Energy in the perspective of the sustainable development : the 2000 W society challenge

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Abstract

As energy plays a central role in the world development, it represents as well a major challenge for sustainable development. Today, more than 80 % of the primary energy consumption is based on fossil fuels and the share is likely to remain high in the future. Even if technology developments will reduce the specific consumption, the world energy demand is likely to increase in line with its population. Energy and material efficiency and the integration of the renewable resources will therefore have to play a major role for sustainable development. The challenge concerns not only the technologies at the conversion and useful energy level, but also the energy management and infrastructures. The 2000 W per capita society initiative launched by the Board of the Swiss Institutes of Technology targets the identification of the major technological breakthroughs to reduce the per capita primary energy use of Switzerland by two thirds within five decades. This study examined the energy saving potentials in the complete conversion chain "from primary energy to energy services" in the main sectors of economy: buildings, transport and industry. The report highlights the possible benefits which could be obtained from new materials, new technologies and an intensification of product and capital use. The systems integration appeared to be of prime importance in order to valorise the exergy potentials of the energy resources. The report emphasizes the political responsibility of developing the enabling society infrastructure: not only for the energy distribution (electrical, gas or heating networks) but also for the information technology, the appropriate regulations, the education and for the necessary integration of the lifetimes of the manufactured artefacts in the pathway to the 2000 W per capita Society.

Key words: Sustainable development, energy policy, energy conversion, energy scenarios, research & development
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1 Introduction

In the beginning of this new century, the rational use of energy becomes a keyword for the world sustainable development both in developed and developing countries. From a present primary energy consumption of 10 Gtoe, the global primary energy demand is expected to raise above 13.5 Gtoe in 2020 with an increasing share of the developing countries in the reference scenario [1]. Considering the threat and consequences of climate change, the expected peak of oil production and the re-concentration of crude oil production in the Near East within the next few decades, *the Board of the Swiss Federal Institutes of Technology* formulated in 1998 the challenging vision of a **2000 Watt per capita society by the middle of the 21^{st} century** [2]. A yearly 2000 Watt per capita energy demand measures the energy intensity of a country. It corresponds to 2000 $\frac{Wattyear}{yearcapita}$ or 65 $\frac{GJ}{yearcapita}$. Further in the paper it will be referred as 2000 W/cap. This target corresponds nearly to the present mean energy intensity of the whole world but a factor 2.5 reduction of today's per capita primary energy use in Europe and about 5.5 reduction for the US figures. Table 1 presents energy demand intensity and the population and the CO_2 emissions for different countries around the world.

Assuming a doubling of GDP (gross domestic product) per capita within the next 50 years, the 2000 Watt society implies a factor 4 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 to reach the goal without reducing the level of comfort and considering the evolution in the energy services. It is obvious that completely new technologies and supporting organisational and entrepreneurial measures are needed to meet this goal. There was a need to search for the pathways that would show the feasibility of the 2000 W society vision and to identify the role that research will play with this respect. This paper is based on the results of a collective work [3] to meet these two objectives. In this paper, the focus is put on the energy conversion sector and the role that thermodynamically based methodologies and advanced energy conversion technologies can play in this context.

2 The analysis

Both efficiencies and energy services demand have to be considered in the analysis. The energy services demand has been first analysed by sectors and in each sector by defining the energy services (such as heated floor space,

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passenger mobility, freight transport in tons·kilometres, tons of steel or cement to be produced) to be provided. In order to estimate the energy services, one also has to consider the population growth and the standards of living of the population. From the beginning, it was considered that for Switzerland, the population was not expected to change significantly in the coming five decades and the standard of living was assumed to increase by 70 %. This picture, however, does not apply to the drivers of future energy demand at the world level since major emerging countries like China and India have an increasing population with a significant economical growth that will lead to an increased demand of energy services. At this stage, it is important to highlight the importance of working with energy services rather then energy consumption since the goal behind the 2000 W society is obviously to supply, with less energy, the energy services required by a sustainable development of the country. We have therefore to go further then just the use of final energy and tackle the problem of the efficiency of the supply of services and the analysis of the whole conversion chain from primary energy to energy services.

Analyzing the trends and the share of the final energy consumption for the World, USA, Japan, EU and Switzerland, we notice significant differences in distribution of the final energy between sectors (table 2). Even if electricity does only represent a percentage varying between 15 to 22% of the final energy being distributed, this percentage when excluding the sector of transport grows in the range from 21 to 33 %, Switzerland with 31 % being in the upper part (table 3). This observation is of crucial importance when evaluating technologies linked with combined production of electricity, heat and other forms of useful energy like cogeneration and heat pumping.

One additional observation which has a high importance in the future is the actual and forseen increase of the share of electricity. In the OECD countries, the annual increase of the percentage of electricity over of the total final consumption has been of 0.3 % over the last quarter of the last century, this increase may be reduced in the future due to declining growth of mechanisation, automation and information/communication technologies.

3 Improving the efficiency of final energy use

In order to reduce the energy consumption, one has to act on the demand side by increasing the efficiency of the energy services supply as well as on the energy conversion by considering both efficiency and energy resources usage aspects.We have therefore analysed the energy using technologies per sector in order to identify the technological breakthroughs on the pathways to the 2000 W society. The analysis is done by searching for and quantifying technological sources of efficiency improvement and by identifying the role of R&D in favouring the emergence of these more efficient new technologies on the market.

