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A CONTRIBUTION TO THE IDENTIFICATION OF PROMISING TECHNOLOGIES FOR THE 2050 SWISS ENERGY R&D POLICY VISION

Schlussbericht

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1 Executive Summary

Purpose of the work

1. This report is a contribution to the identification of promising technologies for an achievement of the four objectives formulated by the ‘Roadmaps Working Group’ in the context of the ‘2’000 W Society’ and aims at supporting the priority setting in energy research programmes by the CORE. For this purpose it reviews existing literature on road mapping of medium-term energy supply, defines different possible ‘Futures’ for the Swiss energy supply and demand by 2050 on a qualitative basis and on a first order quantitative basis, investigates existing R&D competences in the public and private sectors, and thereby attempts to identify promising technologies for an achievement of the objectives formulated by the ‘Roadmaps Working Group’.

Review of international and national roadmapping studies and scenarios

2. On a world basis, there is no consensus on whether major technological breakthroughs are needed or whether incremental improvement of current technology together with adequate support from more stringent environmental policy frameworks could achieve sustainability requirements. By consequence and given the high uncertainties in the field of technological development, an adequate balance needs to be found between fundamental research and applied research.

3. Most scenarios on world energy supply by 2050 found in the international literature show an increase of the renewable sources fraction in primary energy supply together with an increase of primary energy consumption per capita. However, most pessimistic ones project a decrease of the renewable sources share, while most optimistic ones show a decrease of energy consumption per capita. In the studies reviewed, primary energy consumption per capita by 2050 ranges from 1.5 to 5 kWyear per year while renewable sources share in this primary energy supply ranges from about 8 to 82%.

4. Studies conducted on a national basis in various countries express very different visions on the supply side, but there is unanimous recognition of the need for strong demand side efficiency measures. Few national studies look at energy supply beyond 2030 on a quantitative basis, but technical viability of ambitious climate objectives are demonstrated in many target oriented scenarios. The transport sector is perceived as a core challenge – hybrids and hydrogen fuel are expected to play a material role in the considered timeframe. Carbon sequestration or nuclear energy are often given an important role in the electricity supply, Germany being a noticeable exception so far as its Parliamentary Enquete Commission for Energy of the 14th German Bundestag excluded both of those options in a part of the developed scenarios.

Methodology of analysis

5. Setting priorities in public R&D funding for the medium-term energy supply involves a considerable risk of failure as the decision makers face a great deal of uncertainty related to the way numerous relevant boundary conditions may evolve in the future. In a debate often shaped by divergent opinions and various conflicts of interest, there is a need for a more transparent and structured analytical framework. For this purpose a methodology based on the notion of 'Futures' has been developed in order to remain as objective as possible by reducing the number of degrees of freedom in the process of identifying promising technologies to be supported by public R&D.

6. Four different 'Futures' are defined for Switzerland based on different sets of driving forces, which lead to differences in the degree of decentralisation and the degree of fossil fuel substitution in the energy supply. Although characterised by very different energy supply systems, all 'Futures' comply with the **four quantitative objectives** formulated by the 'Roadmaps Working Group' and to be achieved by 2050, i.e.:
   a) no use of fossil fuels for heating requirements in the building sector
   b) reduction by half of the energy consumption in the building sector
   c) increase of the share of biomass in the energy supply using its full ecological potential
   d) reduction of the vehicle fleet's average fossil fuel consumption down to 3 litres per 100 km

7. In order to illustrate the four 'Futures', four different scenarios are investigated in a first order quantitative analysis based on a tool previously developed by the 'Roadmap Working Group'. <u>Those scenarios are illustrative and must by no means be interpreted as projections. Other 'Futures' could be considered, and many other scenarios could indeed be envisioned for a same 'Future'. Furthermore, scenarios are based on an annual energy balance analysis, and do not look into economics.</u>

First order quantitative results of the analysis

8. Results from the first order quantitative analysis indicate a renewable fraction in the primary energy supply ranging from 46 to 61%, and an annual primary energy consumption per capita ranging from 3.5 to 4.2 kWyear per year and per capita. In order to reach those targets, primary energy consumption per capita must be reduced by 20 to 30% and the renewable sources fraction amplified by 2.5 to 3.5 times, compared to the situation in 2001. 'Futures' with low fossil fuel substitution are associated with greater overall conversion efficiency, leading to lower annual primary energy consumption. This is essentially due to greater conversion efficiency in the transport sector: in these 'Futures', in order to comply with the target, the tank to wheel energy efficiency of passenger vehicles must be greater than in other 'Futures', which introduce a greater share of fuel switching. Moreover, alternative fuels are associated with relatively high primary energy consumption.

9. From the point of view of security of energy supply, and when measured by the non-renewable primary energy consumption, meeting CORE's 'Objectives' with an energy system essentially based on hydro, on distributed renewable electricity generation, on distributed biomass-fired integrated energy systems, on a generalised use of heat pump heating and on a high fossil fuel substitution in the transport sector is the most effective option with 1.6 kWyear per year and per capita of primary energy from fossil resources. This applies unless nuclear fuel supply is assumed to be sufficiently secure; in this case an energy system based on hydro and nuclear centralised power generation, on a generalised use of heat pump heating and on a high fossil fuel substitution in the transport sector becomes the most effective option with 1.4 kWyear per year and per capita of primary energy from fossil resources.

10. The CO_2 emission rates resulting from the four 'Futures' investigated range from 2.4 to 4.1 tons of CO_2 per capita and per year. This is a reduction of 40 to 65% compared with the situation in 2001. From the point of view of climate change mitigation, meeting CORE's 'Objectives' with a generalised use of heat pump heating together with an energy system essentially based on hydro, natural gas fired and biomass fired centralised power generation is the most effective option, as long as carbon capture and storage is available and applied to large power plants including biomass fired ones. Otherwise, an energy system essentially based on hydro, distributed renewable electricity generation, and distributed biomass-fired integrated energy systems, or based on hydro and nuclear centralised power generation, with, in both cases, a generalised use of heat pump heating and a high fossil fuel substitution in the transport sector are the most effective options associated with similar emission rates.

11. In all four 'Futures', compliance with 'Objective a' is obtained with a reduction of the room heating requirements per square meter by 75% to compensate for the expected increase of total heated area by 25% and to make up for the limited availability of efficiency measures for water heating while its demand is also expected to increase by 25%. However, time constraint related to long reinvestment cycles in the building sector plays a governing role and absolute reduction of energy requirements is more stringent than reduction of the specific energy demand. Technology diffusion and market confidence are therefore key issues to focus on.

12. Whether a ban of fossil fuels for heating requirements is applied to final energy only or to the overall energy chain leads to significantly different fossil fuel substitution requirements to comply with 'Objective b'. The target is, however, technically achievable in all cases as long as heat pump heating is generalised whether it is driven by electricity from the grid or from distributed cogeneration units. The different interpretations are illustrated in the four different scenarios. Those which belong to 'Futures' with a high fossil fuel substitution consider a strict ban of fossil fuels. In such a case, in a 'Future' with a low degree of decentralisation nuclear and hydro supply the electricity required by the massive introduction of heat pumps in the building sector, while in a 'Future' with a high degree of decentralisation heat pumps are driven by electricity from either biomass-fired cogeneration units or on-site

photovoltaic cells and small wind turbines. Scenarios, which belong to 'Futures' with a low fossil fuel substitution allow the use of fossil fuels in central power plants (low degree of decentralisation) or in distributed cogeneration units (high degree of decentralisation) for supplying the electricity needed by heat pumps. Solar thermal energy plays an important role in all 'Futures', essentially for water heating. Biomass boilers are also significantly introduced when a strict ban on fossil fuels and 'Objective c' requirements are combined constraints.

13. Using the full ecological potential of biomass resources, as requested by 'Objective c', leads to a share of biomass in the primary energy supply ranging between 12% and 14% of total primary energy supply in the four scenarios investigated. Biomass resources are mostly used for meeting 'Objectives' related to the building sector heating demand, either directly or via electricity generation and heat pumps. 'Future LdHfs' is an exception since nuclear plays a significant role in the electricity generation, leaving an important share of biomass resources available for an extensive use in the transport sector (about a third of the biomass potential for ethanol supply). The share of direct use of biomass in the total final energy demand for room and water heating ranges from 10 to 28%, to which must be added the share of biomass resources in the electricity delivered to heat pumps via the grid. Biomass resources account for between 9 and 18% in the total amount of electricity delivered to national users.

14. Compliance with the target of 3 litres average fossil fuel consumption per 100 km for the passenger vehicle fleet is achieved with a mix of efficiency measures and fuel switching. In 'Futures' with lower concerns about energy supply security, fossil fuel substitution is low as there is no policy to prepare the country for a fossil free transport sector. 'Objective d' is achieved with efficiency measures essentially, with a high penetration of hybrid ICE vehicles and advanced ICE vehicles. In 'Futures' with high concerns about energy supply security, fuel switching is used as a complementary measure and in order to prepare for even lower fossil fuel reliance, and ultimately no reliance on fossil fuels at all. In such a case, efficiency improvements do not need to be as important to comply with the given target, but some still need to be achieved to reduce the amount of alternative fuel to be produced for a same service. Note that in such scenarios more stringent targets could be achieved from a technical point of view. The technical potential for domestic hydrogen production is indeed far from being fully exploited, and greater fuel cell vehicle penetration could be envisioned.

Research and development needs for meeting the CORE targets

15. In a first step, those technologies have been analysed that have a high probability to give a substantial contribution to the energy system in all 'Futures' or at least in several of the 'Futures' analysed. Research and development efforts on these technologies imply the lowest risk of a false allocation of resources.

16. Energy efficiency improvements in the building sector are an omnipresent prerequisite in all 'Futures' with for example 75% efficiency improvement for room heating requirements. Therefore, the availability and market penetration of technologies plays a pivotal role. Even though there are still ample fields for technology research and development, such as for example for high efficient insulation or controlled ventilation with heat recovery, there are good reasons to believe that already available technologies can achieve the required goals or at least most of it. Given the long reinvestment cycles in the building sector, the need for market penetration strategies actually is much more stringent.

17. Heat pump technologies will be generally present in all 'Futures' investigated, irrespective of the source of the electricity, which may originate from central or decentralised generation. They provide more than 60% of room heating requirements and more than 20% of water heating requirements in all four 'Futures'. Heat pumps therefore appear as a 'sine qua non' to comply with the CORE targets, and in order to enable heat pumping to reach the required capabilities, research aiming at achieving greater coefficients of performance and seasonal performance, at the development of systems with new working fluids and at better system integration and control strategies will be necessary.

18. For the transport sector the efficiency improvement of passenger vehicles plays the most important role and there, the efficiency increase of the drive train is of special importance with a specific consumption reduction ranging from 35 to 55%. The technology research on advanced internal combustion engines and on hybrid drive trains are seen as the primary challenges in this field with topics such as investigations on combustion processes and control with advanced methods, on-board energy storage and power electronics technologies.

19. The full use of the biomass ecological potential as mandated by the CORE targets and the wide distribution of electricity based heat generation with heat pumps create the necessity for efficient technologies for the conversion of biomass. Gasification technologies offer efficient conversion processes and are associated with a great diversity in the delivered products, which allows also producing biofuels that could play an important role in the transport sector. By consequence, biomass to electricity conversion basing on gasification is of high importance imposing research needs for advanced gas cleaning technologies, for feedstock homogenisation or, alternatively, for more fuel flexible gasification technologies, and for pollution control technologies. Gasification meets between 14 and 19% of electricity requirements in centralised 'Futures' and a large share of room and water heating requirements when associated with district cogeneration units and heat pumps in decentralised 'Futures'.

20. The high diversity of turbomachinery based conversion processes makes gas turbine technologies play an important role in all 'Futures'. Due to the different applications and capacities connected to the energy systems of the respective 'Futures', different research focuses may arise though. In general, the gas turbine research aims at improving energy efficiency, at the use of

alternative fuels and working fluids, at maintaining reliability and availability while continuously reducing atmospheric air pollution emissions. Research topics in this context are inlet temperature increase employing new materials and cooling technologies, advanced blade design and combustion processes with ultra-low NO_x emissions. Further research is needed on system integration in combined cycles, integrated gasification processes, gas recirculation processes, turbine design for alternative fluids in connection with gas cooled nuclear reactors.

21. Gas engine technologies do not necessarily have the largest impact on the achievement of the CORE goals but can find realisation in all 'Futures' and hence can provide a material contribution. Research on gas engine technologies would be directed towards coping with the pollutant emission control problems while achieving increasing conversion efficiencies, maintain competitive costs and allow the use of alternative fuels. The required research work would aim at combustion efficiency and handling of knock phenomena, at low pollutant combustion with lean mixes, catalytic reduction or technologies with recirculation at turbo-charging, and at upstream gas cleaning technologies.

22. In three of the four 'Futures' analysed, PEM fuel cell technologies in passenger vehicles with hydrogen storage make a significant contribution to achieve the transport sector goals (between 2.5% and up to 11% of total transport final energy demand). The main research challenges associated with PEM fuel cells are lifetime increase, cost reduction and system integration. Associated with these challenges, research work aims at electrolytic membrane development, advanced electrode research with lower amount of noble metals, investigation of and prevention of poisoning and degradation of membrane electrolyte assemblies, development of advanced bipolar plates and advanced sealing and system integration concepts.

23. Associated with the application of fuel cell passenger vehicles, there is a need for efficient on-board hydrogen storage technologies. The storage technologies as such do not play a governing role in the efficiency of the energy system but their properties can have a substantial impact on the market success of fuel cell vehicles. Research challenges aim at achieving appropriate volumetric and gravimetric energy densities and thereby satisfying driving ranges at acceptable costs and losses. The associated research work concentrates on the material science of composite materials for pressurised tanks, on tank architecture and insulation concepts for liquefied hydrogen storage, on material sciences of storage technologies basing on metal hydrides or hydrogen absorption, and on chemical compounds.

24. Within the analysed 'Futures' solid oxide technologies play a twofold role: in two of the four 'Futures', solid oxide technologies provide electricity working as fuel cells, whereas in the 'Future' with nuclear technologies, solid oxide technologies could operate as high temperature steam electrolysers. When used as fuel cells, solid oxide technologies could be operated in decentralised cogeneration units with biogas or syngas. Comparable to other fuel cell technologies the main challenges for solid oxide technologies lie in the

increase of lifetime and in achieving cost reduction but also in system integration including combined cycle concepts and upstream gas cleaning technologies. In order to achieve these technology targets, research work is to be carried out on electrode development, new designs and improving electrolytes for lower temperature SOFC. For higher temperature SOFC, work is to be carried out on new designs for better fuel utilisation, and better heat and mass flows management, material science research on coatings for metallic alloy interconnects, for surface treatment for interconnects and for sealant materials as well as work on manufacturing technologies.

25. Second order technologies can be identified that play a material role in all "Futures", which is, however, less important than the first order technologies. Among them are electricity transport and distribution technologies, whereas technologies like advanced superconductors, advanced high voltage DC transmission, advanced AC/DC power conversion and advanced power electronics are in focus of research work. Further, hydropower is contributing a significant share of the electricity demand in all "Futures" and imposes research work on the development of advanced generators, on the investigation of unsteady phenomena, on the reduction of cavitation by advanced blade design and on improvement of reversible turbines for pumped hydro.

26. Some technologies achieve a large realisation only in one 'Future', but in this specific one, they provide a very substantial contribution to the energy system. In the 'Future' with low decentralisation and high fossil fuel substitution (LdHfs), advanced nuclear reactors play a very important role providing 20 % of electricity requirements. Research for the then possibly applied fourth generation reactors aims at increasing inherent safety, reliability, reduction of nuclear waste and at non proliferation issues as well as also on efficiency increases and cost reduction. The further conversion of nuclear energy into hydrogen as an alternative to electricity could be performed by high temperature steam electrolysis (SOFC) or by thermochemical water splitting. For the case of high temperature steam electrolysis, 11% of the total transport final energy demand is met with the hydrogen produced. For the thermochemical water splitting, research focuses on materials sustaining highly corrosive environments at high temperatures and on membrane technologies. In such a 'Future' more biomass could be converted into biofuels opening a large potential for technologies for ethanol. Research aims at technologies capable of handling multiple fermentable feedstocks in a single plant, and lignocellulosic biomass conversion via hydrolysis and fermentation or thermochemical processes.

27. In a "Future" with low decentralisation and low fossil fuel substitution, CO_2 capture and storage could play a central role by allowing the use of fossil fuels like natural gas in the electricity system while maintaining a virtually CO_2 emission free power generation. The research on CO_2 capture and storage focuses on providing a cost efficient and reliable technology. Although different technological routes are followed at the moment, the research topics can be summarised as work on gas separation technologies with solvent processes and with a more long term perspective also with membrane

technologies, work on turbomachinery and combustion processes with alternative fuels like hydrogen and oxidants like pure oxygen and alternative working fluids, especially CO_2. Research on CO_2 storage involves work on reservoir characterisation, storage safety and storage reservoir modelling techniques and prediction methods.

28. Natural gas steam reforming processes may occur both in large-scale (centralised energy system) and in small-scale (decentralised energy system) configurations with the aim to produce hydrogen for transport fuel supply, providing 2.5% in the centralised case and 8% of the total transport final energy demand in the decentralised case. The associated research work directs at the development of advanced catalysts, separation processes, process integration with heat recovery or with partial oxidation processes. For small scale applications, topics such as technologies for a faster start-up, sealing technologies, membrane technologies, and purification technologies come into play.

29. In a 'Future' characterised by a decentralised energy system with high fossil fuel substitution (HdHfs), the new renewable energy sources solar PV, wind power and geothermal energy play a very important role with PV delivering 16 %, wind power 5 % and geothermal energy providing 2 % of the electricity demand. With respect to solar PV, this imposes a need for research on cost reduction, efficiency increase, and lifetime of PV cells as well as cost reduction and reliability of balance of system components among them especially inverters. Research topics range from reduction of material requirements in crystalline cells to material science of thin film structures to nano-technology research on production technologies for dye sensitised solar cells. Regarding wind power the research aims at increasing the size and height of rotors while reducing the weight of the rotor and the drive train equipment. This involves work on composite materials for turbine blades or work on lightweight multipole generators. In the field of geothermal energy, research aims at reducing costs and the risk of failure of drilling projects as well as on the efficiency increase of electricity conversion processes. Associated works encompass geophysical exploration technologies, drilling technologies, borehole and reservoir stimulation technologies and ORC as well as Kalina processes for electricity production.

Views and capabilities in the industry, in the academic research and in the EU

30. The development towards a future energy system in Switzerland will take place in an academic and an industrial context as well as in an international context, which is most importantly influenced by the scientific development and the development on the level of the European Union. Therefore priority setting for a research agenda should incorporate views, plans and capabilities expressed by representatives of these elements of the innovation system in order to benefit from co-operation strategies and to maintain the economic performance of the domestic industrial innovation system.

31. With the pre-study for a 2000 Watt society and with the overview study on the energy research in the ETH-Domain, two major documents give insight into the research capabilities and views on the future energy system based on a very broad academic expertise. It should be noted that the expressed views and plans of academic research are to a very large extent concordant with the CORE goals. The comparison of the 'Futures' assessed showed the greatest amount of coherence between the 'Future' with a centralised energy system basing on a high substitution of fossil fuels. However, the wide range of research activities not only in the ETH-Domain but also in the entire Swiss academic system enables Swiss research to contribute valid pieces of work to any of the analysed 'Futures'.

32. The industrial capabilities showed to be much more difficult to assess. Using patent analysis, several technology fields where Swiss industrial research shows super-proportional capabilities could be identified such as turbo-machinery research, heat pumps or electricity transmission and distribution technologies. However the statistical significance of the quantitative patent analysis proved to be low in many technology fields. Further the view of one large electricity utility – Axpo – has been analysed based on its published scenario, showing that at least this actor from industry is not envisaging a change in paradigms and makes plans for a continuously centralised electricity system with nuclear as well as gas based generation next to hydro and a comparatively small share of new renewables. In the system of the 'Futures' analysed in this study, this view could be expressed as a centralised 'Future' with medium substitution of fossil fuels. It should be kept in mind, that the view of this electricity utility is one example among a range of diverse industrial views and is not to be considered representative for the entire Swiss industry and not for the energy industry either.

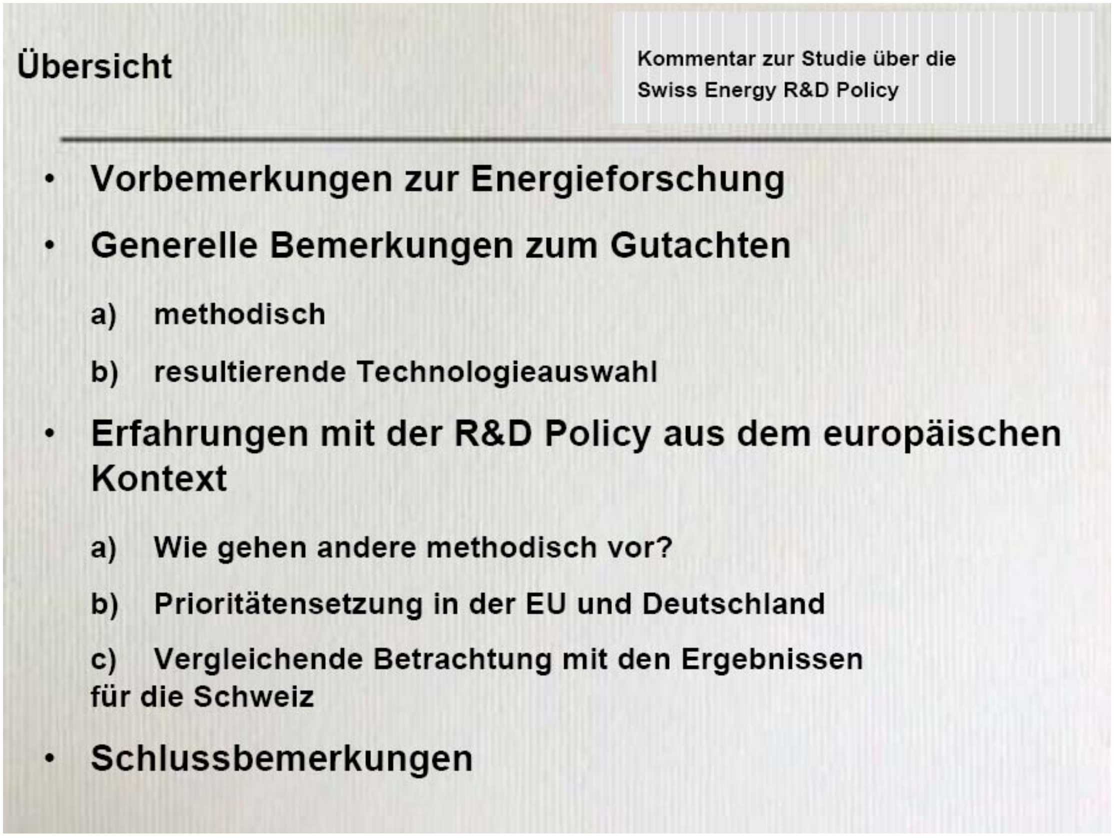
33. The European Union research plans, as expressed by the plans for the seventh framework programme (FP7), combines elements of several 'Futures' except maybe the one with high decentralisation and low fossil fuel substitution. Fields with strong coherence to the identified research needs for Switzerland are energy efficiency, renewable energy research with respect to electricity generation, transport fuels and building energy, hydrogen and fuel cells and smart energy networks. The field of CO_2 capture and storage also fits into the Swiss system, but in the EU the focus lies more strongly on coal technologies like the last element of the FP7 plans, clean coal technologies, which do not contribute directly to the future needs of the Swiss energy system. However, there are research capabilities in Switzerland that can contribute to this field. Lastly, it has to be noted that besides the FP7 under the rule of the EU, there will be a large seventh framework programme under the rule of the EURATOM treaty.

Concluding remarks

34. As a conclusion, it must be stated again that the analysed 'Futures' represent extreme materialisation of the future energy system as it could possibly evolve while meeting the targets formulated by the CORE roadmaps working group.

Besides these four ‘Futures’ other configurations of the Swiss energy system by 2050 can be imagined that equally meet the CORE targets and thereby stand for an approach towards a 2000 Watt per capita society.
The presented analysis deliberately does not allocate probabilities to the different ‘Futures’ investigated nor does it provide a decision about setting research priorities. Instead, the results should be understood as an additional means for priority setting in a research agenda under development by the CORE. Applied this way the developed methodology could help to structure the discussion and decision making process while the collected technical information and the derived quantitative data could elucidate the possible consequences of the options under discussion by the CORE.

2 Comments Dr. Manfred Fischedick



Kommentar zur Studie über die
Swiss Energy R&D Policy

Steigende Anforderungen an die Energieforschung

- Begrenzte Forschungsbudgets mit teilweise rückläufiger Tendenz
- Komplexe Herausforderungen beim Aufbau zukunftsfähiger Energiesysteme:
  - Technologiebedarf
  - Integrationsbedarf
  - Klimaschutz und Versorgungssicherheit
  - Markttransformation u. gesell./pol. Wandel
- Internationalisierung der Energiewirtschaft und -technik (EU, global) - globale Herausforderung

→

Notwendigkeit zum Aufbau strategischer Allianzen

Neue Forschungs-partnerschaften

Gemeinsame Strategie-entwicklung von Gesellschaft, Wissenschaft und Industrie (Diskurs-Orientierung)

Kommentar zur Studie über die
Swiss Energy R&D Policy

Selbstverständnis der Energieforschung

- **Energieforschung leistet Lösungsbeitrag für die konkret anstehenden Problemfelder (national/international)**
- **Energieforschung jedes Landes konzentriert sich auf die Bereiche mit den besten Erfolgsaussichten (Schwerpunktbildung)**
  - für die Forschung selber
  - über die Produktentwicklung für die Wirtschaft
- **Energieforschung versteht sich als partizipativer Prozess und bindet damit die Breite des verfügbaren Know-How's ein**

Generelle Bemerkungen zum Gutachten

Kommentar zur Studie über die Swiss Energy R&D Policy

- Sehr gute Untersuchung mit zum Teil erheblichen Tiefgang (z.B. Technologiebeschreibung)
- Ziel der Untersuchung (Entscheidungsträger für F&E-Prioritätensetzung vorzubereiten) kommt klar heraus - Szenariomethodik dafür geeignete und häufiger angewendete Methode (z.B. ZT NRW, IIASA) - robuste Felder identifizierbar (Schnittmengenanalyse)
- Unklarheiten bestehen bezüglich der Bedeutung des Faktors Technologieentwicklung für den Export (unabhängig für die Schweiz selber)
- Ergänzendes Kapitel bezüglich Vorgehensweise F&E-Prioritätensetzung in anderen Ländern wünschenswert

Generelle Bemerkungen zum Gutachten
Methodik bzw. Szenarioauswahl

Kommentar zur Studie über die Swiss Energy R&D Policy

- Alle Szenarien gehen von den gleichen Entwicklungs-zielen aus - Vergleichbarkeit gewährleistet
- Für Identifikation robuster Technologien nur dann tragfähig, wenn die Ziele allg. anerkannt sind (sonst Einbeziehung von „BAU“-Zukünften erforderlich)
- Ziele adressieren nur Teilbereiche des Energiesystems

  - Sektorziele (z.B. Gebäude) statt gesamtsystemare Vorgaben (z.B. CO_2-cap) blenden ganze Technologiebereiche aus (Energieeffizienz Industrie, Querschnittstechnologien, Klimatisierungsbedarf)

  - Gesamtsystemare Vorgaben fragen auch immer nach den komplementären Technologien „was brauche ich zusätzlich zu Hd/Hfs noch, um CO_2-Ziel zu erreichen?)

Generelle Bemerkungen zum Gutachten
Methodik bzw. Szenarioauswahl

Kommentar zur Studie über die Swiss Energy R&D Policy

- Auswahl der Freiheitsgrade ist sinnvoll

  - Dezentralisierungsanteil der Energieversorgung

  spricht zentrale Optionen im Kraftwerkspark an (Kernenergie, CCS oder dezentrale Optionen (allerdings Achtung: Dezentralisierung ist kein Wert an sich)

  - Substitution fossiler Energien

  spricht erneuerbare Energien und Energieeffizienz an

- Fokussierung auf Entweder/oder-Vorgaben (z.B. dezentral oder zentral) führt zum Teil zu Extremszenarien (Beispiel hoher PV-Anteil, in der Realität setzen sich in der Regel Mittelwege durch)

Generelle Bemerkungen zum Gutachten
Methodik bzw. Szenarioauswahl

Kommentar zur Studie über die Swiss Energy R&D Policy

- Andere typische Verfahren:

  - Vorgabe von klaren CO_2-Zielen und Storylines (vgl. Enquête)

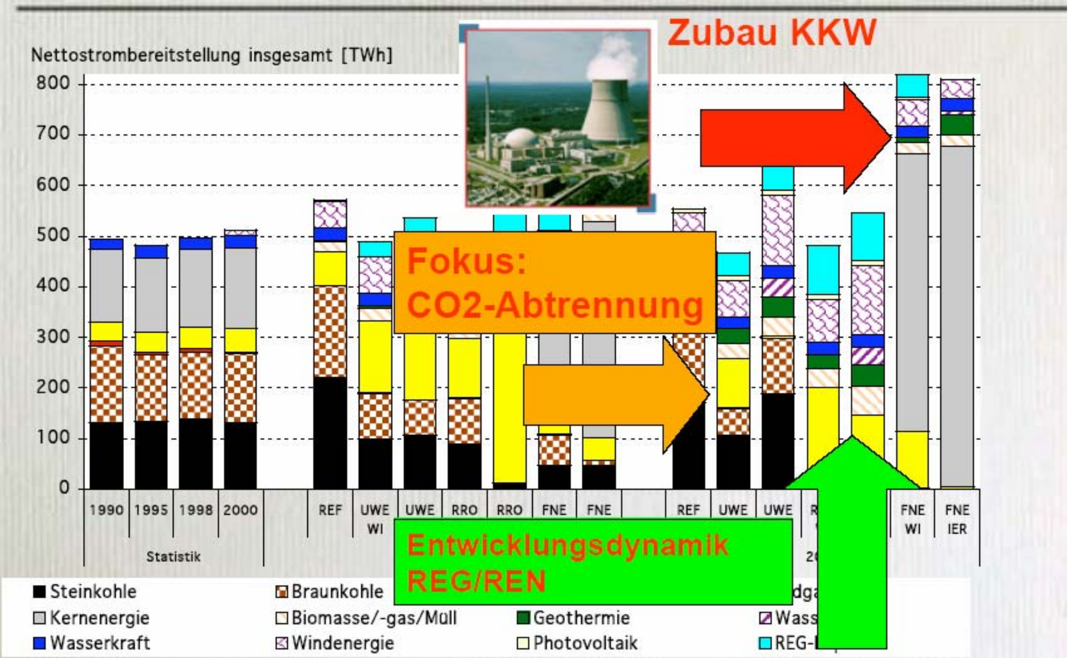
  - Frage nach einzeltechnologischen Optionen, die zur Erfüllung bestimmter Ziele eine kritischen Masse als Lösungsbeitrag beisteuern können (vgl. Wedges principle - Princeton University)

  - Frage nach Kernfragen der Energiewirtschaft aus Systemsicht

  - etc.

Generelle Bemerkungen zum Gutachten
Methodik bzw. Szenarioauswahl

Kommentar zur Studie über die Swiss Energy R&D Policy



Generelle Bemerkungen zum Gutachten
Technologieauswahl

Kommentar zur Studie über die Swiss Energy R&D Policy

- **Vermisste Technologien (speziell aus globaler Perspektive)**

  - Biogas (Vergärung, Methanisierung) als Kraftstoff/Energieträger, Einspeisung in das Erdgasnetz

  - (kleine) advanced Gas-Wärmepumpen

  - Ergänzende stärkere Fokussierung auf Systemlösungen statt Einzeltechnologien, z.B.

  a) Integration REG und dezentrale Optionen (inkl. Lastmanagement, Speicher etc.) in dezentrale Energiemanagementsysteme - gerade mit Blick auf Hd-futures

  b) hocheffiziente Büro-Gebäude (Verknüpfung Angebots- und Nachfrageseite)

  - Energieeffizienztechnologien Strom (effiziente Haushaltsgeräte, Bürokommunikation, eff. Antriebe in der Industrie etc.)

- **Vermisste Technologien (speziell aus globaler Perspektive)**

  - Nahwärmenetztechnik

  - Klimatisierung und Kühlung (inkl. solare Kühlung, passive Kühlung, KW(K)K)

  - Import von REG-Strom

  - Sozio-ökonomische Forschung (inkl. Akzeptanz- und Marktanalyse)

  - Anmerkungen zu Grenzbereichen:

  a) Materialeffizienz und ihr potenzieller Beitrag zur Energieeinsparung (z.B. material-effizientere Produktionsverfahren, neue Produkte)

  b) Energietechnologien, die nicht mehr vermeidbaren Klimawandel antizipieren (z.B. passive Kühlung)

Beispiel Systemlösung: Dezentrales Energiemanagement durch Technologieverknüpfung

Ausgewählte Vergleichsanalysen

Kommentar zur Studie über die Swiss Energy R&D Policy

- **Wie gehen andere bei der Technologieauswahl methodisch vor?**

  Expertenbefragung

  - European Energy Delphi Survey (2004)

  Typische Frage: Welche Technologien sind zum Zeitraum x von wesentlicher Bedeutung?

