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An Agenda for Energy and Material Efficiency Policy – an element of technology policy for a more sustainable use of natural resources

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An Agenda for Energy and Material Efficiency Policy – An Element of Technology Policy for a More Sustainable Use of Natural Resources

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Abstract

Discussions about the future options of the energy systems of industrialised countries are held almost exclusively in terms of alternative resources of energy supply and related technologies. This paper tries to broaden the view of the technological options by focusing on the technical and theoretical potentials of a more efficient use of energy and materials. Such options are generally overlooked since a more efficient use of energy resources tends to be assessed by its economic potential. This analysis starts from the basic human needs of an industrialised country which lead to the material and energy services that influence energy-related drivers. The analysis of the energy system's losses, from useful energy to final and primary energy and the analysis of a more efficient use of materials hint at huge technical and theoretical potentials for more efficient use of energy. This new agenda of the technology-based research of resource efficiency is labelled as the vision of the 2000 Watt per capita society. It may not only influence energy and material research and policy agendas, but also transform the present rather narrow-minded understanding of energy policy into a resource efficiency concept as part of an innovation policy oriented towards sustainable development. From this perspective, suggestions are made to extend the R&D energy and material policy agendas.

Keywords: Innovation policy, energy efficiency policy, material efficiency, R&D energy policy

JEL Classification Nos.: D62; E61; O32; Q41; Q48; Q55

1. Energy use – an indirect need – and energy-related world challenges

Energy plays a central role in the economy of both industrialised and developing countries. Energy is used to meet basic needs such as living comfortably, mobility, and services. These basic needs are satisfied by the present capital stock and status of technologies, most of which, however, are highly inefficient according to both the first and second law of thermodynamics (see Figure 1). There are numerous reasons for the inefficiencies of energy use: present technical knowledge, past and present R&D priorities (between energy supply options, energy efficiency options, space research, new materials, information and communication technology etc). Even present economic potentials of energy efficiency in any sector of the economy are not being fully exploited due to energy price levels that do not reflect the total generating, transport and distribution costs or the costs induced by their use (external costs, IPCC 2001). Other reasons include classical market deficiencies such as lack of knowledge and market surveys, the investor-user dilemma, limits of credit lines etc. (DeCanio, 1993 and 1998; Flury-Kleubler / Gutscher 2001, Frahm, 1997), other preferences of investors due to social prestige, fashions, and group-specific value systems (DeGroot, 2001, Sorell et al., 2000; Kaufmann-Hayoz et al., 2001).

These inefficiencies do not only cover energy conversion and use (see below), but also inefficiencies in using materials (unnecessarily heavy constructions and vehicles and unnecessary material waste in industry, construction, trade and private households, lack of recycling; Jochem 2004), and the capital stock (e.g. owning instead of pooling appliances, cars or plants with low annual operating hours of between 10 and 300 hours). These inefficiencies may be justified by consumer preferences as long as they do not conflict with the principles of sustainable development. This is not the case for today's energy and material use, particularly not in industrialised countries, as every country (and the world) 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 in the EU, is likely to remain high during the next decades given the economics and limited acceptance of nuclear power and the small economic potentials and present market shares of renewable energies. This situation conflicts with the pressing need to reduce energy-related CO_2 emissions which are driving global climate change. Its future impacts are a major threat to mankind in this century according to the Intergovernmental Panel on Climate Change (IPCC, 2001). Today, the first adaptation costs already amount to billions of Euro per year in Europe and world-wide (EEA 2004).

- In recognition of 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 peaking and then declining oil production, energy price levels are likely to increase substantially. This could induce high economic losses due to stranded investments of energy-intensive capital goods (IEA 2004).

- Energy policy will also have to give greater consideration to *diversity and security aspects* given that global road, air and sea transportation is currently almost 100 % dependent on oil; and that, in addition, two thirds of the remaining oil resources are concentrated in the Near East, a region of considerable political instability.

Conventional energy and material efficiency policy which yields a 1 % annual increase in resource efficiency, will not be sufficient to meet these challenges nor will it bring about an increased use of renewable energies or nuclear energy as a substitute for fossil fuels. Of the available options, energy and material efficiency is highly underestimated due to specific disadvantages in society in which the media and powerful lobbies play a major role (Jochem, 2003).