3.1 Buildings and households consumptions

Although it is possible to build highly efficient new buildings such as slar passive houses and buildings with a yearly energy demand for heating of about 10 to 20 kWh/m^2, the impact of the new building stock is and will still be limited due to the size and the lifetime of the existing buildings stock (average yearly energy demand at 190 kWh/m^2). The challenge in the building sector is therefore the refurbishment of building stock where energy saving measures have to be combined with actions for improving the quality of the buildings : less noise, more comfort, by improved air quality and optimised use of floor plans. In the field of building, R&D needs mainly concern high performance and compact insulation systems, efficient ventilation systems that should be integrated with improved heat and cold recovery systems. An important area of research also relates to the integration of renewable energy sources like PV panels for electricity or thermal panels for hot water, heating or cogeneration purposes. This integration influences the architectural concept as well as the energy conversion system. Here the role of system design, considering the useful energy to be provided and the optimal system management using IT technologies [4] will be of first importance.
The energy savings in this area are expected to be almost 80% as an absolute maximum achievable within five or six decades compared to present specific energy demand. This maximum assumes that the standard of solar passive houses will be achieved within the next 10 years for new buildings and for refurbishment within the next 20 years as standard practice [5]. Floor area is expected to increase by 0.5 % per year.

3.2 Industry

New production routes, complete substitution of energy-intensive processes by low energy processes, and more integrated processes appear to be the key issue. In Switzerland, like in many industrialised countries, not only the efficiency gain will be important, but the future reshaping of the industry will affect the energy use of the sector. The pharmaceutical industry and the specialty chemicals have an important place in Switzerland, but also the food industry or fine textiles. It is expected that the bioprocesses should substantially contribute to the energy efficiency increase, not only because these routes will be based on renewable natural resources but also because they are operated at lower temperatures and heat requirements. Therefore, they will offer better opportunities for process integration and combined heat and power and heat pumping. Process design methodologies will consequently play an important role. These should be considered not only to design efficient production routes but also to design more integrated process (multi-products and multi-energies) considering the process itself, the energy conversion and the waste treatment. Not all the sectors have been studied in this area, but the efficiency gains are expected to reach depending on the industrial branch and possible substitution by new processes between 20 % to 85 %, and on average by 65% at constant industrial structure compared to present specific energy demand of industry [6]. Besides this efficiency improvements an interindustrial structural change to less energy-intensive industries (e.g. in favour of investment goods industries) of about 0.3 % yearly is assumed leading to a total reduction of energy intensity of industry of 70 %. The growth of industrial production was assumed to be 50 % during the five decades.

3.3 Transport

Several options have been identified to increase the efficiency of the transportation services :

- With a short model subsitution time of about 10 years, the passenger cars offer a potential of nearly 70% reduction of energy consumption. This potential will be obtained from the better car design, improvement in materials that will allow the production of lighter cars offering lower rolling resistance. The optimal design of hybrid cars recuperating breaking energy and allowing engines to work in better conditions will need not only technology developments but also efficient tools and methods to design the integrated drive train and optimise their operation. Fuel cells and hydrogen cars will give the opportunity of introducing renewable energy resources (from biomass, sun and hydro) in the transportation services.
- In the field of aircrafts, even if new concepts integrating hydrogen as fuel with new aircraft design appear to offer good efficiency improvements, the long reinvestment cycle will not offer great opportunities for energy savings in this sector.
- New concepts of high speed trains using new materials and new designs have a potential of 60% energy efficiency increase. The high speed train will be more and more competitive compared to aircraft with the possible rebound effect of increasing the traffic consumption.
- Efficiency increase in the light and heavy trucks is not as high as it is for the passenger cars mainly by the fact that they are already operated in more constant regimes. Nevertheless, efficiency gain of 30% for busses and of 60 % for light trucks are expected benefiting from the technological developments

in the passenger cars.

- Traffic and model split optimal management based on the extensive use of IT technologies offer good opportunities of energy saving. Experiences like Mobility in Switzerland (http://www.mobility.ch) show the potential of such an approach.

In this field, the projections give a saving potential of almost 65% [7]. The growth of mobility and freight is assumed to be almost 30 % in Switzerland until 2050.

3.4 New materials, recycling and substitution

In the field of the materials, the major strategic options are (1) recycling and reuse of energy-intensive waste materials in which metals, paper, glass, asphalt, and plastics hold a large place, (2) substitution of energy intensive materials by new materials or new technologies, (3) and a more efficient use of materials and (4) a more intensified use of products, vehicles, and machinery (pooling instead of owning). In all of these fields, the system analysis including life cycle optimisation and improvement of the engineering practice to produce better multifunctional designs will be a major issue. In the field of materials, R&D will play an important role in the domain of the micro and the nano technologies, articicial photosynthesis, the use of bio materials which may involve gene technology to design the polymers needed. In Switzerland the efficiency potential of the materials sector is expected to be of 170 to 340 W/cap [8] and [9]. This contribution being trans-sectoral[10], it has been accounted in the corresponding sectors and their efficiency improvements reported in table 4

4 Energy conversion

Considering efficiency definitions, we considered that energy conversion means converting primary or final energies into useful energy supply or combined with electricity generation.
In the present situation, heating services are mainly produced by combustion of fossil fuels (with exergy efficiencies [11] often under 10%) while electricity is primarily produced in centralized power plants (hydro with efficiencies in the 90% range and nuclear with extremely low exergy efficiencies [12]). The last decade has seen a fast growth in decentralized production (conversion of wastes and cogeneration) reaching 4.3% (42 W/cap) in 2000 in Switzerland. The trend towards decentralized production and cogeneration (electricity, heat) or trigeneration (+cold) often combined with heat temperature upgrading using

heat pumps is expected to be valid for many countries around the world and an opportunity for Swiss industry. The integration of cogeneration and heat pumps for heating purposes represents a large improvement potential with at least a doubling of the exergy efficiency but also savings by reducing grid losses by their proximity to the electrical user.