  Szenarioorientierte Technologieauswahl: Identifikation robuster Technologien (z.B IIASA)

  Lösungs- und systemorientierte Ansätze

  ⇨ das Denken in lösungs- und systemorientierten Ansätzen nimmt stark zu

Ergebnisse einer ersten europaweiten Energie-Delphi-Studie

Kommentar zur Studie über die Swiss Energy R&D Policy

- *Ein internationales Forschungskonsortium kommt in einer Delphi-Befragung zur Zukunft der europäischen Energieversorgung bis zum Jahr 2030 zu folgendem Ergebnis:*
- „Die befragten 670 Experten räumen durchgängig denjenigen Technologien die höchste Priorität ein, die den Energieverbrauch senken ("Steigerung der Energieeffizienz").
- Zudem zeichnet sich ein eindeutiger Trend zur dezentralen Energieversorgung ab und zum Ausbau von Speicherkapazitäten.
- Umstritten unter den befragten Experten war hingegen die Zukunft der Nuklearenergie“. (IZT, 12.5. 2005)

Identifikation robuster Technologien mit Hilfe der Szenarioanalyse

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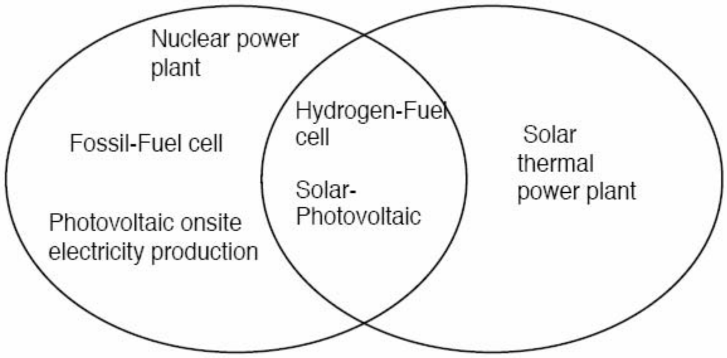
Successful Technologies in 2100 (scenario survey - over 400 scenarios): IIASA Sustainability-Scenarios/ Electricity Production



Most successful TP clusters

Most successful IS clusters

⇨ Defines market success clusters in SD scenarios

Lösungs- und systemorientierte Ansätze

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Energieforschungskonzepte im intern. Vergleich

- <u>**NRW:**</u> Road Map Energieforschung (in der Entwicklung)

  Schwerpunktthemen: Optimierung Kraftwerkspark, Systemintegration REG, effiziente Gebäude- und Siedlungsstrukturen, Kraftstoffe, nationalen und globale Energienetze

  lösungsorientierter Ansatz ★★★

  partizipativer Prozess ★★★

- <u>**Niederlande:**</u> Energy Research Strategy (EOS), minez, minvrom

  Schwerpunktthemen: Systemintegration (Netze), effizientes Bauen, new gas / clean fossil fuels; Biomasse, Effizienz (Industrie, Landwirtschaft)

  lösungsorientierter Ansatz ★☆☆

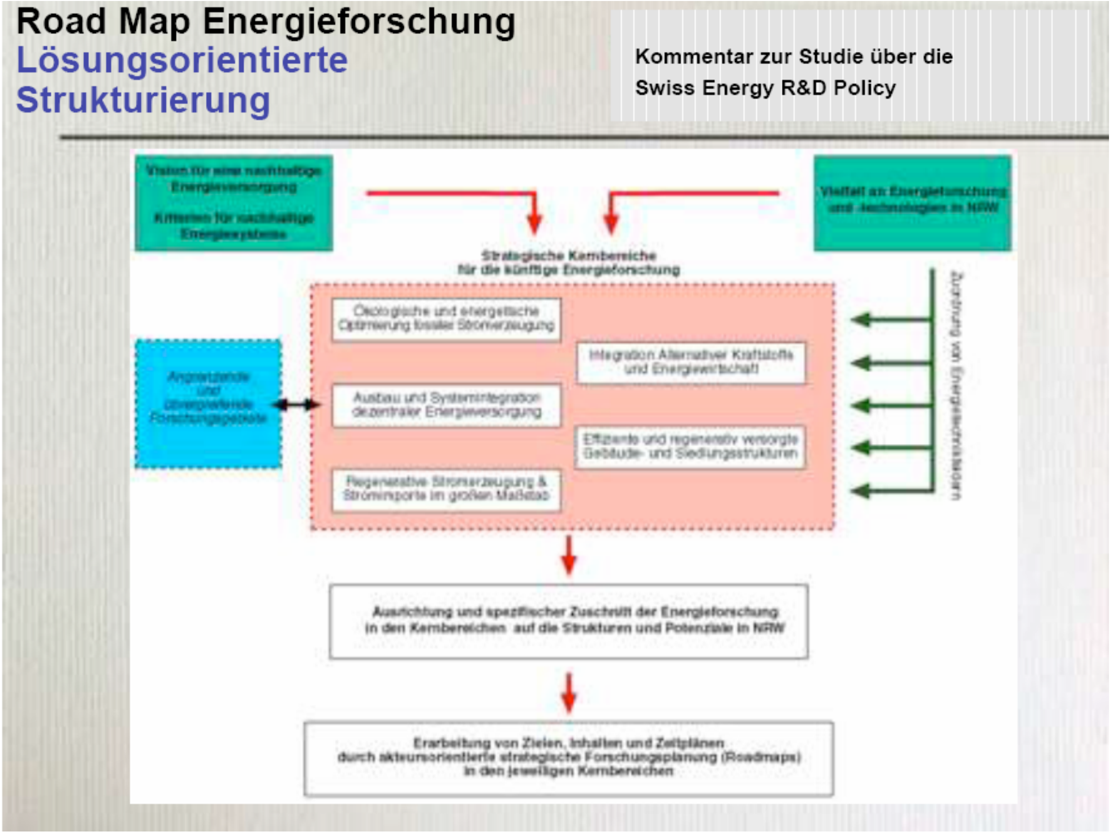
  partizipativer Prozess ★★☆

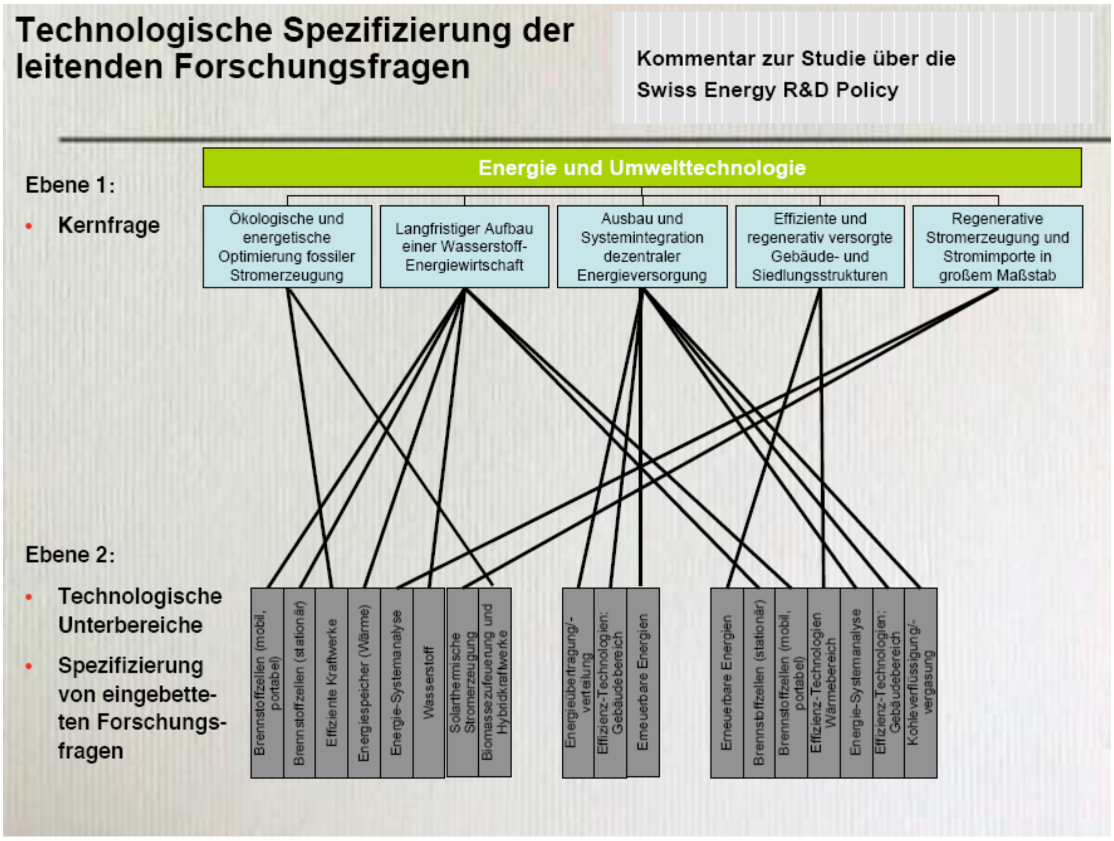
- <u>**Europäische Union (6. FRP):**</u>

  mittel-/langfristige Perspektive (DG RTD): eher Technologieorientierung (z.B.: „Neue u. fortschrittliche REG-Technologien“)

  Stärkere System-Lösungsorientierung im Bereich DG TREN: Fokus auf kurz-/mittelfristiger Perspektive (DG TREN): eher Systemorientierung (z.B.: Initiative CONCERTO mit Verbindung von

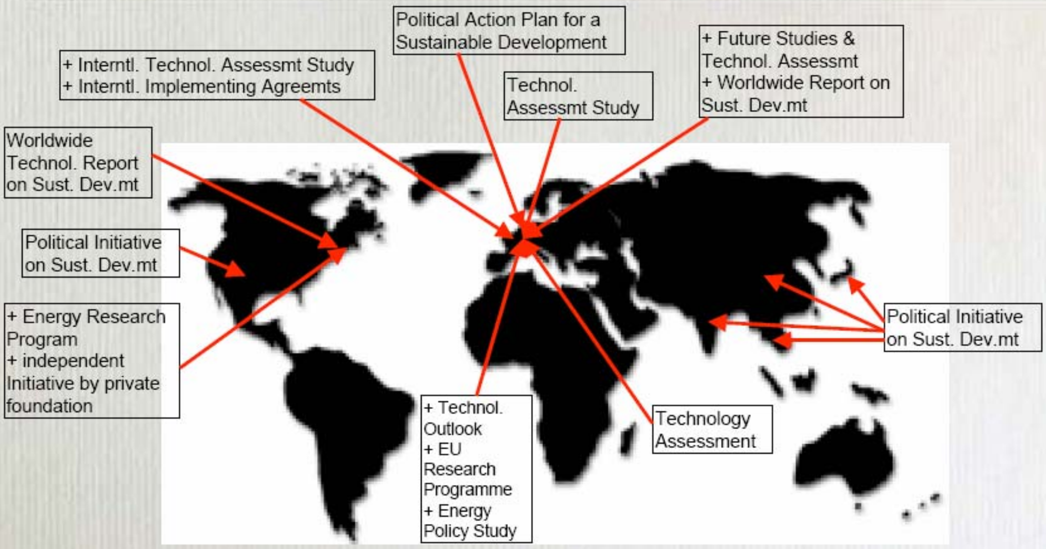
  (1) Großmaßstäblicher Integration REG
  (2) Eco-Buildings
  (3) Polygeneration (KWKK)


Road Map Energieforschung
Lösungsorientierte Strukturierung
Kommentar zur Studie über die Swiss Energy R&D Policy
Vision für eine nachhaltige Energieversorgung
Kriterien für nachhaltige Energiesysteme
Vielfalt an Energieforschung und -technologien in NRW
Strategische Kernbereiche für die künftige Energieforschung
Angrenzende und übergreifende Forschungsgebiete
Ökologische und energetische Optimierung fossiler Stromerzeugung
Integration Alternativer Kraftstoffe und Energiewirtschaft
Ausbau und Systemintegration dezentraler Energieversorgung
Effiziente und regenerativ versorgte Gebäude- und Siedlungsstrukturen
Regenerative Stromerzeugung & Stromimporte im großen Maßstab
Zuordnung von Energietechnikfeldern
Ausrichtung und spezifischer Zuschnitt der Energieforschung in den Kernbereichen auf die Strukturen und Potenziale in NRW
Erarbeitung von Zielen, Inhalten und Zeitplänen durch akteursorientierte strategische Forschungsplanung (Roadmaps) in den jeweiligen Kernbereichen


Technologische Spezifizierung der leitenden Forschungsfragen
Kommentar zur Studie über die Swiss Energy R&D Policy
Ebene 1:
• Kernfrage
Ebene 2:
• Technologische Unterbereiche
• Spezifizierung von eingebetteten Forschungsfragen
Energie und Umwelttechnologie
Ökologische und energetische Optimierung fossiler Stromerzeugung
Langfristiger Aufbau einer Wasserstoff-Energiewirtschaft
Ausbau und Systemintegration dezentraler Energieversorgung
Effiziente und regenerativ versorgte Gebäude- und Siedlungsstrukturen
Regenerative Stromerzeugung und Stromimporte in großem Maßstab
Brennstoffzellen (mobil, portabel)
Brennstoffzellen (stationär)
Effiziente Kraftwerke
Energiespeicher (Wärme)
Energie-Systemanalyse
Wasserstoff
Solarthermische Stromerzeugung
Biomassezufeuerung und Hybridkraftwerke
Energieübertragung/-verteilung
Effizienz-Technologien: Gebäudebereich
Erneuerbare Energien
Erneuerbare Energien
Brennstoffzellen (stationär)
Brennstoffzellen (mobil, portabel)
Effizienz-Technologien Wärmebereich
Energie-Systemanalyse
Effizienz-Technologien: Gebäudebereich
Kohleverflüssigung/-vergasung

Übersicht ausgewählter Untersuchungen aus dem Bereich Technologievorausschau

Kommentar zur Studie über die Swiss Energy R&D Policy



Representative cross section due to
a) Regional variety b) Coverage of all types of approaches (R&D programs, scenarios ...)

Quelle: Wuppertal Institut

Übersicht ausgewählter Untersuchungen aus dem Bereich Technologievorausschau

Kommentar zur Studie über die Swiss Energy R&D Policy

Technologieübersicht (spezieller Blickwinkel Klimaschutz und Versorgungssicherheit) vgl. Zielsetzung Untersuchung für die Schweiz

- **Efficient Coal Technologies**
  Supercritical power plants
  Carbon capture and storage (CCS)
- **Natural Gas / Gas Combined Cycle**
- **Decentralized Cogeneration Technologies**
  Fuel cells
  Microgasturbine
  Stirling
  Block-type thermal power station
- **Solar Appliances**
  Solar heating & cooling
  Solar thermal power stations
  Photovoltaic
- **Wind Energy**
- **Geothermal Energy**
- **Biomass Options**
  Efficient stationary use of biomass (cogeneration, gasification)
  Bio Fuels
- **Energy Efficiency Technologies**
  Efficient household appliances
  Efficient electrical propulsion
  LED
  Information- & communication technologies
  Industrial efficiency technologies
- **Energy Storage Systems**
- **Efficient Vehicles**

Denken in Systemlösungen nimmt zu (Beispiel: Systemlösungen aus dem Blickwinkel Klimaschutz und Versorgungssicherheit

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Thinking in Systems:

- **Efficient Buildings (Demand side)**

  Residential buildings with focus on passive houses

  Commercial buildings, (including air conditioning engineering,energy management)

  Sustainable cooling (including passive cooling, solar cooling)

- **Efficient Buildings (Supply side)**

  Efficient buildings + combined heating/cooling and electricity generation

Thinking in Systems:

- **Decentralized Intelligent Energy Systems** (including net connection, system integration, storage battery, virtual power stations
- **Rural Electrification** (including stand alone sytems)
- **New Fuels & Energy Carriers** (including Hydrogen)

Wo liegt der Fokus (Technologie-auswahl) in anderen Ländern?

Kommentar zur Studie über die Swiss Energy R&D Policy

- Ausgewählte Analysen
  - Europäische Union
    - Besondere Schwerpunkte heute (ERA-Nets)
    - 7 Rahmenprogramm
  - Energieforschungsprogramm Deutschland

Forschungsförderung der Europäischen Union

Kommentar zur Studie über die Swiss Energy R&D Policy

Forschungsfelder im 7. Rahmenprogramm (2007-2013)

(a) Health;
(b) Food, Agriculture and Biotechnology;
(c) Information and Communication Technologies;
(d) Nanosciences, Nanotechnologies, Materials and new Production Technologies;
(e) Energy;
(f) Environment (including Climate Change);
(g) Transport (including Aeronautics);
(h) Socio-economic Sciences and Humanities;
(i) Security and Space.

Forschungsförderung der Europäischen Union

Kommentar zur Studie über die Swiss Energy R&D Policy

Budget breakdown of the Seventh Framework Programme of the European Community (EC) (2007-2013) and Euratom (2007-2011) (in EUR million)

Themes (Using all funding schemes. Including international cooperation.)		Anteil Cooperation
Health	8317	18,7%
Food, Agriculture and Biotechnology	2455	5,5%
Information and Communication Technologies	12670	28,5%
Nanosciences, Nanotechnologies, Materials and new Production Technologies	4832	10,9%
Energy	**2931**	6,6%
Environment (including Climate Change)	2535	5,7%
Transport (including Aeronautics)	5940	13,4%
Socio-economic Sciences and the Humanities	792	1,8%
Security and Space	3960	8,9%
Total COOPERATION	**44432**	**100,0%**

Total COOPERATION	**44432**
IDEAS	
European Research Council	11862
PEOPLE	
Marie Curie Actions	7129
CAPACITIES	
Research Infrastructures	3961
Research for the benefit of SMEs	1901
Regions of Knowledge	158
Research Potential	554
Science in Society	554
Activities of International Co-operation	358
TOTAL CAPACITIES	7486
Non-nuclear actions of the Joint Research Centre	1817
TOTAL EC	**72726**

Energie ist ein „Mittelgewicht“ bei der Förderung

Forschungsförderung der Europäischen Union

Kommentar zur Studie über die Swiss Energy R&D Policy

- **7. Forschungsrahmenprogramm - Zielsetzung**
  - ¬ Technologien zu entwickeln, die einen Beitrag zur Lösung der wichtigsten Probleme (Aufgaben der Energiepolitik) leisten können
    - Verringerung der Importabhängigkeit
    - Klima- und Umweltschutz
    - Wettbewerbsfähigkeit (Wirtschaft)
  - ¬ Auswahl der unterstützten Technologien entsprechend ihres positiven Lösungsbeitrages

> - Increasing **energy efficiency**
> - Achieving a **properly functioning internal market** for gas and electricity for the benefit of all our citizens
> - Promoting **renewable energy**
> - Strengthening **nuclear safety and security**
> - Security of Europe's energy supplies and further developing **external energy policy relations**
> - Improving the **links between energy policies and environmental and research** policies

European Energy Priorities (Piebalgs 2005)

Forschungsförderung der Europäischen Union

Kommentar zur Studie über die Swiss Energy R&D Policy

- **7. Forschungsrahmenprogramm - Zielsetzung**
  - ¬ Technologien zu entwickeln, die einen Beitrag zur Lösung der wichtigsten Probleme (Aufgaben der Energiepolitik) leisten können
    - Verringerung der Importabhängigkeit
    - Klima- und Umweltschutz
    - Wettbewerbsfähigkeit (Wirtschaft)
  - ¬ Auswahl der unterstützten Technologien entsprechend ihres positiven Lösungsbeitrages
  - ¬ Aktivitäten umfassen alle Zeithorizonte und gesamte Kette von der Grundlagenforschung bis zur angewandten Forschung und Demonstrationsprojekt (Lighthouse projects)
  - ¬ Technologisch orientierte Forschung wird unterlegt mit cross-cutting Analysen und sozio-ökonomischen Betrachtungen
  - ¬ Integrierter Ansatz zwischen den relevanten stakeholdern wird angestrebt
  - ¬ „World leadership" in Kernbereichen der Energietechnologien

Forschungsförderung der Europäischen Union Woher kommen die Kernpunkte?

Kommentar zur Studie über die Swiss Energy R&D Policy

- **Besondere Schwerpunkte heute, die helfen sollen zukünftige Prioritätensetzung vorzubereiten**

  Technology platforms[1]

  - Hydrogen and Fuel cells

  - Photovoltaics

  - Biofuels

  - Zero emission power generation

  - Future electricity networks

1 Im Rahmen der Technlogy platforms soll die praktische Relevanz der Forschung sichergestellt werden. Die „strategic research agenda“ als ein output der Plattformen bündelt die F&E-Erfordernisse

Forschungsförderung der Europäischen Union

Kommentar zur Studie über die Swiss Energy R&D Policy

- **Besondere Schwerpunkte heute, die helfen sollen zukünftige Prioritätensetzung vorzubereiten:ERA-Net‘s**[1]

  - FENCO (The cleaner fossil energy coalition)

  - BIOENERGY

  - PV ERA Net (Photovoltaik)

  - HY-CO (Hydrogen Coordination)

  - ERABUILD (Buildings)

  - INNER(Innovative energy research) - Verknüpfung der Energieforschungskompetenz selber

1 ERA-Nets sind transnationale von der EU unterstütze Forschungsnetzwerke mit dem Ziel nationale F&E Anstrengungen miteinander zu verknüpfen und zu koordinieren

Forschungsförderung der Europäischen Union

Kommentar zur Studie über die Swiss Energy R&D Policy

- 7. Forschungsrahmenprogramm - Schwerpunkte Energie

  - Hydrogen and fuel cells (stationary, transport and mobile applications)

  Clear Goals based on Technology platform (incl. breakthrough in materials and emerging technologies)

  - renewable energies:

    ¬(integrated technologies for) electricity generation (special focus on wind, biomass and photovoltaics)

    ¬renewable fuel production (incl. new production technologies,logistics and distribution)

    ¬renewable for heating and cooling (incl. Industrial applications for seawater desalination, districts heating and cooling, energy storage)

Forschungsförderung der Europäischen Union

Kommentar zur Studie über die Swiss Energy R&D Policy

- 7. Forschungsrahmenprogramm - Schwerpunkte Energie

  - CO2-capture and storage technologies for zero emission power generation

  - clean coal technologies

  - smart energy networks (incl. Innovative ICT solutions, storage technologies for RES, feed in renewable gas into the natural gas grid)

  - energy efficiency and savings

    ¬technologies for buildings and industry

    ¬optimisation of local community energy system (incl. demand side management)

  - knowledge for energy policy making (incl. Modelling and scenarios, research regarding upcoming needs and uncertainties, e.g. climate change, massive fuel price increases)

Forschungsförderung der Europäischen Union

Kommentar zur Studie über die Swiss Energy R&D Policy

- **7. Forschungsrahmenprogramm - Schwerpunkte Verkehr**

  - greening of surface transport (rail, road, waterborne)

  (incl. alternative fuels and efficiency improvement)

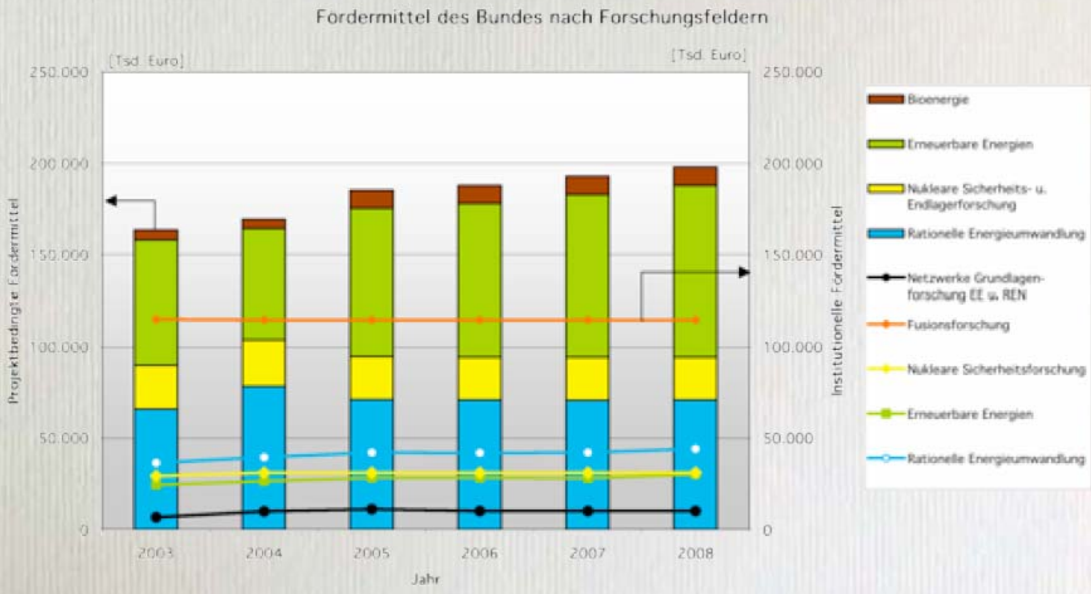
  Achtung: kein Schwerpunkt im Bereich Fahrzeug-Effizienz (nur indirekt angesprochen)

  - aeronautics and air transport

  - Support to the European global satellite navigation system (Galileo)

Forschungsförderung in Deutschland

Kommentar zur Studie über die Swiss Energy R&D Policy



Forschungsförderung in Deutschland

Kommentar zur Studie über die Swiss Energy R&D Policy

Übersicht über die Themen im 5. Energieforschungs-Programm der Bundesregierung

Ministerium	Forschungsfeld	Forschungsthemen	Strategien u. Ansatzpunkte
BMWA	Rationelle Energieumwandlung	Kraftwerkstechnik (Kohle, Gas)	Steigerung Energieeffizienz bei Kohle-DKW
			Steigerung Energieeffizienz bei GuD-kW
			CO2-Speicherung
		Brennstoffzellen	MCFC
			SOFC
			PEMFC
			DMFC
		Speichertechnologien und Wasserstoff	Leistungs-/Kurzzeitspeicher
			Energie-/Langzeitspeicher
			Beobachtung der H2-Grundlagenforschung (Material, Speicher)
		Energieoptimiertes Bauen	Optimierung Neubauten
			Optimierung Gebäudesubstanz
		Energieeffizienz (Industrie, Gewerbe, Handel, Dienstleistungen	aussichtsreiche High-Tech Entwicklungen (Zielgruppe KMU)
		Systemanalyse und Informationsverbreitung	Projekt "EduaR&D"
			BINE Info-Dienst

Ministerium	Forschungsfeld	Forschungs-themen	Strategien u. Ansatzpunkte
BMWA	Nukleare Sicherheits- u. Endlagerforschung	Reaktorsicherheitsforschung	
		Endlagerforschung	
		Kompetenzerhaltung und internationale Kooperation	
BMU	Erneuerbare Energien	Photovoltaik	
		Windenergie	
		HAT-Solarthermie	
		NT-Solarthermie	
		Geothermie	
		Wasserkraft und Meeresenergie	
		Ökologische Begleitforschung	
BMVEL	Bioenergie	Kraftstoffe	

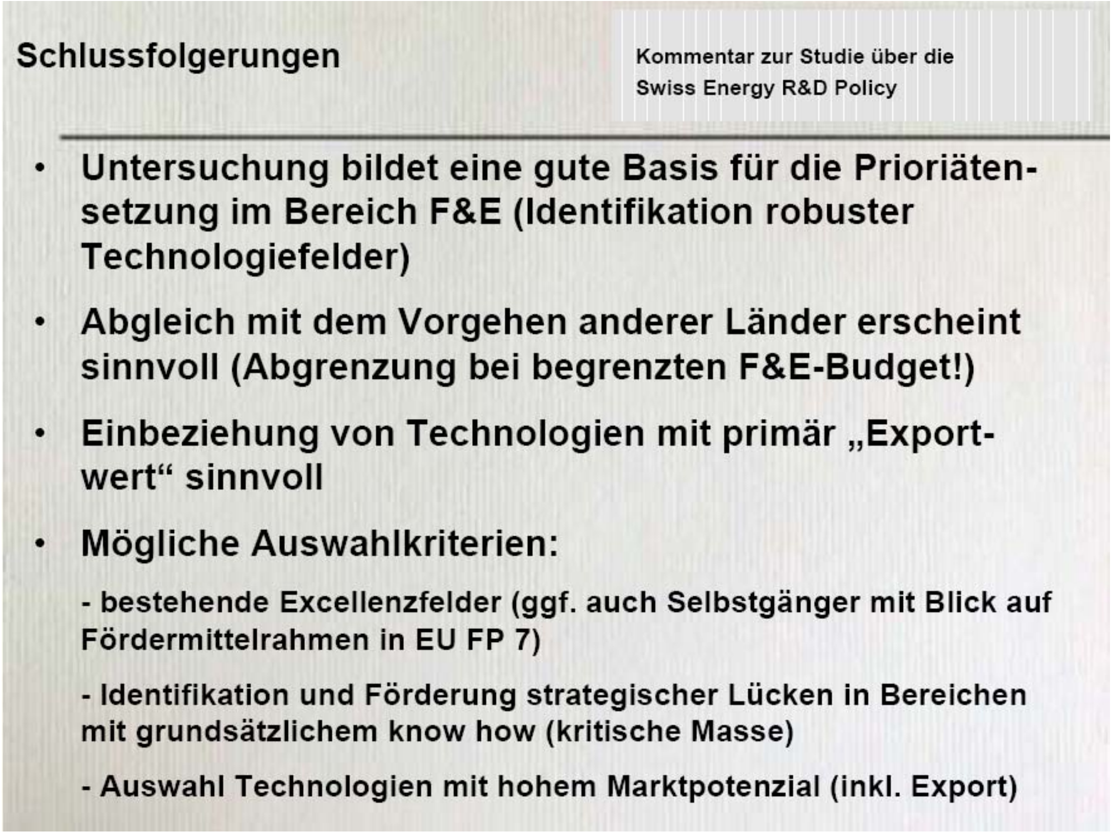
Institutionelle Förderung

Ministerium	Forschungsfeld
BMBF	Rationelle Energieumwandlung
BMBF	Erneuerbare Energien
BMBF	Nukleare Sicherheitsforschung
BMBF	Fusionsforschung
	Netzwerke Grundlagen-forschung EE u. REN

Forschungsschwerpunkte im Vergleich

Kommentar zur Studie über die Swiss Energy R&D Policy

		Schweiz (vorgeschlagen)	EU 7. RP		Deutschland	general technology focus (climate policy, energy security)
Case 1	1st order	low energy housing	X		x	x
		heat pumps	x	including gas heat pumps	(X)	x
		internal combustion engines vehicles (incl. hybrid)	-	focus: alternative fuels	(X)	x
				focus: clean coal technologies, biomass		
		gasification (esp. Biomass)	x	included in REN research	x	x
		advanced gasturbine technology	x	see above	x	x
		gas engine technology	x		(x)	x
		PEM fuel cell passenger vehicle	X		x	x
		hydrogen storage	X		x	x
		solid oxide technology (fuel cell)	X		x	x
	2nd order	electricity transport and distribution (efficiency improvements)	x	focus: integration renewables and decentralized options	x	x
		hydropower	x		(x)	x
Case 2	LdHfs	advanced nuclear reactors	x	EURATOM	-	x
		high temperature electrolysis	x		-	x
		thermochemical water splitting	x		-	x
		ethanol production	x	broad range of biofuels	x	x
Case 3	LdLfs	CO2 capture and storage	X		x	x
		natural gas steam reforming	x		x	x
Case 4	HdLfs	small scale reformer	x		x	x
Case 5	HdHfs	photovoltaics	X		x	x
		wind turbines	X		x	x
		geothermal heat and electricity	x		x	x
		PEM electrolysis	x		x	x
		zusätzlich:	clean coal technologies energy efficiency (industry, SME etc.) system analysis solar cooling		clean coal technologies energy efficiency (industry, SME etc.) system analysis nuclear safety research research concerning final disposal	clean coal technologies energy efficiency (industry, SME etc.) rural elctrification solar cooling



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3 Introduction

Energy R&D is an essential component in the design of an energy policy, which aims at providing a sustainable, secure and economical energy supply to a country. The Swiss Federal Energy Research Commission (CORE) has established a 'Roadmaps Working Group' in order to provide recommendations and guidelines in energy R&D that is expected to contribute to the achievement of a double objective for the next 50 years, namely a society of 2'000 watts per capita and of around 1 ton of CO_2 average annual emissions per capita. In this context, E4tech and CEPE have been asked to provide a contribution to the identification of technically promising technologies for the 2050 time horizon.
Regarding the time and resources allocated to this study (4 person months), an exhaustive assessment and a full roadmap analysis were not achievable, but an appropriate level of details provides conclusions robust enough to facilitate the formulation of recommendations from the CORE for priorities in energy related R&D.

Previous work undertaken by the 'Roadmap Working Group' has delivered four quantitative 'Objectives' the CORE believes to be necessary for the achievement of a sustainable energy supply in Switzerland, i.e.:

a) no use of fossil fuels for heating requirements in the building sector
b) a reduction by half of the energy consumption in the building sector
c) an increase of the share of biomass in the energy supply while using its full ecological potential
d) a reduction of the vehicle fleet's average fossil fuel consumption down to 3 litres per 100 km

The 'Roadmap Working Group' has also recently been investigating two scenarios for the Swiss energy supply till 2050 with the help of a modelling tool developed for that purpose: the reference scenario N (with nuclear power) and the reference scenario A (without nuclear power) [Zogg, 2004].
However, the observed difficulties setting priorities in the field of energy research, the need for more preliminary quantitative analysis, the need of locating the Swiss energy research within the international framework, and the need for a market perspective for energy technologies have led to this complementary work.

This new study has essentially performed the following tasks:

- ❑ a review of existing international literature dealing with medium-term energy supply visions,

- ❑ the identification of technically promising technologies for the achievement of the four given objectives based on a first order quantitative analysis, and of relevant related R&D activities,

- ❑ a discussion of the objectives formulated by the CORE 'Roadmaps Working Group',

- the assessment of existing R&D competences as well as of manufacturing capacities and capabilities for the retained technologies in the scientific and industrial arenas in Switzerland,

- and recommendations to the CORE on priorities to be set in R&D for an optimal achievement of the objectives formulated by the 'Roadmaps Working Group'.

The results contribute to answer questions such as:

- Do the given objectives look achievable, both separately and altogether, in the timeframe considered, i.e. by 2050 the latest? Where do they stand compared to other countries' objectives?
- What technologies offer good technical prospects in meeting the given objectives in the considered time frame, i.e. by 2050 the latest?
- What set of technologies would create significant value added to Swiss economy by inducing demand for domestic research and development activities?
- What set of technologies would improve the business position of the Swiss exporting industries?

First a review of international literature on medium-term energy supply visions is presented. Both worldwide energy supply studies and a selection of national energy supply studies with an emphasis on European countries have been reviewed.
Then the methodology used for the analysis is briefly discussed with, as a central point, the definition of 'Futures'.
A survey of R&D status and prospects of all technologies considered has been undertaken and the outcomes are provided as an appendix. Those are used as inputs for the quantitative analysis, which illustrates four possible 'Futures' for the Swiss energy supply by 2050.
The identification of promising technologies is based on results obtained from the qualitative and quantitative analysis. These results are then reflected against the framework of Swiss academic competences and strategies, and against industry views and capabilities apprehended with the help of published strategic documents such as the Axpo-Scenario but also with help of a patent analysis. A comparison of the results with strategies for energy research in the EU follows.
Finally, recommendations for the energy R&D technology strategy are proposed to the CORE based on the overall outcome.

4 Literature Review on Medium-term Energy Supply

4.1 Review of International Literature on Medium-term Energy Supply

Stabilisation of GHG concentration in the atmosphere and security of energy supply are subject to an intense international debate, source of abundant international literature on primary energy supply prospects or visions often supported by scenario analysis. The expected contribution of non fossil fuel resources and the potential for energy efficiency improvements play a central role in this debate.

Reviewing literature on medium-term energy supply contributes to answering the following questions:

– How do Swiss energy policy and related objectives formulated by the ‘Roadmap Working Group’ in the context of ‘Vision 2050’ compare with visions or prospects of a range of international studies?

– What range of technical and economic performance is assumed in international literature for the different advanced technologies considered by 2050?

– How does the global market for various advanced technologies look like by 2050 according to international literature?

Some experts advocate for major share of R&D funding towards fundamental research as according to them major technological breakthroughs are necessary to achieve stabilisation at a reasonable cost [Hoffert et al., 1998, 2002]. Emphasising fundamental research tends to delay measures of emissions reduction with the hope that the job can be done more effectively later on. Others argue that incremental improvement and diffusion of known advanced technology, encouraged with adequate policy, can meet the requirements [Pacala, Socolow, 2004]. Such a position is in favour of early action and implies a major share of R&D funding towards applied research, pilot & demonstration projects, and socio-economic issues related to the identification of market drivers and barriers.

Besides identifying what would be an adequate distribution of R&D funding between fundamental and applied research, another dilemma exists: shall it focus on a few supposedly very promising options and increase the chances to be competitive internationally, or maintain a high diversity of energy research activities in order to cope with a high degree of uncertainty? The right balance needs to be found given a very limited budget compared with worldwide R&D energy research funding.

Figure 4-1 is a possible illustration of priority setting in the field of R&D public funding of technologies depending on their technical potential on one hand, i.e. their potential contribution to meeting CORE’s objectives by 2050, and their economic potential on the other hand, i.e. the value added they could bring to the Swiss economy.