2. Today's inefficient energy system

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 largest conversion losses occur in road vehicles (almost 80 %) and thermal power generation (more than 60 %; see Figure 1 for Germany as an industrialised country). From the viewpoint of the second law of thermodynamics, massive losses (more than 90 %) also occur in low temperature heat generation by fossil fuels, electricity and wood energy. Low temperature heat accounts for almost 50 % of total useful energy. Regarding these extreme losses of energy the largest "energy source" of this century may be a more efficient energy use at all levels of energy conversion at use.

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

- Energy losses at the level of useful energy (currently about 39 % of the German primary energy demand) could be substantially reduced or even avoided through such technologies as low-energy buildings, passive solar houses, 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).

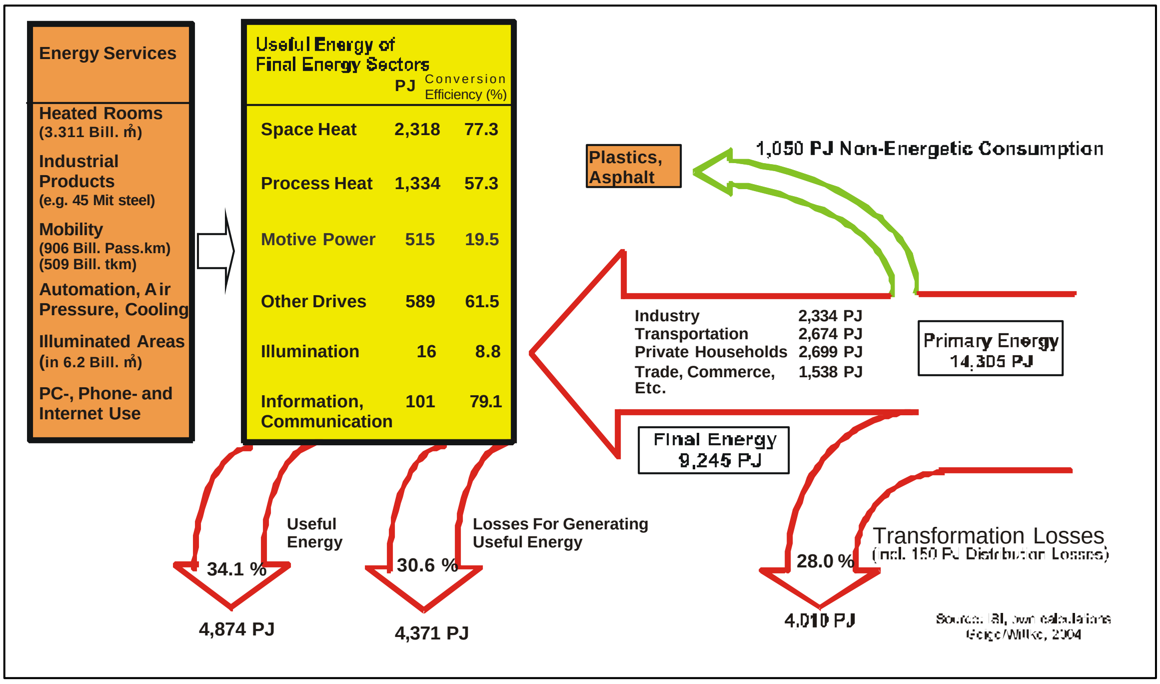

Figure 1: Demand for energy services and induced energy demand along the energy chain, Germany 2002, an example of present industrialised countries

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. Enquete-Commission, 1991; Jochem et al., 2002). Given the above-mentioned challenges connected with energy use and the high potentials for resource 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 (or European) per capita primary energy use by two thirds while per capita income may increase by two thirds during this period of time. The technical feasibility of improving energy use by a factor of five has been positively assessed, but not its economic or political feasibility (see Section 3).

The challenges energy-related research faces at the beginning of this century should not only be seen as threats. The technical and entrepreneurial solutions represent great opportunities for industries and service sectors, particularly for industrialised countries, as the present intensive (or wasteful) use of energy and materials will be substituted by capital goods and know-how. Furthermore, new technologies may induce high export potentials for highly industrialised regions. Countries and firms that invest in these technologies, related R&D and innovation policy are likely to benefit from first mover advantages, boost the resource-relevant parts of their economies and make a significant contribution to the pressing problems of climate change and the imminent peaking of world oil production on a path towards sustainable development.