Three major scales have been analysed: (1) centralized plants generally located outside town and producing electricity only, (2) district plants usually designed to deliver both electricity and heating and/or cooling via district networks, and (3) domestic plants at the private house or building level primarily delivering thermal services and/or electricity. The two other scales: room units usually considered for thermal services and human dedicated units (from electric blankets to future active clothes for comfort conditioning) have not been considered to contribute significantly to the target.

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

In the present situation, the major non-renewable resources in Switzerland are: oil, natural gas and nuclear energy. The **renewable energy resources** (RES) are mainly hydropower (with very low efficiency growth potential) and biomass (including part of wastes and wood) with the potential of at least a doubling of the exergy efficiency using integrated technologies including gasification and/or (bio)methanisation. The other renewable energy resources (wind, solar with significant efficiency progress potential) are presently playing a very limited role. All these resources have to be considered not only with respect to their renewability but also to their availability (limit of hydro potential or daily variation for solar) and ease of conversion, which is not directly reflected in terms of energy efficiency (or better of exergy efficiency). The emergence of wind and solar will increase the need for efficient energy storage and backup technologies and electrical grid management unless hybrid systems are implemented (ex: solar-(bio)fuel).

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

Different strategies may be considered with respect to the energy conversion:

we assumed that hydropower capacity (681 W/cap) is almost fully exploited in Switzerland, except for a small potential in mini-hydro (with units lower than 300 kW) representing in 2000 only about 3 W/cap. The share of electricity demand is growing and the trend will be hard to reverse in view of its growing role in transportation, in industry as well as in energy transfer, for example between cogeneration and electrically driven heat pump units, when not necessarily located on the same site. In Switzerland as in other industrialised countries like Germany, keeping the nuclear plants operational or shutting them down remains a major issue. Shutting them down would boost the present growth of fossil fuel based electricity, as renewables are unlikely to be on time to play a major substitution role. Therefore efficiency improvement in fossil fuel based conversion technologies is both a need and a significant industrial opportunity, particularly when considering the fact that such improvements will also directly benefit to biomass conversion. Due to its low cost and the huge reserves, coal resources will keep playing an important role worldwide, especially if combined with a successful development of CO_2 capture and disposal strategies.

The Advanced Zero Emissions Power Plant (AZEP) [13] developed in an international cooperation by ALSTOM Power Technology (figure 4) addresses the development of a specific, zero emissions, gas turbine-based, power generation process to reduce local and global emissions in a cost-effective way. In this innovative cycle, 100% of $\mathrm{CO_2}$ capture will be made possible, with NO_x lower than 1 ppm. Cost of CO_2 separation (compared to tail-end capture) is expected to be reduced by 25-35% within the next few years and by 35-50% within the decade. Conventional, air-based, gas turbine equipment can be utilised, allowing retrofitting. Loss in power plant efficiency is expected to be less than 2 percentage points, compared with 7 to 10 points loss of efficiency when conventional tail-end CO_2 capture methods are employed [14]. The integrated systems concepts will allow to design very efficient power plants systems like the advanced power plant of figure 4 that combines a gas turbine with a solid oxide fuel cell. The fuel cell is first converting at high temperature natural gas into electricity and syngas that is burned in the combustion chamber of the gas turbine. The fuel conversion efficiency is expected to reach 70% and produces remaining heat to be used in cogeneration applications [15]

Among renewables, biomass has so far the most significant diversification and energy efficiency potential both in Switzerland and worldwide, especially if we consider its conversion into liquid and gaseous fuels including hydrogen. In Switzerland, the potential of biomass is near 670 W/cap if the resources were well exploited [16]. According to the 2000 W-society projections, this corresponds to about 1/3 of the targeted primary energy demand.
Solar thermal is significant for heat services with 18 W/cap in Switzerland and a growth rate of 7% per year and the exergy efficiency potential lies primarily in systems based on vacuum and concentrating technologies. Geothermal energy