Obviously, first priority of R&D funding should be given to technologies, which show both high technical potential and high economic potential. Given the limited Swiss energy R&D budget in absolute terms (see Figure 4-3 and Figure 4-4),

funding priorities must be focused enough to maintain chances for Swiss energy research and industry to compete on a global market of technology development.
However, technologies that show high technical potential and medium economic potential, or vice versa, should be considered as well, although at a second level of priority, in order to insure a high enough degree of diversity in the energy research community. This allows accounting for the great deal of uncertainty associated with technology prospects, and implies greater interfacing with other research fields and thus greater probability for spin-off benefits.
Finally, evaluation of technical and economic potentials is based on current perception, and unexpected major breakthroughs that might occur in the near future could significantly alter the priority list. Technologies that show both technical and economic medium potentials should be kept in the picture of R&D funding in order to maintain the minimum know-how required for a fast adaptation to the occurrence of such unexpected events. For similar reasons, a technology associated with a low economic potential but with a high technical potential may also be considered for R&D funding.

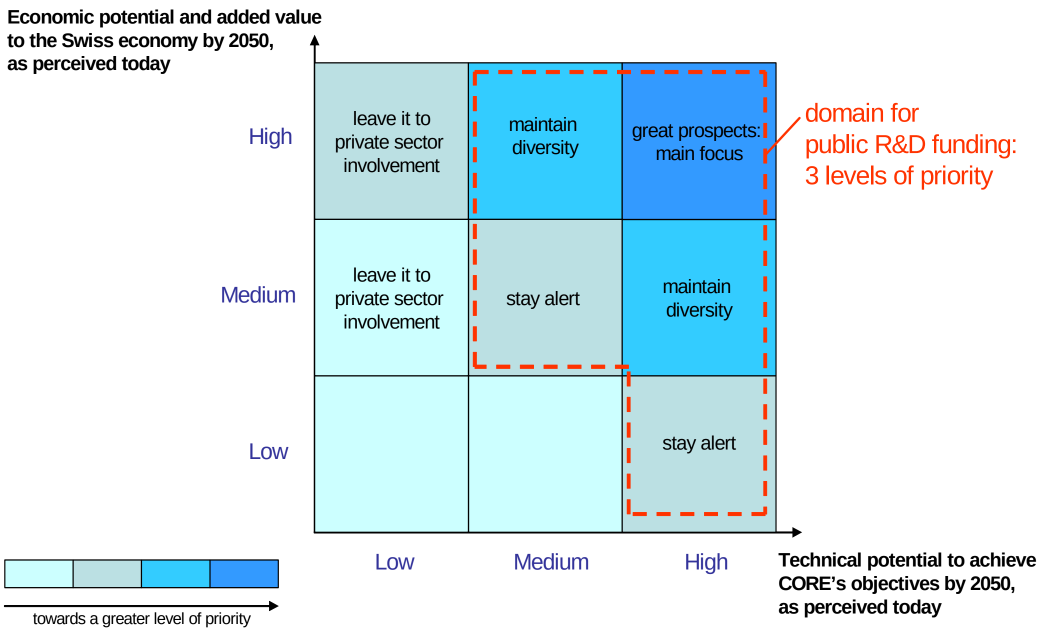


Figure 4-1: Setting priority in R&D public funding

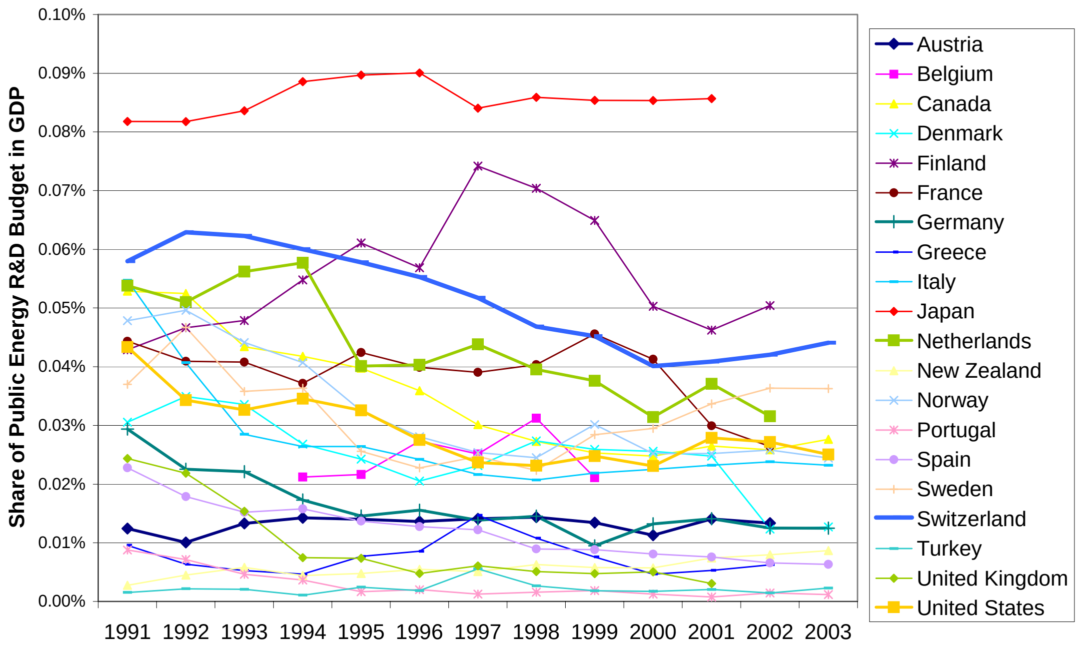


Figure 4-2: Share in GDP of public energy related R&D expenditures of OECD countries; Source: IEA R&D budget database. Please note that the EU-R&D budgets are not included.

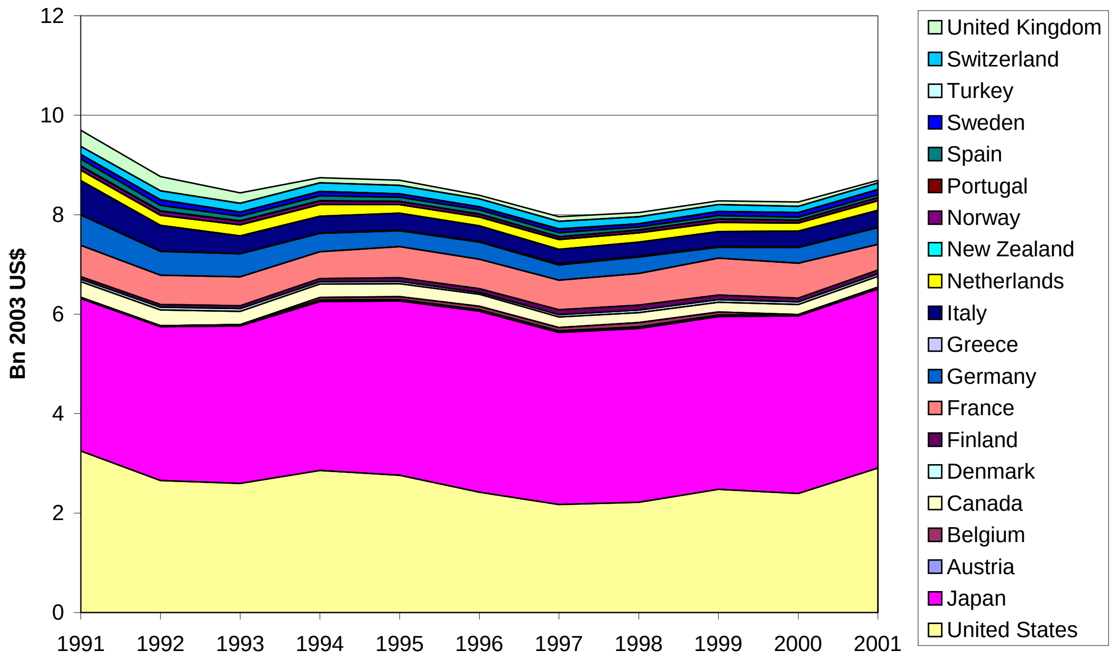


Figure 4-3: Public energy related R&D expenditures of OECD countries; Source: IEA R&D budget database. Please note that the EU-R&D budgets are not included.

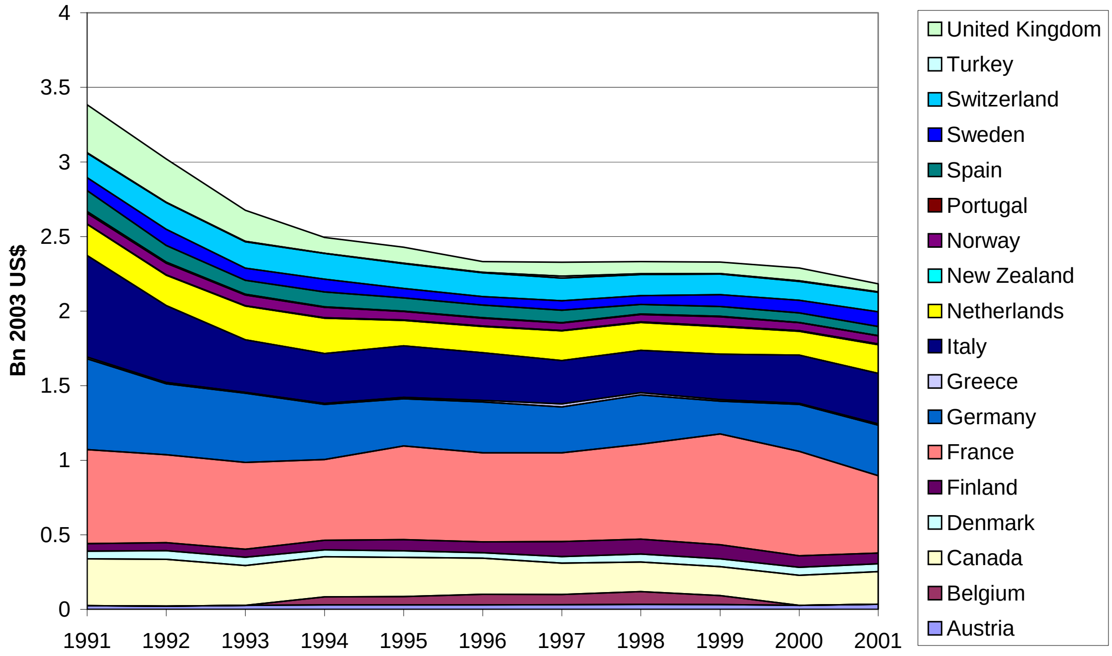


Figure 4-4: Public energy related R&D expenditures of OECD countries without US and Japan; Source: IEA R&D budget database. Please note that the EU-R&D budgets are not included.

A far from exhaustive list of published studies on worldwide energy supply prospects by 2050 is briefly described below. Irrespective of which scenario variant is taken as reference, it is however evident and largely undebated that a business as usual development of today would cause significantly growing primary energy consumption, growing CO_2 emissions and thus increasing CO_2 concentrations in the atmosphere.

A standard scenario often used as a reference is the IPCC's IS92a scenario [IPCC, 1992]. Assumptions used in this scenario result in a global decrease of energy intensity of 0.8% annually in the period to 2025, and 1.0% annually from 2025 to 2100. Following such a path would imply a 15% share of carbon neutral sources in the 708 EJ of global primary energy by 2025, and a 43% share of carbon neutral sources in the 1453 EJ of global primary energy by 2100. Such a scenario would, however, not lead to a stabilisation of the CO_2 concentration in the atmosphere. Initiating a still ongoing debate, [Hoffert et al.,1998] gave an estimate of the capacity of carbon free energy required in order to stabilise concentration of CO_2 in the atmosphere at 550 ppm, 450 ppm, and 350 ppm, respectively, for similar boundary conditions as the IS92a scenario (same level of primary energy consumption as can be seen in Figure 4-1). Results are 15, 25 and more than 30 TW, respectively. Today's total capacity is about 12 TW, of which 85% is fossil-based.

The most recent set of scenarios released by the IPCC [IPCC, 2000] involved six international modeling teams and resulted in 40 different scenarios, out of which 6 have been selected as 'illustrative scenarios' based on a consensus opinion: A1F1, A1T, A1b, A2, B1, and B2 – their associated respective renewable energy share by 2050 varies from 11 to 33% of 968 and 1213 EJ, respectively, of total annual primary energy supply. By 2050, the share of carbon neutral sources in the primary energy supply varies between 14 and 43% across all 40 scenarios with

primary energy supply ranging from 813 to 1431 EJ per year – see Figure 4-5. This range is due to different assumptions regarding demographic change, social and economic development, technological change, and modeling methodology.
The world Energy Council and IIASA published six scenarios with a renewable penetration ranging between 22 and 39% of 1042 and 596 EJ, respectively, of total primary energy consumption by 2050 – see Figure 4-6 [Nakicenovic et al., 1998].

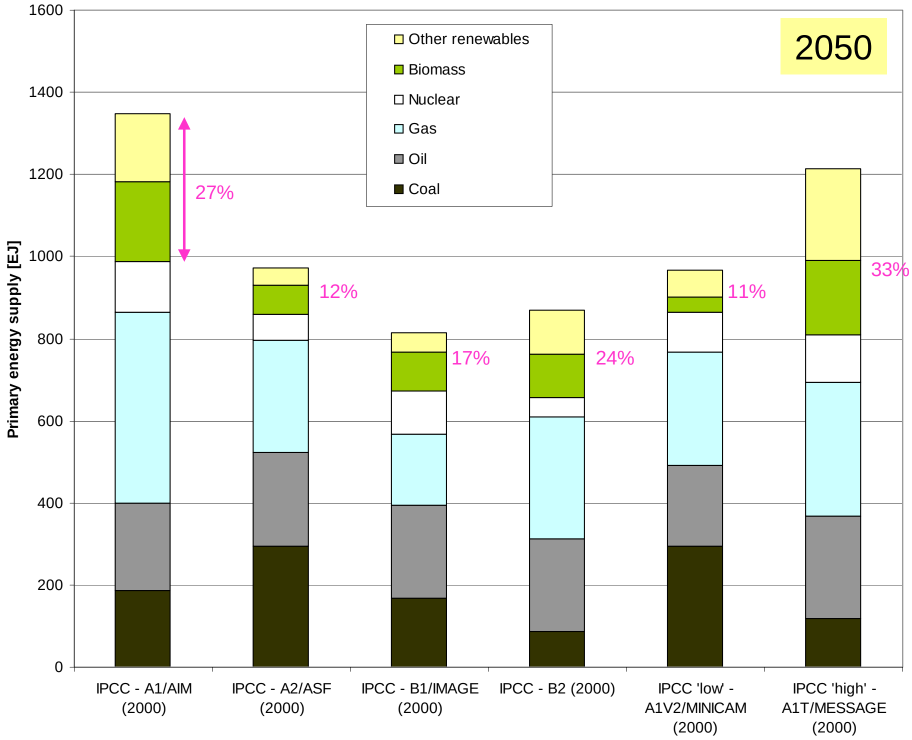


Figure 4-5: Six illustrative IPCC scenarios [IPCC, 2000].

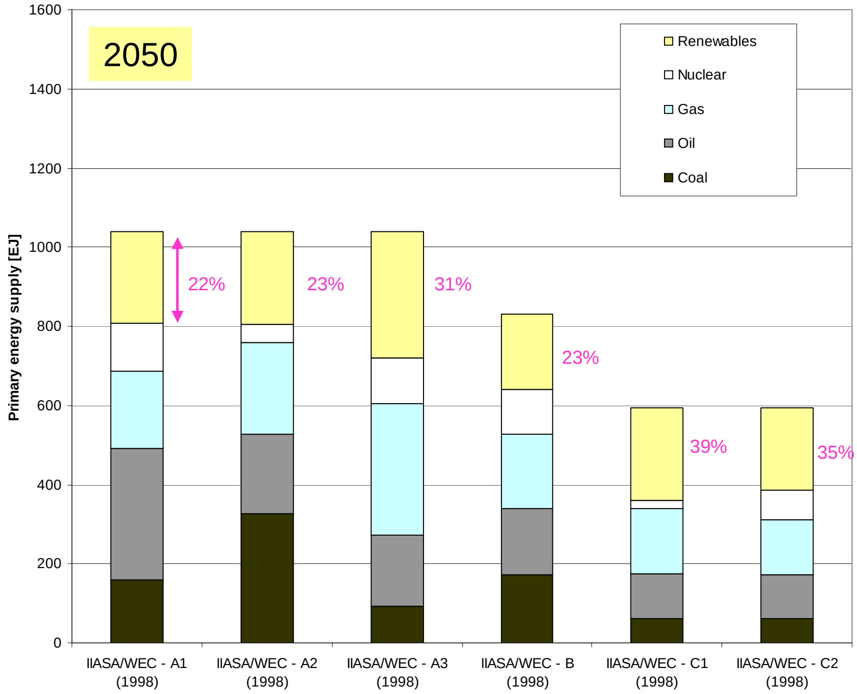


Figure 4-6: WEC/IIASA scenarios [Nakicenovic et al., 1998].

Two scenarios developed by Shell [Shell International, 2001] indicate significant renewable penetration with 33 and 28% of 854 and 1217 EJ, respectively, of total primary energy consumption by 2050. Biomass plays an important role in both scenarios with 52 and 108 EJ.
The International Solar Energy Society indicates a potential for a very high share of renewable sources with 50% of a total of 653 PJ primary energy supply by 2050 [Aitken, 2003].
The Wuppertal Institute and DLR published even more aggressive scenarios in terms of renewable energy penetration by 2050 with the 'Factor 4' scenario and its 62% share of renewable energy sources (total primary energy supply 426 EJ) [Hennicke, Lovins, 1999], and the 'Solar Energy Economy' scenario associated with a 77% share (total primary energy supply 653 EJ) [Nitsch, 1999].
By contrast, [Bauquis, 2001] expects a share of only 8% for renewable energy sources in the total primary energy supply of 754 EJ, i.e. a lower share than the current one.

All studies reviewed are displayed in a graph with the share of renewable energy sources in the primary energy supply as the horizontal axis, and the consumption of primary energy per capita as the vertical axis – see Figure 4-7. Today's world and Switzerland situations are also shown in that graph, as well as the situation in Switzerland by 2050 resulting from the two scenarios developed by the 'Roadmap Working Group' in a previous work [Zogg, 2004].
The graph illustrates two main families of visions. 'Target-oriented' scenarios are clearly more aggressive as they base the analysis on technical potential, and from there advocate for policies to be put in place to reach targets. The 'Roadmap Working Group' exercise clearly belongs to this family. Scenarios belonging to the other family tend to be much less optimistic as either they do not assume the

introduction of aggressive energy policies or they consider more or less severe limitation in the success of implemented policies.

Most scenarios on world energy supply by 2050 found in the international literature show an increase of the renewable sources fraction in primary energy supply together with an increase of primary energy consumption per capita. However, most pessimistic ones project a decrease of the renewable sources share, while most optimistic ones show a decrease of energy consumption per capita. In the studies reviewed, primary energy consumption per capita by 2050 ranges from 1.5 to 5 kW year per year while the renewable sources share in this primary energy supply ranges from 8 to 82%.

Such a wide diversity of views on the world energy supply by 2050 highlights the need for a methodology, which sets upfront a framework within which technologies can be assessed more objectively in terms of their potential for meeting CORE' objectives. This is done further with the definition of so-called 'Futures' characterised by different boundary conditions shaping the energy supply by 2050.

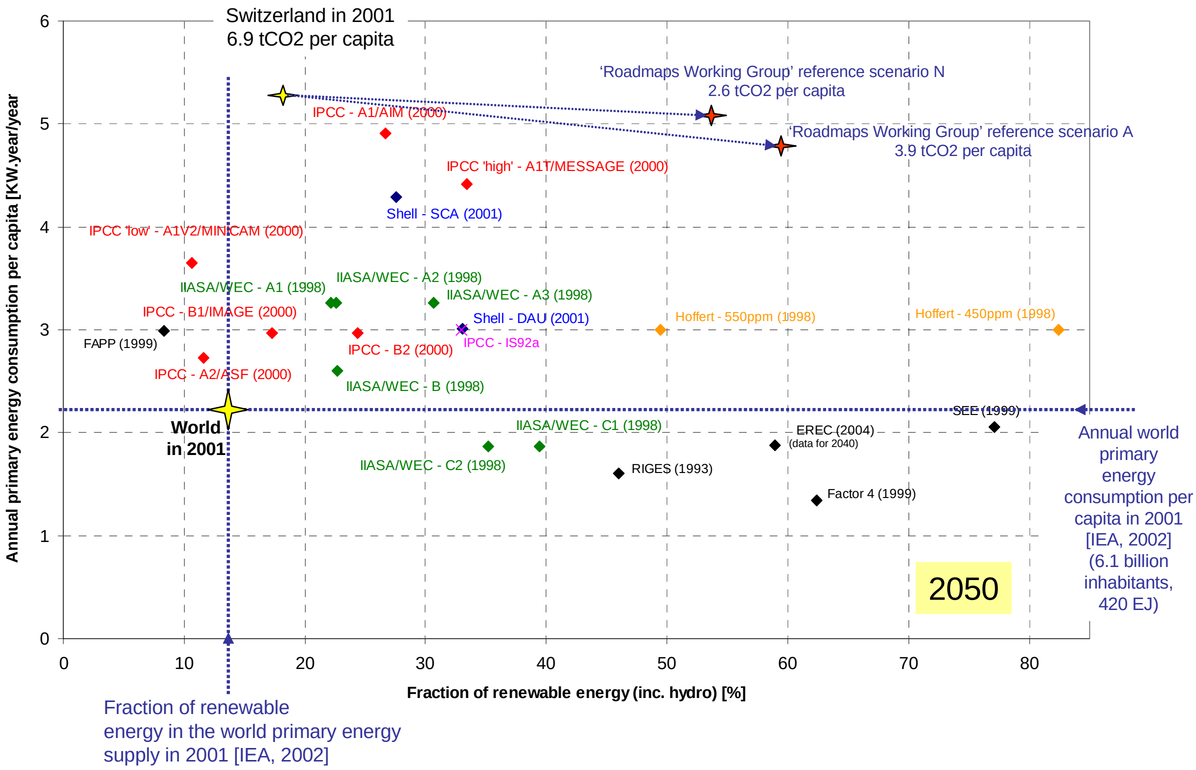


Figure 4-7: Review of international studies on world primary energy supply by 2050 (note: for Hoffert scenarios, points actually represent carbon free sources fraction required to meet indicated stabilisation targets and not necessarily only renewable energy fraction as nuclear can be considered as an option).

Other studies looking at worldwide energy supply prospects, which have been conducted on a shorter time frame basis are also of interest when discussing possible paths from the current energy supply situation to the one expected by 2050.

The IEA World Energy Outlook allocates a 6.4% share to renewable energy sources in the 643 EJ of total annual primary energy supply by 2030, most of it being combustible renewable and waste [IEA, 2002]. Nuclear is given a share of 4.6%.

The World energy, technology and climate policy outlook (WETO) looking at energy supply expects fossil fuels to still represent 90% of total world primary energy supply by 2030, with oil accounting for the largest share (34%). Renewable sources and nuclear altogether would account for about 20% of EU energy supply [European Commission, 2003].

Exxon Mobil expects a little more than 10% of 623 EJ of total annual primary energy supply to be met by renewable sources by 2020 [ExxonMobil, 2004]. Biomass represents the largest share, followed by hydro. Wind and solar altogether are given a share lower than 1%. Nuclear and renewable sources altogether would meet about 18% of the demand.

The European Renewable Energy Council (EREC) published a study on the potential of renewable energy sources to meet a substantial share of primary energy supply [EREC, 2004]. It argues that a target of close to 50% for the share of renewable sources in total world primary energy supply is achievable by 2040, if an aggressive environmental policy is generalised (total primary energy supply is based on IIASA work and is assumed to be 558 EJ). Biomass resources account for the largest share (close to 25%), followed by solar energy (10%) – see Figure 4-8. The study investigated two different scenarios respectively based on a moderate and an aggressive environmental policy framework. A set of growth rates for the various renewable energy sources was defined based on expert knowledge for both scenarios in order to derive the share of renewable sources by 2040 – see Figure 4-9.

Note that numbers derived are based on the Eurostat convention as it is the case for most of the reviewed studies. A calculation based on the substitution principle would lead to higher percentages.

In the advanced policy scenario:

- biomass shows a low but steady annual growth rate (between 2 and 3%) over the whole period.
- wind shows the greatest annual growth rate in the short term, with about 35% annually. However, this rate rapidly decreases to end up with less than 5% after 2030, when most of the suitable sites are exploited.
- photovoltaic, solar thermal electricity, marine power, and solar thermal show their highest growth rate between 2010 and 2020, with 30, 22, 22, and 16%, respectively.
- small hydro and geothermal show their highest growth rate between 2010 and 2020 with 10 and 8%, respectively.

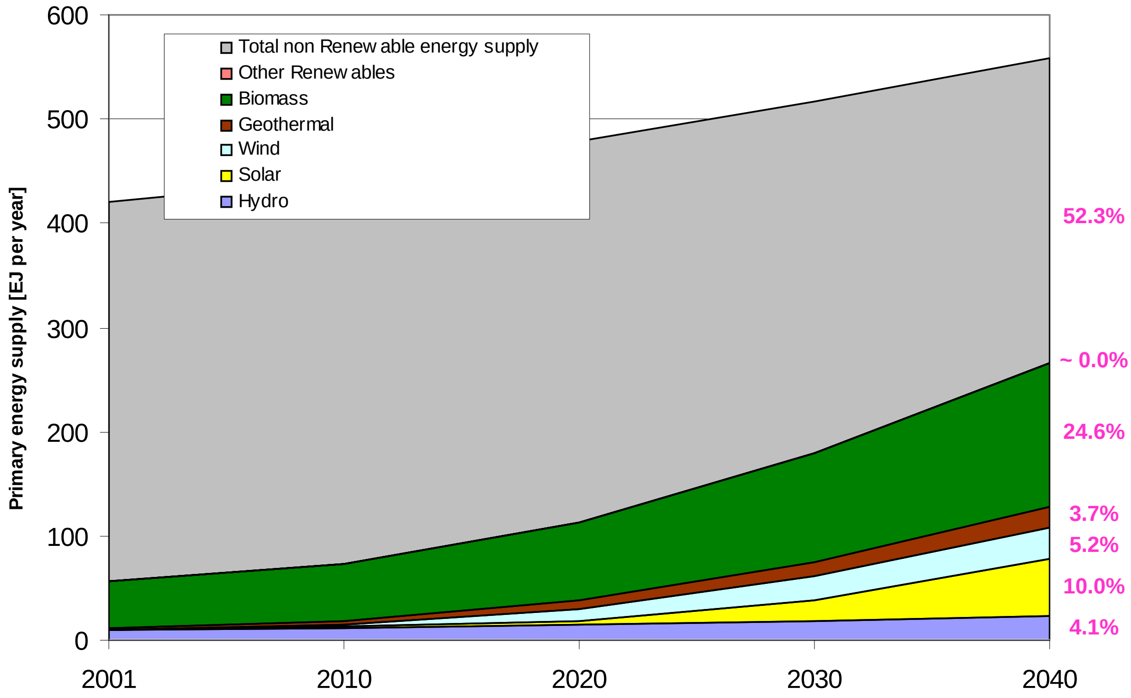


Figure 4-8: **EREC Advanced International Policy Scenario [EREC, 2004].**

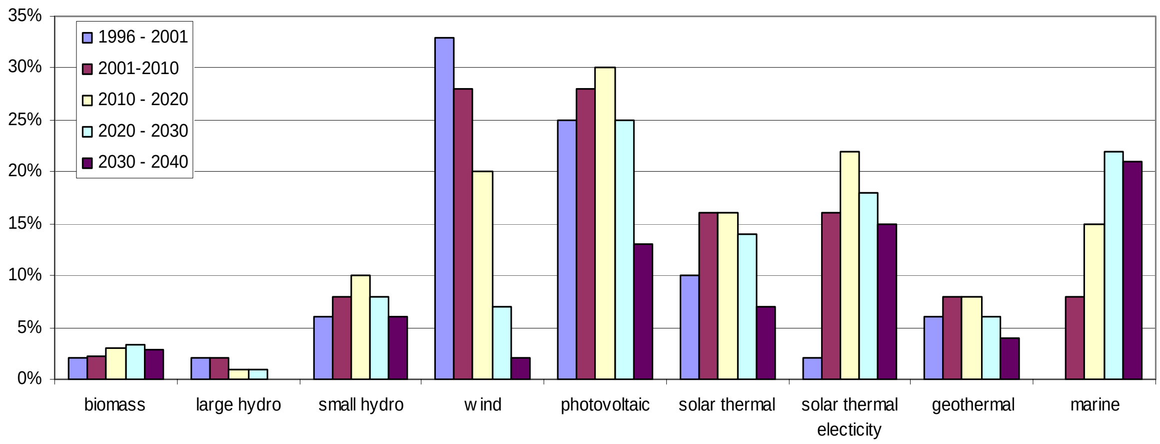


Figure 4-9: **EREC Advanced International Policy Scenario; average annual growth rates of various renewable sources [EREC, 2004].**

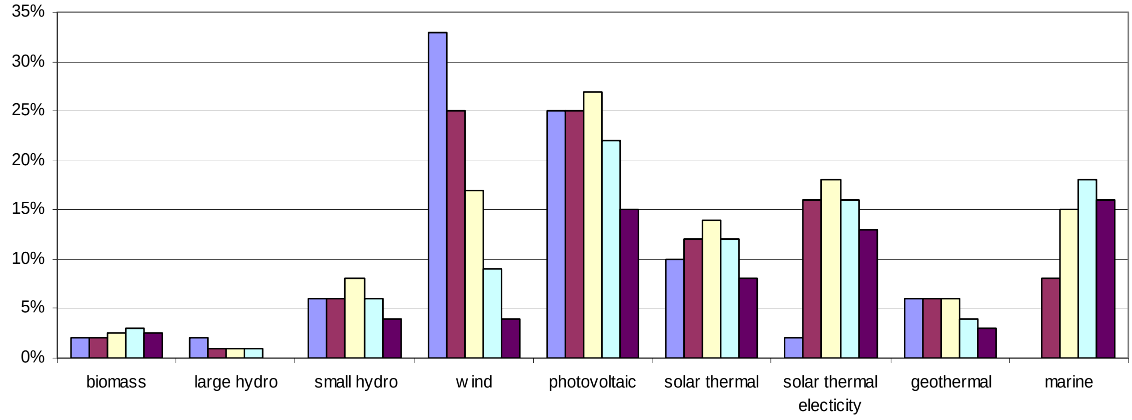


Figure 4-10: EREC Dynamic Current Policy Scenario; average annual growth rates of various renewable sources [EREC, 2004].

When compared with the technical potential associated to the renewable sources in the World Energy Assessment [Goldemberg, 2000], this vision leads to:

- the use of about 50% of the technical potential for world biomass resources or about 5% of the theoretical potential by 2050
- the use of about 3,5% of the technical potential for world solar resources, or about 0.001% of the theoretical potential by 2050
- the use of about 4,5% of the technical potential for world wind resources, or about 0.5% of the theoretical potential by 2050
- the use of about 0.4% of the technical potential for world geothermal resources, or about 0.0% of the theoretical potential by 2050
- the use of about 46% of the technical potential for world hydropower resources, or about 16% of the theoretical potential by 2050

Table 4-1: Technical potential associated to the renewable sources in the World Energy Assessment [Goldemberg, 2000].

Resources	Technical Potential	Theoretical Potential
Biomass	>276	2'900
Solar	>1'575	3'900'000
Wind	640	6'000
Geothermal	5'000	140'000'000
Hydropower	50	147
Ocean	-	7'400

4.2 *Review of National Studies on Medium-term Energy Supply*

Studies undertaken on a national level tend to focus on shorter term issues, for example on the first commitment period of the Kyoto Protocol. Some studies looking at the 2050 time horizon have however been conducted. This section does not provide an exhaustive review but briefly presents a few examples – Germany, France, the United Kingdom, and the United States.

Germany is of particular interest as a neighbour country, which pursues an aggressive policy for the promotion of renewable energy, which has taken the decision to progressively phase out nuclear, and which is among the leaders in hydrogen R&D activities.

France is of particular interest as a neighbor country, which has very low carbon intensity in the power sector similarly to Switzerland, and which is a leading country in nuclear R&D activities.

United Kingdom is of particular interest as this country is willing to take the lead in climate change mitigation activities within the European Union and set itself an aggressive CO_2 reduction target by 2050.

Finally, the United States are of particular interest due to their leading role in R&D activities, together with Japan.

4.2.1 Germany and Energy Supply Prospects by 2050

The German official forecasting of the energy markets "Die Entwicklung der Energiemärkte bis zum Jahr 2030" is to be published in the near future. The preceding study from the year 1999 has a forecast horizon of 20 years only and lacks actuality.[1]

In terms of time horizon and target orientation, the scenarios and model runs for the Parliamentary Enquete Commission for Energy of the 14th German Bundestag are most appropriate for the appraisal of the CORE targets [Prognos/IER, 2002].

The prospects developed for the Enquete Commission contain several scenarios. On top, due to the political nature of the parliamentary work, the scenarios have been modelled twice. Each scenario model was calculated by two different institutions, the Wuppertal Institute and the Institute of Energy Economics and the Rational Use of Energy (IER, University of Stuttgart). The modelling has been guided by the Swiss institute Prognos.

For the purpose of comparison with the CORE targets the reference scenario and the scenario "Renewables and Efficiency Push" are summarised below.

The **reference scenario** for the Enquête Commission is based in principle on the continuation of already implemented energy and environmental policy measures. With the course of time e.g. the existing building standards will be improved. The energy efficiency in the different energy consuming sectors is developing according to the existing trends. The reference scenario does not imply specific targets on CO_2 emissions reductions that have to be met in the model calculations.