3. More emphasis on resource efficiency policy as a technology and innovation policy

The technical feasibility of the vision of the 2000 Watt per capita industrial society promoted by the Board of the Swiss Federal Institutes of Technology in 1998 was checked in a collective effort by some 10 Swiss scientists between 2002 and 2004 (Jochem et al., 2002; Jochem et al., 2004a). In order to derive absolute energy and material saving potentials, a quantitative analysis had to be applied to an industrialised country (here Switzerland) by developing a methodological concept that takes into account future economic growth, major structural changes in all sectors, the re-investment cycles of the energy-using capital stock, the progress implied by a more efficient use of materials and energy by new technologies and entrepreneurial innovations.

Assuming frozen structures and technologies and an increase in economic growth of some 70 % between 2000 and 2050, the primary energy demand would grow at the same rate as the GDP (see Figure 2; not yet included). If structural changes in the economy to less energy-intensive branches and consumption and saturation processes are considered (at an assumed (often observed) yearly rate of declining energy intensity of 0.4 %/a), primary energy would not rise as much as the GDP, amounting to some 1 700 PJ in 2050 (or 7 470 W/cap). This scenario still assumes technology to be "frozen" at its state in the year 2000 (see Table 1 and Figure 2).

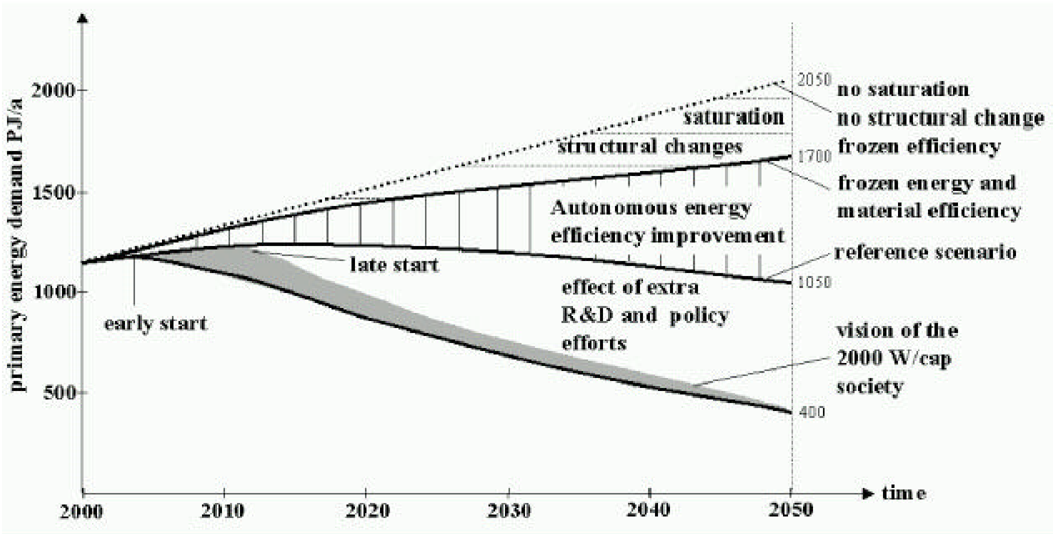

Figure 2: Drivers of Swiss primary energy demand: economic growth, saturation, structural changes, autonomous and policy-induced energy and material efficiency

Source: Jochem et al. 2004a

The reduction in the Swiss energy system necessary to reach 2000 W/capita (or 65 GJ/cap) in 2050 therefore amounts to almost 75 % or, in absolute terms, moving from 1 300 PJ of primary energy down to a target of 400 PJ (2000 W/cap).

A supply-demand model was used to account for changes in efficiency, re-investment cycles, and technology substitutions at sectoral, branch and technology levels (e.g.):

- lighter products, less waste during industrial production, more recycling, which all would contribute to the structural change mentioned above,

- low energy buildings, solar passive houses, lighter vehicles, new low temperature industrial processes instead of present medium temperature processes, intensive use of heat recovery and heat transformers, feed-in of brake energy into the electrical grid, LED lighting instead of bulbs, improved logistics, which would all substantially reduce the demand for useful energy.

- In addition, intensive use of high efficient heat pumps, co- and tri-generation (including fuel cells) and variable speed drives that would reduce conversion losses from final to useful energy.