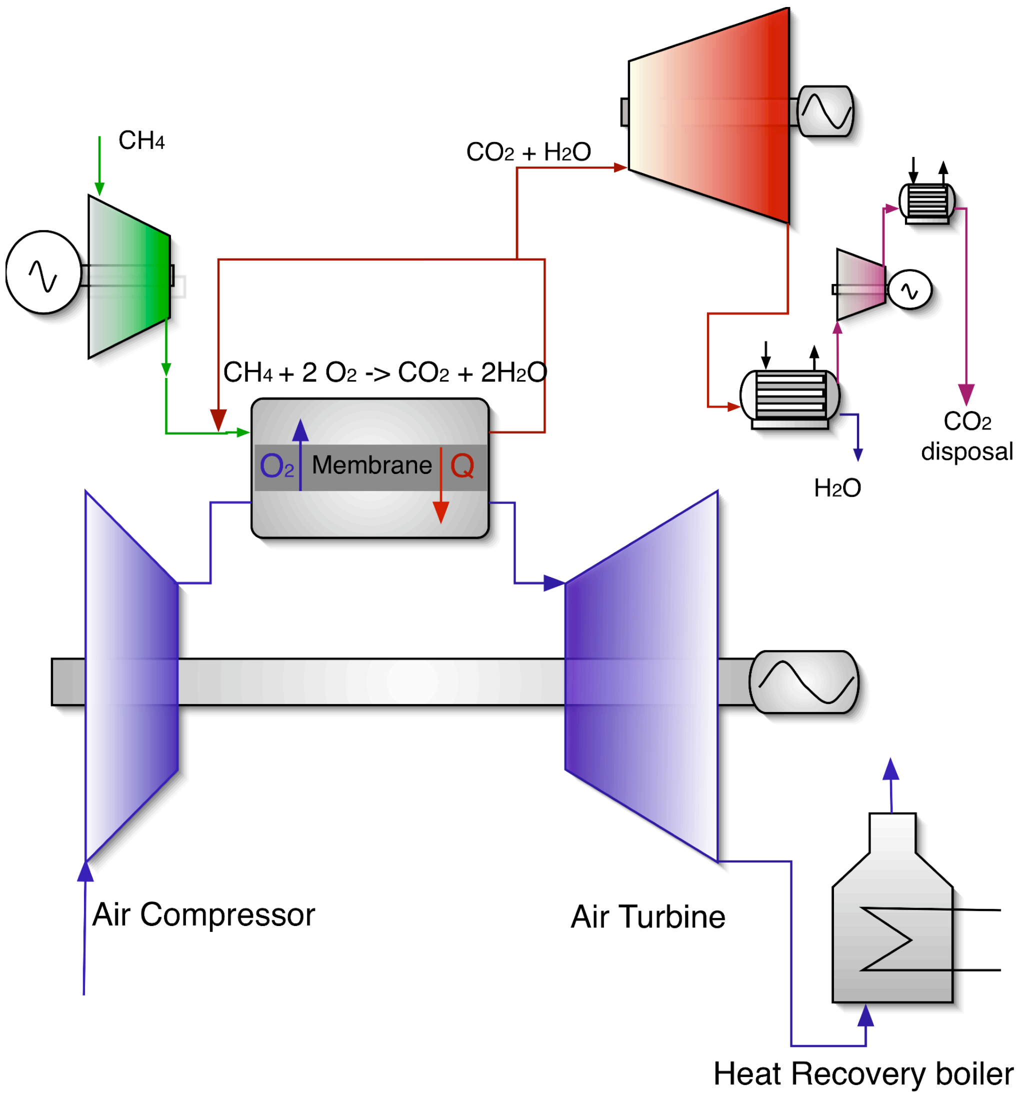

Fig. 1. Advanced zero emission plant concept by ALSTOM Power Technology

reserves are potentially enormous but technological challenges are very high with major uncertainties. Although geothermal energy is already exploited in heat pump applications for house heating, R&D effort should also be put on projects like Deep Heat Mining [17] that will allow combined heat and power power production and will require good integration with district network systems.

From the technology analysis we can develop general recommendations for R&D priorities focussing on areas with a high potential for efficiency improvement and impact on the Swiss equipment producing industry in a World market. Some of the research fields concern several energy conversion technologies and are, for example, strongly related to material sciences and other cross cutting technologies like IT:

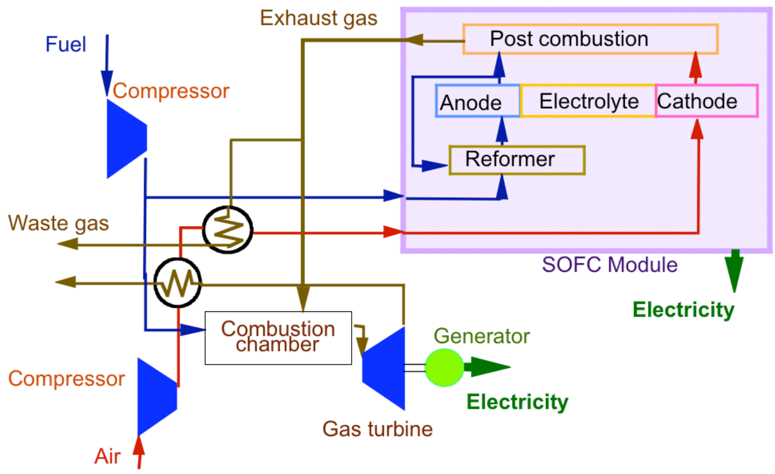

Fig. 2. Advanced power plant combining fuel cell and gas turbine technologies

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

cation, pyrolysis and biological conversion. Research should also be put on biomass to fuel conversion (synfuels, hydrogen) and on efficient conversion technologies of biomass to heat and electricity.

- Heat pumps and trigeneration: in this area the emphasis should be put on efficiency increase and system costs reduction, variable speed oil free compressors, enhanced heat transfer technologies (incl absorption) and the use of new fluids (pairs),...
- Hydrogen technologies: hydrogen is considered as the future energy vector, the effort should be put on the development of efficient hydrogen production systems (new catalysts, autothermal reactors) as well as on reliable distribution and storage schemes.
- Fuel cells: the most promising technologies are the SOFC and the PEMFC, Both will play a role in the energy conversion sector with specific application areas. The research should be put on materials and system design and operation.
- Fusion: this very long term R&D effort should be kept in close collaboration with international programs with very fundamental research aspects [18], but also a need for successful demonstration steps and a growing attention for plant predesign
- Solar thermal : the main areas of research are advanced concentration with high temperature storage and processes and for solar photovoltaic (with or without concentration, flexible or not, on transparent support or not, etc.)
- Geothermal : research is required on efficient low temperature conversion cycles and the development of hot dry rock technologies (crack generation, sealing technologies and anti-deposit technologies, ...
- Electricity Storage and transport: super capacitors, supra conductors, electrolysers to be further developed.