The scenario **"Renewables and efficiency push"** is characterised by a distinct increase in the combined use of efficient technologies for energy conversion and

[1] The forecast study has been published meanwhile but had not been available when this report has been written.

energy use. In parallel, the forced development of renewable energies is taking place. The principle of energy service and contracting has fully penetrated the sectors of energy use. Taxation of energy on a European level increases the costs for the use of energy. Decentralised power generation is increasingly gaining importance. The capture and storage of CO_2 is excluded from the list of technology options. The Ren/eff-push scenario is a target oriented scenario with a reduction target of -80 % of CO_2 emissions with respect to 1990.
Socio-economic framework assumptions for both scenarios are briefly summarised below:

- Time horizon 2000 to 2050
- Average GDP growth of 1.4 % (1.8 % growth of GDP per capita due to shrinking population)
- Floor area of residential buildings increasing from 3.3 bn m² to 3.9 bn m²
  (40.2 m²/cap to 58.6 m²/cap)
- Passenger transport increases from 968 bn person kilometres to 1027 bn pkm
- Freight transport increases from 483 bn ton kilometres to 964 bn tkm

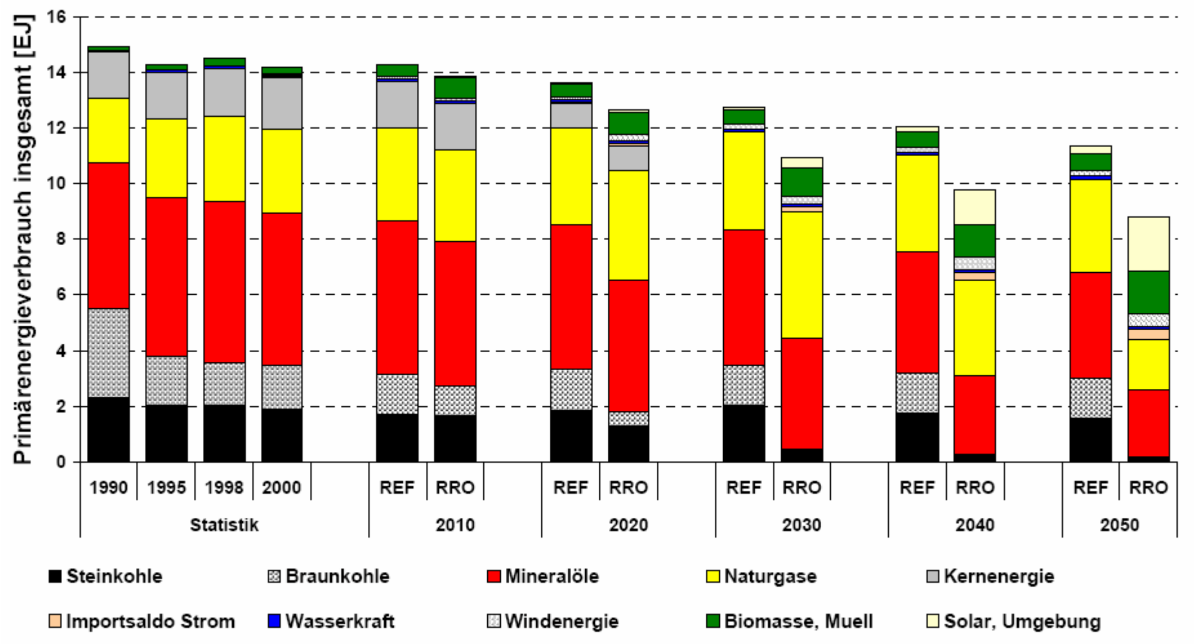


Figure 4-11: Primary energy supply in the two selected scenarios for Germany; Source: [Prognos/IER – Szenarienstudie, 2002].

Table 4-2: Results of the 'reference scenario' of the Enquête Commission; Source: [Prognos/IER, 2002]

Final energy consumption in the reference case model run of IER for the Enquête Commission					
Year	Industry	Tertiary sector	Households	Transport	Total
2000	2430	1472	2550	2745	9197
2010	2509	1518	2841	2838	9705
2020	2508	1511	2865	2757	9641
2030	2486	1526	2710	2639	9362
2040	2401	1494	2461	2485	8842
2050	2299	1389	2221	2299	8208
Reduction in energy demand	5.4%	5.6%	12.9%	16.2%	10.8%

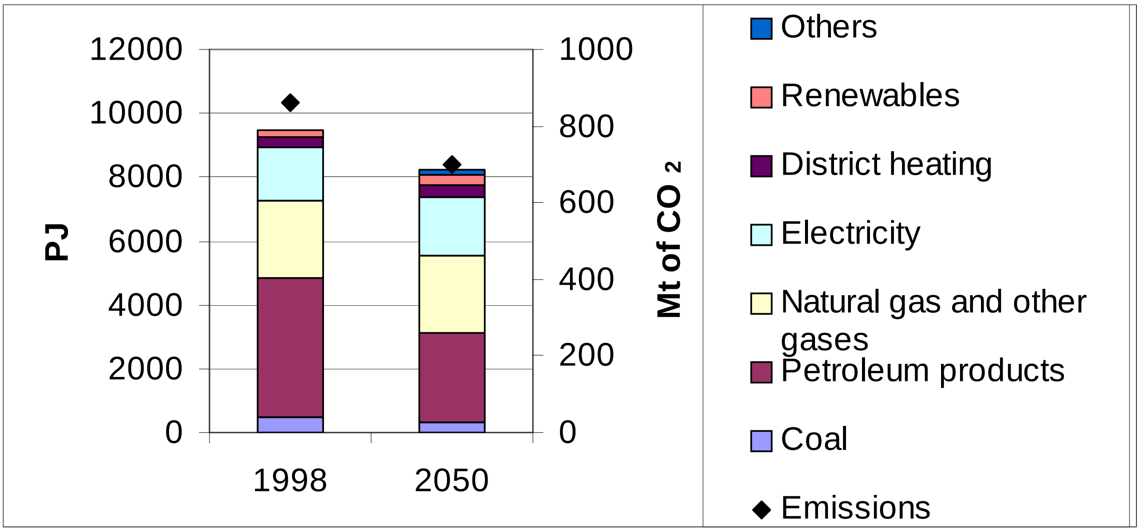


Figure 4-12: Structure of final energy consumption in the Reference Case and CO_2 emissions for the reference scenario of the Enquête Commission; Source: [Prognos/IER, 2002]

Table 4-3: Results of the 'renewables and efficiency push' scenario of the Enquête Commission; Source: [Prognos/IER, 2002].

Final energy consumption in the Ren/Eff-push case model run of IER for the Enquête Commission					
Year	Industry	Tertiary sector	Households	Transport	Total
2000	2397	1576	2779	2692	9444
2010	2479	1497	2789	2738	9503
2020	2401	1472	2748	2566	9187
2030	2214	1466	2450	2351	8481
2040	1897	1395	2128	2085	7505
2050	1530	1057	1654	1669	5910
Reduction in energy demand	36.2%	32.9%	40.5%	38.0%	37.4%

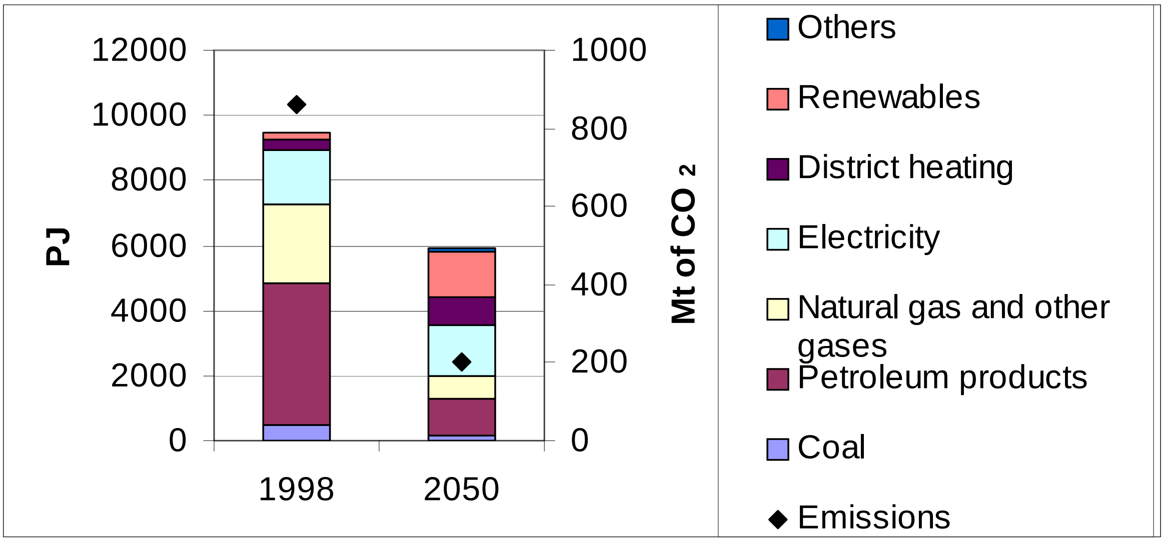


Figure 4-13: Structure of final energy consumption in the Reference Case and CO_2 emissions for the reference scenario of the Enquête Commission; Source: [Prognos/IER, 2002].

4.2.2 France and Energy Supply Prospects by 2050

Results from a study commissioned by the 'Direction Générale de l'Energie et des Matières Premières' (Ministère de l'Economie, des Finances et de l'Industrie) and coordinated by Enerdata have been released very recently [ENERDATA, 2005]; the study investigates energy supply prospects up to 2050, using the modeling tools MEDEE and POLES.
The aim of the study was to assess the feasibility of a so-called 'factor 4' scenario, i.e. the reduction of GHG emissions by a factor 4 relatively to 1990 levels, promoted by the French 'Plan Climat' for the 2050 time horizon.
The authors underline the fact that the models used are well adapted to projections up to 2030. Beyond this time horizon, results must be used with caution as uncertainties about cost and performance of technologies considered, due for example to a possible shift towards a radically different approach for energy supply, e.g. a much greater contribution of decentralised generation, would significantly affect the demand-supply equilibrium computed.
Apart from the 'Business as Usual' scenario, one alternative scenario has been investigated so far which leads to a generalised use of electricity for final energy requirements and to a share of nuclear energy as large as 56% of the 8164 [PJ] of total primary energy by 2050[2]. As the authors indicate, it is not certain that the availability of uranium or thorium would be sufficient to meet such requirements, and that establishing such a share of nuclear capacity in the given time frame is difficult.

The total capacity of renewable energy sources by 2050 is similar in both scenarios: 1591 PJ for the 'Factor 4' scenario, versus 1297 PJ for the BAU scenario. However, in terms of shares, the 'Factor 4' scenario leads to 19% renewable energy use versus only 9% in the BAU scenario due to a 43% lower total primary energy consumption.

[2] Note that in the mean time, several other scenarios have been released.

The shares of the various resources in the final energy consumption for the industrial sector, the transport sector, and the residential, commercial and agriculture sector are indicated in Figures 3.16 to 3.19.
While in the BAU scenario, oil still represents about 89% of transport final energy consumption by 2050, the 'Factor 4' scenario reduces its consumption by about 3 down to 950 PJ, accounting then for about 53% of the total final energy consumption. Electricity is the main substitute, followed by hydrogen with respective shares of 30 and 13%. Biofuels play a role in the advanced scenario with up to 3% while their contribution is negligible in the BAU scenario.
The evolution for private vehicles is based on a progressive reduction of the average specific CO_2 emissions rate from 140 g $_{CO2}$ per km in 2008 to 30 g CO_2 per km in 2050. By then, 40% of the vehicles are supposed to be pure electric vehicles (urban environment) and 30% of them fuel cell vehicles running on hydrogen. The remaining 30% are shared between hybrid vehicles (45%), and gasoline and diesel vehicles (55%) with a 10% biofuels blend.

The public transportation usage by road and train increases from 2000 km per capita and per year in 2001 to 6700 km per capita and per year in 2050, with two third of it on fast speed trains.
In the residential sector, ultra low consumption housings are progressively introduced, with one third of the new buildings from 2010 to 2020, two thirds from 2020 to 2030, and 100% beyond. In addition, 25% of the existing building stock is refurbished every 10 years starting in 2010.
In the commercial sector, new buildings are becoming 15% more efficient every 10 years, and refurbishment is undertaken on the same basis than for residential buildings. A fraction of 20% of the building stock is connected to district heating based on wood, waste or geothermal energy.

Also in the residential sector,

- 20% of the building stock is assumed to be connected to district heating based on wood or waste resources;
- starting in 2010, half of the new residential buildings are supposed to be equipped with solar thermal providing 50% of their heat requirements – complement with electric heating;
- starting in 2005, all new individual housing and 25% of the existing individual housing every 10 years, are supposed to be equipped with solar thermal providing 70% of their heat requirements – complement with electric heating;
- electricity requirements not related to heating are maintained at the level of 2010.

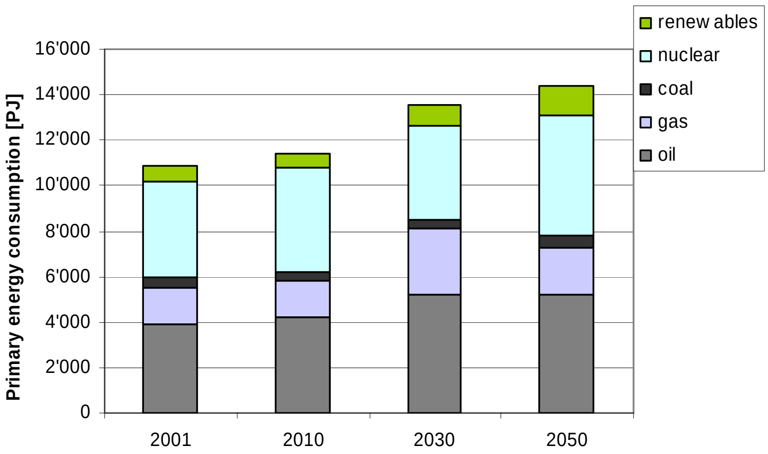


Figure 4-14: **Results in terms of total primary energy consumption of the ENERDATA study on medium-term energy supply in France for the 'Business as Usual' scenario. Source: [ENERDATA, 2005]**

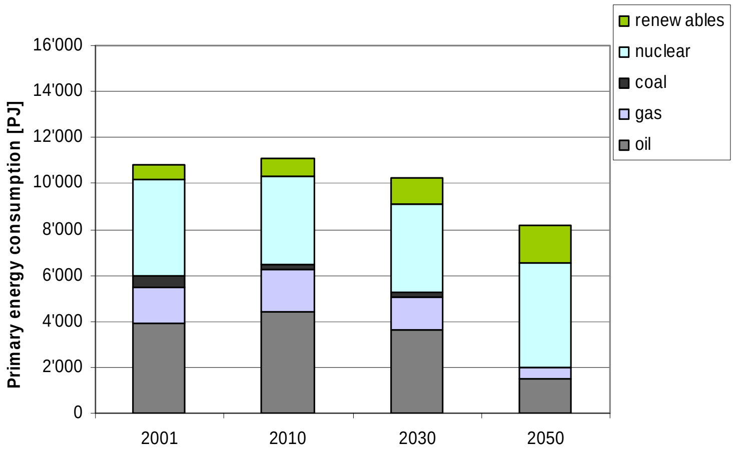


Figure 4-15: **Results in terms of total primary energy consumption of the ENERDATA study on medium-term energy supply in France for the 'Factor 4' scenario. Source: [ENERDATA, 2005]**

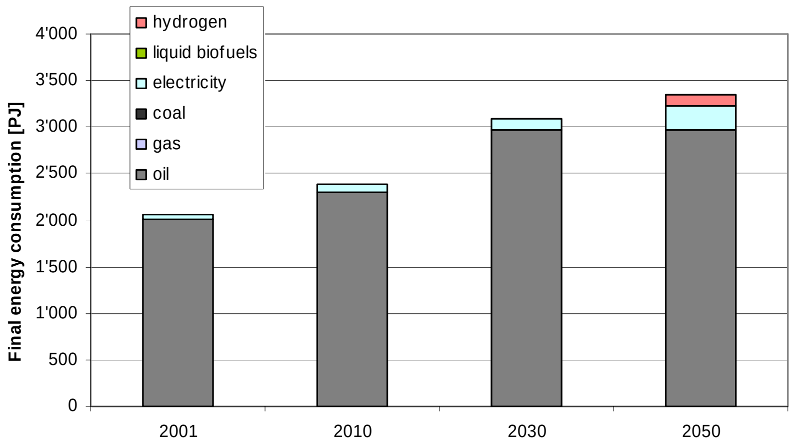


Figure 4-16: **Results in terms of primary energy consumption in the transport sector of the ENERDATA study on medium-term energy supply in France for the 'Business as Usual' scenario. Source: [ENERDATA, 2005].**

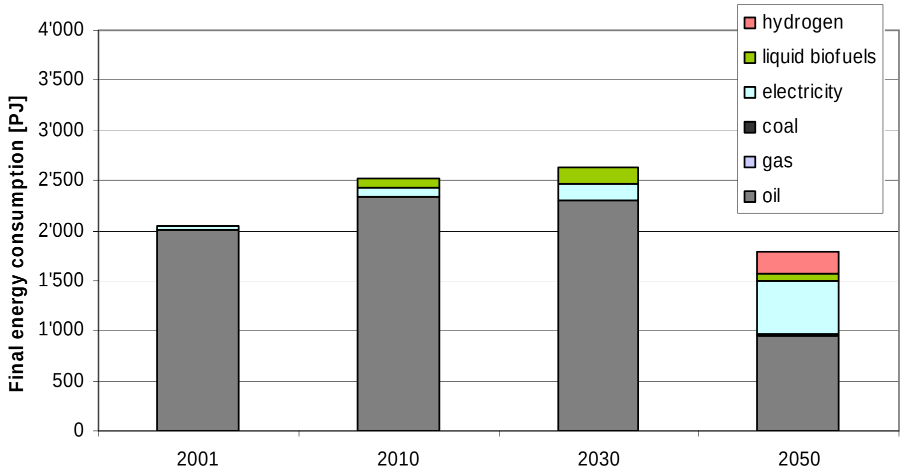


Figure 4-17: Results in terms of primary energy consumption in the transport sector of the ENERDATA study on medium-term energy supply in France for the 'Factor 4' scenario. Source: [ENERDATA, 2005].

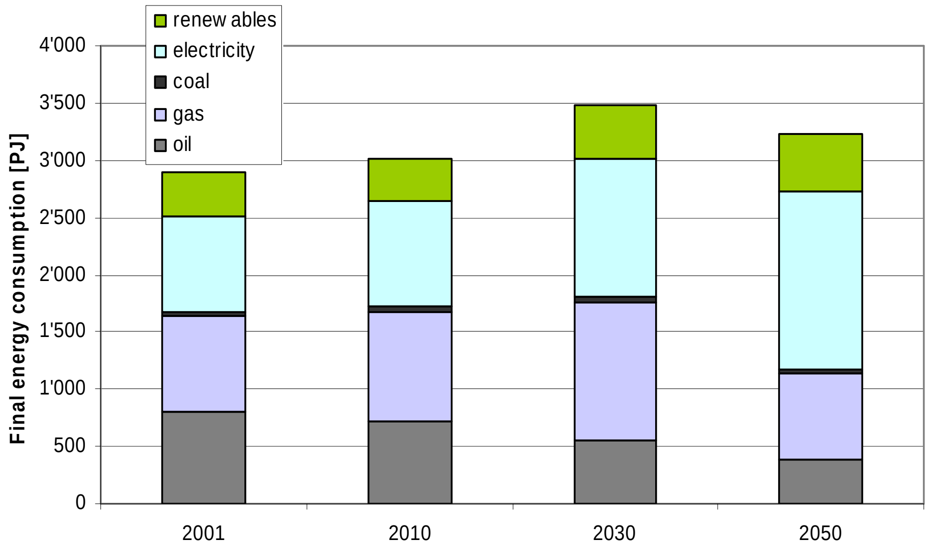


Figure 4-18: Results in terms of primary energy consumption in the residential & commercial sector of the ENERDATA study on medium-term energy supply in France for the 'Business as Usual' scenario. Source: [ENERDATA, 2005].

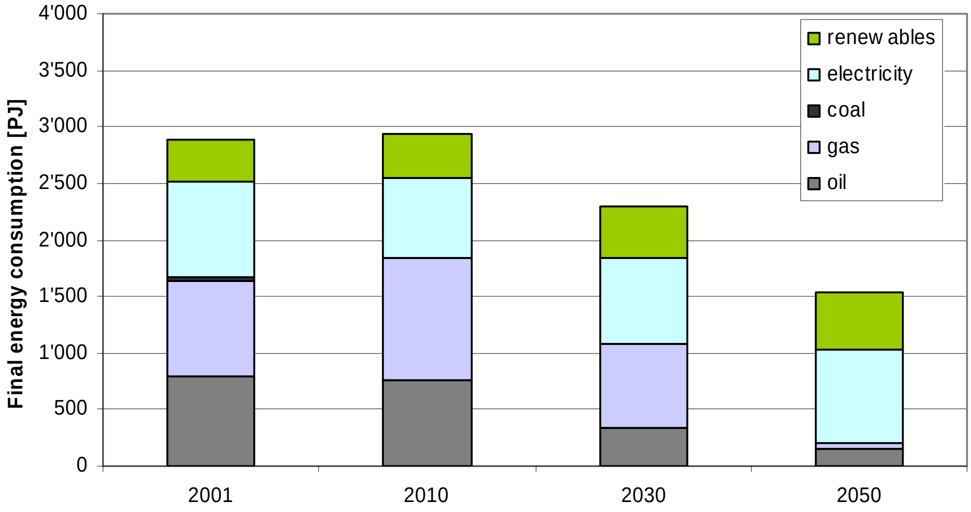


Figure 4-19: Results in terms of primary energy consumption in residential & commercial sector of the ENERDATA study on medium-term energy supply in France for the 'Factor 4' scenario. Source: [ENERDATA, 2005].

4.2.3 The UK and Energy Supply Prospects by 2050

The United Kingdom's Energy White Paper calls for a 60% carbon emissions cut by 2050 relatively to 1997 levels together with a maintained reliability of energy supplies and the promotion of competitive markets in the UK and beyond, helping to raise the rate of sustainable economic growth and to improve productivity [DTI, 2003 a].

Numerous studies have looked at medium-term energy supply. Figure 4-20 illustrates outcomes of several of them in terms of energy intensity improvements on one hand, and carbon intensity on the other hand [Carbon Trust, 2002].

Carbon Trust/ICCEPT analysis concluded that energy efficiency and increased deployment of renewables, supported by hydrogen in the longer term could achieve the expected transition [Carbon Trust, 2001].

As a main support to the White Paper, the DTI published a study, which looked at three different scenarios for the UK energy supply by 2050 [DTI, 2003 b]. Sub-scenarios consider situations without a carbon constraint, and with a carbon emissions reduction required of 45, 60 and 70%, respectively. The Baseline scenario (and its sub-scenarios) considers that society values remain unchanged and that policy intervention in support of environmental objectives is pursued in a similar way as currently. Figure 4-21 gives the resulting mix of energy supply by 2050. Gas is dominant in the primary energy supply. Nuclear is dominant in the electricity supply, followed by offshore wind, biomass and gas potentially associated with CO_2 capture. In case of a carbon constraint greater than 45% reduction, hydrogen largely dominates the final energy demand in the transportation sector.

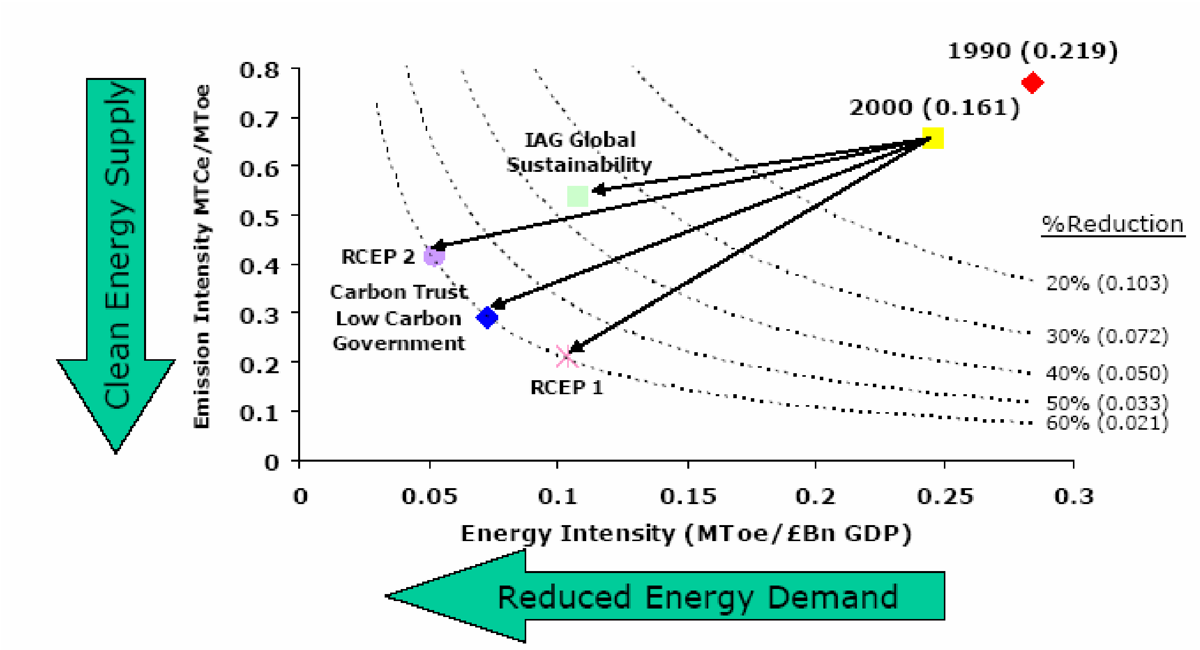


Figure 4-20: Emission intensity and energy intensity by 2050 according to various studies undertaken in the UK. Source: [Carbon Trust, 2002].

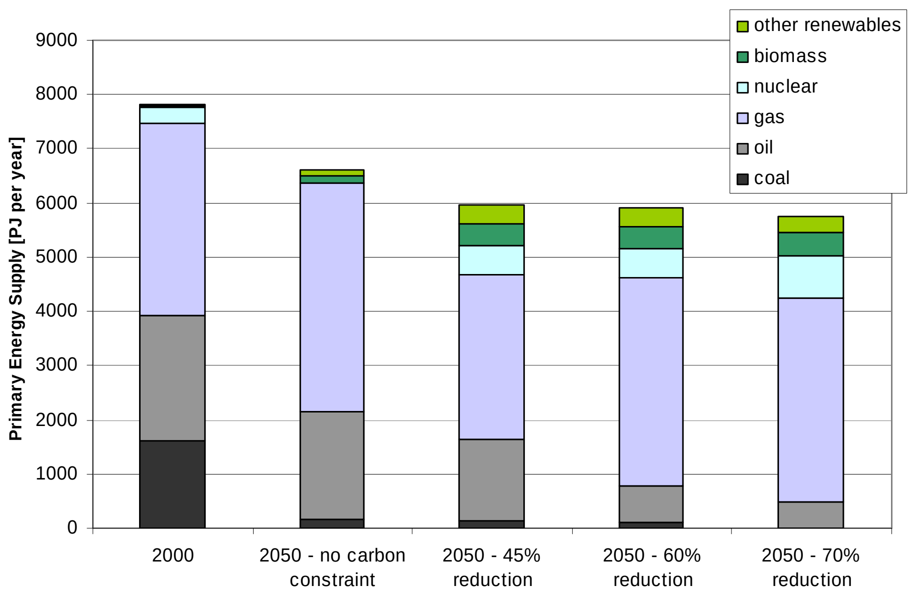


Figure 4-21: Total primary energy supply in the UK by 2050 according to various scenarios investigated by the DTI for a contribution to the Energy White Paper. Source: [DTI, 2003 b].

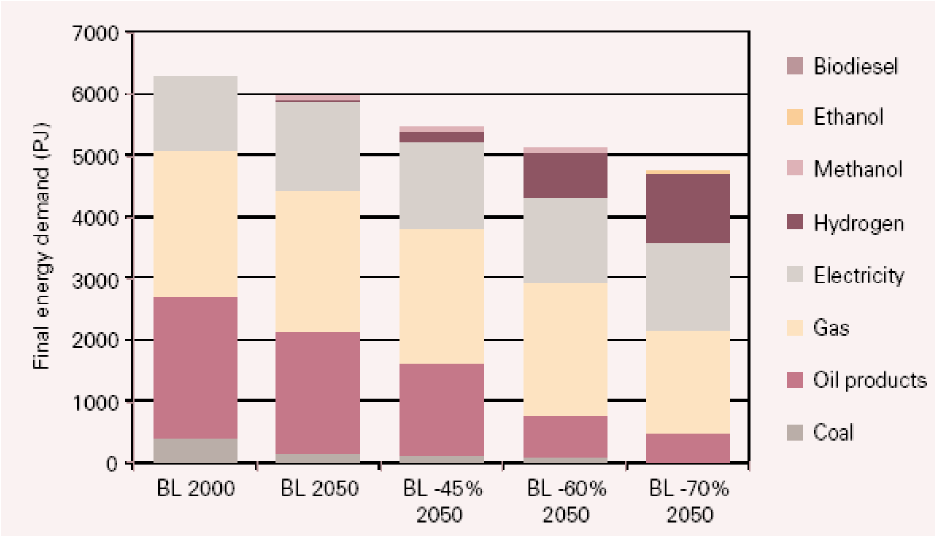


Figure 4-22: Share of the various energy sources in the energy supply of the UK by 2050 according to various scenarios investigated by the DTI for a contribution to the Energy White Paper. Source: [DTI, 2003 b].

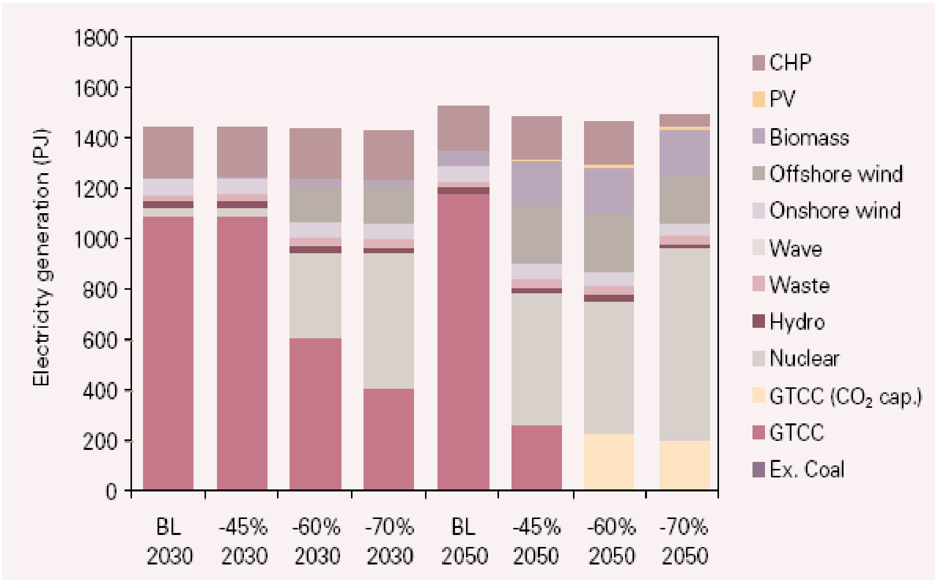


Figure 4-23: Electricity generation in the UK by 2050 according to various scenarios investigated by the DTI for a contribution to the Energy White Paper. Source: [DTI, 2003 b].

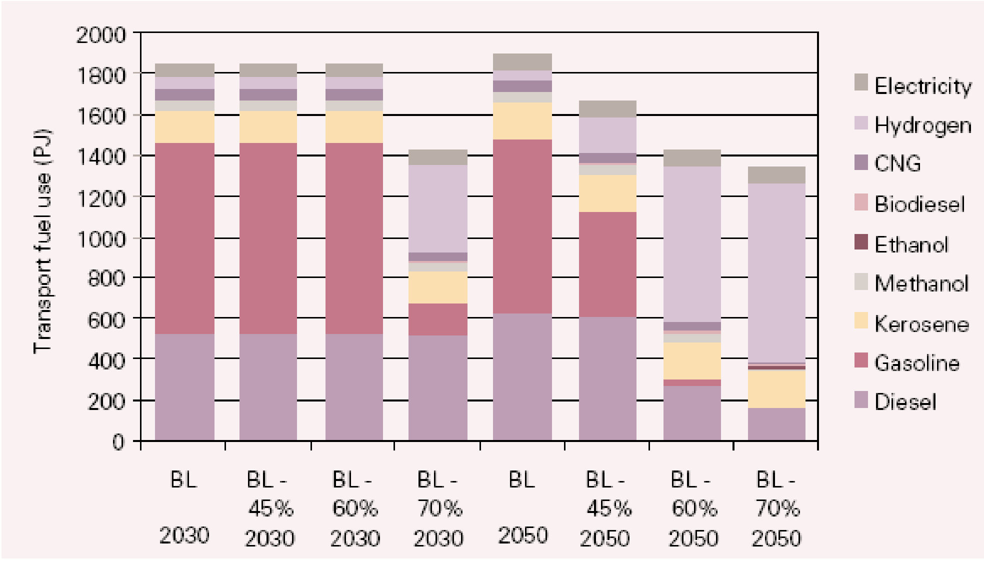


Figure 4-24: Transport fuel use in the UK by 2050 according to various scenarios investigated by the DTI for a contribution to the Energy White Paper. Source: [DTI, 2003 b].

4.2.4 The United States and Energy Supply Prospects by 2050

The National Renewable Energy Laboratory (NREL) recently conducted a study in order to demonstrate the benefits expected from the 2005 R&D funding request of the Office of Energy Efficiency and Renewable Energy (EERE) [NREL, 2004]. This provides an interesting view as it follows a different approach, starting from a given R&D budget and looking at its impact potential.

Criteria such as reduction in non-renewable energy consumption, consumer energy expenditures, energy system cost, or CO_2 emissions have been considered in an analysis looking at futures with and without R&D funding in EERE activities.

The study first establishes a baseline which provides a representation of a future of US energy markets without the effect of EERE programs – see Figure 4-25. EERE programs are then expressed in terms of cost and performance of new technologies, which will compete against existing technologies in the baseline. Benefits are finally derived with models taking feedbacks and interactions between the different funded programs into account. Some of the programs R&D funding and corresponding benefits are illustrated in Figure 4-26 to Figure 4-29. A lot of benefits are expected from the vehicle technology and hydrogen and fuel cell programs. Interestingly, while solar and biomass programs R&D requests are quite high, expected benefits are not that high.

Modeling results show that the R&D 2005 funding request of EERE would in 2050 among other benefits: 1) reduce the expected increase of US energy demand by 60%, 2) reduce the expected increase of US CO_2 emissions by 54%, 3) reduce the expected increase of US oil consumption by 84%, and 4) reduce the expected increase of US gas consumption by 21%.

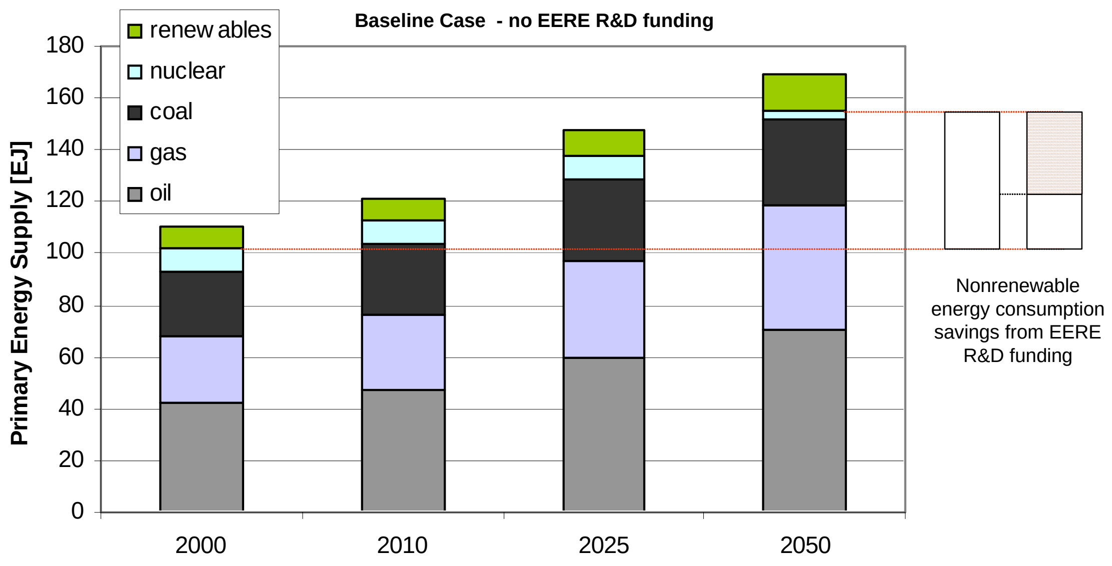


Figure 4-25: Primary energy supply by 2050 in the United States under Business as Usual and effect of EERE programs on non-renewable energy consumption savings [NREL, 2004].