The energy gains which seem feasible for the different final energy sectors vary between 63 % (including intra-industrial structural change) and 80 % (commercial/public sector) and amount to some 70 % in the average. Additional 10 percentage points can be realised by substitution of petrochemicals, reduced transmission losses and improved efficiencies in the conversion sector (see Table 1). The results show that the 2000 W society target appears to be technically feasible within five decades as the minimum time span. There is no doubt, however, that both economic and political feasibility involve many additional aspects, and that the realisation of the 2000 Watt/cap will certainly require longer than five decades.

Table 1: Energy use for Switzerland in 2001, with frozen technology in 2050, and efficiency gains by technical potentials of efficient energy and material use under the perspective of a 2000 Watt/cap society by 2050 in (W/cap)

	Present 2001	Frozen 2050	Target 2050	Share[1]	Gain[2]
Industry	759	1,000	370	18.4%	63 %
Transportation	1,300	1,950	700	34.8 %	64 %
Residential	1,065	1,350	310	15.4 %	77 %
Commerce, public, agriculture	718	1,100	220	11.0 %	80 %
Total final energy	3,842	5,400	1,600	79.6 %	70 %
Non energetic use	98	150	20	1.0 %	87 %
Conversion & trans. Losses	1,364	1,920	390	19.4 %	80 %
Primary energy	5,304	7,470	2,010	100 %	74 %

Source: Marechal et al. 2005

There is a chance that the necessary efficiency gains in material use, the final energy sectors and the conversion sector 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 within this century. Of course, as a first result, these estimates are partially still hypothetical since several estimates involve new technologies which still have to be realised in laboratories and pilot plants. However, the results indicate that the vision of a 2000 Watt society is not beyond the boundaries of theoretical possibility.

This conclusion of the technical feasibility of the *vision of the 2000 Watt per capita society* is based on the following observations and prerequisites:

- Not only improvements of energy conversion technologies (primary to final energy and final to useful energy) are needed, but larger options and potentials can be identified by reducing

[1]Share of primary energy demand in 2050

[2]Reduction of the energy demand in the sector due to improved energy and material efficiencies in relation to 2001 technologies and their efficiencies.

losses of useful energy, and increasing material efficiency or material substitution (see Table 1).

- It is fortunate that the sector with the longest re-investment cycle, the building sector, which presently uses about one third of final energy for heating, does not require as many additional research and development successes 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 efficiency target of about 80 % compared to the present building stock. Key technologies include new types of insulation and window systems, highly efficient low temperature heating and heat recovery systems, decentralised combined heat, cold, and power generation, integrated photovoltaic and solar thermal systems as well as ground-coupling systems for seasonal heat storage (Jakob et al., 2002).

- A 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 improved efficiencies of energy and material use (e.g. changed properties of surfaces due to nanotechnology, brake energy recovery using power electronics). Energy-intensive manufacturing equipment will undergo substantial changes through heat 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 of up to 80 % and 90 %). These technology substitutions must be regarded as back stop technologies which often is only attributed to the various renewable energies.

- With regard to transport, further advances in internal combustion engines and fuel cell technology, braking energy recuperation systems, light-weight frames and new tyre materials are very promising. The performance of air planes can be considerably ameliorated by improved turbines, improved structural and aerodynamic efficiency as well as air traffic management techniques. Telematics offer helpful solutions to implement traffic and modal split management as well as freight logistics. New trans-shipment and container technology will be important to make multi-modal freight traffic more efficient and attractive.

- More efficient material use, additional recycling of energy-intensive materials or substitution by less energy-intensive materials (e.g. biomass based polymers), 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 80 %).

- The foreseeable technical efficiency options at all levels of energy and material use are likely to be still insufficient to meet the target. Entrepreneurial innovations will support these options by more professional planning, operating, and maintenance of energy converting technologies (e. g. contracting of boilers, co-generation, generation of compressed air or cooling), and traditional bat enlarged and new entrepreneurial forms of pooling (instead of owning) will intensify the use of machinery, plants, and vehicles (Mont 2000).

- Structural changes to less energy-intensive production (partially induced by improved material efficiency or by saturation processes of energy-using appliances and infrastructures in wealthy industrial countries, particularly with ageing populations) will support the necessary efficiency gains. On the other hand, these gains may be (or are being) compensated by ever increasing mobility, particularly long distance air travel, hedonistic lifestyles, or even by climate changes resulting in higher summer temperatures which induce additional air conditioning demand.