4.1 The conversion of energy resources into useful energy services - exploiting the second law of thermodynamics

From energy services analysis, we could consider that one of the key issue is the system analysis that is pushing towards integrated systems. When converting energy resources into useful energy, the highest efficiency is obtained when the designed system is targeting the combined production of more than one type of energy services. The best example is the cogeneration of heat and power that may be used in both the industry and the residential sector. The energy saving resulting from producing simultaneously heat and power allows important energy savings in the range of 25%. The benefit of integration is identified in all the sectors. If the building sector will increase its efficiency mainly by new materials and new design concepts, combined heat, cold and power production is cited as being one of the major issue. In the industrial sector, the increase of efficiency will mainly concern the innovation of novel production routes, process intensification as well as process integration, trying to valorize synergies between production processes, and energy conversion. Advances will also come from new materials (including biomaterials, high temperature materials) and new technologies (micro and nanotechnologies). However, major efficiency gains will be obtained from the proper integration of these new technologies in the system (process) and the way it will be operated. In the transport sector, system integration approaches in car design (like hybrid cars) as well as in the transportation services supply (multi-modal systems) appear to be among the necessary paths. Even the efficiency of the hydrogen production for fuel cell cars will benefit from using the excess heat to supply heating services. From this analysis it becomes difficult to dissociate energy services from energy conversion.

From the R&D perspective, a multidisciplinary approach will have to integrate contributions from different fields of engineering: mechanical, chemical, material, electrical, control, ... as well as economy and social sciences [19]. The challenge in this field is the design of the full system, considering the advanced equipments, the operational aspects as well as the possible evolution of the energy services demand. Systemic approaches based on the use of computer aided methodologies will therefore be needed. These methods should have a strong scientific basis and integrate the advances in the fields of information technology and mathematics. Life cycle analysis, exergy analysis as well as operation research and artificial intelligence should therefore receive a strong support. This means that R&D will not only concern the technologies themselves but also the enabling technologies (e.g. technology control and management) as well as methodologies improving engineers creativity. This requires a strong integration between research and teaching in such a way that such methodologies can be known by the highest number of inventors, industrialists and stakeholders to allow the technological emergence of innovative solutions.

In the field of final use of energy and energy conversion technologies, exergy analysis is a key instrument. Exergy measures the thermodynamic value of energy. It defines the maximum work which could ideally be obtained, from each energy unit being transferred or stored, using reversible cycles with the atmosphere as one of the energy sources either hot or cold. The exergy approach (e.g. Kotas [20]) is used to represent in a coherent way both the quantity and the quality of the different forms of energy considered. The concept of exergy presents the major advantage of efficiency definitions which are compatible with all cases of conversion of energy resources into useful energy services (heat and electricity, heat-cold-electricity, refrigeration, heat pumps, etc.) and for all domains of use of energy. While energy efficiencies are higher than 100 % for heat pumping systems (because ambient energy is not accounted), exergy efficiencies are always lower than 100%. It gives an indication of how well a potential of an energy resource is exploited in different technical concepts in competition. The figure 4.1 compares the energy and the exergy efficiencies of energy conversion systems for space heating showing for example that, although the energy efficiency of space heating using electricity is nearly 100%, its exergy efficiency is in the order of 7%, a confirmation that the value of energy has been degraded [15]. Such an approach has been introduced today in the law of the Geneva canton (Switzerland) with the aim of promoting the emergence of more efficient technologies in the design practices of architects and engineers.

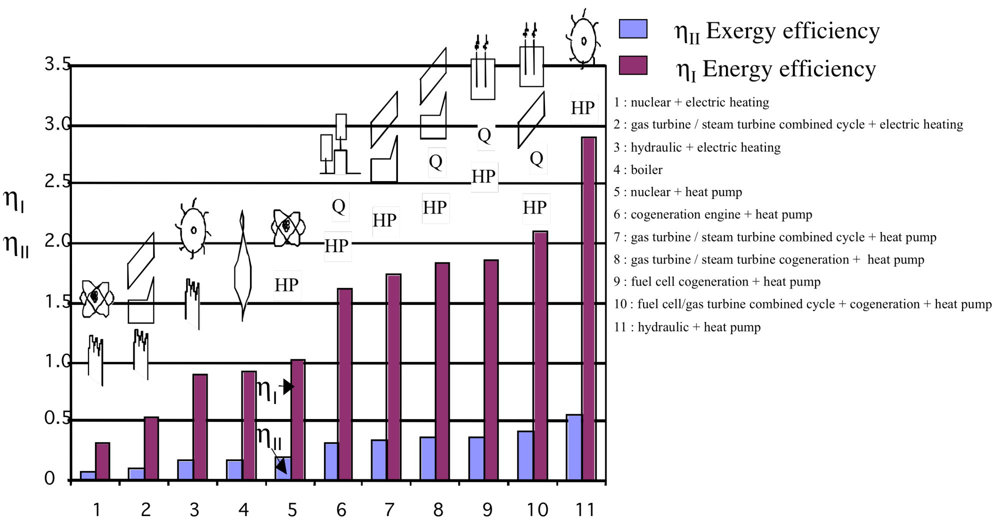

Fig. 3. Energy and exergy efficiencies of heat services, the importance of integrated systems
Data computed with : Grid losses = 4%, Network thermal losses = 5%, Heat pump exergy efficiency = 65%, Network temperature = 65°C, Atmosphere temperature = 0°C, Cogeneration unit thermal losses = 10 %

Another illustrating example is the multi-services technologies that produce more than one form of energy for a given energy resources (figure 4.1). Replacing the conventional solution (left) with advanced integrated system including solid oxide fuel cell - gas turbine combined cycle, compression and absorption heat pumping allows to reach high level of energy savings for both heating (up to 62% of savings) and cooling (up to 67% of savings) modes. [15].