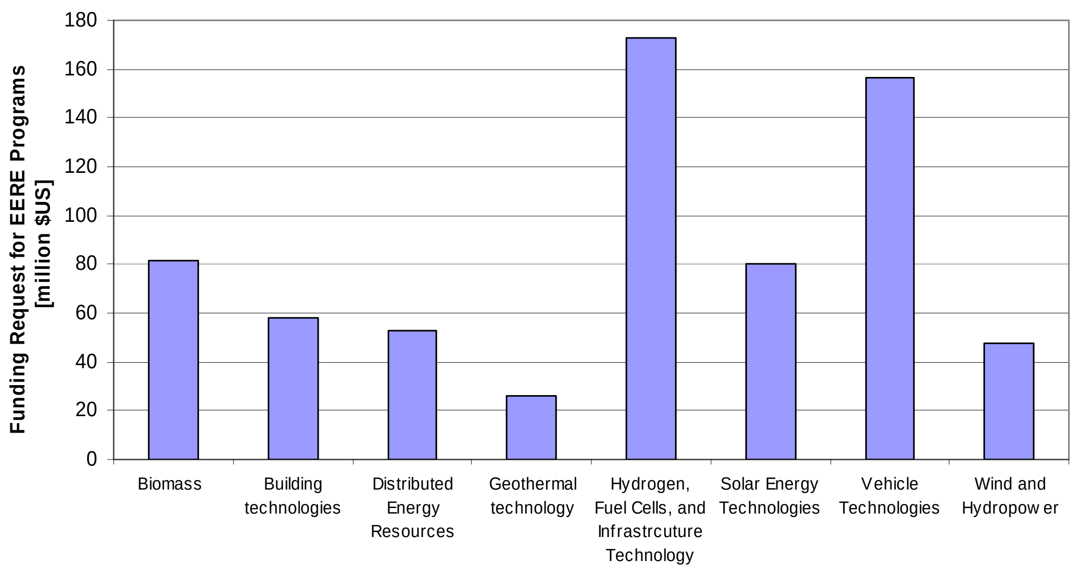


Figure 4-26: Funding request for EERE programs [NREL, 2004].

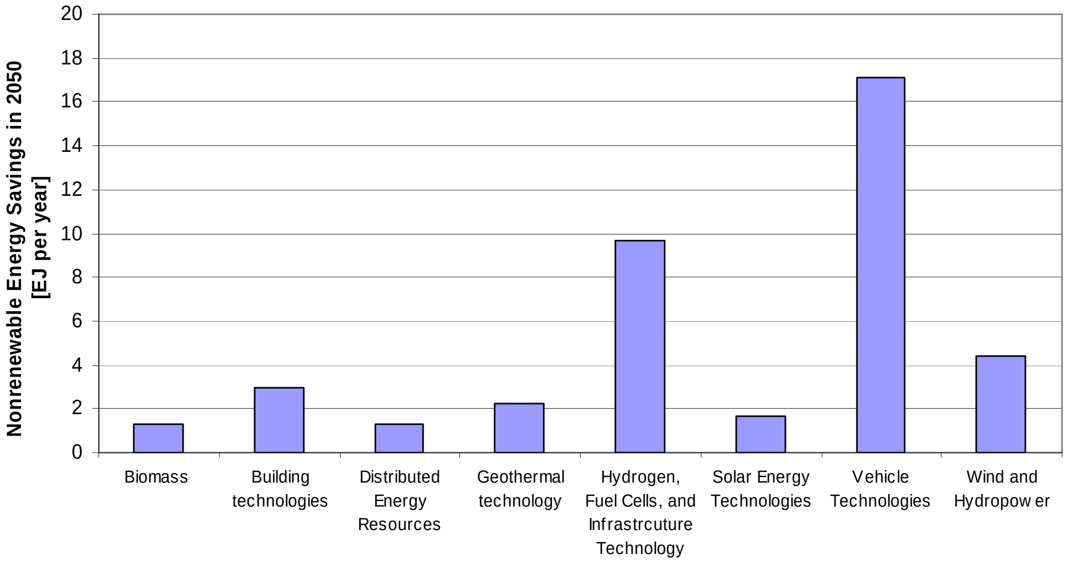


Figure 4-27: Expected non-renewable energy savings associated with the funding of EERE programs by 2050 [NREL, 2004]

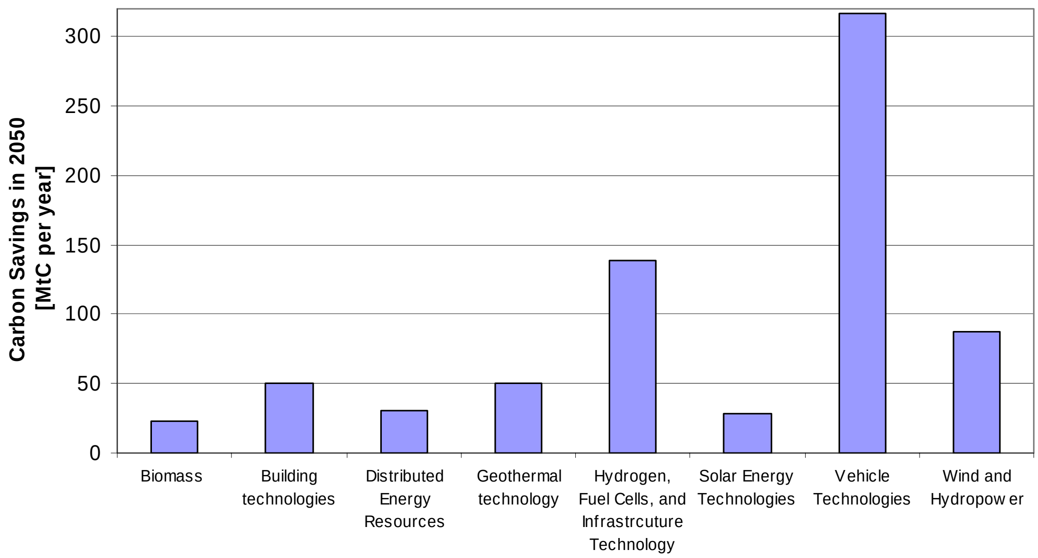


Figure 4-28: Expected carbon savings associated with the funding of EERE programs by 2050 [NREL, 2004].

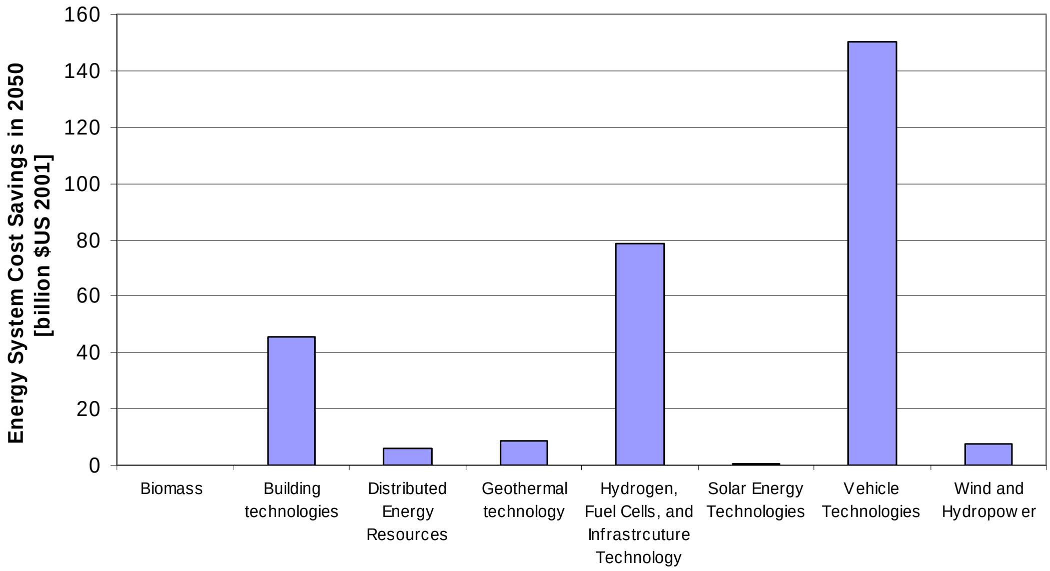


Figure 4-29: Expected energy system cost savings associated with the funding of EERE programs [NREL, 2004]:

5 Methodology for the identification of promising technologies

Setting priorities in public R&D funding for the medium-term energy supply is very challenging for decision makers who face a great deal of uncertainty related to the way numerous relevant boundary conditions may evolve in the future. As illustrated in the section on international literature review, very different views are expressed and argued for. In a debate often shaped by divergent opinions and various conflicts of interest (the ongoing debate around nuclear technology is an obvious example), there is a need for a more transparent and structured analytical framework. A main goal in this study is to provide such a framework within which discussion can take place in a scientific manner.

For this purpose a methodology based on the notion of 'Futures' has been developed in order to remain as objective as possible by reducing the number of freedom degrees in the process of identifying promising technologies to be supported by public R&D.

As illustrated in Figure 5-1, the four objectives formulated by the 'Roadmaps Working Group' act as new constraints on the energy supply system and define a suitable domain for the future of energy supply in Switzerland. Objectives b and d play in favour of a lower primary energy consumption, and objectives a and c in favour of a greater fraction of renewable energy in the primary energy supply.

Different 'Futures' can be described which comply with each of the four objectives, and thus are part of the suitable domain by 2050. 'Futures' shape the general framework within which discussion can take place: once a 'Future' is given, the scientific debate around the potential of investigated technologies is separated to a great extent from more political issues. Those are left for a debate among decision makers who can try to agree on a most probable 'Future' or to allocate a probability to each set of driving forces. A given set of driving forces leads to a given 'Future', which in turn leads to an identified set of promising technologies to be supported by public R&D funding. When a probability is associated with each set of driving forces, a degree of priority can be allocated to each promising technology identified.

This is likely to remain difficult however, and this work also proposes a prioritisation process based on the set of technologies, which are associated with high priority in all 'Futures'. This can be seen as a complementary set of ideas for the decision making process within CORE, and may or may not be considered by its members.

'Futures' can be reached via various alternative technological development paths, or 'Roadmaps'. Those paths depend on how novel technologies are implemented over time. This requires an analysis taking into account issues such as infrastructure development, or technology transfer and market penetration mechanisms. 'Roadmaps' are characterised by different evolutions of the primary energy consumption and the fraction of renewable sources over time. Note however that different roadmaps may lead to an identical final situation.

This study identifies technologies, which show good prospects for reaching the suitable domain by 2050. Their selection relies therefore at this stage on their possible contribution to meet requirements on time, together with additional benefits they deliver to the Swiss economy. However, the way these technologies should be implemented over time is left to a future investigation. This work is therefore not an overall roadmap analysis, which requires further work, but a process for the identification of technologies, which could allow Switzerland to comply with CORE's objectives by 2050.

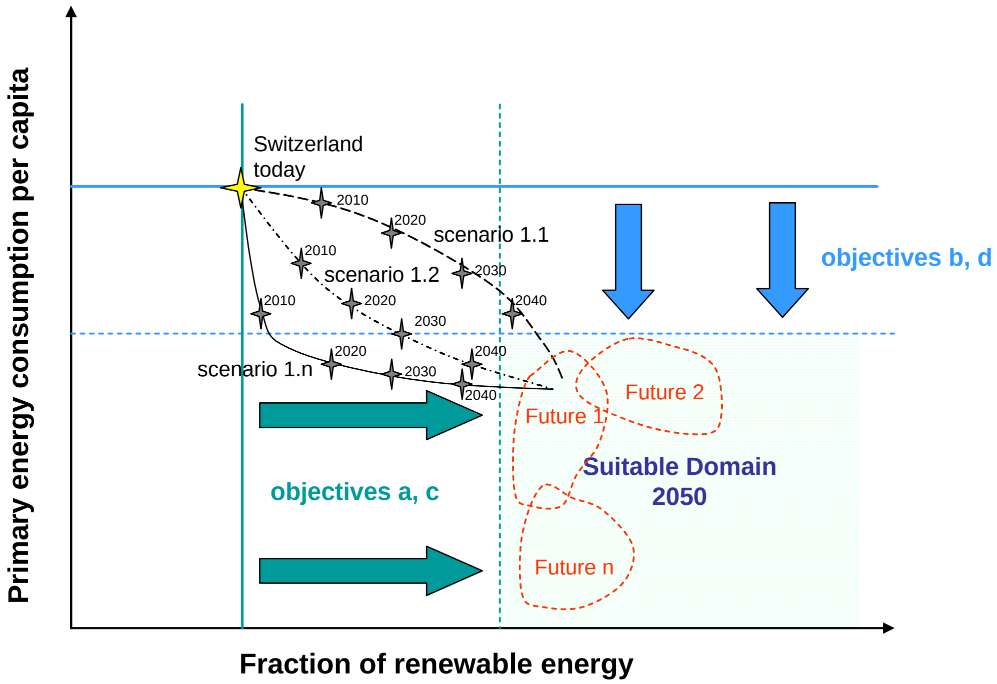


Figure 5-1: 'Futures' and compliance.

In this analysis, four 'Futures' are defined based on their respective degree of decentralisation and degree of fossil fuel substitution – see Figure 5-2. A hybrid 'Future' might also be defined as the intersection of the four 'Futures' investigated.

The degree of fossil fuel substitution is simply related to the share of renewable energy sources and nuclear technology in the primary energy supply by 2050. The degree of decentralisation is related to the way electricity and transport fuels are supplied by 2050. Note that the definition of the degree of decentralization does not look at how heat is supplied, as heating is currently mostly performed in a very decentralised way already.

Each 'Future' is seen as the result of a set of driving forces as illustrated in Figure 5-3. Major driving forces responsible for the occurrence of each of the four 'Futures' are given in Table 5-1.

Table 5-1: Driving forces leading to the four different 'Futures' considered.

Future LdHfs	Future HdHfs
• Conservative development of energy system structure • Public support for nuclear • High price development of fossil fuels • Failure or limited success of liberalisation process • Great concerns about safe and affordable energy supply	• Repetitive failures of energy transport & distribution networks • Strong public opposition to nuclear • High price development of fossil fuels • Successful liberalisation process • Great concerns about safe and affordable energy supply
Future LdLfs	**Future HdLfs**
• Conservative development of energy system structure • Strong public opposition to nuclear • Moderate price development of fossil fuels • Failure or limited success of liberalisation process • Limited concerns about security of energy supply	• Repetitive failures of energy transport & distribution networks • Strong public opposition to nuclear • Moderate price development of fossil fuels • Successful liberalisation process • Limited concerns about security of energy supply

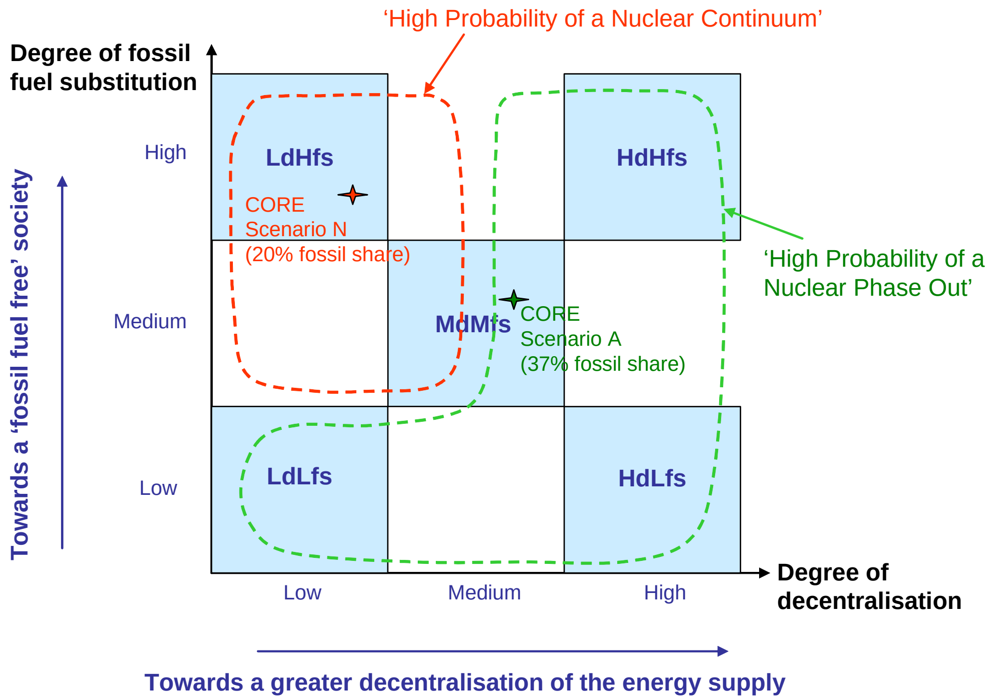


Figure 5-2: Definition of the different ‘Futures’ investigated (CORE Scenario N and A are scenarios investigated in previous work [Zogg, 2004] and which are located here as reference points.

As mentioned in the section about international literature on medium-term energy supply, very different visions are expressed on the supply side, but there is unanimous recognition of the need for strong demand side efficiency measures. ‘Futures’ investigated here are therefore essentially differentiated based on their supply side options as they all consider drastic demand-side efficiency measures driven by objectives b and d for the building sector and the transport sector, respectively.

When designing those ‘Futures’, the constraints imposed on the supply side by objective a and c must be kept in mind.

‘Futures’ with a low degree of fossil fuel substitution still consider an increase of the fraction of renewable energy sources as this is imposed by those two objectives, but renewable energy supply is in large part limited to the building sector which allows compliance with both objectives simultaneously. In those ‘Futures’, transport still essentially relies on fossil fuels, although the remaining biomass ecological potential can be directed towards the production of some biofuels once the building sector heating demand is met. Renewable sources other than hydro do not play an important role in the electricity sector in those ‘Futures’ due to the lack of incentives for aggressive policies in favour of a massive introduction.

By contrast, ‘Futures’ with a high degree of fossil fuel substitution greatly extend their renewable energy use in the transport sector. This happens because in a ‘Future’ with a low degree of decentralisation nuclear power generation capacity renewal allows meeting ‘Objective a’ via heat pump heating without the need of most of the biomass ecological potential - which opens the door to a greater penetration of biofuels (case of a ‘Future’ with a low degree of decentralisation), Or the extended use of renewable energy in the transport sector takes place because aggressive policies in favour of the use of solar, wind and geothermal

sources allows distributed ‘fossil free’ electrolytic hydrogen supply (case of a ‘Future’ with a high degree of decentralisation). In a ‘Future’ with a high degree of fossil fuel substitution where nuclear technology plays a central role, most of the fossil fuel substitution by 2050, however, comes from available ‘fossil free’ electrolytic hydrogen due to rather limited domestic biomass resources.
‘Futures’ are described in much more details later on in a section providing a first order quantitative analysis. A given ‘Future’ can be associated with various scenarios, a scenario being one possible way among others to comply with the four objectives formulated by the CORE for a given ‘Future’ without violating other constraints such as the estimated potential of the respective renewable energy sources by 2050. Results from four representative scenarios investigated in this work on a first order quantitative basis are given to illustrate the different ‘Futures’ and provide decision makers with a vision of what could be the annual energy balance of the Swiss energy system by 2050 under each one of those different ‘Futures’.

The identification of promising technologies for a given ‘Future’ is conducted in four successive steps illustrated in Figure 5-3.

On a first level, basic information on each relevant technology is gathered via literature review and interview of specialists and compiled in a synthetic form referred to as ‘technology fact sheets’. Those fact sheets, available in Appendix 1, provide condensed information on the status of each technology retained, together with prospects by 2050 if listed actions are taken for their improvement and further development. Those ‘technology fact sheets’ also mention R&D activities and topics which could be supported in order to reach expected technical potential by 2050. An example is given below for the polymer electrolyte fuel cell technology.

On a second level, information gathered at the first level above and during the international literature review is used for a brief preliminary assessment of those technologies relatively measured to seven criteria on a simplified scale: poor/small, medium, or excellent/large:

1) Potential contribution to CORE’s objectives
2) Swiss academic expertise
3) Swiss industrial expertise and involvement
4) Technology maturity
5) Technology acceptance
6) Domestic market size
7) International market size

Such an assessment is largely based on implicit knowledge and should be given much more time and resources to be supported by statistical data and actual bibliography. This was beyond the scope of this work and could be best done within an internal process at BFE, involving program managers.

On a third level, technologies are allocated to the different ‘Futures’ based on both qualitative and quantitative analysis using the methodology described above as well as outcomes from the previous steps. Results are given in the next section and provide a set of promising technologies for each ‘Future’ together with their respective share in the Swiss annual energy supply associated with a representative scenario, and examples related R&D activities that should be supported to commit with CORE's objectives.

Finally, priorisation must be made for the identification of the technologies to be actually supported by public R&D funding. This is the responsibility of CORE members, but this study provides some recommendation, which should be seen as a complementary set of ideas for the decision making process within CORE and not more, and which may or may not be considered in the priorisation process.

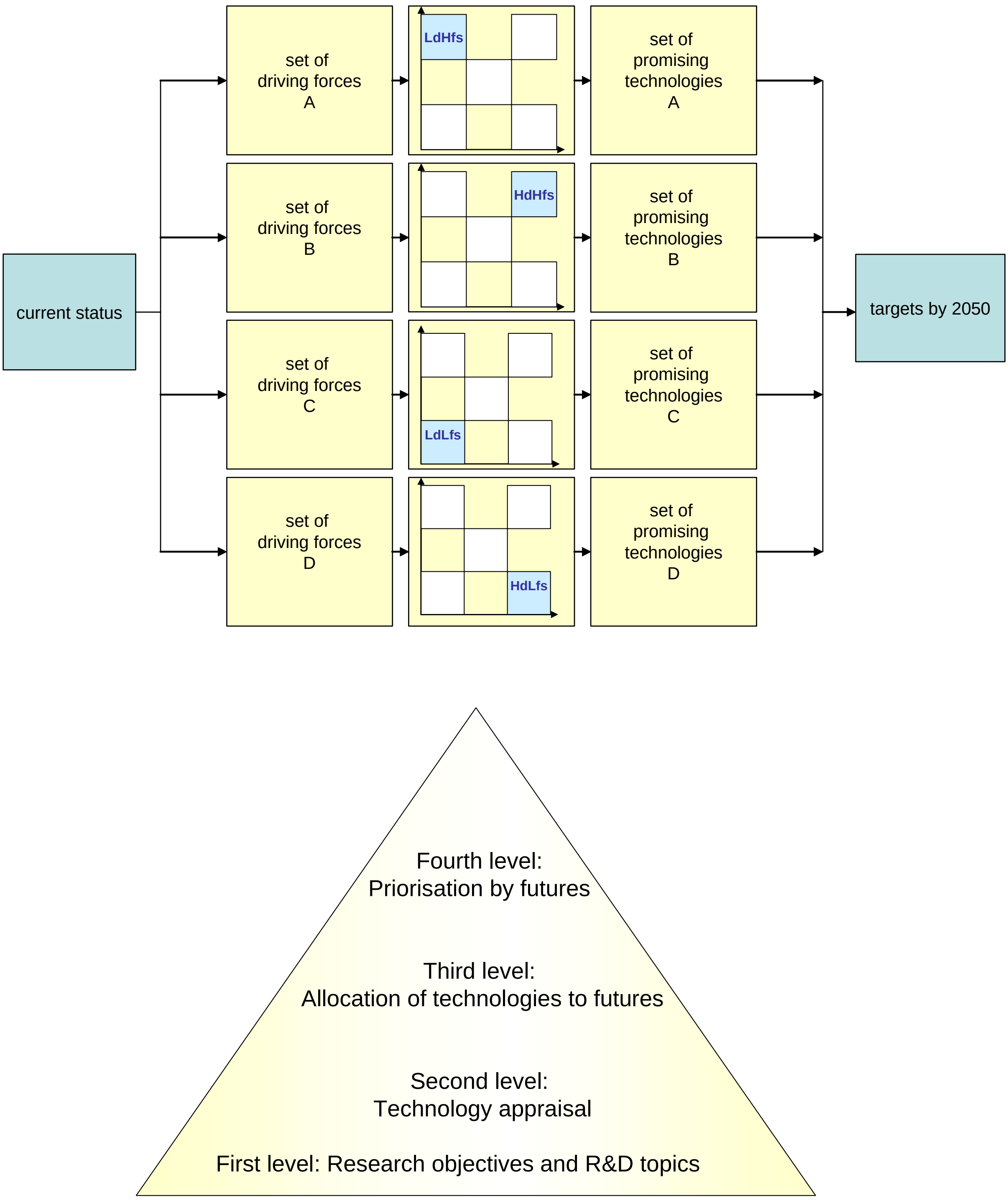


Figure 5-3: General approach followed for the identification of promising technologies.

Polymer Electrolyte Fuel Cell Fact Sheet (1) - Example

- fuel cell technology of choice for transport applications and suitable for stationary applications – synergies, technology transfer between different markets, more actors involved

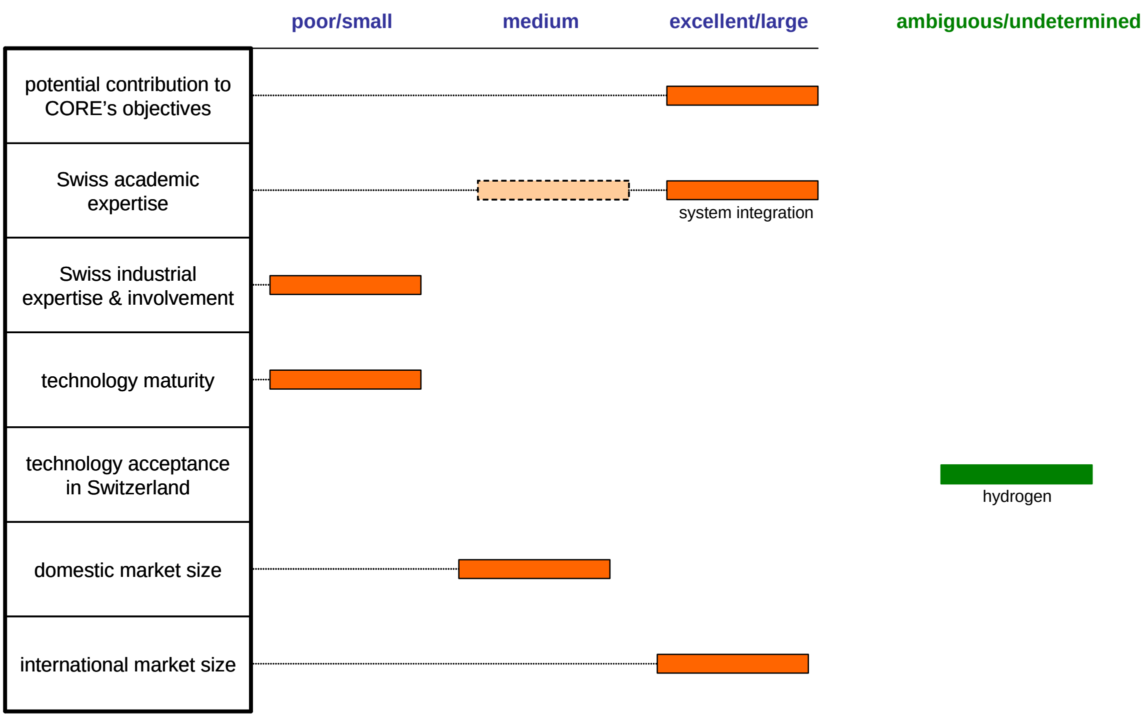
- some good Swiss academic expertise; however, very little Swiss industrial involvement so far

- recent breakthrough in membrane technology may greatly facilitate the development of viable systems

- fuel cell vehicle can be more than twice as efficient than conventional ICE vehicles on a tank to wheel basis; although lower efficiency gains on a well to wheel basis compared to hybrid vehicles, very high diversity of sources exist to provide hydrogen in the longer term, including carbon neutral ones

- quite large domestic market potential in a 'Future' with highly decentralised energy supply

- very large worldwide export market potential



Polymer Electrolyte Fuel Cell Fact Sheet (2) - Example

Status: 2005

- most funded fuel cell technology worldwide
- current demonstrated lifetime is typically up to 2'000 hours
- current cost 2'000 to 10'000 euros per kWe
- small-scale cogeneration units: numerous manufacturers, no Swiss industrial actor, ~1 to 10 kWe, ~30 to 35% LHV electric efficiency
- medium-scale cogeneration units (~10 to 250 kWe): very few manufacturers, Alstom was involved at one point but program aborted
- transport: all major car manufacturers involved; two small Swiss companies for niche market of ultra-light vehicles
- small-scale natural gas or other hydrocarbon stationary reformers with ~65% conversion efficiency
- on-board reforming abandoned by most developers

2010 2020 2030 2040

- develop more robust MEAs
- develop alternative bipolar plates
- develop more reliable auxiliaries
- improve system integration (heat and water management, fuel processing)
- achieve large volumes of production – high economies of scale in manufacturing
- reduce material cost

Prospects: 2050

- lifetime: stationary ~40'000 hours, transport ~5'000 hours
- cost: small-scale stationary ~ 1'000 euros per kWe, medium to large scale stationary ~ 800 euros per kWe, transport ~50 euros per kWe (30 for the stack)
- small-scale cogeneration units: 50 to 60% LHV electric efficiency
- new MEAs: high operating temperature up to ~200 C, low or no water requirements, and CO tolerant
- metal or polymer bipolar plates
- freeze start -30 C
- stack volumetric density ~2'500 W per litre (transport applications)

Objectives

- reduce cost: 10 fold for stationary, 200 fold for transport
- increase lifetime: about 2 to 3 fold for transport, 20 fold for stationary
- enlarge workable domain: operate at higher temperature, start at very low temperatures
- increase electrical efficiency
- develop more compact systems
- increase stack power density
- fuel processing and availability

Research topics

development of advanced membranes: high operating temperature, high CO tolerance, low or no humidification, low degradation rate, low cost	Nafion (Dupont) was so far the best compromise; however, recent breakthroughs may lead to improvement
development of alternative bipolar plates: improvement of carbon-based plates (composites), development of coated or uncoated metal or conducting polymer plates,…	bipolar plates make up an important share of the final cost; metal plates allow better conductivity, more compact systems and cheaper manufacturing; polymer plates allow channels manufacturing by moulding
new designs for reactant distribution and reaction product removal	better reactant access to active sites; increase fuel utilisation rate
development of alternative electrodes: high surface catalyst support (nanostructured catalyst layers), low Pt loading electrodes, alternative oxygen reduction catalysts (alloys such as Pt-Ni or Pt-CO), CO tolerant anodes (Pt-Ru),…	better utilisation of a given amount of Pt; reduced degradation rate due to poisoning
development of advanced reformers and gas cleaning techniques: new catalysts, POX, ATP, PSA, activated carbon,…	can benefit from the development of small reformers for the industrial sector
better system integration and development of dedicated auxiliaries: air and water management systems	current generating set around the stack can represent half of the system volume and consume 25% of the power generated
in-situ monitoring techniques	better understanding of degradation mechanisms
integration with on-board H_2 storage	for R&D on H_2 storage, see related slide

6 Characterisation of the four 'Futures' and identification of their respective set of promising technologies and associated required R&D activities

This section provides a quantitative analysis of a representative scenario for each one of the four defined 'Futures' together with a set of technologies and related examples of required R&D activities. Scenarios presented are illustrative and must by no means be considered as projections. Many other 'Futures' can be defined, and many other scenarios are possible for a same 'Future'.

It is also important to note here that given the limited time and resources allocated to this project, this exercise provides only a first order quantitative analysis. According to a request formulated by the CORE, and in an attempt to link this work with previous activities within the 'Roadmap Working Group', the quantitative analysis is indeed undertaken using an existing tool recently developed in this framework [Zogg, 2004], which is based on an annual energy balance and does not take into account instantaneous matching of supply and demand. For example, possible seasonal mismatch when a large share of the energy supply is based on intermittent renewable energy sources cannot be investigated using this tool, and adjustment is therefore left implicitly to import/export and is not accounted for. In addition, although the tool was adequately designed for the investigation of two specific scenarios in previous work, it is not fully appropriate for more analytical work and is therefore subject to several important limitations.

Results from this analysis provide therefore a first order assessment of what could possibly be the energy supply of Switzerland by 2050 under various 'Futures'. A detailed analysis would require the development of a more sophisticated tool, which was beyond the scope of this study. In addition, the analysis is conducted on a technical basis and does not consider economics. Further work could investigate the notion of cost of compliance with CORE's 'Objectives' for the different scenarios, but this implies technology cost forecasting and the use or development of an appropriate optimisation algorithm.

First, a cross comparison of results obtained for the four 'Futures' is presented for a better understanding of major differences among them.

Then, results are given and organised by 'Future'. For each 'Future', the set of driving forces is indicated first as a reminder. Then a short description of the 'Future' is provided together with a summary of the quantitative results. Readers who are interested in more details can read the quantitative results given by sector, where the main assumptions and graphs illustrating the share of different primary energy sources in the energy supply of each sector are provided. Others can just read through the summaries and the tables which provide the list of technologies retained for each 'Future' as well as examples of corresponding R&D activities required for the technology to be able to reach the technical potential assumed in the quantitative analysis.

The contribution of each technology to meet CORE's objectives in a given 'Future' is also assessed with various sensitivity analyses by looking at carbon emissions per capita and non-renewable primary energy use with and without the introduction of the technology, the rest being equal apart from the alternative more conventional technology used instead to meet the demand. Note again that those sensitivity analyses are illustrative and that many different alternatives exist for the investigation of the scenario without a given technology.

6.1 Cross comparison of the four 'Futures' and short discussion of CORE's objectives

The results obtained for the four 'Futures' in terms of fraction of renewable sources in the primary energy supply, annual primary energy consumption per capita, and annual CO_2 emissions per capita are given in Figure 6-1 and Table 6-2.

