial countries in the iron age of history in the energy sector

Abstract

The paper first outlines the challenges the global energy system is facing. It then summarises the present knowledge on energy efficient solutions in all energy using sectors from primary energy to useful energy and, *more importantly, from useful energy to energy services* (material efficiency and substitution). The examination of these potentials considers the lifetimes of manufactured artefacts: buildings and infrastructure that will save or waste energy within the next 60 to 70 years. The result – a reduction of present energy use per capita by a factor of 3, labelled as a 2000 Watt/capita society, is shortly discussed as well as organisational measures and entrepreneurial innovations which could be immediately taken up. Besides the traditional reasoning why many profitable energy efficiency potentials are not realised, the article also calls for more creativity to rely on the motivation and opportunities of actors and to analyse the relevant actors of the related innovation system. Finally, the recent activities of the Energy Summit of the German government and the Commission's Action Plan for Energy Efficiency are shortly discussed under the criteria developed in the article.

Introduction – the challenges and opportunities from a global perspective

In 2003, almost 450,000 PJ of global primary energy demand delivered around 295,000 PJ of final energy to customers, resulting in an estimated 141,000 PJ of useful energy after conversion in end-use devices. Thus, around 300,000 PJ – or two thirds – of primary energy are presently lost during energy conversion, e. g. in power plants, refineries, kilns, boilers, combustion engines, and electrical motors, mostly as low- and medium-temperature heat. These losses also include the small share of losses from the transmission, transformation and distribution of grid-based energies (see fig. 1).

Conversion efficiencies in primary energy are somewhat better in countries with high shares of hydropower (like Norway, Switzerland), but the large conversion losses in road vehicles (around 80%) offset most of this advantage. Carbon-emitting fossil fuels such as coal, oil and natural gas comprise some 80% of the primary energy demand, and contribute CO_2 emissions of approx. 26 billion t per year. This trend is increasing annually by 1.5%, mostly due to the fast growth of fossil fuel use in emerging countries. Today's CO_2 emissions are already four times more than what the atmosphere is able to absorb in this century, assuming the global mean surface temperature does not increase by more than 2 °C within this period. The adaptation and damage costs of extreme climate events have already started increasing to noticeable levels that are not included in the cost of fossil energy use (EEA 2004).

Mankind is facing several major energy-related challenges in this century: the threat and consequences of climate change, the re-concentration of crude oil production in the Middle East, and the energy price risks of peaking oil production. In the light of these perspectives, the Board of the Swiss Federal Institutes of Technology (1998) is promoting the vision of a «2000 Watt per capita society by the middle of the 21st century». A yearly 2000 Watt per capita demand of primary energy corresponds to 65 GJ/capita per year, which is equivalent to one third of today's per capita primary energy use in Europe. Assuming a doubling of GDP (gross domestic production) per capita in Europe within the next 60 to 70 years, the 2000 Watt/capita society implies an improvement in primary energy use by a factor of 4 to 5, admitting some influence of structural change on less energy-intensive industries and consumption patterns. This vision poses a tremendous challenge to research and development, the political system and technology producers 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.

Considerations of future improvements in energy efficiency often focus on energy-converting technologies (e. g. thermal power plants, gas turbines, or combustion engines).There are, however, two additional areas for reducing future energy demand which presently receive little attention (see fig. 1):

- Energy losses at the level of useful energy (presently about 34% of the primary energy demand in Germany or almost 32% at the global level) could be substantially reduced or even avoided by using technologies such as low-energy or passive buildings, membrane techniques or biotechnology processes instead of thermal processes in industry, lighter vehicles, storage of braking energy, or more intensified heat recovery in many sectors.
- Secondly, the demand for energy-intensive materials could be reduced by recycling or substitution of those materials, by improving their design based on new knowledge such as bionics, or by improved material properties that are still emerging from material science and nanotechnology (Stahel 1997). The partial substitution of plastics and other chemical products based on petro-chemicals by products based on biomass is also an option to reduce the dependence on fossil fuels, even though