4.2 Enabling technologies

The emergence of information and communication technology as well as of the new technologies in the power electronics makes possible the development of integrated interconnected energy conversion systems remotely operated; those systems are likely to be the key instrument of efficient management for energy services companies (ESCO)in the future. These technologies will favour the emergence of decentralised combined heat, cold and power production where

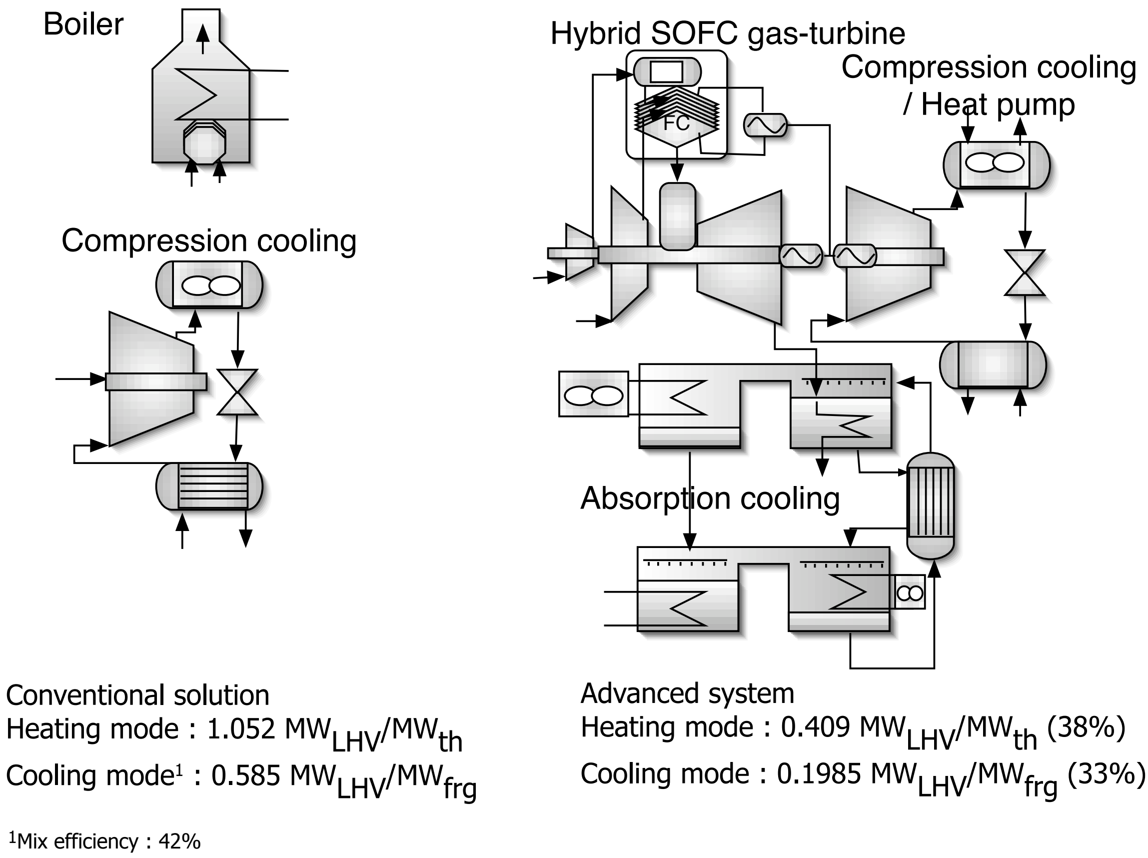

Fig. 4. Example of integrated system for polygeneration

the role of energy storage and energy management will be off growing importance. The efficiency gain will come from the technologies themselves as well as from better and more intelligent control and management strategies that will allow a better integration in more flexible markets. Cross cutting technologies such as information and communication technology [21] [22], variable speed drives and power electronics will be very important despite the short re-investment cycles for the single elements of the energy-using systems considered.

5 Behaviours, marketing and R&D planning

The role of the human behaviours will shape our energy future. If technological solutions for the 2000W society will be developed by the researcher, the market penetration of the technologies will relate mainly on human behaviours. The social analysis of the society and the behaviours ([19]) will therefore be needed. Societal analysis should include the market penetration path as well as the marketing techniques. As an example, the labelled green electricity of Geneva Industrial Services has been adopted in full consciousness by more then 90% of the customers even when informed that this was not necessarily the cheapest solution. This attitude creates a demand for "green power" and put pressure on the producers.

6 Conclusions

6.1 R&D towards a 2000 Watt per capita society – first results

In order to estimate absolute energy saving potentials, an idea of the energy demand with frozen technology by 2050 had to be developed. Assuming an increase in economic growth of some 70% between 2000 and 2050, the primary energy demand at frozen structures and technologies would grow at the same rate as the GDP (see 5). If structural changes to less energy-intensive branches and consumption in the economy and saturation processes are considered (at an assumed (often observed) yearly rate of declining energy intensity of 0.4%/a), primary energy will increase less, amounting to some 1'700 PJ in 2050 (or 7'188 W/cap) still assuming frozen technology of the year 2000. The reduction of the Swiss energy system necessary to reach 2 000 W/capita (or 65 GJ/cap) in 2050, therefore, amounts to almost 75% or in absolute terms about 1'300 PJ of primary energy down to a target of 400 PJ (1945 W/cap) (see Figure 5). Considering the sectorial analysis, a demand-supply model has been used. The feasible targets expected for the different sectors given in W/cap have been converted from PJ figures [23] (see Table 4). The results show that the 2000 W society target appears to be technically feasible [24], whether this may be economically and politically feasible involves many additional aspects.