While all four 'Futures' comply with the four 'Objectives', they are associated with very different energy supply systems leading to a renewable fraction in the primary energy supply ranging from 46% to 61%, and an annual primary energy consumption per capita ranging from 3.5 to 4.2 kWe per year and per capita. In order to reach those targets, primary energy consumption per capita must be reduced by 20 to 30% and renewable sources fraction amplified by 2.5 to 3.5 times, compared with the situation in 2001. Table 6-1 gives the detailed share of the various renewable energy sources in the primary energy supply for the four different 'Futures'. Regarding security of energy supply and the non-renewable primary energy consumption, meeting CORE's 'Objectives' with an energy system essentially based on hydro, distributed renewable electricity generation, and distributed biomass-fired integrated energy systems, and with a generalised use of heat pump heating and a high fossil fuel substitution in the transport sector, is the most effective option among those investigated. This 'Future' would lead to a primary energy demand from fossil fuel resources of 1.6 kWyear per year, which is the lowest value obtained unless nuclear fuel supply is assumed to be sufficiently secure. In this case an energy system based on hydro and nuclear centralised power generation, and with a generalised use of heat pump heating and a high fossil fuel substitution in the transport sector becomes the most effective option with 1.4 kWyear per year and per capita of primary energy from fossil resources.
The resulting CO_2 emission rates range from 2.4 to 4.1 tons of CO_2 per capita and per year. This is a cut by 40 to 65% compared with the situation in 2001. From the point of view of climate change mitigation, the most effective option to meet CORE's 'Objectives' is the one with a generalised use of heat pump heating together with an energy system essentially based on hydro, natural gas fired and biomass fired centralised power generation, as long as carbon capture and storage is available and applied to large power plants including biomass fired ones. Otherwise, an energy system essentially based on hydro, distributed renewable electricity generation, and distributed biomass-fired integrated energy systems, or based on hydro and nuclear centralised power generation, with in both cases a generalised use of heat pump heating and a high fossil fuel substitution in the transport sector are the most effective options associated with similar emission rates.
In order to comply with the four 'Objectives', 'Futures' with low fossil fuel substitution are associated with greater overall conversion efficiency, leading to lower annual primary energy consumption, i.e. 3.5 and 3.6 kWe per year and per capita versus 4.0 and 4.2 kWe per year and per capita for the 'Futures' with high fossil substitution. This is due to greater efficiency improvements in the transport sector and lower use of alternative fuels, which are energy intensive.

All ‘Futures’ achieve a reduction by half of the final energy consumption in the building sector in order to comply with ‘Objective b’. Such an achievement, which would lead to less than 0.3 kW per year and per capita for all four ‘Futures’ (less than water heating demand) requires drastic measures. It is indeed for example more stringent than the target expressed in the advanced scenario of the German Parliamentary Enquete Commission for Energy for final energy demand in the building sector. This target proposes a reduction by 37% of final energy demand in households and tertiary sector together (see section on literature review). On the other hand, as confirmed by the technology review undertaken in this work, such a target is technically reachable with advanced insulation and glazing technology and with building integration techniques. In all four ‘Futures’ compliance with ‘Objective a’ is obtained by reducing the room heating requirements per square meter by 75% to compensate for the expected increase of total heated area by 25% and make up for the fact that limited efficiency measures are available for water heating while demand for it is also expected to grow by 25%. However, time constraint related to long reinvestment cycles in the building sector plays a governing role and absolute reduction of energy requirements is more stringent than reduction of the specific energy demand. Technology diffusion and market confidence are therefore key issues to focus on.

The achievement of ‘Objective b’ facilitates compliance with ‘Objective a’, which requires the ban of fossil fuel for heating in the building sector. Various interpretations can be made of this ‘Objective’. Whether ban of fossil fuels is applied to final energy only or to the overall energy chain leads to significantly different fossil fuel substitution requirements. The target is however technically achievable in all cases as long as heat pump heating is generalised, and whether it is driven by electricity from the grid or by distributed cogeneration units.
The different interpretations of ‘Objective a’ are illustrated by the four different scenarios. Those scenarios, which belong to ‘Futures’ with a high fossil fuel substitution consider a strict ban of fossil fuels. In such a case, in a ‘Future’ with a low degree of decentralisation nuclear and hydro supply the electricity required by the massive introduction of heat pumps in the building sector, while in a ‘Future’ with a high degree of decentralisation heat pumps are driven by electricity from either biomass-fired cogeneration units or on-site photovoltaic cells and small wind turbines. Scenarios, which belong to ‘Futures’ with a low fossil fuel substitution allow the use of fossil fuel in central power plants (low degree of decentralisation) or in distributed cogeneration units (high degree of decentralisation) for supplying the electricity needed by heat pumps.
Solar thermal plays an important role in all ‘Futures’, essentially for water heating. Biomass boilers are also significantly introduced when a strict ban on fossil fuels and ‘Objective c’ requirements are combined constraints.

Using the full ecological potential of biomass resources as requested by ‘Objective c’ leads to a share of biomass in the primary energy supply ranging between 11.8 and 14.3% of total primary energy supply in the four scenarios investigated. Biomass resources are mostly used for meeting ‘Objectives’ related to the building sector heating demand, either directly or via electricity generation and heat pumps. ‘Future LdHfs’ is an exception since nuclear plays a significant role in the electricity generation, leaving an important share of biomass resources available for an extensive use in the transport sector (about a third of the biomass potential for ethanol supply).

The share of direct use of biomass in the total final energy demand for room and water heating ranges from 10 to 27.6%. To which must be added the share of biomass resources in the electricity delivered to heat pumps via the grid. Biomass resources account for between 9 and 18.3% in the total amount of electricity delivered to national users.

Compliance with the target of 3 litres average fossil fuel consumption per 100 km for the passenger vehicle fleet is achieved with a mix of efficiency measures and fuel switching. In 'Futures' with lower concerns about energy supply security, fossil fuel substitution is low as there is no policy to prepare the country for a fossil free transport sector. 'Objective d' is essentially achieved with efficiency measures, with a high penetration of hybrid ICE vehicles and advanced ICE vehicles. In 'Futures' with high concerns about energy supply security, fuel switching is used as a complementary measure and in order to prepare for even lower fossil fuel reliance, and ultimately no reliance on fossil fuels at all. In such a case, efficiency improvements do not need to be as important to comply with the given target, but some still need to be achieved to reduce the amount of alternative fuel to be produced for a same service. Note that in such scenarios more stringent targets could be achieved from a technical point of view. The technical potential for domestic hydrogen production is indeed far from being fully exploited, and greater fuel cell vehicle penetration could be envisioned.

Table 6-1: Fraction of the various renewable energy sources (apart from hydro) in the primary energy supply

Future	Renewable source	Fraction in the total primary energy supply [%]
LdLfs	Biomass	14.4
	Solar	13.6
	Wind	0.8
	Environment	6.0
	Geothermal	2.4
HdHfs	Biomass	11.8
	Solar	18.8
	Wind	3.1
	Environment	4.6
	Geothermal	3.0
LdHfs	Biomass	12.8
	Solar	15.5
	Wind	0.9
	Environment	5.1
	Geothermal	0.3
HdLfs	Biomass	13.1
	Solar	10.8
	Wind	0.6
	Environment	5.2
	Geothermal	0.3

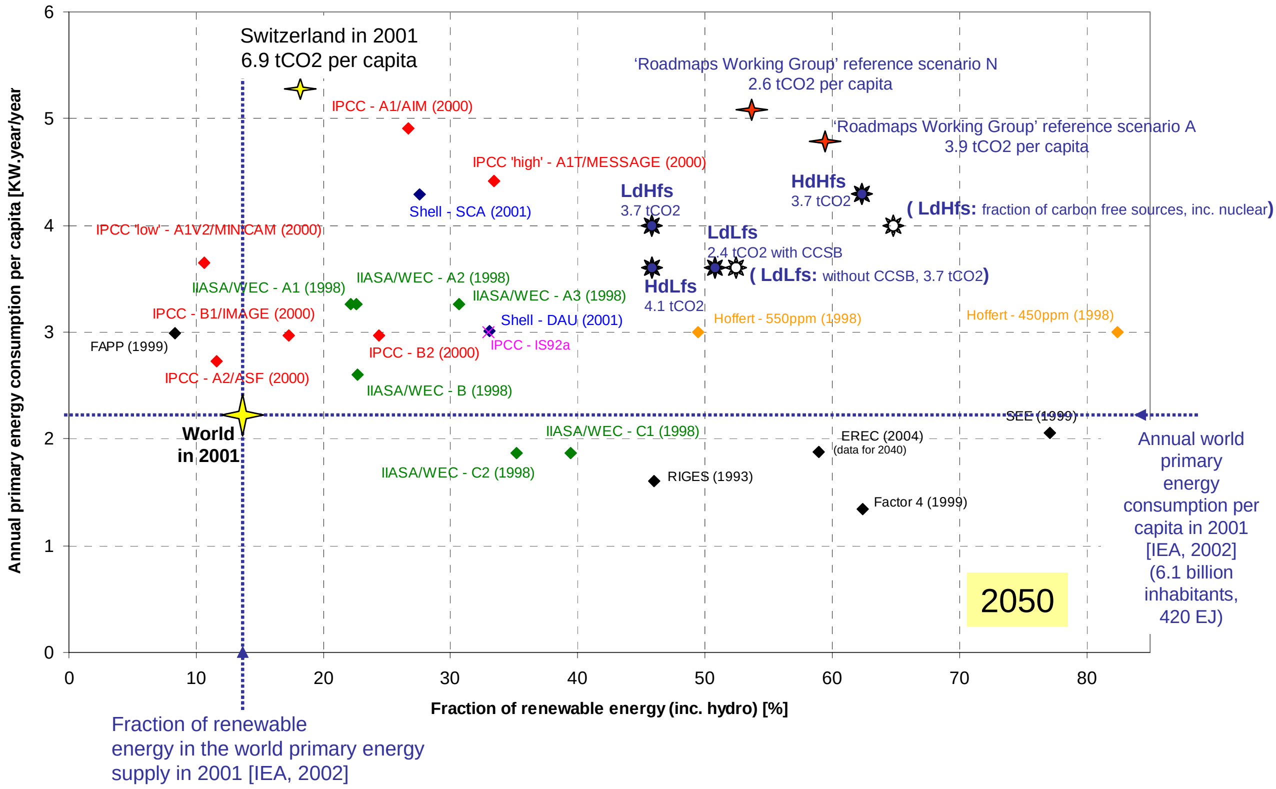


Figure 6-1: Results for the four 'Futures' investigated in terms of fraction of renewable sources in the primary energy supply, annual primary energy consumption per capita, and annual CO_2 emissions per capita, in comparison with today's situation, with the two previous scenarios investigated by the 'Roadmap Working Group', and with the various world medium-term energy supply visions reviewed[3].

Table 6-2: Results for the four 'Futures' investigated in terms of fraction of renewable sources in the primary energy supply, annual primary energy consumption per capita, and annual CO_2 emissions per capita

Future	Fraction of renewable sources in the primary energy supply [-]	Primary energy supply [kW year per year and per capita]	CO_2 emission rate [tCO_2 per year and per capita]
LdLfs with CCSB[4]	0.51	3.6	2.4
LdLfs without CCSB	0.52	3.6	3.7
HdHfs	0.61	4.2	3.7
LdHfs	0.46	4.0	3.7
HdLfs	0.46	3.5	4.1

[3] for Hoffert scenarios, points actually represent carbon free sources fraction required to meet indicated stabilisation targets and not necessarily only renewable energy fraction as nuclear can be considered as an option

[4] carbon capture and sequestration considered for large biomass power plants as well

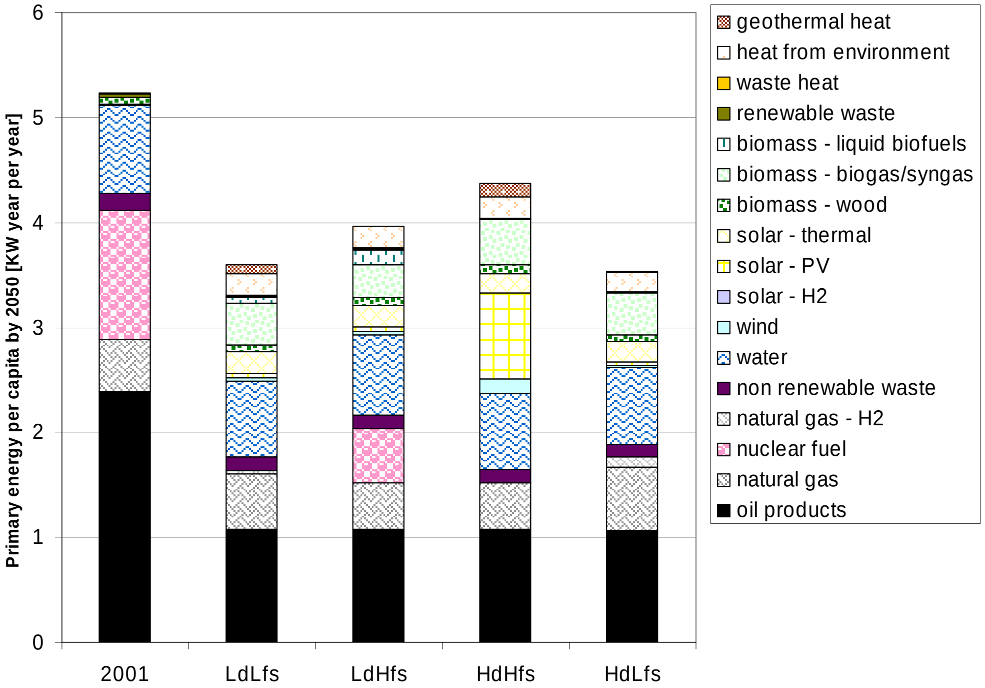


Figure 6-2 Results for the four 'Futures' investigated in terms of fraction of the various primary energy sources in the total primary energy supply by 2050.

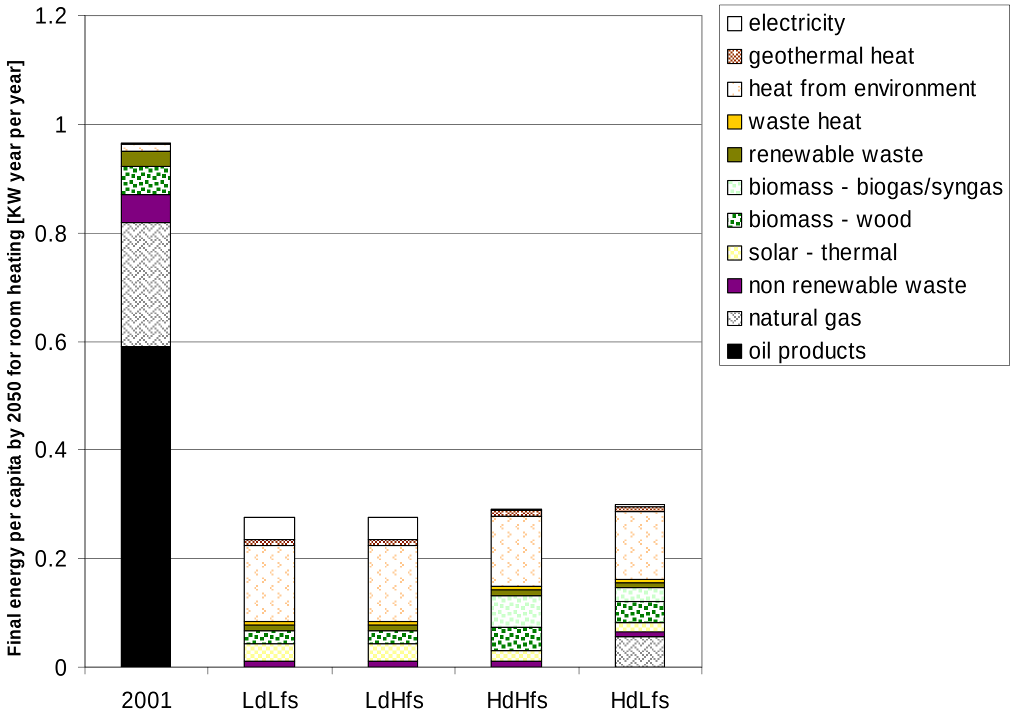


Figure 6-3 Results for the four 'Futures' investigated in terms of fraction of the various energy sources in the final energy supply for room heating by 2050.

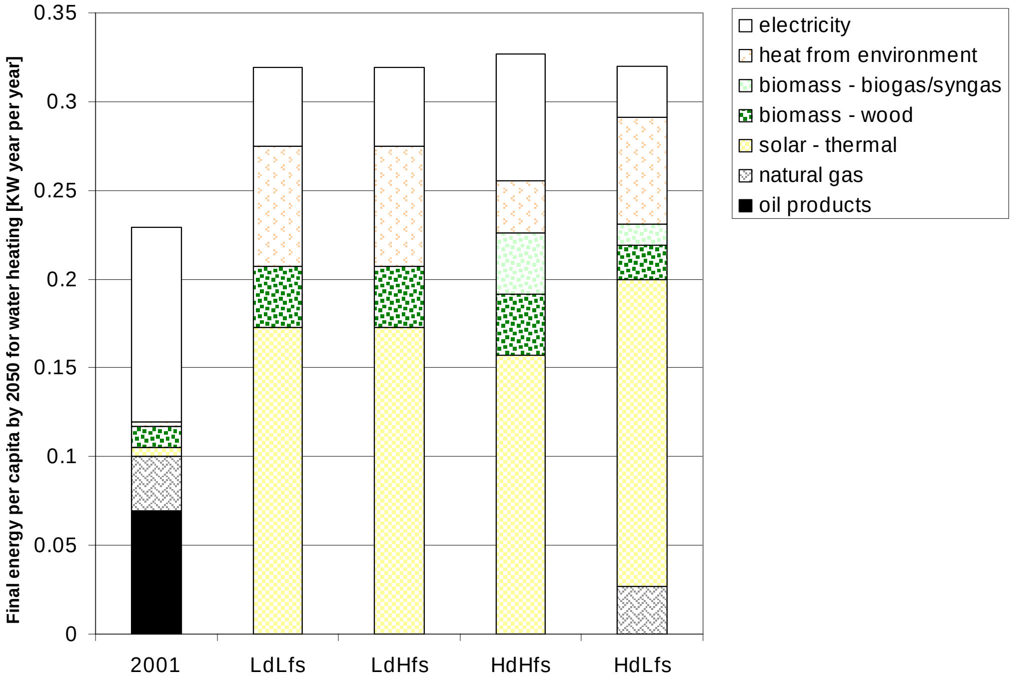


Figure 6-4 Results for the four 'Futures' investigated in terms of fraction of the various energy sources in the final energy supply for water heating by 2050.

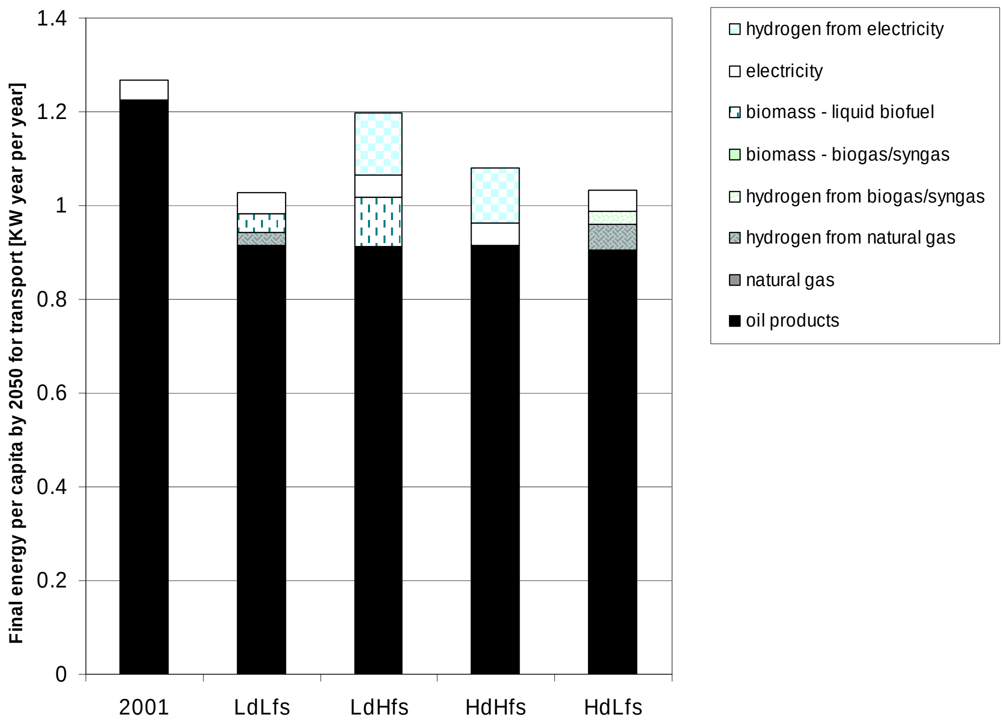


Figure 6-5 Results for the four 'Futures' investigated in terms of fraction of the various energy sources in the final energy supply for transport by 2050.

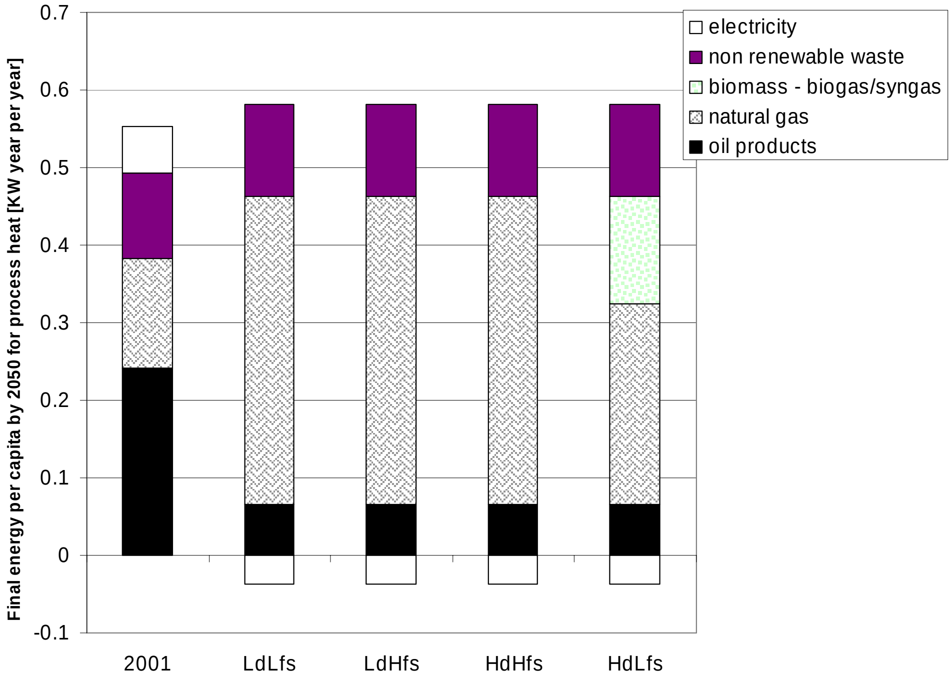


Figure 6-6 Results for the four 'Futures' investigated in terms of fraction of the various energy sources in the final energy supply for process heat by 2050.

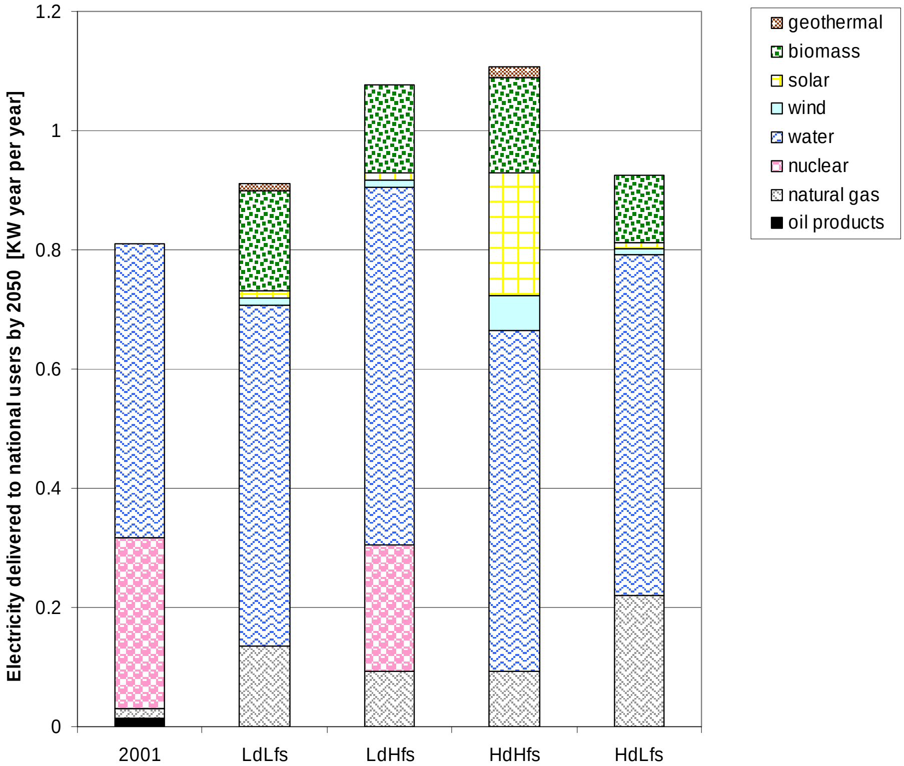
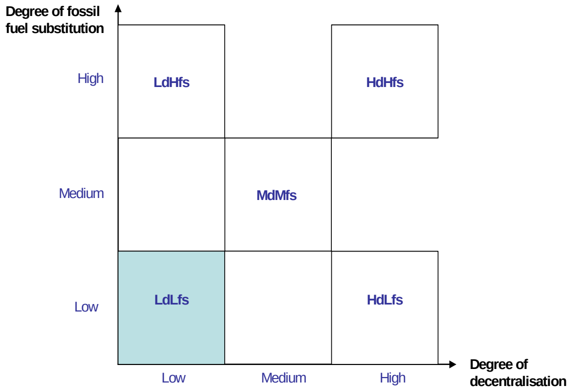


Figure 6-7 Results for the four 'Futures' investigated in terms of fraction of the various energy sources in the electricity delivered to the national users by 2050.

6.2 'Future LdLfs': low degree of decentralization and low degree of fossil fuel substitution

Future LdLfs



- Conservative development of energy system structure
- Strong public opposition to nuclear
- Moderate price development of fossil fuels
- Failure or limited success of liberalisation process
- Limited concerns about security of energy supply

Figure 6-8: Future description for LdLfs

Summary of the quantitative results LdLfs (for more details, see descriptions by sector)

- Aggressive policy is put in place to reduce by half the final energy consumption in the building sector. Building standard rapidly approaches Minergie level and develops towards zero energy housing. Final energy demand for room heating is reduced by 70% down to 65.3 PJ. This is lower than the final energy demand for water heating which increases up to 75.5 PJ.
- Heat pump heating driven by electricity from the grid is generalised in the building sector and covers about 66% of room heating requirements and 35% of water heating requirements. Although a large share of the electricity injected into the grid is generated from domestic renewable sources, heating of the building sector cannot be strictly qualified as 'fossil free' due to some material share of fossil fired generation and to likely imports of electricity in winter. However, in such a 'Future' with low fossil fuel substitution, a soft interpretation of 'Objective a' is assumed which means that use of fossil fuel is banned in buildings for the final energy use only. Electricity generated from fossil fuel and used for driving heat pumps is therefore accepted.
- Solar thermal capacity is greatly increased, mostly for water heating with a supply of more than half of the requirements (54%), but also to meet a little more than 12% of the final energy demand for room heating.
- The remaining heat demand for room and water heating requirements combined is met with about 10% of the available biomass resources, both via traditional heating and within district heating networks (20%), together with some waste direct combustion (4%), waste heat recovery (1%), and geothermal heat (2%).
- Negotiations with car importers and policies in favour of fuel economy improvement, fuel switching, efficient driving behaviour, and modal transfer lead to a reduction of the average fossil fuel consumption for the passenger vehicle fleet down to 3 liters of gasoline equivalent per 100 km, i.e. 124 PJ for the passenger vehicle fleet as a whole. Advanced ICE vehicles and ICE hybrids make up most of the passenger cars fleet with a 48% share each. Fuel

cell vehicles and pure electric vehicles make up the rest of the fleet with 3% and 1%, respectively.

- Oil products still account for 89% of the total final energy consumption for transport.
- Some lignocellulosic biomass resources are converted into ethanol in a large scale plant to meet 5% of total passenger vehicle fleet consumption on an energy basis (mostly as a blend), i.e. 4% of the transport final energy demand. This plant uses about 8% of the total ecological biomass potential.
- Some hydrogen is produced via natural gas reforming in a central plant equipped with carbon capture technology and meets 3% of total passenger vehicle fleet consumption, i.e. 2.5% of the total transport final energy demand.
- Electricity meets 4% of total transport final energy demand.
- Final energy demand for industrial process heat increases by about 20%, accounting for efficiency measures reducing the specific demand for process heat per unit output by 35%.
- Natural gas meets a large share, i.e. about 70% of process heat requirements in the industrial sector with natural gas fired cogeneration units playing a significant role .
- Electricity requirements other than those related to electric transportation and heat supply in the building and industrial sectors increase by a little less than 25% up to 174.7 PJ, accounting for demand-side efficiency measures reducing the specific electricity demand by 25%. Total national electricity requirements amount to 215.4 PJ, out of which 22.1 PJ are met with industrial cogeneration. The remaining 193.3 PJ must be generated in central plants and distributed through the grid, versus 191.8 PJ in 2001.
- Nuclear electricity generation capacity is phased-out.
- Repowering projects maintain the capacity of hydro at the current level, supplying about 63% of total national electricity requirements.
- A large fraction of biomass resources, i.e. about 75% of the total ecological biomass potential, is converted into electricity in 5 advanced thermal power plants with an average 300 MWe unit capacity based on gasification technology. Those plants provide a little more than 18% of total national electricity requirements. Carbon capture facilities are installed and lead to negative emission rates for those plants.
- Geothermal power plants are moderately introduced and play a limited role in the electricity supply with about 1.3% of total national electricity requirements.
- Wind farms and solar PV are moderately introduced and play a limited role in the electricity supply with 1.3% of total national electricity requirements each.
- The remaining 15% of total domestic electricity requirements are met with natural gas, through industrial cogeneration units, and with a 340 MWe advanced natural gas-fired power plant equipped with carbon capture technology.
- Bottom line: if CCS is applied to biomass-fired power plants, such a scenario leads to a 51% renewable share in the primary energy supply, to a 3.6 kW year per year primary energy consumption per capita, and to 2.4 tons of CO_2 emissions per year and per capita; the case of a similar scenario but where CCS is not applied to biomass-fired power plants has also been investigated – such a case leads to a 52% renewable share in the primary energy supply, to a

3.6 kW year per year primary energy consumption per capita, and to 3.7 tons of CO_2 emissions per year and per capita

Energy resources	Share in the Primary Energy [-]	
	2001	**2050**
oil products	0.46	0.30
natural gas	0.09	0.14
nuclear fuel	0.23	0.00
natural gas - H2	0.00	0.01
non renewable waste	0.03	0.04
water	0.16	0.20
wind	0.00	0.01
solar - H2	0.00	0.00
solar - PV	0.00	0.01
solar - thermal	0.00	0.06
biomass - wood	0.01	0.02
biomass - biogas	0.00	0.11
biomass - liquid biofuels	0.00	0.02
renewable waste	0.01	0.00
waste heat	0.00	0.00
heat from environment	0.00	0.06
geothermal heat	0.00	0.02

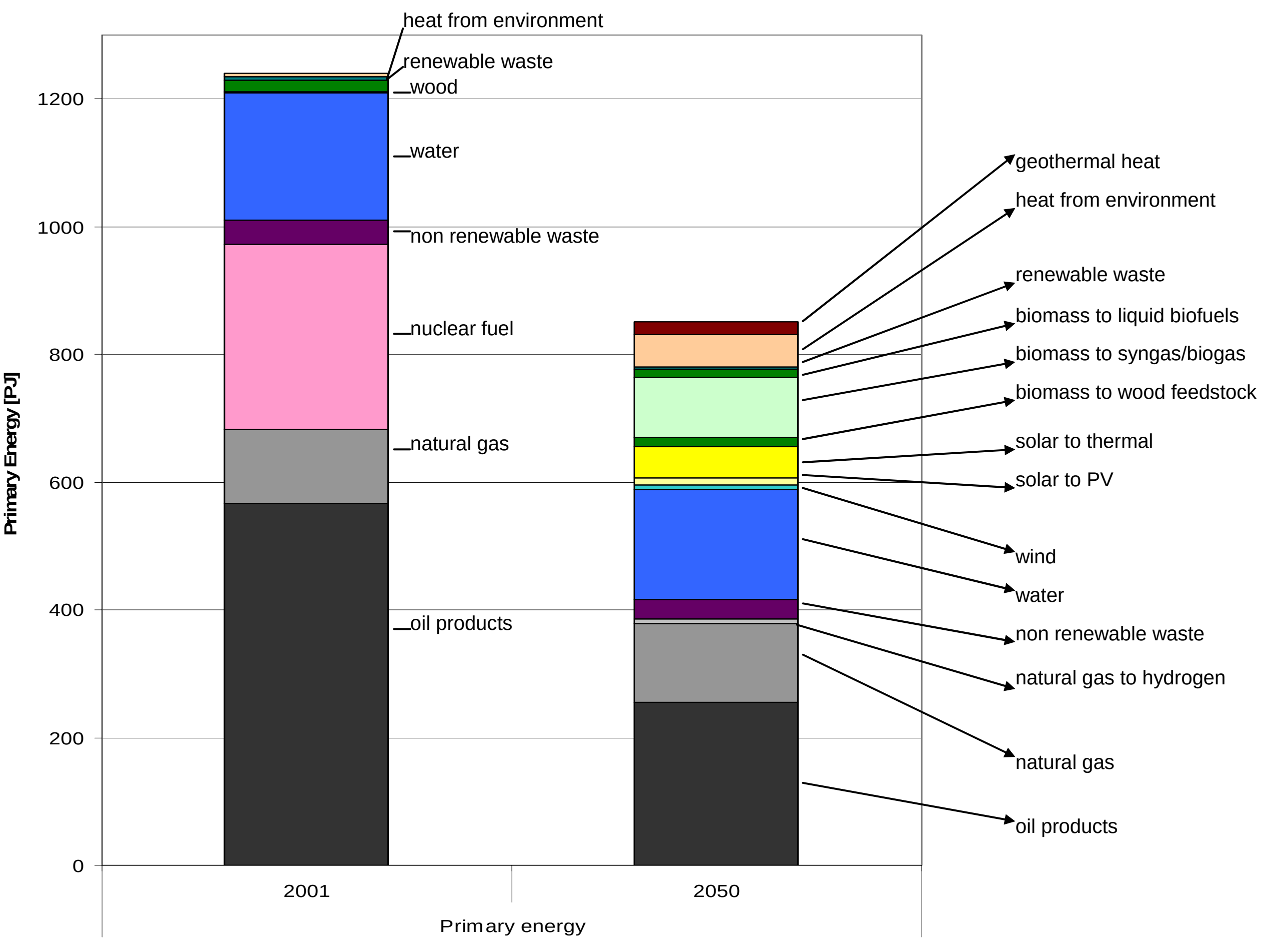


Figure 6-9: Share of the different energy resources in the primary energy supply by 2050 under a 'Future' with low degree of decentralization and a low degree of fossil fuel substitution (LdLfs) – case with CCS applied to large power plants, inc. biomass-fired ones.