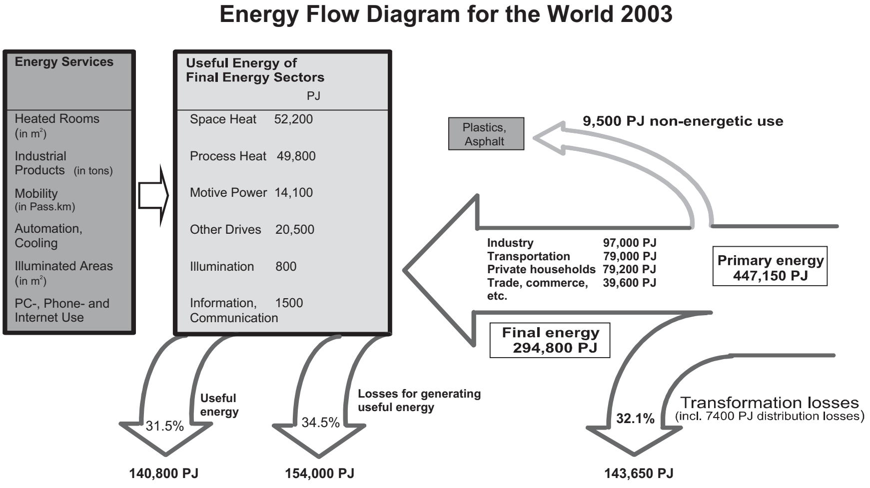

Fig. 1: The Energy System from Services to Useful, Final and Primary Energy, World 2003 (sources: OECD 2005, own calculations)

this only represents a small share of 2.6% of total fossil fuel use (Patel 2005). Finally, when measured in yearly operating hours, many appliances, machinery, industrial plants, and cars are not used intensively; it would make sense therefore to intensify their use by pooling (e.g. car-sharing, leasing of machines; Fleig 2000).

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. Enquete Commission 1991). This complies with the vision of the Board of Swiss Institutes of Technology and was confirmed by a major analysis of its technical feasibility (Jochem et al. 2002, 2003). Within this context, the authors consider technological advances that lead to highly efficient energy use to be promising investments. Research and development (R&D) that furthers these technologies is a crucial prerequisite. Countries and firms that invest in these technologies and related R&D are likely to boost their economies. On top of this, they will make a significant contribution to the pressing problems of climate change and re-concentration of world oil production, and help to manage the secure supply of energy and counter the risks of high energy prices in view of peaking world oil production within the next 10 to 20 years.

1 How to speed up the advances in energy efficiency?

The vision of the Board of Swiss Institutes of Technology may sound over-optimistic as the overall yearly improvement of efficient energy use would have to be doubled (to 2.0–2.3%/a) compared to the efficiency improvements actually achieved in OECD countries (about 1%/a) over the last 35 years (IEA 2005). In order to identify promising activities, innovation policy and research areas for efficient energy use and conversion, one has to distinguish short-term and long-term options and consider the re-investment cycles of the capital stock in the various fields of energy use and conversion as one of the major limitations. The following analytical issues then result:

- *Organisational options and short-term investments* are likely to contribute towards speeding up the efficient use of energy and materials and «buying down» the cost of new energy-efficient technologies in this and the next decade (e.g. highly-efficient electrical motors, components of low energy and passive houses, condensing boilers, heat pumps, etc.).

Almost everybody is aware of the cost decreasing effects of learning and economies of scale when it comes to renewable energies or fuel cells – but the fact that many technologies of efficient energy use follow the same pattern of specific cost reductions has hardly been a subject of analysis so far (for example, the experience curve of highly-efficient window systems has a coefficient comparable to that of wind power [Jakob et al. 2003]).