Politically, the feasibility of a 2000 Watt per capita society may be at stake due to present OECD societies' short-term decision horizons in the economy and the political system, a similar orientation and behaviour of many private households and the hesitant attitudes of many actors and responsible organisations (Jochem 2003). Many interest groups such as manufacturers of capital goods and vehicles, the chemical industry, planners, product-based services, or the banking sector as well as the political system being focussed on aspects like limiting the increase of social security and health insurance cost may not be aware of the opportunities and co-benefits offered by the shift towards greater resource efficiency:

- Many industries and product-based services would benefit from greater turnover in lead markets, higher product quality due to better controlled production processes and logistics, reduced cost for materials and energy (presently representing some 40 % of total production cost in industry and 25 % in construction; Alberti et al 2005). Public and private households would benefit from reduced energy cost and less expensive industrial products, higher comfort in buildings (less noise, better air quality, (Jakob 2005) adequate temperatures during heat waves), and higher productivity in office buildings.

- The political system is presently not aware of the ancillary benefits such as new jobs due to substitution of imported energy, raw materials or intermediate goods through domestically produced efficiency goods and related services, lower external costs due to reduced pollution from burning fossil energies and reduced increase of insurance tariffs for extreme weather events, and fewer adaptation investments to climate change in the long term (IPCC 2001).

In conclusion, the challenges of energy and material use at the global level become so demanding (but also promising) that the portfolio of technical and entrepreneurial options has to be broadened and energy and climate policy must be understood as comprising part of an innovation policy which is substantially driven by aspects of sustainable development.

4. Realising R&D visions depends on innovation systems

The transition to a 2000 Watt per capita society within this century would imply a total turnover of the present capital stock of today's industrialised countries (and of a newly built, highly efficient capital stock in developing countries anyway). The transition requires a fundamental change in the innovation system (e.g. research policy, education, professional training, technical standards, incentives, intermediates and entrepreneurial innovations), but also in foreign trade and capacity building. The innovation system (illustrated for the institutional situation in Switzerland in Figure 3) would have to be continuously extended, evaluated, and improved over the coming decades from the perspective that it should be integrated into the country’s policy on innovation and sustainable development.

Therefore, the research and innovation system of a country has to be analysed and the actors have to be convinced by the new vision to strive for a 2000 W per capita society. The research and innovation systems of a country encompass the “biotopes” of all those institutions (see Figure 3; Smits and Kuhlmann, 2002) that are:

- engaged in scientific research and the accumulation and immediate diffusion of new knowledge into applied research and development (i.e. research institutions, universities, technical colleges, industrial research and laboratories),
- engaged in education and professional training as well as the dissemination of new knowledge to broader audiences (educational and training institutions, research administration, and most importantly: media),
- developing and producing new technologies, processes, and products; and commercialising and distributing them (e.g. technology producers, intermediates, infrastructure, technology producers, trade).