Summary of key technologies for the domestic market in Future LdLfs and examples of related R&D needs (see technology fact sheets in Appendix for more details):

<table>
<tr><th>Technologies required for the domestic market - LdLfs</th><th>Examples of required R&D activities</th></tr>
<tr><td rowspan="2">advanced gas and steam turbine technology:

- for a 340 MWe natural gas fired combined cycle associated with either end-of-pipe CCS or precombustion CO_2 removal technology (5% of domestic electricity needs by 2050); 58% LHV electric efficiency target, inc. CCS

- for five 300 MWe biomass fired combined cycles equipped with gasification and pre-combustion CO_2 removal technology (18% of domestic electricity needs by 2050); 58% LHV electric efficiency target and 77% biomass to syngas conversion efficiency target

- for industrial cogeneration units running on natural gas (meets part of the 10% share in total electricity requirements); 35% electric efficiency target</td><td>- advanced combustion
- advanced cooling
- advanced GT-ST combined cycles (system integration)
- alternative fuel firing – oxyfuel, hydrogen
- advanced hot gases heat exchangers, advanced heat recovery steam generators
- atmospheric pollutants abatement technology</td></tr>
<tr><td><u>Swiss academic 'know-how' (non exhaustive):</u>

- EPFL – ISE (LTT, LENI, LTCM, LMF, LIN), IMX (LMCH, LTP)
- ETHZ – IET (LAV, LTNT, LSM), IFD
- PSI – ENE (CRL)
- EMPA</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current technology for combined cycles with post-combustion CCS (typically 50% LHV electric eff.) would lead to 3.5% greater non renewable primary energy consumption per capita, and 4.3% greater CO_2 emission per capita
- not implementing hydrogen rich fuel fired gas turbines in biomass-fired power plants with pre-combustion CCS and using available biomass in direct combustion plants with post-combustion CCS instead (typically 40% LHV electric eff.) would lead to 9.2% greater non renewable primary energy consumption per capita and 11.8% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">carbon capture & storage technology:

- for a 340 MWe natural gas fired and five 300 MWe biomass fired combined cycle associated with either end-of-pipe CCS or pre-combustion CO_2 removal technology (23% of domestic electricity needs by 2050); 58% LHV electric efficiency target, inc CCS

- for a natural gas reforming central plant providing enough hydrogen to meet 2.5% of total final energy demand for transport</td><td>- adsorption on solid materials
- high selectivity separation membranes
- advanced absorber solvents
- oxygen separation units & exhaust gas recirculation
- chemical looping
- CO_2 underground storage</td></tr>
<tr><td><u>Swiss academic 'know-how' (non exhaustive):</u>

- ETHZ - IAC, IPE
- PSI – ENE (LAC)</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- not implementing CC at central power generation plants would lead to 3% lower non renewable primary energy consumption per capita and 34.9% greater CO_2 emission per capita (greater conversion efficiency as no more penalty from CCS, but emissions from gas plant and no more 'negative emission rate' from biomass power plants)</td></tr>
</table>

<table>
<tr><td rowspan="2">gasification technology (large scale):

- for five 300 MWe biomass fired combined cycle equipped with gasification and pre-combustion CO_2 removal technology (18% of domestic electricity needs); 77% biomass to syngas conversion efficiency target

- for a central ethanol production plant based on a thermochemical pre-processing providing enough ethanol to meet 5% of advanced ICE and ICE hybrid vehicles final energy demand as a blend, or 4% of the total final energy consumption for transport; target 70% biomass to ethanol conversion efficiency</td><td>- system reliability – tars & particulates related issues
- appropriate gas monitoring & cleaning technologies
- fuel flexible gasifiers with priority to low or negative cost feedstock such as wastes - feeding mechanisms & reactors
- feedstock quality homogenisation and standard
- advanced heat exchangers
- oxygen separation membranes
- dedicated catalyst for syngas to ethanol conversion or dedicated microorganisms for syngas fermentation</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- PSI – ENE (LSK)
- WSL
- ETHZ – IET (LTNT, PRE)
- EPFL – ISE (LTCM), ISIC (LGRC)</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- not developing gasification for central biomass-fired power plants with pre-combustion CCS and using corresponding available biomass in direct combustion plants with post-combustion CCS instead (typically 40% LHV electric eff.) would lead to 9.5% greater non renewable primary energy consumption per capita, and 11.7% greater CO_2 emission per capita
- not substituting oil products with such an amount of ethanol and using corresponding available biomass in power plants as above instead would lead to 9.4% greater non-renewable primary energy consumption per capita and 5.4% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">advanced gas engine technology:

- for industrial cogeneration units running on natural gas (meets part of the 10% share in total electricity requirements); 55% electric efficiency target</td><td>- low irreversibility engines – advanced combustion, lower heat and friction losses, energy recovery
- adapted or dedicated engines fired with alternative fuels
- affordable and robust atmospheric pollutants emission control
- system integration - mechanically coupled heat pumps, bottoming cycles</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- ETHZ – IET (LAV)
- EPFL – ISE (LENI)
- PSI – ENE (CRL)
- EMPA - ICEL</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- not implementing industrial cogeneration would lead to 4.4% greater non renewable primary energy consumption per capita and 6.4% greater CO_2 emission per capita</td></tr>
<tr><td>advanced hydropower:

- for a total hydro power generation capacity maintained at the current level (62% of electricity needs by 2050); 87% conversion</td><td>- advanced blade design for reduced cavitation problems - three dimensional modelling of turbine flow phenomena
- mechanical stability under unsteady phenomena
- advanced generators
- micro-hydro</td></tr>
</table>

efficiency target (versus 82% in 2001)	Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LMH) - EPFL – ISE (LME) - EPFL – ENAC (LCH)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for hydro would lead to 2.6% greater non renewable primary energy consumption per capita and 2.6% greater CO_2 emission per capita (greater gas use given fixed maximum hydro and biomass primary energy potentials)	
advanced electricity transport network: - overall electricity transport losses reduced down to 5% (versus 8.4% in 2001)	- advanced superconductors with higher temperatures and higher inner coherence – reduced risk of resistance at grain/crystal interfaces - advanced high voltage DC transmission concepts - advanced AC/DC power conversion technologies - advanced power electronics for load control
	Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LEI, LRE) - ETHZ – EE (PES, EEH)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for electricity transport would lead to 2.6% greater non renewable primary energy consumption per capita and 3.1% greater CO_2 emission per capita (greater gas use given fixed maximum hydro and biomass primary energy potentials)	
advanced compression heat pumps: - grid driven and for a 66% share of room heating requirements by 2050; target average COP 4.5 - grid driven and for a 35% share of water heating requirements; target average COP 3.5	- products for both water & room heating or for the retrofit market – new working fluids and specific components - monitoring & control for operating strategy - advanced compressors and cycles - advanced heat exchangers
	Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LENI, LTCM) - HT Basel – IE - HT Luzern – WTT - HT Winterthur - HT Rapperswil - IET
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - assuming an average COP of 3.5 instead of 4.5 and 2.5 instead of 3.5 would lead to 1.9% greater non renewable primary energy consumption per capita and 2.0% greater CO_2 emission per capita - assuming an average COP 3.5 and 3 times lower market penetration for room heating, and no material market penetration for water heating, would lead to 10.5% greater non renewable primary energy consumption per capita and 15.9% greater CO_2 emission per capita	
advanced solar thermal, inc. storage: - for a 54% share of water heating	- advanced heat storage concepts - low cost production technologies for vacuum tubular solar thermal technologies - system integration – in-house and advanced low cost control technology

<table>
<tr><td>requirements by 2050; target 50% available heat to useful heat efficiency

- for a 12% share of room heating requirements by 2050; target 50% available heat to useful heat efficiency and seasonal storage with 40% annual efficiency</td><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- HT Rapperswil - SPF
- EI Vaud – IGT (LESBAT)
- EPFL – ENAC (LESO)
- Uni Genève - CUEPE</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- assuming similar market penetration for water heating but with 40% overall eff. and no material market penetration for room heating due to lack of satisfactory enough seasonal storage, would lead to 1.2% greater non-renewable primary energy consumption per capita and 1.6% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">advanced biomass boilers:

- for district heating networks (meets most of the 9% share of wood in room heating and 10% share of water heating)</td><td>- feedstock quality homogenisation and standard
- techniques for NOx and particulate matter reduction</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- Ökozentrum Langenbruck</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- assuming that only half of the expected market penetration is achieved and the rest is met with natural gas fired boilers instead would lead to 0.7% greater non-renewable primary energy consumption per capita and 0.9% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">polymer electrolyte fuel cell technology for transport:

- for FC passenger vehicles with on-board hydrogen storage, with a 2.5% share in the total transport final energy demand; target vehicle consumption of 2.5 litres gasoline equivalent per 100 km, 5’000 hours MEA’s lifetime</td><td>- optimal system integration - heat and water on-board management
- low manufacturing cost for bipolar plates
- dedicated auxiliaries
- more robust MEAs - advanced membranes and electrodes</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- PSI – ENE (ECL)
- ETHZ – IMRT
- HT Luzern
- HT Biel
- EI Vaud</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- not developing PEM technology for FC vehicles and assuming that advanced ICE vehicles and ICE hybrid vehicles (in a 50%/50% ratio) running on a blend gasoline/ethanol are used instead so that the average 3 litres of fossil fuel consumption per 100 km is met, would lead to 2.6% greater non-renewable primary energy consumption per capita and 13.3% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">on-board hydrogen storage:

- for FC passenger vehicles with on-board hydrogen storage, with a 2.5% share in the total transport final energy demand; 9% weight capacity and 2.7 kWh per litre targets</td><td>- cost reduction of storage technologies (all types)
- increase of volumetric and gravimetric storage density
- reduction of boil of losses of liquid hydrogen storage</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- Uni Fribourg
- Uni Genève
- EMPA – MET
- EPFL – ISIC (LCOM)</td></tr>
</table>

scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not developing hydrogen storage technology for FC hybrid vehicles and assuming that advanced ICE vehicles and ICE hybrid vehicles (in a 50%/50% ratio) running on a blend gasoline/ethanol are used instead so that the average 3 litres of fossil fuel consumption per 100 km is met, would lead to 2.6% greater non renewable primary energy consumption per capita and 13.3% greater CO_2 emission per capita	
advanced on-board electric storage: - for ICE hybrid passenger vehicles and pure electric vehicles, with a cumulated 51% share in the total transport final energy demand; target 2.5 litres gasoline equivalent per 100 km for ICE hybrids, and 2 litres gasoline equivalent per 100 km for pure electric	- advanced batteries: cost reduction - advanced batteries: long term usability (increase of charging cycles) - advanced batteries: improved energy density - super-capacitors Swiss academic 'know-how' (non exhaustive): - PSI – ENE (ECL) - EPFL – ISE (LEI), ISIC (LPI, LCIC, GGEC), IMX (LTP)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for on-board batteries, and assuming 2 times lower hybrid ICE market penetration and no material pure electric vehicles market penetration as a consequence and the use of advanced ICE with a greater share of ethanol so that the average 3 litres of fossil fuel consumption per 100 km is met, would lead to 8.4% greater non renewable primary energy consumption per capita and 27% greater CO_2 emission per capita	
advanced ICE vehicles for transport: - for a 48% share in the total transport final energy demand; target 5 litres gasoline per 100 km for ICE and 2.5 litres gasoline per 100 km for hybrid ICE	- advanced combustion - camless operation - adaptive calibration of engine parameters - in-cylinder sensing - continuous variable transmission - advanced injection - advanced heat recovery - lightweight vehicles: low cost composite structure production processes, optimisation of composite structure design, lightweight hybrid body structures (multi material sandwich structures) Swiss academic 'know-how' (non exhaustive): - ETHZ - IET (LAV, LTNT, LSM), IFD - EPFL – ISE (LENI) - PSI – ENE (CRL) - EMPA - ME - HT Rapperswill - HT Biel
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current (new) technology for ICE vehicles (7.7 litres per 100 km) and assuming a similar ratio between hybrid ICE and ICE vehicles and the use of more ethanol so that the average 3 litres of fossil fuel consumption per 100 km is met, would lead to 14.6% greater non-renewable primary energy consumption per capita and 40% greater CO_2 emission per capita	

hydrolysis & fermentation technology: - for a central plant providing enough ethanol to meet 5% of advanced ICE and ICE hybrid vehicles final energy demand as a blend, or 4% of the total final energy consumption for transport; target 70% biomass to ethanol conversion efficiency	- greater diversity of biomass resources - multi-feedstock processing - process integration – multi-output plants - advanced pretreatment process - higher yield of fermentable sugars, lower or zero amount of fermentation inhibiters, chemical recycling, lower amount of residues, lower cost enzymes - simultaneous sacharification and fermentation or direct conversion of lignocellulosic fraction into ethanol - pentose and hexose simultaneous conversion in a same reactor
	Swiss academic 'know-how' (non exhaustive): - EPFL – ISIC (LGCB), ENAC (LBE, LASEN) - ETHZ – IB
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not substituting oil products with such an amount of ethanol would lead to 2.3% greater non renewable primary energy consumption per capita, and 4.3% greater CO_2 emission per capita; but using the corresponding available biomass in biomass fired combined cycles equipped with gasification and pre-combustion CO_2 removal technology instead would lead to 9.3% lower CO_2 emission per capita with a similar non-renewable primary energy consumption per capita	

advanced natural gas reforming technology (large scale): - for a natural gas reforming central plant providing enough hydrogen to meet 4% of total final energy transport demand: target 80% natural gas to hydrogen conversion efficiency (versus 65-70% with steam reforming currently)	- advanced catalysts - partial oxidation - autothermal reforming - concentrated solar reforming
	Swiss academic 'know-how' (non exhaustive): - ETHZ – IET (PRE) - PSI – ENE (LST, LEMC) - EPFL – ISE (LENI), ISIC (LCPM) - EMPA – MET
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current natural gas steam reforming technology would lead to less than 1% greater non-renewable primary energy consumption per capita and less than 1% greater CO_2 emission per capita	

low energy housings: advanced insulation, glazing, lighting, and ventilation : - for a 75% decrease of the average annual specific energy consumption per square meter for room heating - for a 50% decrease of the average annual energy demand in the building sector	- vacuum insulation construction site usability - long time integrity of vacuum - detection technologies for ventilated vacuum panels - vacuum glazing - surface coating for advanced glazing - heat recovery - system cost reduction by cost reduction of components - energy efficient framing technologies - switchable glazing - improvement of heat recovery rate – advanced heat exchangers - intelligent and robust control systems and strategy - efficiency increase of electric motors and drives

<table>
<tr><td></td><td><u>Swiss academic 'know-how' (non exhaustive):</u>

- EMPA
- EPFL – ENAC (LESO)
- HT Winterthur
- HT Luzern
- HT Basel</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- assuming that insulation, glazing, and ventilation technology only allows 50% reduction of the average annual specific energy consumption for room heating (instead of 75%) would lead to 4.6% greater non renewable primary energy consumption per capita and 6% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">photovoltaic cells:

- for 1.5% of the electricity requirements; target 25% electric efficiency</td><td>- cost reduction by decrease of material losses in production e.g. by improved sawing technologies
- improved industrial manufacturing technologies to approach mass production efficiency to the values of lab efficiency
- cost reduction and improved reliability of balance of system components (especially inverters)
- increase of module efficiency</td></tr>
<tr><td><u>Swiss academic 'know-how' (non exhaustive):</u>

- Uni Neuchâtel - IMT
- EPFL – ISIC (LPI), CRPP, ENAC (LESO)
- ETHZ - TFP
- EMPA – FPL
- Uni Bern
- Uni Genève – CUEPE
- LEEE - TISO</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- not implementing such a share of photovoltaic cells in the electricity supply would lead to 1.6% greater non-renewable primary energy consumption per capita and 1.2% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">wind turbines (large):

- for 1.5% of the electricity requirements; target 45% electric efficiency</td><td>- increase of rotor area by improved strength properties of rotor material (e.g. carbon fibre/epoxy)
- gear box and drive train long term stability improvement
- weight reduction of gearless multipole generators
- improved short to mid term power prediction methodologies for grid integration
- new service and maintenance concepts for O&M cost reduction</td></tr>
<tr><td><u>Swiss academic 'know-how' (non exhaustive):</u>

- EPFL – ENAC (LASEN)
- HEVS
- EIVD
- EIG</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- not implementing such a share of wind turbines in the electricity supply would lead to 1.6% greater non renewable primary energy consumption per capita and 1.2% greater CO_2 emission per capita</td></tr>
</table>

geothermal plants: - for 3.7% of demand for room heating and based on ORC technology; target 15% electric efficiency, 75% overall efficiency - for 1.5% of the electricity requirements with ORC technology; target 18% electric efficiency	- low cost drilling technologies - geophysical mapping and exploration - borehole activation and rock fracturing - corrosion resistant materials Swiss academic 'know-how' (non exhaustive): - Uni Neuchâtel – CREGE, CHYN - EPFL – ENAC (LMS) - Uni Lausanne – IG - ETHZ - IG
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not implementing such shares of geothermal in the heat and electricity supply would lead to 1.7% greater non renewable primary energy consumption per capita and 2.4% greater CO_2 emission per capita	

6.2.1 Results of the first order quantitative analysis by sector

Room heating:

- Aggressive policy is put in place to reduce by half the final energy consumption in the building sector. Building standard rapidly approaches Minergie level and develops towards zero energy housing. Given an expected 25% increase of the total heated area by 2050, the average specific annual heat consumption of the whole building stock for room heating must be reduced by 75%, so that the sum of room heating and water heating is reduced by half[5]. This is achieved with advanced insulation, advanced glazing, and building system integration. As a result, and after the implementation of the other measures below, the total final energy demand for room heating is reduced by 70%, i.e. from 228.3 PJ in 2001 down to 65.3 PJ in 2050.
- Direct electric heating is banned.
- Non-renewable fuel fired boilers (fuel oil and natural gas) in use within existing district heating networks are substituted with wood fired boilers, assuming that advanced wood-fired boilers reach a similar heating efficiency as the replaced fossil-fired installations. Wood as a whole makes up **8.7%** of the room heating final energy demand by 2050, i.e. 5.7 PJ. This requires 6.3 PJ of wood biomass resources assuming that 10% of the wood primary energy potential is used for the conversion into a usable final feedstock, i.e. **4.7%** of the total biomass ecological potential[6].

[5] This supposes that electricity consumption in buildings is also reduced by half – a detailed analysis of this point is out of the scope of this quantitative analysis as in this existing tool, electricity consumption is aggregated.

[6] In the way the existing tool is designed, the energy required for the conversion of a biomass resource into usable final feedstock and for its transportation to the point of use is supposed to be fully provided by the biomass resource itself; this is the most optimistic case and not likely in practice. On the other hand, advanced concepts such as multi-output plants (for example delivering power to the grid while producing ethanol) cannot be modeled with this existing tool although they benefit from much better energy balance. A more sophisticated modeling tool would take into account interactions between the various primary energy resources among the different applications.

- A **66%** share of the room heating final energy demand, i.e. 43.1 PJ, is met with the use of compression heat pumps driven by electricity imported from the grid. Heat pumps in new housings become business as usual, and heat pumps dedicated to the retrofit market are importantly diffused, including units for multi-family housings in urban areas. Heat pumps are associated with a 4.5 average COP.
- New district heating networks based on some geothermal heat (2.4 PJ)[7], direct combustion of some of the available non renewable waste (2.5 PJ), direct combustion of some of the available renewable waste (2.5 PJ) and available waste heat (1.3 PJ) supply heat within urban areas, accounting for **13.3%** of the total final heat supply. Geothermal heat is supplied by cogeneration plants based on ORC technology which deliver electricity to the grid at a 15% electric efficiency and are associated with a 75% overall energy conversion efficiency.
- Solar thermal accounts for **12%** of the final energy supply for room heating, i.e. 7.7 PJ, and is applied to building clusters thanks to the development of appropriate seasonal storage associated with an annual efficiency of at least 40%. Solar thermal installations are associated with a 50% heating efficiency (final heat to useful heat ratio) and require an equivalent of 5% of the final heat delivered in the form of electricity for operation. Assuming solar panels delivering 500 kWh per m^2 and per year, about 4.3 million m^2 (or about 0.6 m^2 per capita[8]) must be installed by 2050. This is about 3% of the estimated 138 million m^2 of available roof area [Erneuerbare Energien und neue Nuklearanlagen, BFE 2005] and requires about 100’000 m^2 to be installed yearly in average between 2005 and 2025, and about 200’000 m² yearly in average between 2025 and 2050, accounting for a 20 years lifetime for the solar panels. As a comparison, currently 35’000 m^2 are installed every year in Switzerland[9].

	Room heating - final energy [PJ]	
	RH 2001	RH 2050
oil products	139.8	-
natural gas	53.7	-
non renewable waste	12.2	2.5
solar - thermal	-	7.7
wood	12.3	5.7
renewable waste	6.6	2.5
waste heat	-	1.3
heat from environment	3.1	33.4
geothermal heat	-	2.4
electricity	0.6	9.7
	228.3	65.3

[7] Assuming 6’000 hours of operation per year for room heating in the building sector, this means that between 5 and 6 plants such as the one in construction in Basel (20 MWth) are installed by 2050.
[8] Assuming 7.5 million inhabitants by 2050
[9] In terms of ‘standard’ capacity installed, 200’000 m^2 per year is equivalent to 140 MWth per year, according to the convention from the IEA Solar Heating Cooling Programme, i.e. 0.7 kWth per m^2, to be compared with 1250 MW of solar thermal capacity expected to be installed in whole Europe in 2005 (www. estif.org)

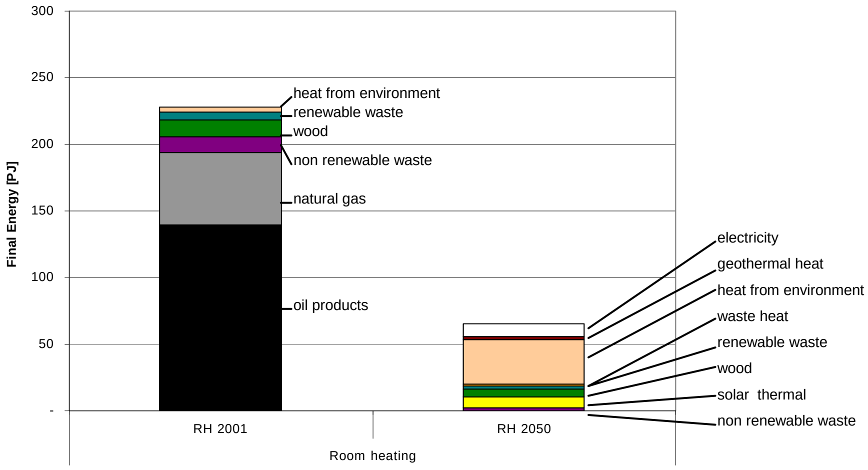


Figure 6-10 Share of the various energy sources in the room heating final energy supply (LdLfs).

Water heating:

- Efficiency measures reduce the specific energy demand for water heating by 12%, but an increase of hot water consumption by 25% leads to an actual increase of the final energy demand for water heating by 10% by 2050 up to 59.7 PJ. Fuel switching measures also contribute to an additional increase of the final energy demand for water heating up to 75.5 PJ (effect of solar thermal final energy to useful energy ratio). Efficiency measures for room heating however insure that the sum of room heating and water heating demand is reduced by half.
- Non-renewable fuel fired boilers (fuel oil and natural gas) in use within existing district heating networks are substituted with wood fired boilers, assuming advanced wood-fired boilers reach a similar heating efficiency as the replaced fossil-fired installations. Wood as a whole makes up **10.9%** of the water heating final energy demand by 2050, i.e. 8.2 PJ. This requires 9 PJ of wood biomass resources assuming that 10% of the wood primary energy potential is used for the conversion into a usable final feedstock, i.e. **7.4%** of the total biomass ecological potential[10].
- Solar thermal accounts for **54%** of the final energy demand for water heating, i.e. 40.8 PJ. It is required by rule for new housings, and is applied to single family or multi-family housings and to building clusters associated with local district heating. Solar thermal installations are associated with a 50% heating efficiency (generated heat to useful heat ratio) and require 5% of the final heat delivered in the form of electricity for their operation. Assuming solar panels delivering 500 kWh per m^2 and per year, about 21.5 million m^2 or about 3 m^2 per capita[11] must be installed by 2050, or about 15% of the estimated 138 million m^2 of available roof area [Erneuerbare Energien und neue Nuklearanlagen, BFE 2005]. This requires a yearly installation of about 480'000 m^2 in average between 2005 and 2025, and about 960'000 m^2 yearly in average between 2025 and 2050, accounting for a 20 years lifetime for the

[10] see footnote 2
[11] Assuming 7.5 million inhabitants by 2050

solar panels, to be compared with 35'000 m^2 currently installed every year in Switzerland[12].

- Heat pump based water heaters driven by electricity imported from the grid account for **35.1%** of the final energy demand for water heating, i.e. 26.5 PJ.

	Water heating - final energy [PJ]	
	WW 2001	WW 2050
oil products	16.4	-
natural gas	7.2	-
solar - thermal	1.2	40.8
wood	2.9	8.2
heat from environment	0.5	16.0
electricity	25.9	10.5
	54.2	**75.5**

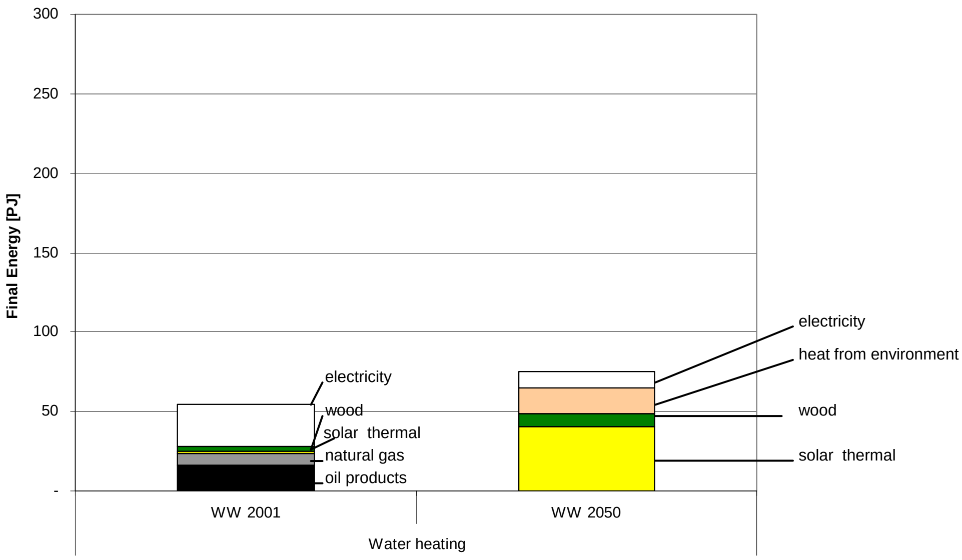


Figure 6-11 Share of the various energy sources in the water heating final energy supply (LdLfs).

<u>Transport</u>:

- Negotiations with car importers and policies in favour of fuel economy improvement, fuel switching, efficient driving behaviour, and modal transfer lead to a reduction of the average fossil fuel consumption of the passenger cars fleet down to 3 litres of gasoline equivalent per 100 km by 2050.
- A 55% demand growth of passenger vehicle transport demand is expected. The tank to wheel average conversion efficiency is increased by 56% and some fossil fuel substitution is introduced so that the total final fossil fuel consumption of the passenger vehicle fleet is reduced from 221.3 in 2001 to 124 PJ by 2050[13]. Fossil fuel substitution is obtained essentially with the use

[12] In terms of 'standard' capacity installed, 960'000 m^2 is equivalent to 672 MWth per year, according to the convention from the IEA Solar Heating Cooling Programme, i.e. 0.7 kWth per m^2, to be compared with 1250 MWth of solar thermal capacity expected to be installed in whole Europe in 2005 (www. estif.org)

[13] the average fuel consumption in 2001 was 8.4 liters gasoline per 100 km [Plan Directeur 2004-2007]

of ethanol as a blend. Some limited amount of hydrogen is also considered in this 'Future', but it cannot be accounted for fossil fuel substitution since its production does not rely on renewable energy sources but on natural gas.

- The efficiency increase and reduction of fossil fuel demand is achieved with:
    1) an improvement of ICE vehicles' average fuel economy down to 5 litres gasoline per 100 km. Those vehicles account for 48% of the total passenger vehicles fleet. A fraction equivalent to 5% (on an energy basis) of the gasoline used by those vehicles is replaced by ethanol from lignocellulosic biomass.
    2) an important market penetration of ICE hybrid vehicles which are supposed to account for 48% of the new passenger vehicles fleet. They are considered to be running on gasoline with an average specific fuel consumption equivalent to 2.5 litres per 100 km. A fraction equivalent to 5% (on an energy basis) of the gasoline used by those vehicles is replaced by ethanol from lignocellulosic biomass.
    3) some penetration of fuel cell vehicles running on hydrogen and associated with an average 2.5 litres gasoline equivalent per 100 km. Those are supposed to make up 3% of the fleet.
    4) some pure electric urban passenger vehicles (taxi vehicles for example) associated with a 60% power train efficiency. Those make up the rest of the fleet, i.e. 1%.
- Heavy road vehicles, rail, and air transport final energy demands are assumed to increase by 176.7%, 82.5%, and 84.8%, respectively, compared to 2001, accounting for efficiency measures reducing the specific energy demand by 7%, 50%, and 60%, respectively.
- Oil products make up **89%** of the 243.2 PJ total final energy consumption for transport.
- Ethanol from lignocellulosic biomass accounts for **4%** of the total final energy consumption for transport, i.e. 9.7 PJ. This requires 13.6 PJ of lignocellulosic biomass potential assuming a large scale processing plant[14] with a 70% overall ethanol chain conversion efficiency, i.e. **11.1%** of the total biomass ecological potential[15]. In this 'Future' where carbon capture and storage technology (CCS) is assumed to be commercially available, it is not obvious whether it would be applied to such a large ethanol production facility. Given an already high cost of carbon mitigation in the transport sector, this option is not considered for ethanol production in this scenario but left to the power sector.
- Electricity accounts for **4.4%** in the total final energy consumption for transport, i.e. 10.8 PJ.
- Hydrogen from natural gas accounts for **2.5%** in the total final energy consumption for transport, i.e. 6.1 PJ. This requires 7.6 PJ of primary energy in the form of natural gas, i.e. about 7% of the natural gas consumption in Switzerland in 2001, assuming a reforming process in a central plant associated with 80% conversion efficiency. One plant with an annual hydrogen output of 560 million Nm^3 is required[16]. This plant is associated with

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[14] based on hydrolysis or thermochemical preprocessing
[15] see footnote 2
[16] a typical capacity for current large scale natural gas steam reforming plants producing hydrogen for the needs of the industrial sector is about 800 million Nm^3

very limited CO_2 emissions due to 90% recovery with carbon capture equipment.

	Transport - final energy [PJ]	
	VK 2001	VK 2050
oil products	289.6	216.6
hydrogen from natural gas	-	6.1
liquid biofuel	-	9.7
electricity	10.2	10.8
	299.7	243.2

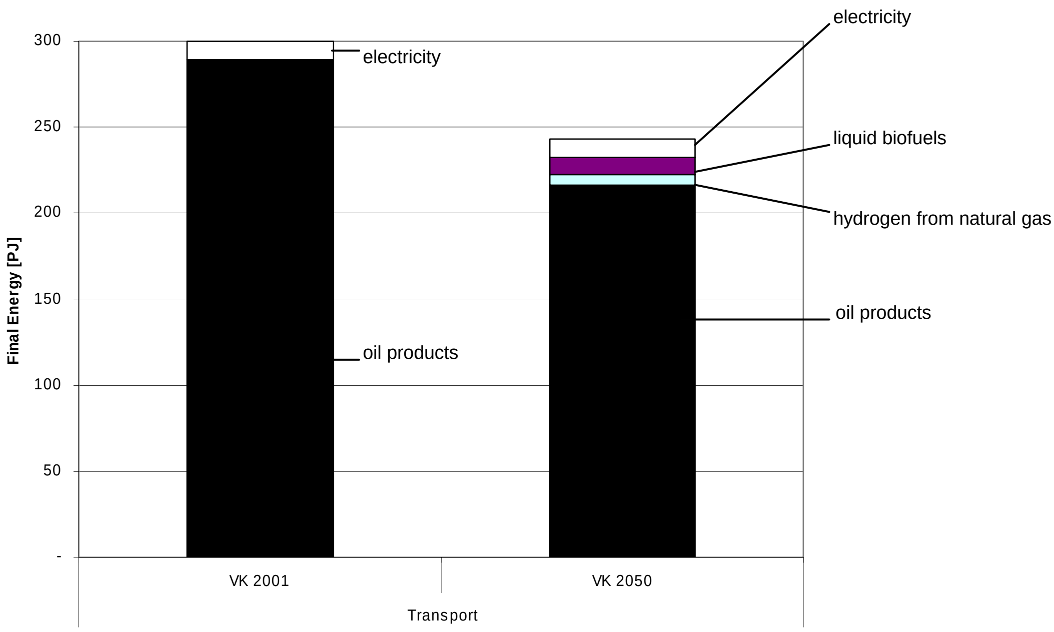


Figure 6-12 Share of the various energy sources in the transport final energy supply (LdLfs).

<u>Process heat</u>:

- Final energy demand for industrial process heat increases by 22.7%, i.e. from 130.6 PJ in 2001 up to 140.1 PJ in 2050, accounting for efficiency measures reducing the specific demand for process heat per unit output by 35%.
- Additional measures for a reduction of heat distribution losses are implemented, leading to a total heat demand of 137.6 PJ.
- Measures such as the replacement of a fourth of the compression chillers by absorption chillers running on waste heat reduce the share of electricity in the final energy demand for process heat.
- Cogeneration running on natural gas with a 40% average electric efficiency and 95% global conversion efficiency is aggressively pursued and accounts for 42.7%, i.e. 55.1 PJ, in the final energy demand for industrial process heat. The amount of electricity generated, i.e. 22.1 PJ, exceeds internal needs for process heat and 8.7 PJ of electricity can be directed towards internal electricity final needs or exported to the grid.

- Half of the remaining oil products requirements are substituted with natural gas, leading to a 73% total share of natural gas (94 PJ) in the total final energy demand for industrial process heat.
- The rest of the demand is met with direct combustion of non renewable waste, i.e. 28 PJ, and oil fired boilers, i.e. 15.6 PJ.

	Process heat - final energy [PJ]	
	PW 2001	**PW 2050**
oil products	57.1	15.6
natural gas	33.5	94.0
non renewable waste	26.1	28.0
electricity	14.0	-8.7
	130.6	128.8

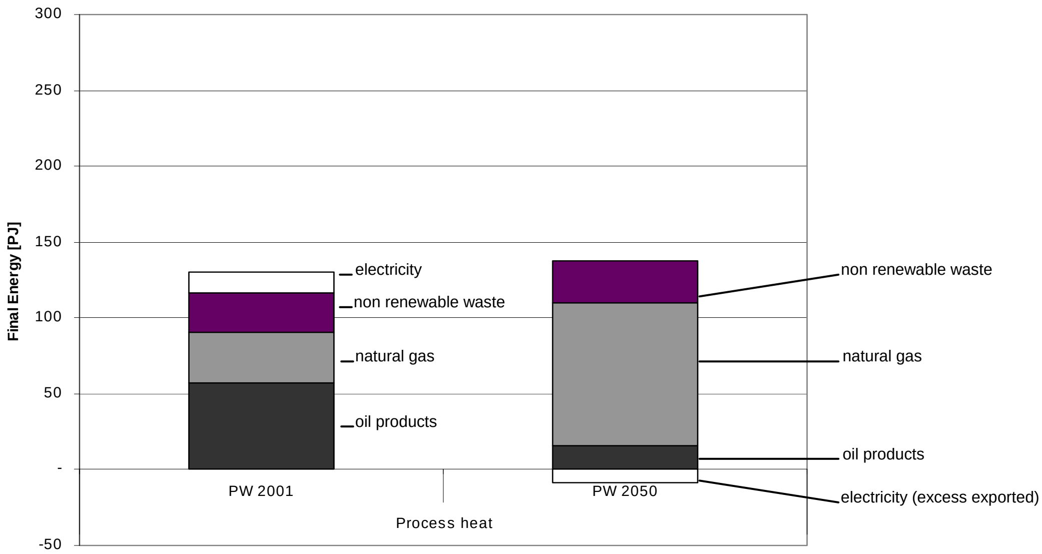


Figure 6-13 Share of the various energy sources in the process heat energy supply (LdLfs).