- In the longer term, *new technologies* may significantly contribute to a 2000 Watt per capita society in their second generation phase. This search *focuses on technology substitution* and less on technology improvements, which are often small and incremental. Passive houses, for instance, reduce the final energy demand by a factor of 8 to 10 relative to the present average final energy demand of the housing stock; light and efficient cars may cut gasoline demand by more than 50%, and membrane technologies can reduce the energy demand of thermal separation processes by 60 to 90%.
- The rather low rate of some 1% energy efficiency improvement per year over the last 35 years raises several questions: What are the major obstacles and market imperfections that have to be addressed by policy measures in order to speed up the realisation of energy and materials efficiency potentials? Since the reflections on obstacles and market imperfections have been around for a long time already (IPCC 2001), are there any additional concepts of motivation or opportunities which have not yet been applied but which are likely to speed up activities and boost markets for realising energy efficiency options?

These three analytical steps will be used to structure the article into the following sections.

2 How to realise short-term and long-term efficiency potentials?

– Short-term efficiency potentials

Although short-term energy efficiency improvements may be quite welcome to reduce energy costs and CO_2 emissions in the short term, they still have to be checked against the criteria of sustainable development. On the one

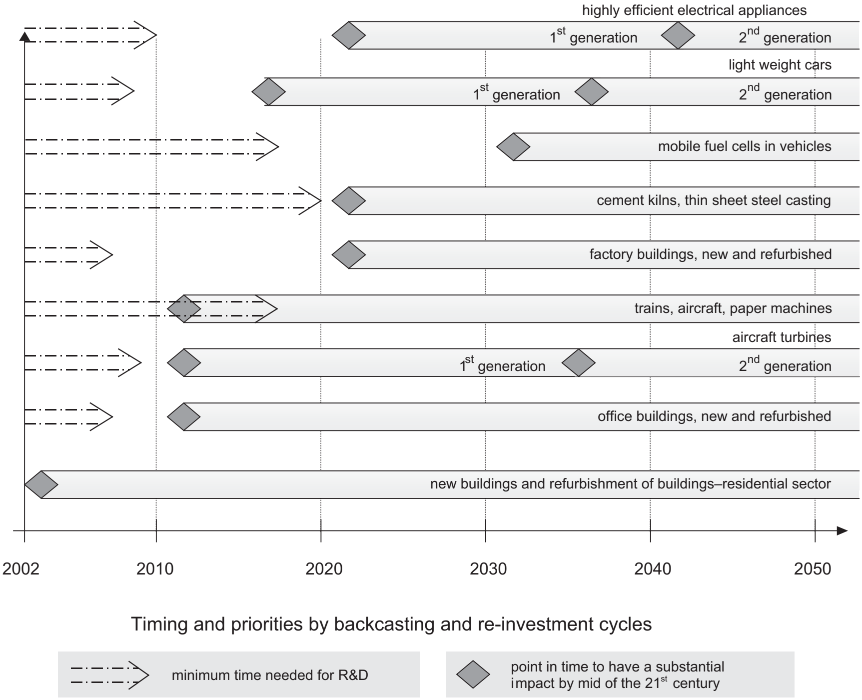

Fig. 2: Timing and priority-setting of efficiency policies and R&D using back-casting and re-investment cycles, avoiding lock-in pathways

hand, minor efficiency improvements in long-lasting capital stocks such as buildings, railways, roads, or central power plants today with re-investment cycles of 40 to 60 years may lead to a lock-in situation (e. g. a building not insulated during refurbishment today will generate high energy costs over the next 50 years); on the other hand, costly efficiency improvements – possibly subsidised by tax payers or energy consumers – in product areas with re-investment cycles of 3 to 5 years may result in a waste of resources if they are expected to be much less expensive and more profitable in 4 to 6 years time.