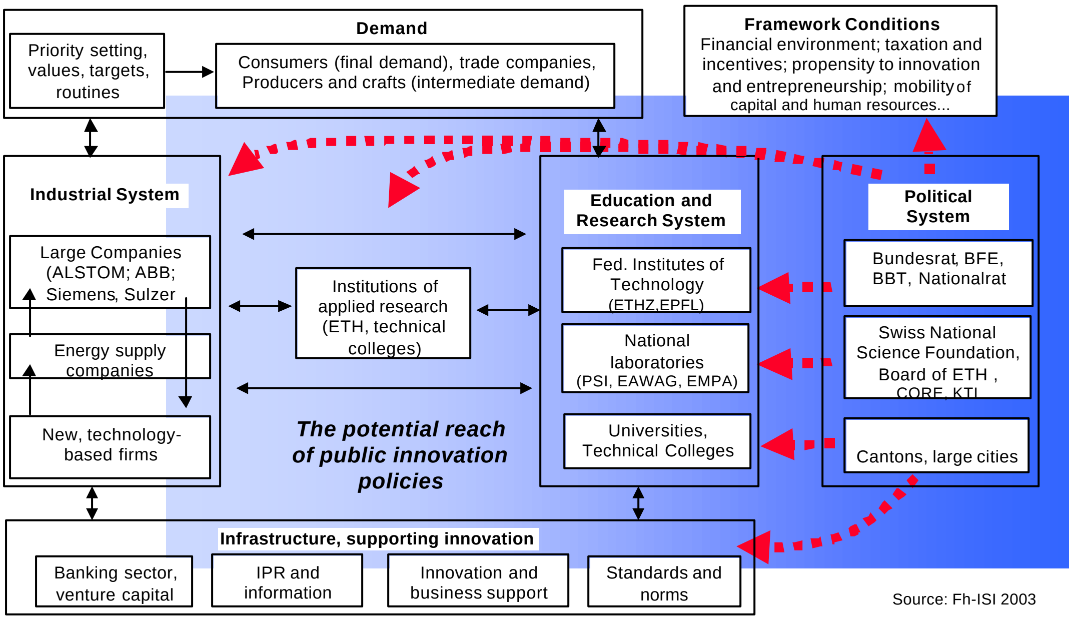

Figure 3: Diagram of the Swiss energy and energy and material efficiency research and innovation system – a heuristic scheme

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 (Dosi, 1988). Each innovation system of a country (and even of a sector or a technological area within a country such as low energy homes and buildings, use of wood energy) is unique and develops its profiles and strengths only over decades. Each is based on stable relationships among the institutions of science and technology, industry, commerce, and the political system. Since the progress of energy and material efficiency is dispersed over all sectors of the economy and private households, the innovation system of resource efficiency is characterised by:

- *a high degree of compartmentalisation* (e.g. materials, buildings, road transportation, industrial branches, energy supply companies and trade) and corresponding sectorisation of the political administration with low inter-departmental exchange and co-operation. In many cases, researchers of new technologies or materials (and the related research officials in the R&D administration) are often not aware of the relevance of their results for an efficient use of energy and are motivated by career incentives and priorities set by the research institutions and academia which do not include sustainability aspects;

- *non-interlinked* arenas (corporatist negotiation deadlocks involving sovereignty of regions in federal states, e.g. cantons in Switzerland in cases such as building codes; co-generation using fossil fuels and heat pumps following a systems view, or of member states of the European Union) and related failed attempts at restructuring responsibilities in national and regional 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) focusing on energy supply options (such as costly renewables or fusion energy where economic or even technical feasibility will be an open question for many decades to come); these political traditions neglect major opportunities at the useful energy and energy service level as well as energy-related material efficiency in most cases. This dominance of the supply side is often reflected in the human resources allocated in public institutions responsible for energy policy (Fed. Government of Germany: 23 units for energy supply aspects and one unit for energy efficiency aspects).

These characteristics of the present innovation system of resource efficiency 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, and also on the policies of neighbouring countries and trading partners.

The weaknesses of an under-coordinated R&D and innovation policy-making, which seem to prevail in the energy and material efficiency field at the national and international levels should be analysed in more detail. Topics here include the poorly articulated demand for new resource-efficient technologies and materials, and weak networks which hinder fast knowledge transfer, legislation, and market boundary conditions in favour of incumbent technologies of energy supply (with often high external costs), flows and traditions in the capital markets (focusing on large-scale technologies and players); and insufficiently organised actors in academia and industry at the national and international level. The initiative-inducing role of Non-Governmental Organisations (NGOs) may also require some consideration when analysing the innovation system of energy and material efficiency.

Preconditions for success in realising the 2000 Watt per capita society include research on an innovation-focused and co-ordinating role of government, addressing the large portfolio of technologies and innovations, reinforcing user-producer relations, supporting the building of new networks at the national and international levels; 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.

5. Conclusions and suggestions for a R&D agenda on resources efficiency

Besides the analysis of actors, their interests and roles within the innovation system, the following aspects should also be on the research agenda:

- developing an understanding of possible techno-economic options (e.g. efficiency options, substitution options such as renewables, material substitution, CO_2 capture and storage, pooling strategies (instead of owning) and related entrepreneurial innovations);
- analysis of potentials at each stage of research, development, demonstration and market diffusion in order to design road maps of possible technology paths and to identify the adequate point in time as window of opportunity and the possible contribution of a particular technology;
- analysis of the potentials of cost decreases by learning and economies of scale; and also identification of co-benefits of the new technological solutions at the useful energy level, which is often more important than cost dynamics;
- analysis of actors in manufacturing, services and final users, their preferences, motivations and present or expected transaction costs (e.g. Ostertag, 2002);
- analysis of obstacles and market imperfections to identify the needs of group-specific or technology-specific policies or business strategies.