These figures have been obtained considering the re-investment cycles that vary from one sector to another. Some sectors like the building sector have very long re-investment cycles meaning that the 2050 figures will incorporate technologies that are nearly available today while other sectors like the private car sector or the electric appliances market have shorter re-investment cycles allowing two or three new technology generations to emerge before 2050.

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, these estimates are still hypothetical, but they indicate that the 2000 Watt society vision is not out of the range of theoretical possibility. There are techno-economic bottlenecks and existing obstacles to the development, acceptance,

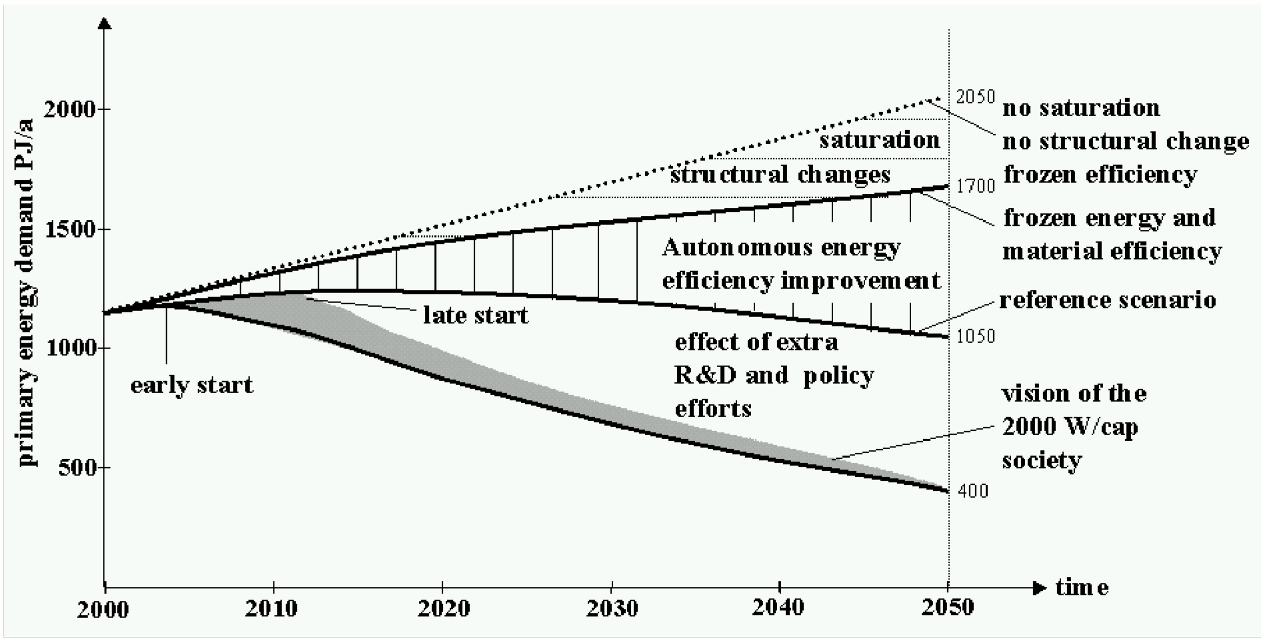

Fig. 5. Scheme of drivers on Swiss primary energy demand: economic growth, saturation, structural changes, autonomous and policy-induced energy and material efficiency

and market diffusion of innovative technologies [25,26]; it may be important to simultaneously consider them even at the R&D stage.

6.2 Energy conversion and renewable energy sources

Considering the sectorial consumption figures of table 4, the energy conversion is analysed by assuming a final consumption of 661 W/cap of standard use of electricity (lightning, cooking, work, air conditioning without heating,...). These figures have been obtained considering the share of electricity in the final consumption as being of 50% for the industry, of 70% for the household and the services sectors and of 15% in the transportation sector. This requirement is lower than the present hydropower production capacity in Switzerland (681 W/cap).

A conservative figure has been considered for the penetration of integrated useful energy production equipment. It is possible to imagine even more efficient energy conversion scenarios that favour the use of renewable energy. The introduction of cogeneration devices together with the potential of biomass introduces difficulties in the estimation of the energy primary consumption. Consider as an example the ultimate figure where the heating requirement (30% of the household and trade & commerce sectors final consumption) is produced by cogeneration (with an electrical efficiency of 40 % and an overall first law efficiency of 90 %) and the produced electricity is used to drive heat pumps with an COP of 4. In this case, each unit of heat will cost 0.48 unit of fuel (i.e. the primary energy consumption is lower than the heat supplied). This supposes a repartition of 77% of heat produced by heat pumps and 23% by cogeneration. Using the 2050 demand figures given on table 4, satisfying the energy demand of the household and trade & commerce sectors would require 73 W/cap of fuel and 371 W/cap of electricity, i.e. 1/2 of the hydropower capacity. It is important to keep in mind that the use of hydropower can not be considered as a full option for driving heat pumps since the peak heating demand (mid winter) unfortunately coincides with a minimum of hydropower availability [27]. This is shown on figure 6 that compares the accumulation level in the dams with the degree days (these have been computed assuming a heating temperature threshold of 12°C, considering the increased level in building insulation. The analysis can not therefore only consider the energy requirement but also the power requirement in order to practically design integrated systems.