The technique of back-casting can be used as an aid to prioritise short-term options and long-term innovations based on their re-investments cycles and the correct timing for their introduction. This is helpful to avoid lock-in technology pathways by examining re-investments cycles and the necessary R&D periods which have to be considered (see Figure 2). One example is stationary fuel cells which may ultimately generate too many CO_2 emissions after 2040. This concept has to be combined with the usual bottom-

Express check for organisational measures in firms, public administrations and private households (a selection)

Heating

- Is the room temperature setting correct (e. g. 18 °C, 20 °C)? Is it possible to lower the temperature overnight when rooms, halls, or workshops are not used?
- Are the operating hours of boilers and circulation pumps correctly controlled overnight and at weekends? Is the pressure of the extension container correct?

Steam generation and distribution

- Is the pressure level really necessary for the processes served?
- Are there any losses of the condensate system? Any leakages, steam losses when the condensate pressure is reduced?

Warm water supply

- Are boiler temperatures higher than maximum temperature needed for the processes? (Avoid related losses in the boiler, storage, and piping.)
- Does the daily operating time of the warm water storage and the circulating pumps match the daily pattern of demand (showers, one-shift working day)?

Ventilation

- Are the filters serviced on a regular basis?
- Do controlled operating hours fit the demand patterns of production processes or the use of the building?
- Is free ventilation used under favourable weather conditions (by windows, etc.)?

Box 1: *Organisational measures and short-term small investments in energy efficiency*

up models as a new optimisation strategy for energy efficiency policy (IEA 2006). As the challenges of oil resources and climate change are pressing, the strategic concern is less «minimal cost at a given level of emissions», but rather a «minimal time span over decades reducing specific energy demand by a factor of 4 to 5 at acceptable cost».

There are numerous profitable short-term investments and organisational measures for more efficient energy use in any final energy sector and in the conversion sector (Romm 1999, UNDP/WEC/UNDESA 2000, IEA 2006). There are even many very simple organisational measures to avoid losses of useful energy or energy for conversion which are not known or not considered in many cases (see Box 1). If these organisational measures and small investments are profitable, why are they so often neglected and not implemented to reduce energy costs?

3 Buildings

Source: standard information material within learning networks of energy efficiency

- **Efficiency potential of the second re-investment cycle and the role of R&D**

Over the long term, additional and dramatic gains in energy and material efficiency are possible at all stages of energy conversion, particularly from «useful energy» to «energy services» as well as in the more efficient design and use of energy-intensive products and vehicles. Thermodynamic analyses show that most current technologies are not close to reaching the theoretical limits for energy efficiency and that very significant improvements in the whole energy system may eventually be achieved by replacing traditional technologies. This could improve the efficiency by a factor of 5 over six to eight decades (Jochem et al. 2002, 2003).[1]

The identification of potentially relevant energy-efficient technologies can be structured along the lines of the traditional energy economic sectors and then extended by examining materials and systems efficiency as well as behavioural and entrepreneurial aspects. This process results in five steps of the analysis and potential efficiency gains:

1) Significantly *improved degrees of efficiency at both conversion steps* – primary to final energy and final to useful energy; achievable by the application of new technologies (e.g. co-generation and tri-generation (including cooling) plants, fuel-cell technologies, substitution of burners by gas turbines or heat pumps (including heat transformers), ORC turbine systems, Stirling engines);
2) 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, light-weight architecture of mobile parts and vehicles, recuperation and storage of kinetic energy (Levine et al. 1995, IPCC 2001);

3) Enhanced recycling and re-use of energy-intensive materials and increased material efficiency by improved design, construction, or material properties, which result in a significantly reduced primary material demand per material service unit (Fleig 2000);
4) Intensification of the utilisation of durable and consumer goods through increased leasing of machines and equipment, car-sharing and other product-dependent services (Stahel 1997); and finally
5) Improved spatial configuration of new industrial and residential areas according to energy-relevant aspects, and improved merging of residential services in order to reduce the need for motorised mobility.