Without any doubt, designing a research and development agenda in such a broad field of technological options and entrepreneurial innovations constitutes a major challenge and is a huge task. Within the limited possibilities of such a paper, therefore, only a few general indications can be made of how to go about this:

- design possible policy options based on the available technical analyses (e.g. Jochem et al., 2002 and 2004a) and their economic perspectives (which still have to be made in most cases);

- identify and communicate (even prefer) those options which have imbedded flexibility regarding energy carriers, use of materials, and entrepreneurial options, given the increasing uncertainties regarding the availability of oil and gas resources, the mid-depletion point of oil production and associated energy price increases, the economic development of developing countries and their energy needs, and the necessity to limit greenhouse gas emissions depending on expected damages and adaptation costs (still unclear at present);

- consider these options and uncertainties regarding the context of the research activities of the European Union, and an effective division of labour between national governments, the European Commission, and applied industrial research, and

- keep in mind the needs of developing countries and export potentials of European manufacturers and service companies as an opportunity on emerging global markets.

In many cases, technologies or entrepreneurial options are actually available today (e.g. solar passive houses which reduce energy demand by 80 to 90 %, three litre cars which lower fuel demand by 50 %, variable speed drives which reduce electricity demand by 30 to 50 %, or car sharing which can reduce material demand by 80 %). In these cases, innovation policies are required to take available technologies and know-how off the shelf. This may require research to improve the efficiency and efficacy of policy measures:

- analyse and use the experiences of efficient policy measures in the EU member countries and other countries to design new policy activities at the national or EU level (or OECD level such as taxation of jet fuel); keep efficiency aspects of policies in mind when designing (or re-designing) regulations such as technical standards for mass-produced products, or regulation to improve market information such as labelling. On the other hand, de-regulation of traditional rules, standards, ordinances, and laws may also be needed, if these are based on traditional status of technology and knowledge and hinder new technologies from penetrating new markets;

- avoid and eliminate subsidies for energy production, distribution and use if the technology involved is mature; harmonize taxation schemes but also technical standards and information standards among the European countries in order to enlarge homogenous markets and benefit from the resulting economies of scale potentials;

- try to internalise present and future externalities using economic mechanisms such as emissions trading, taxes, or surcharges, or by economic incentives such as reduced value added taxes or other tax deduction;
- use socio-psychological drivers among the actors (e.g. energy tables reducing transaction costs and stimulating priority shifts in companies at the local and regional level (Jochem et al., 2004b), television spots by popular stars inducing new shopping behaviour and value systems, etc. (see Jochem et al., 2000).

Finally, several *methodological conclusions and recommendations* seem useful given the present limitations of analytical and prospective methods and the risk of interpreting their results too narrowly:

- There is a need to step up the efforts to link process-oriented and macro models in a dynamic way in order to simulate policy-induced technical progress which at present is more or less limited to price policies in macroeconomic models. Given the advantages and limitations of both types of models the attempt to combine the two model worlds is quite obvious and has made some progress during the last few years (Kumbaroglu and Madlener 2003). At least from a theoretical perspective, bottom-up and top-down models are not structurally different, but rather differ in the level of aggregation and the œteris paribus assumptions. Recently, the synthesis of bottom-up and top-down models has been shown to be feasible for a CGE model (Böhringer 1998). Such combined or integrated models exist at the national level for CGE models and for the macro-econometric input-output model PANTA RHEI (Lutz et al. 2005), but usually only for the power industry or selected energy-intensive industry sectors.
- In addition, existing process-oriented models with rather deterministic characteristics need less deterministic structures (reflecting more behavioural options of the relevant actors). Multi-Agent modelling techniques and game theory based modelling may open up a new era of economic modelling that would adequately simulate obstacles and market imperfections of energy and material efficiency and herewith simulate the effectiveness of policy measures and bundles of them. This extension may only be achievable by involving more socio-psychological research and concepts as well as empirical policy studies in order to simulate behavioural and decision making aspects and the impact of changed policy design.

- Finally, back-casting methods combined with risk assessment of R&D options have to be developed in order to allow for more consistent plausible strategies and decisions on R&D related to material- and energy-efficient technologies that are related to a vision like the 2000 Watt per capita industrial society.

Besides these policy and methodological consideration there certainly are two next analytical steps: more detailed analysis of the technical potentials of material efficiency in all its forms given the high share (40 %) of material cost in total productions cost, and the economic feasibility of a 2000 Watt per capita society in order to identify high cost bottle necks and related R&D on cost reducing options.

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