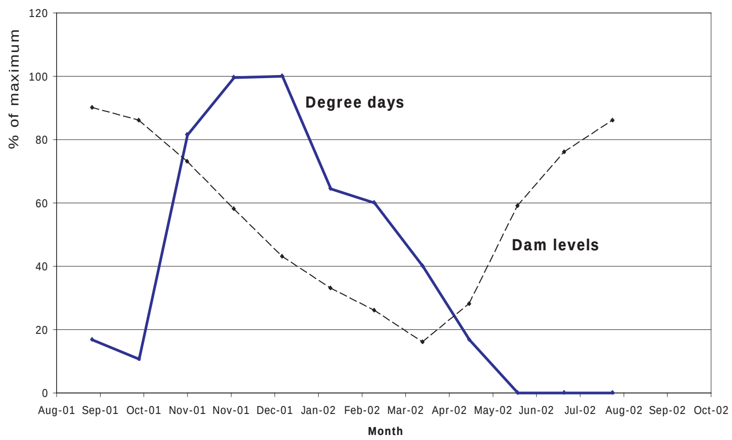

Fig. 6. Comparison of the monthly water accumulation level and the monthly degree days (scales in % of maximum)

Using a similar reasoning for industry requirements and assuming a share of 50% for the electricity consumption, we would reach a level of 185 W/cap in terms of heat and 185 W/cap in terms of electricity. Assuming : a cogeneration device (with 45 % of electrical efficiency and 90% of overall efficiency) used for delivering 80% of the industrial heat requirement; 10% high temperature heat requirement supplied by direct fuel firing (with an efficiency of 90%) and 10% of heat pumping (with a COP of 4), we obtain a fuel consumption of 410 W/cap and a combined production of electricity that amounts at 175 W/cap. Summing up the three sectors fed by cogeneration and heat pumping devices, we obtain a final fuel consumption of 483 W/cap and 387 W/cap of electricity. Considering the transformation losses (80% for the electricity production by hydropower and 3% transformation losses for the fuels, assumed to be mainly natural gas), the final energy demand would be around 1726 W/cap.

From the 681 W/cap available from the hydropower, only 387 W/cap are required under this scenario for these three domains, which leaves 294 W/cap for the transport sector. When deducing the 15% of electricity consumption targeted for the transportation sector (105 W/cap), it remains 189 W/cap from the hydropower capacity. This electricity could be for example converted to hydrogen by electrolysis with an efficiency of 75%, leaving a bit more than 450 W/cap to be supplied by other forms of energy. The biomass potential of Switzerland is of 670 W/cap but the conversion will not be perfect since we need a fuel in a suitable form for cogeneration (i.e. wood gasification or wood to methane conversion [28,29] that has an efficiency of 55%). Therefore, from the remaining 965 W/cap, 370 W/cap could come from the biomass conversion, leading to a final non renewable fuel consumption of 616 W/cap or 1.07 t_{CO_2}/cap. It should be mentioned that the renewable energy scenario is based on proven if not widespread technologies and would require a primary energy consumption of 2150 W/cap (due to the low efficiency of the biomass to fuel conversion) but with a share of 75% of renewable energy resource. The above scenario relying essentially on hydro, biomass and natural gas shows that not only the 2000 W target could be achieved by the technical view, but further reliance on renewable energies (including solar, wind and geothermal) could help to reduce CO_2 emissions more than primary energy demand, i.e. more than 75 % relative to 2001.

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Table 1
Energy Intensity indicators in selected countries in W/cap [1]

Country	W/cap	population (Mhab)	CO2 (tCO2/cap)
USA	11050	273	20.5
OCDE	6210	1116	11.0
Japan	5401	127	9.14
EU	5228	379.4	8.46
Switzerland	4966	7.2	5.6
Former USSR	4178	290	7.9
Middle East	2820	162	5.5
Whole world	2192	5921	3.9
Latin America	1450	408	2.1
China	1115	1260	2.4
Africa	833	775	0.9
Asia	731	1850	1.0
Bangladesh	183	127	0.2

Table 2
Analysis of the final consumption of energy (data source : statistics 2001 : http://www.iea.org)

	TPES (W/cap)	TFC (W/cap)	Eff -	Industry -	Transport -	Others -	Non energ. -
World	2192	1529	69.7%	31.5%	25.8%	39.9%	2.8%
Japon	5309	3485	65.6%	36.0%	28.1%	33.5%	2.5%
EU(15)	5099	3643	71.4%	30.0%	29.9%	37.4%	2.8%
Switzerland	4966	3864	77.8%	20.8%	32.0%	45.6%	1.9%
USA	11050	7300	66.1%	26.2%	39.5%	29.9%	4.4%

TPES : Total Primary Energy Supply
TFC : Total Final Consumption

Table 3
Analysis of the share of electricity in the final consumption of energy/TFC) (data source : statistics 2001, http://www.iea.org)

	TFC (W/cap)	Electricity (W/cap)	Industry -	Transport -	Others -	Total -	Excl. transport -
world	1529	239	20.7%	1.1%	22.1%	16%	21%
Japon	3485	806	26.1%	1.7%	39.6%	23%	33%
EU(15)	3643	659	25.9%	0.2%	27.6%	18%	27%
Switzerland	3864	835	35.4%	3.4%	28.9%	22%	31%
USA	7300	1362	22.5%	0.1%	42.5%	19%	33%

Table 4
Energy use for Switzerland in (W/cap), from present figures to the 2050 2000W society target

	Present 2001	Frozen 2050	Target 2050	Share [1]	Gain [2]
Industry	759	1000	370	21%	63%
transportation	1300	1950	700	39%	64%
Private household	1065	1350	310	17%	77%
Trade and commerce	718	1100	220	12%	80%
Total consumption	3842	5400	1600	89%	70%
Non energetic use	98	150	20	1.0%	84%
Conversion losses	1364	1920	200	10%	-
Primary Energy	5304	7470	1820	100%	75%
Conversion Efficiency	72%	75%	88%		

Share : Share of Total in the 2050 target
Gain : Reduction of the energy consumption in the sector with respect to 2050 frozen technologies figures