If the efficiency potentials are as high as a factor of 4 or 5 in the long term from a theoretical point of view, then the process of R&D – both its decision making and its performance – has to be improved. This means creating a process which identifies the present technical and cost bottlenecks of a new efficient technology with greater accuracy and which makes the right selection of promising new and efficient technologies (including their acceptance by the target groups involved in the innovation process).

In general, in order to be selected for further R&D efforts, a technological field has to meet the following *selection criteria* (Jochem et al. 2006):

- A minimum energy demand of at least 0.2 to 0.3% of a country's primary energy demand at present, or a similar percentage to be realised by the new technology in 2050.
- An envisaged energy-efficiency 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.

Beside these selection criteria, the analysis used some *evaluation criteria* to cover quantifiable and non-quantifiable aspects:

- the position in the technology cycle, major technical bottlenecks and the position relative to competing or traditional technologies;
- cost reduction potentials of the new technologies considered due to learning and economies of scale effects;
- a present favourable (or in the future achievable) export position of German or European technology producers who are capable of producing the new technology;
- perceived favourable acceptance of the new technologies or present market obstacles that are to be overcome during the next decades; and finally

- the timing of re-investment cycles and the length of periods of R&D necessary for possible market introduction.

These selection and evaluation criteria were systematically applied to four technological fields, three of which contribute to new energy-efficient solutions: *passive houses* for example, with their major components of insulation solutions, window systems, ventilation, and control techniques are close to market diffusion within the next ten years. Fuel cells for mobile uses in vehicles, on the other hand, are a long way from market introduction due to unresolved problems of membrane fouling and the need for cost reductions by one order of magnitude. Other types of fuel cells for stationary uses may be closer to market introduction due to less severe technical bottlenecks and better economic competitiveness.

4 Why are so many efficiency potentials not realised? Untapped opportunities

Consulting engineers usually return from on-site visits to companies with substantial energy efficiency potentials that are easy to realise and usually have high rates of internal return (Romm 1999). Even the energy managers of large companies are often uninformed about all the new innovations of efficient energy use. The limited realisation of profitable efficiency potentials has been the subject of discussions about obstacles and market imperfections for a decade (IPCC 2001), and the heterogeneity of these obstacles and potentials has been tackled by sets of policy measures and instruments.

Surveys and interviews show that the attention given to energy efficiency investments in companies, public administrations or private households is often very low and heavily influenced by the priorities of those responsible for the company, the building management, or the private household's decisions (Stern 1992, Rahmesohl 2000, DeGroot 2002, Schmid 2004). In other cases, project-based economic evaluations do not consider the relatively high transaction costs of the investor and the substantial risks involved in the case of long-term investments; both aspects may be decisive for small efficiency investments (Ostertag 2002).

Traditional investment priorities steer the motivation and behaviour of the staff and determine the careers of young engineers and their efforts; energy engineers often have difficulties in «making a convincing case» to the management (Schmid 2004). The co-benefits of energy-efficient new technologies are rarely identified and not included in the profitability calculations by the energy or process engineers due to the lack of a systemic view of the whole production site and possible changes related to the efficiency investments (Madlener/Jochem 2004).

Besides the economic reasons behind this priority setting of companies, public administrations, and private households, there are also psychosocial, motivational, and behavioural aspects, which have rarely been analysed except by some sociologists and psychologists in the 1990s (e. g. Stern 1992, Jochem et al. 2000, Flury-Kleubler et al. 2001). Social relations such as competitive behaviour, mutual estimation and acceptance not only play a role between enterprises, but also internally within a company. Efforts to improve energy efficiency are influenced by the intrinsic motivation of companies' actors and decision makers, the interaction between those responsible for energy and the management, the internal stimuli of key actors and their prestige and persuasive power (InterSEE 1998, Schmid 2004).

5 Widening the view from energy-related research to innovation systems

These concepts of obstacles and market imperfections sound like a rather mechanical concept, claiming that obstacles simply have to be removed and proper boundary conditions have to be set. However, accelerated innovation and more effective R&D will only become a reality if the system of innovation in place is ready to consider new means and entrepreneurial solutions and invest in R&D and new products and technologies. The existence of a proven technology's energy-saving potential alone does not further the 2000 Watt/capita society. Only when a technology's (behavioural) potential has materialised due to research and development and the technology is broadly marketed and used, energy is actually saved.

Therefore, the research and innovation system of a country has to be analysed and must be convinced by the opportunities and the new vision of a 2000 Watt/capita society. Any recommended efficiency policy portfolio and R&D efforts have to be evaluated within the context of the relevant research and innovation boundary conditions of the actors and institutions involved (see Figure 3). The research and innovation systems of a country encompass the «biotopes» of all the institutions 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, trade).

An innovation system also comprises the relevant policy institutions that set the economic, financial (e. g. venture capital), and legal boundary conditions and regulatory bodies (standards, norms) as well as the public and private investments in the appropriate infrastructure. Each innovation system of a country (and even of a sector or a technological field within a country) is unique and develops its profiles and strengths only over decades. Each is based on stable exchange relationships and interactions among the institutions of science and technology, industry, commerce, and the political system (Edquist 1997).

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

- a high degree of compartmentalisation (e. g. buildings, road transportation, industrial branches, energy companies) and a corresponding sectorisation of the political administration with low inter-departmental exchange and co-operation;
- non-interlinked arenas (corporatist negotiation deadlocks involving the sovereignty of regions in federal states (e. g. cantons in Switzerland in cases concerning building codes), or of member states of the European Union and related failed attempts at restructuring responsibilities in governments or at the EU level);
- dominance of a «linear model» of energy supply in political approaches (and among related technologists, energy economics researchers and consultants) focussing on energy supply options (such as costly renewables or fusion energy for which the technical and economic feasibility will remain an open question for many decades to come) and neglecting opportunities at the useful energy and energy service levels.

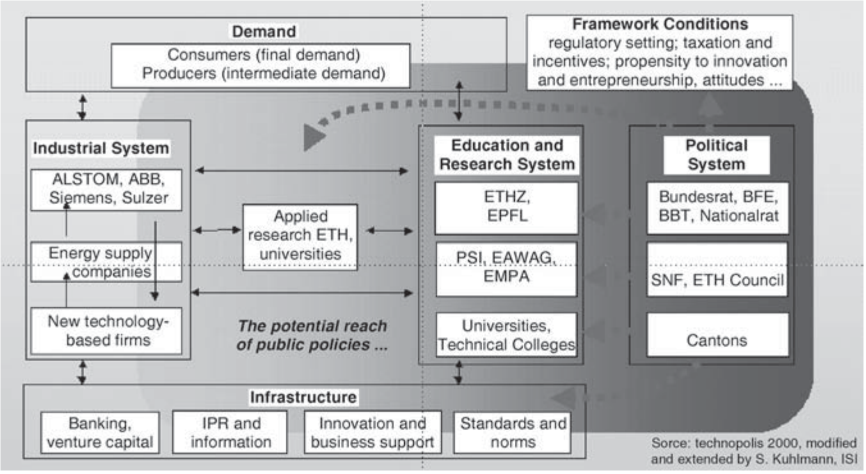

Fig. 3: *Scheme of Swiss energy and energy efficiency research and the innovation system (source: Jochem et al. 2004)*

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. 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 which favour incumbent technologies (with high external costs) as well as flows in the capital markets (focussing on large-scale technologies and players); and insufficiently organised actors.

6 The Action Plan of the European Commission and the recent status of energy efficiency policy in Germany

In the light of the challenges faced by the global energy system, the potentials of energy efficiency and related opportunities, and the obstacles and market imperfections, the reader may wonder whether the most recent policy declarations on the energy and material efficiency policies of the European Commission (2006) and of its member states like Germany reflect these