<u>Electricity</u>:

- Electricity requirements other than those related to electric transportation and heat supply in the building and industrial sectors increase by 23.7%, i.e. from 141.2 PJ in 2001 up to 174.7 PJ in 2050, accounting for demand-side efficiency measures reducing the specific electricity demand by 25%. Adding electricity requirements related to room and water heating in the building sector and to transport leads to a total need for 215.4 PJ of electricity out of which 22.1 PJ are met with industrial cogeneration. The remaining 193.3 PJ must be generated in central plants and distributed through the grid. In 2001, 256.4 PJ were generated, of which 191.8 PJ were supplied to domestic consumers and 43 PJ were exported, the rest being lost during transport.
- The efficiency of electricity transport and distribution via the grid is increased from 91.6% in 2001 to 95% by 2050.

- Repowering projects maintain the capacity of hydro at the same level as in 2001, therefore supplying 135.3 PJ of electricity in 2050 (after transport losses are accounted for), i.e. **62.8%** of total national needs. Assuming a conversion efficiency of 87% (versus 82% in 2001), this requires 163.7 PJ of primary energy from water resources.
- Existing nuclear power plants are decommissioned and no new nuclear capacity is installed. In such a 'Future' with low fossil fuel substitution, there are no strong drivers for a nuclear capacity renewal.
- Central combined cycle power generation plants based on biomass resources gasification supply 39.4 PJ or **18.3%** of national electricity requirements in 2050 (after transport losses are accounted for). Assuming 7'000 hours of operation annually and an average 300 MWe unit capacity, 5 plants are installed by 2050. In this 'Future' where carbon capture and storage technology (CCS) is assumed to be commercially available, it is not obvious whether it would be applied to biomass-fired plants or not[17].
    - If CCS is applied to those biomass-fired plants, and assuming a 45% overall conversion efficiency for integrated gasification combined cycles equipped with precombustion carbon capture technology with a 90% recovery rate (77% biomass feedstock to syngas conversion efficiency and 58% syngas to electricity conversion efficiency taking into account the efficiency penalty due to CCS), the five plants require **75.9%** of the total biomass ecological potential, i.e. 92.6 PJ.
    - If CCs is not applied to biomass-fired plants, and assuming a 50% overall conversion efficiency for integrated gasification combined cycles (65% syngas to electricity conversion efficiency, and 77% biomass feedstock to syngas conversion efficiency), **67.8%** of the total biomass ecological potential is required, i.e. 82.7 PJ. Note that since less biomass is required per unit of output, its share in the power supply can be increased to 42.9 PJ or 21.2%.
- Solar photovoltaic cells are moderately introduced and supply 2.9 PJ or **1.3%** of national electricity requirements by 2050, assuming an average conversion efficiency of 25%. Assuming 200 kWh per m^2 and per year, this requires about 4 million m^2 in total and the installation of about 70'000 m^2 each year in average between 2005 and 2030, and 180'000 m^2 each year between 2030 and 2050, when considering a 20 years lifetime. Current capacity connected to the grid is about 18 MWpeak, i.e.160'000 m^2, and about 2 MWpeak are being installed each year, equivalent to 20'000 m^2 given current average conversion efficiency (~10 m^2 per kWpeak). The maximum potential of building integrated PV in Switzerland is estimated to be 18.4 TWh per year, associated with 138 millions m^2 on roofs and 52 millions m^2 on facades [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005].
- Wind turbines supply 2.9 PJ or **1.3%** of national electricity requirements by 2050 (after transport losses are accounted for), assuming a conversion efficiency of 45%. This represents 70% of the estimated maximum acceptable potential for wind farms by 2050[18], i.e. about 1'150 GWh per year associated

[17] given that biomass resource considered are already carbon neutral (sustainable potential).
[18] note that another 2'850 GWh could be generated but with on-site wind turbines in a Future with a high degree of decentralisation

with 726 wind turbines installed among 96 different sites [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005].

- Geothermal plants (not associated with district heating networks) supply 2.9 PJ or **1.3%** of national electricity requirements by 2050 (after transport losses are accounted for), assuming a conversion efficiency of 18%.
- Natural gas makes up the last **14.8%** of national electricity requirements, i.e. 31.9 PJ, with on one hand industrial cogeneration supplying 22.1 PJ and on the other hand a 340 MWe combined cycle plant delivering 9.8 PJ (after transport losses are accounted for). The combined cycle plant is equipped with CCS technology and requires 17 PJ of natural gas (about 15% of 2001 consumption), assuming a conversion efficiency of 58% (taking into account the efficiency penalty due to CCS with a 90% recovery rate).

	Electricity supplied to the users [PJ]	
	EL 2001	EL 2050
oil products	3.5	0.0
natural gas	3.5	31.9
nuclear	68.1	0.0
water	116.7	135.3
wind	0.0	2.9
solar	0.0	2.9
biomass	0.0	39.4
geothermal	0.0	2.9
	191.8	215.3

note: case with CCS for large power plants, inc. biomass-fired ones

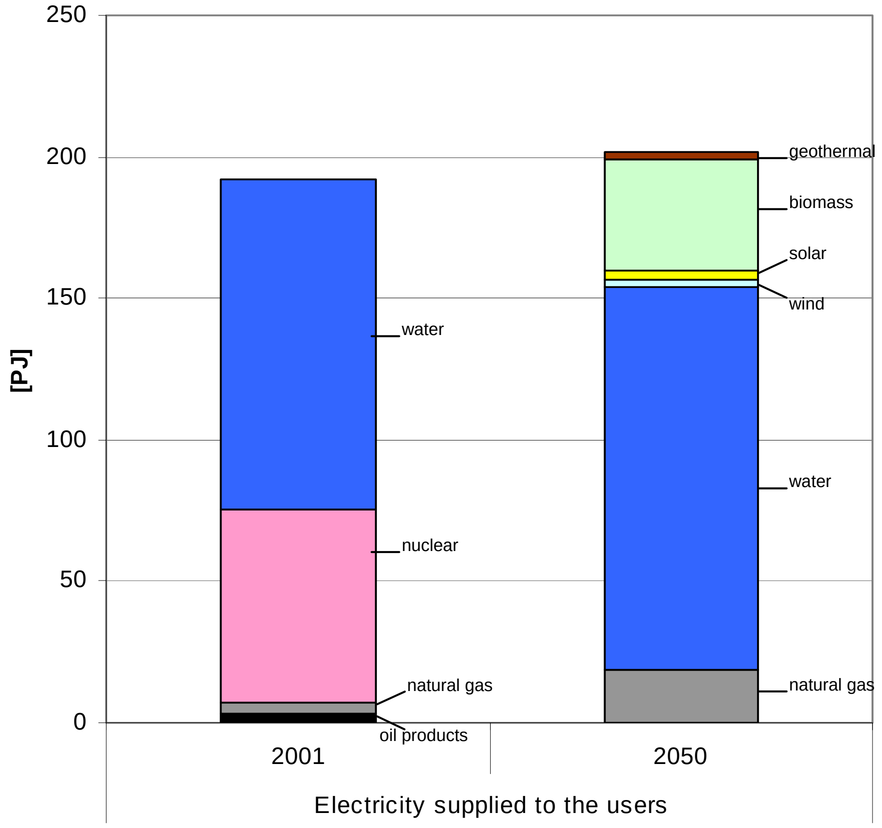
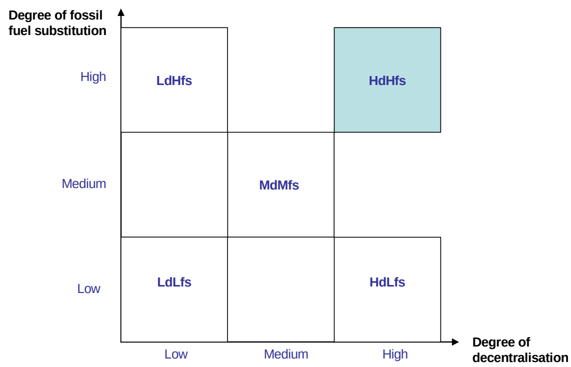


Figure 6-14 Share of the various energy sources in the electricity delivered to national users (LdLfs) - note: case with CCS for large power plants, inc. biomass-fired ones.

6.3 Future HdHfs: high degree of decentralization and high degree of fossil fuel substitution

Future HdHfs



- Repetitive failures of energy transport & distribution networks
- Strong public opposition to nuclear
- High price development of fossil fuels
- Successful liberalisation process
- Great concerns about safe and affordable energy supply

Figure 6-15: Future description and summary of the quantitative results HdHfs (for more details, see descriptions by sector)

- Aggressive policy is put in place to reduce by half the final energy consumption in the building sector. Building standard rapidly approaches Minergie level and develops towards zero energy housing. Final energy demand for room heating is reduced by 69% down to 68.8 PJ. This is lower than the final energy demand for water heating, which increases up to 75.8 PJ.
- Heat pump heating via local heating networks is generalized in densely populated areas and related electricity requirements are essentially met with district medium scale cogeneration units running on biogas generated via gasification and anaerobic digestion from respective suitable types of biomass feedstocks. In less densely populated areas, some heat pump heating is also in place in association with on-site microcogeneration based on solid biomass-fired boilers and with photovoltaic cells or on-site wind turbines. In such a 'Future' where 'Objective a' is given a strict interpretation, heat pumps running on electricity from the grid are not considered as this electricity can not be qualified as strictly 'fossil free'[19]. And cogeneration units running on natural gas are not considered either, as fossil use in the final energy demand is banned under the strict interpretation. About 65% of room heating requirements and 35% of water heating requirements are met in total with cogeneration units.
- Solar thermal capacity is greatly increased mostly for water heating with a supply of about half of the requirements (49%), but also to meet some of the room heating final energy demand (7%). In less densely populated areas, solar thermal is combined with biomass fired boilers.
- The remaining heat demand for room and water heating requirements combined is met with about 15% of biomass resources both within district

[19] even though there is no domestic fossil-fired grid electricity generation in this 'Future' apart from a small amount of electricity from natural gas fired industrial cogeneration, imports will occur in winter due to the very high share of intermittent and seasonal dependant renewable sources.

heating networks and for traditional heating (25%), and with non renewable and renewable waste (3.5%), available waste heat (1%), and geothermal (1.5%) within urban areas via district heating, and some water electric heating (4%).

- Negotiations with car importers and policies in favour of fuel economy improvement, fuel switching, efficient driving behaviour, and modal transfer lead to a reduction of the passenger vehicle fleet average fossil fuel consumption down to 3 liters of gasoline equivalent per 100 km, i.e. 124 PJ for the passenger vehicle fleet as a whole. Advanced ICE vehicles and ICE hybrids make up most of the passenger cars fleet with a 44% share each. Fuel cell vehicles have a material share with 11%. Pure electric vehicles make up the rest of the fleet with less than 1%.
- Oil products still account for about 85% of the total final energy consumption for transport.
- Hydrogen accounts for about 11% of the total final energy consumption for transport and is produced via distributed advanced electrolysis based on renewable power (photovoltaic cells and wind turbines at fuelling sites).
- Electricity accounts for about 4% in the total final energy consumption for transport.
- Final energy demand for industrial process heat increases by about 20%, accounting for efficiency measures reducing the specific demand for process heat per unit output by 35%.
- Natural gas meets a large share, i.e. about 73%, of process heat requirements in the industrial sector with a significant role played by natural gas fired cogeneration units.
- Electricity requirements other than those related to electric transportation and heat supply in the building and industrial sectors increase by a little less than 25% up to 174.7 PJ, accounting for demand-side efficiency measures reducing the specific electricity demand by 25%. Total national electricity requirements amount to 250.4 PJ, out of which 34.9 PJ are met with cogeneration in both the industrial and building sectors. The remaining 227.1 PJ, versus 191.8 PJ in 2001, are met with hydro and decentralized renewable power.
- Nuclear electricity generation capacity is phased-out.
- Repowering projects maintain the capacity of hydro at the current level, supplying about 54% of total national electricity requirements.
- A number of 20 distributed power generation plants with an average nominal capacity of 50 MWe and based on biomass resources gasification supply 9.9% of total national electricity needs. This requires a little more than 60% of the total biomass ecological potential.
- An aggressive policy in favour of solar photovoltaic cells is put in place and those are able to account for 16% of total national electricity requirements by 2050. This requires a little more than a third of the estimated maximum potential for building integrated PV.
- Wind turbines supply about 5% of total national electricity requirements by 2050 with a large share of on-site wind turbines. This is close to the estimated full maximum potential, wind farms and on-site wind turbines combined.
- Geothermal plants (not associated with district heating networks) supply 4.6 PJ of electricity by 2050 (after transport losses are accounted for), i.e. about 2% of domestic electricity needs, assuming a conversion efficiency of 18%.

- Bottom line: such a scenario leads to a 61% renewable share in the primary energy supply, to a 4.2 kW year per year primary energy consumption per capita, and to 3.7 tons of CO_2 emissions per year and per capita.

Energy resources	Share in the Primary Energy [-]	
	2001	2050
oil products	0.46	0.26
natural gas	0.09	0.10
nuclear fuel	0.23	0.00
natural gas - H2	0.00	0.00
non renewable waste	0.03	0.03
water	0.16	0.17
wind	0.00	0.03
solar - H2	0.00	0.00
solar - PV	0.00	0.16
solar - thermal	0.00	0.04
biomass - wood	0.01	0.02
biomass - biogas	0.00	0.10
biomass - liquid biofuels	0.00	0.00
renewable waste	0.01	0.00
waste heat	0.00	0.00
heat from environment	0.00	0.05
geothermal heat	0.00	0.03

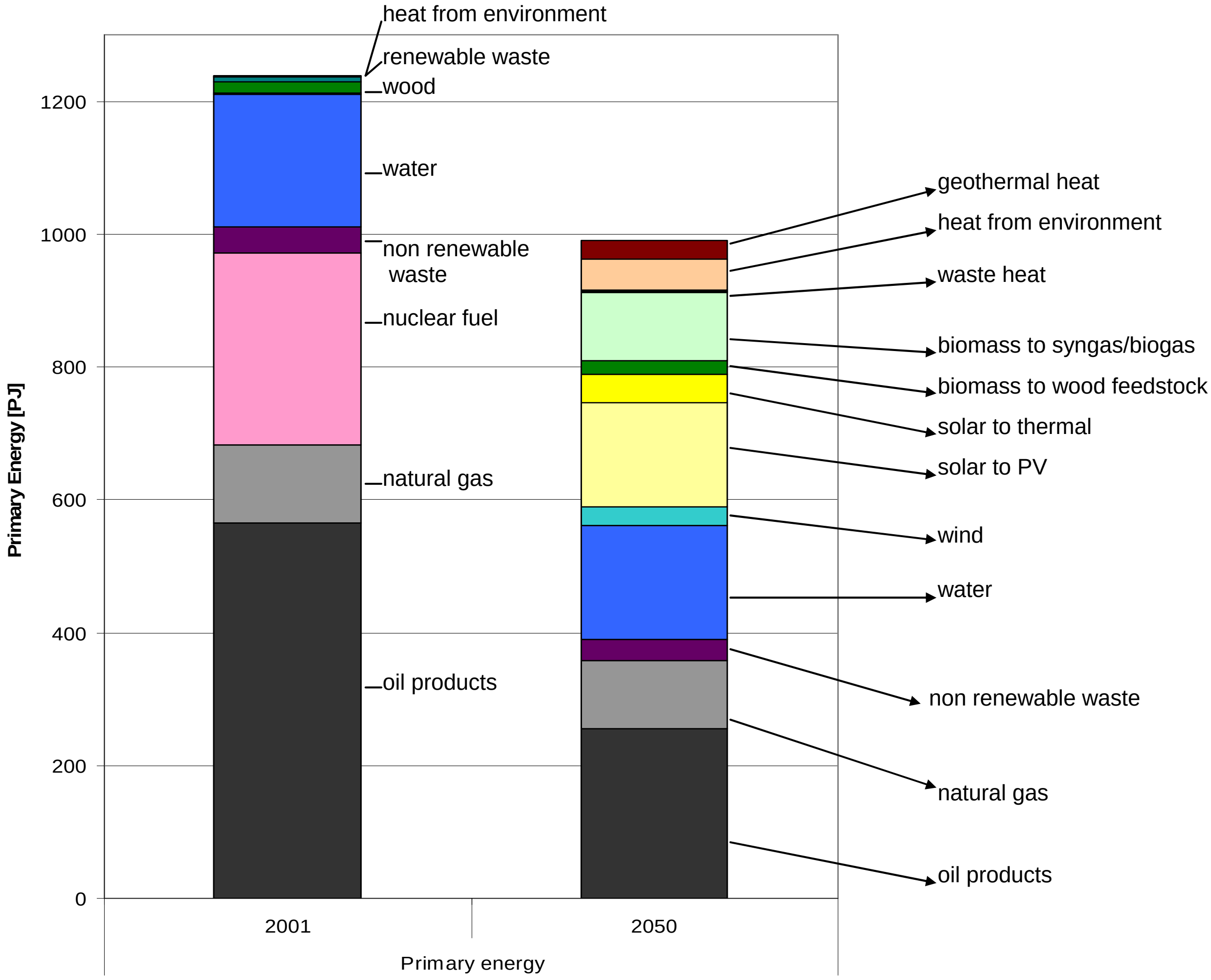


Figure 6-16 Share of the different energy resources in the primary energy supply by 2050 under a 'Future' with low degree of decentralization and a low degree of fossil fuel substitution (HdHfs).

Summary of key technologies for the domestic market in Future HdHfs and examples of related R&D needs (see technology fact sheets in Appendix for more details):

<table>
<tr><th>Technologies required for the domestic market - HdHfs</th><th>Examples of required R&D activities</th></tr>
<tr><td rowspan="2">advanced gas and steam turbine technology:

- for district combined cycle cogeneration units running on syngas from on-site gasifiers or biogas from AD, and associated with district heating networks including heat pumps (meets a large share of the 64% and 23% shares of cogeneration/HP plants in room and water heating requirements, respectively); 60 to 70% syngas to electricity conversion efficiency target, and overall First Law heating efficiency between 2.5 and 3 depending on the chosen integration

- for industrial cogeneration units running on natural gas (meets part of the 9% share in total electricity requirements); 35% electric efficiency target</td><td>- advanced combustion
- advanced cooling
- advanced GT-ST & SOFC-GT combined cycles: system integration, advanced small-scale steam turbines, unfired gas turbines
- alternative fuel firing
- advanced hot gases heat exchangers, advanced heat recovery steam generators
- atmospheric pollutants abatement technology</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- EPFL – ISE (LTT, LENI, LTCM, LMF, LIN), IMX (LMCH, LTP)
- ETHZ – IET (LAV, LTNT, LSM), IFD
- PSI – ENE (CRL)
- EMPA</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current technology for combined cycle district units (typically 45% LHV electric eff.) but assuming a similar market penetration would lead to 1.8% greater non renewable primary energy consumption per capita and 1.6% greater CO_2 emission per capita
- given the trend towards more stringent pollution standards, remaining with atmospheric emission rates currently associated with those units could severely limit their market penetration: a 4 times lower market penetration of those district units would lead to 14.7% greater non renewable primary energy consumption per capita and 14.0% greater CO_2 emission per capita
- not implementing industrial cogeneration would lead to 0.5% greater non renewable primary energy consumption per capita and 1.6% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">advanced gas engine technology:

- for district cogeneration units running on syngas generated by on-site gasifiers or biogas from AD, and associated with district heating networks including heat pumps (meets a large share of the 64% and 23% shares of cogeneration/HP plants in room and water heating requirements respectively); 50 to 55% syngas to electricity conversion efficiency target, and overall First Law heating efficiency between 2 and 2.5

- for industrial cogeneration units running on natural gas (meets part of the 9% share in total electricity requirements); 55% electric efficiency target</td><td>- low irreversibility engines – advanced combustion, lower heat and friction losses, energy recovery
- adapted or dedicated alternative fuels fired engines
- affordable and robust atmospheric pollutants emission control
- system integration - mechanically coupled heat pumps, bottoming cycles</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- ETHZ – IET (LAV)
- EPFL – ISE (LENI)
- PSI – ENE (CRL)
- EMPA - ICEL</td></tr>
</table>

scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for gas engine district cogeneration units (typically 42% LHV electric eff.) and assuming a similar market penetration would not much affect the results given the much larger share allocated to gas turbine and solid oxide fuel cells in this scenario; however, if gas engines were assumed to cover most of the demand for those district units, remaining with current technology for gas engine units would lead to 1.1% greater non renewable primary energy consumption per capita and 1% greater CO_2 emission per capita, but a 4 times lower market penetration for similar reasons as above would lead to 13.6% greater non renewable primary energy consumption per capita and 13% greater CO_2 emission per capita - not implementing industrial cogeneration would lead to 0.5% greater non renewable primary energy consumption per capita and 1.6% greater CO_2 emission per capita	
solid oxide fuel cell technology: - for district cogeneration units running on syngas from on-site gasifiers or biogas from AD, and associated with district heating networks including heat pumps (meets a large share of the 64% and 23% shares of cogeneration/HP plants in room and water heating requirements, respectively); SOFC-GT: 70% syngas to electricity conversion efficiency target, and, overall, First Law heating efficiency of about 3, SOFC: 60% syngas to electricity conversion efficiency target, and, overall, First Law heating efficiency of about 2.5 - for industrial cogeneration units running on natural gas (meets part of the 9% share in total electricity requirements); 60% electric efficiency target	- new designs & materials for greater mechanical and chemical stability at high operating temperature - advanced interconnects & sealants - in-situ monitoring techniques - low cost ceramic processing & manufacturing - compact & high performance gas to gas heat exchangers - advanced fuel processing & appropriate gas cleaning technology - system integration – GT/SOFC cycles, coupling with heat pumps - alternative electrolytes for lower operating temperature Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LENI) - ETHZ – MAT (NIN) - EMPA – HPCL
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for combined cycle district units (typically 45% LHV electric eff.) but assuming a similar market penetration would lead to 1.8% greater non renewable primary energy consumption per capita and 1.6% greater CO_2 emission per capita - SOFC technology is associated with very low atmospheric pollutants emission: a 4 times lower market penetration of cogeneration district units that would be due to non compliance with stricter atmospheric pollution standards when using more conventional technology would lead to 14.7% greater non renewable primary energy consumption per capita and 14.0% greater CO_2 emission per capita	
gasification technology (medium scale): - for district cogeneration units running on syngas from on-site gasifiers and associated with district heating networks including heat pumps (meets a large share of the 64% and 23% shares of cogeneration/HP plants in room and water heating requirements, respectively); 77% biomass to syngas conversion efficiency target	- system reliability – tars & particulates related issues - appropriate gas monitoring & cleaning technologies - fuel flexible gasifiers with priority to low or negative cost feedstock such as wastes - feeding mechanisms & reactors - feedstock quality homogenisation and standard - advanced heat exchangers Swiss academic 'know-how' (non exhaustive): - PSI – ENE (LSK) - WSL - ETHZ – IET (LTNT, PRE) - EPFL – ISE (LTCM), ISIC (LGRC)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not developing gasification for district cogeneration plants, assuming that a third of the plants run on biogas from anaerobic digestion, and using the rest of corresponding available biomass in direct combustion plants instead (typically 45% LHV electric eff.) would lead to 12.6% greater non renewable primary energy	

consumption per capita and 12.1% greater CO_2 emission per capita	

ORC technology: - for solid-biomass fired on-site cogeneration units (meets 5% of the 64% and 23% shares of cogeneration/HP plants in room and water heating requirements, respectively); 20% electric efficiency target - for geothermal cogeneration plants (meets 3.5% of demand for room heating); 15% electric efficiency and 75% overall efficiency targets - for geothermal power plants (meets 1.6% of the electricity requirements); 18% electric efficiency target	- oil circulation or pressurised biomass-fired boilers - dedicated scroll turbines & pumps for small units - radial turbines for medium-scale units - suitability of alternative working fluids Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LENI)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not implementing ORC technology for on-site cogeneration/HP units, geothermal cogeneration plants and power plants and assuming that it would be substituted by natural gas fired boilers and natural gas based electricity would lead to 4.4% greater non renewable primary energy consumption per capita and 3.7% greater CO_2 emission per capita; compliance with the objective of no fossil fuel for the building sector heat supply would require a substitution with biomass fired boilers and additional renewable electricity	

Stirling engine technology: - for solid-biomass fired on-site cogeneration units (meets 5% of the 64% and 23% shares of cogeneration/HP plants in room and water heating requirements, respectively); 35% biomass to electricity conversion efficiency target	- advanced heat exchangers - lower friction & heat losses Swiss academic 'know-how' (non exhaustive): - Ökozentrum Langenbruck - HT Basel
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not implementing Stirling engines for on-site cogeneration units and assuming that it is substituted by natural gas fired boilers and natural gas based electricity would lead to 0.6% greater non renewable primary energy consumption per capita and 0.5% greater CO_2 emission per capita; compliance with the objective of no fossil fuel for the building sector heat supply would require a substitution with biomass fired boilers and additional renewable electricity	

advanced biomass boilers: - for district heating networks (meets 8% of wood in room heating and 10% share of water heating) - for on-site domestic biomass-fired boilers (meets 6.5% of room heating requirements)	- feedstock quality homogenisation and standard - techniques for NOx and particulate matter reduction Swiss academic 'know-how' (non exhaustive): - Ökozentrum Langenbruck

<u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required), - assuming that only half of the expected market penetration is achieved and the rest is met with natural gas fired boilers instead would lead to 1.2% greater non renewable primary energy consumption per capita and 1.4% greater CO_2 emission per capita	
advanced hydropower: - for a total hydro power generation capacity maintained at the current level (54% of electricity needs by 2050); 87% conversion efficiency target (versus 82% in 2001)	- advanced blade design for reduced cavitation problems – three dimensional modelling of turbine flow phenomena - mechanical stability under unsteady phenomena - advanced generators - micro-hydro <u>Swiss academic 'know-how' (non exhaustive):</u> - EPFL – ISE (LMH) - EPFL – ISE (LME) - EPFL – ENAC (LCH)
<u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for hydro while using the same potential would lead to 1.8% greater non renewable primary energy consumption per capita and 1.3% greater CO_2 emission per capita (more gas use as lower biomass share in the power supply given a fixed biomass potential)	
advanced electricity transport network: - overall electricity transport losses reduced down to 5% (versus 8.4% in 2001)	- advanced superconductors with higher temperatures and higher inner coherence – reduced risk of resistance at grain/crystal interfaces - advanced high voltage DC transmission concepts - advanced AC/DC power conversion technologies - advanced power electronics for load control <u>Swiss academic 'know-how' (non exhaustive):</u> - EPFL – ISE (LEI, LRE) - ETHZ – EE (PES, EEH) - EIA-FR - EIVD
<u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for hydro while using the same potential would lead to 1.5% greater non renewable primary energy consumption per capita, and 1.1% greater CO_2 emission per capita (more gas use as lower biomass share in the power supply given a fixed biomass potential)	
advanced compression heat pumps: - coupled with cogeneration units and for a 62% share of room heating requirements by 2050; target average COP 4.5 - coupled with cogeneration units or driven by renewable electricity and for a 35% share of water heating requirements; target average COP 3.5	- products for both water & room heating or for the retrofit market – new working fluids and specific components - monitoring & control for operating strategy - advanced compressors and cycles - advanced heat exchangers <u>Swiss academic 'know-how' (non exhaustive):</u> - EPFL – ISE (LENI, LTCM) - HT Basel – IE - HT Luzern – WTT - HT Winterthur - HT Rapperswil - IET
<u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required), - assuming an average COPs of 3.5 instead of 4.5 and 2.5 instead of 3.5 would lead to 2.3% greater non renewable primary energy consumption per capita and 1.9% greater CO_2 emission per capita - remaining with current technology for heat pumps, and assuming average COP 3.5 and similar market penetration for heat pump based cogeneration (district heating) but no market penetration for heat pump based water heaters would lead to 2.8% greater non renewable primary energy consumption per capita and 2.1% greater CO_2 emission per capita	

advanced solar thermal, inc. storage: - for a 49% share of water heating requirements by 2050; target 50% available heat to useful heat efficiency - for a 7% share of room heating requirements by 2050; target 50% available heat to useful heat efficiency and seasonal storage with 40% annual efficiency	- advanced heat storage concepts - low cost production technologies for vacuum tubular solar thermal technologies - system integration – in-house and advanced low cost control technology Swiss academic 'know-how' (non exhaustive): - HT Rapperswil - SPF - EIVD – IGT (LESBAT) - EPFL – ENAC (LESO) - Uni Genève - CUEPE
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for solar thermal, and assuming similar market penetration for water heating but with 40% overall eff. and no material market penetration for room heating due to lack of satisfactory enough seasonal storage, would lead to 1% greater non renewable primary energy consumption per capita and 1% greater CO_2 emission per capita	
advanced small-scale electrolysis: - for distributed hydrogen fuelling stations providing enough hydrogen to meet 11% of the total final energy consumption for transport; 80% electricity to compressed hydrogen conversion efficiency target (~3.8 kWh per Nm^3 of hydrogen compressed @ 700 bars)	- integration with intermittent energy sources - advanced monitoring and control strategy - reliable and low cost PEM technology - solar to hydrogen direct conversion (photoelectrolysis) Swiss academic 'know-how' (non exhaustive): - EPFL – ISIC (LPI) - PSI – ENE (ECL) - ETHZ – IMRT
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for small-scale distributed electrolysis (typically 60% electricity to compressed hydrogen conversion efficiency) would lead to 2.5% greater non renewable primary energy consumption per capita and 1.9% greater CO_2 emission per capita	
polymer electrolyte fuel cell technology for transport: - for FC passenger vehicles with on-board hydrogen storage (11% share in the total transport final energy demand); target 2.5 litres gasoline equivalent per 100 km , 5'000 hours lifetime	- optimal system integration – heat and water on-board management - low manufacturing cost for bipolar plates - dedicated auxiliaries - more robust MEAs – advanced membranes and electrodes Swiss academic 'know-how' (non exhaustive): - PSI – ENE (ECL) - ETHZ – IMRT - HT Luzern - HT Biel - EI Vaud
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not developing PEM technology for FC vehicles and assuming that their share is taken up by additional ICE hybrid vehicles would not allow to comply with an average 3 litres of fossil fuel consumption per 100 km and would lead to 11.4% greater non renewable primary energy consumption per capita and 11.9% greater CO_2 emission per capita; compliance would require a much greater use of pure electric vehicles and for fossil fuelled vehicles greater tank to wheel conversion efficiency improvement (both with greater share of hybrid vehicles and greater specific efficiency improvement)	

on-board hydrogen storage: - for FC passenger vehicles with on-board hydrogen storage (11% share in the total transport final energy demand); 9% weight capacity and 2.7 kWh per litre targets	- cost reduction of storage technologies (all types) - increase of volumetric and gravimetric storage density - reduction of boil of losses of liquid hydrogen storage Swiss academic 'know-how' (non exhaustive): - Uni Fribourg - Uni Genève - EMPA – MET - EPFL – ISIC (LCOM)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not developing hydrogen storage appropriate enough for FC hybrid vehicles and assuming that their share is taken up by additional ICE hybrid vehicles would not allow to comply with an average 3 litres of fossil fuel consumption per 100 km and would lead to 11.4% greater non renewable primary energy consumption per capita and 11.9% greater CO_2 emission per capita; compliance would require a much greater use of pure electric vehicles and for fossil fuelled vehicles greater tank to wheel conversion efficiency improvement (both with greater share of hybrid vehicles and greater specific efficiency improvement)	
advanced on-board electric storage: - for ICE hybrid passenger vehicles and pure electric vehicles, with a cumulated 44% share in the total transport final energy demand; target 3 litres gasoline equivalent per 100 km for ICE hybrids, and 2 litres gasoline equivalent per 100 km for pure electric	- advanced batteries: cost reduction - advanced batteries: long term usability (increase of charging cycles) - advanced batteries: improved energy density - super-capacitors Swiss academic 'know-how' (non exhaustive): - PSI – ENE (ECL) - EPFL – ISE (LEI), ISIC (LPI, LCIC, GGEC), IMX (LTP)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for on-board batteries, and assuming 2 times lower hybrid ICE market penetration and no material pure electric market penetration as a consequence would lead to 7.4% greater non renewable primary energy consumption per capita and 7.8% greater CO_2 emission per capita and would fail to comply with an average 3 litres of fossil fuel consumption per 100 km; compliance would require a much greater tank to wheel conversion efficiency improvements for ICE engines and/or a greater fuel cell vehicles market penetration	
advanced ICE vehicles for transport: - for a 44% share in the total transport final energy demand; target 6 litres gasoline per 100 km for ICE and 3 litres gasoline per 100 km for hybrid ICE	- advanced combustion - camless operation - adaptive calibration of engine parameters - in-cylinder sensing - continuous variable transmission - advanced injection - advanced heat recovery - lightweight vehicles: low cost composite structure production processes, optimisation of composite structure design, lightweight hybrid body structures (multi material sandwich structures)

<table>
<tr><td></td><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- ETHZ - IET (LAV, LTNT, LSM), IFD
- EPFL – ISE (LENI)
- PSI – ENE (CRL)
- EMPA - ME
- HT Rapperswill
- HT Biel</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current (new) technology for ICE vehicles (7.7 litres per 100 km) and assuming the same ratio of hybrid ICE and ICE vehicles would lead to 8% greater non renewable primary energy consumption per capita and 8.2% greater CO_2 emission per capita, and would fail to comply with an average 3 litres of fossil fuel consumption per 100 km; compliance would require greater hybrid ICE and/or fuel cell vehicles market penetration</td></tr>
<tr><td rowspan="2">low energy housings: advanced insulation, glazing, lighting, and ventilation :

- for a 75% decrease of the average annual specific energy consumption per square meter for room heating

- for a 50% decrease of the average annual energy demand in the building sector</td><td>- vacuum insulation construction site usability
- long time integrity of vacuum
- detection technologies for ventilated vacuum panels
- vacuum glazing
- surface coating for advanced glazing
- heat recovery - system cost reduction by cost reduction of components
- energy efficient framing technologies
- switchable glazing
- improvement of heat recovery rate – advanced heat exchangers
- intelligent and robust control systems and strategy
- efficiency increase of electric motors and drives</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- EMPA
- EPFL – ENAC (LESO)
- HT Winterthur
- HT Luzern
- HT Basel</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- assuming that insulation, glazing, and ventilation technology only allows 50% reduction of the average annual specific energy consumption for room heating (instead of 75%) would lead to 4.6% greater non renewable primary energy consumption per capita and 6% greater CO_2 emission per capita</td></tr>
<tr><td>photovoltaic cells:

- for 16% of the electricity requirements: target 25% electric efficiency</td><td>- cost reduction by decrease of material losses in production e.g. by improved sawing technologies
- improved industrial manufacturing technologies to approach mass production efficiency to the values of lab efficiency
- cost reduction and improved reliability of balance of system components (especially inverters)
- increase of module efficiency</td></tr>
</table>

	Swiss academic 'know-how' (non exhaustive): - Uni Neuchâtel - IMT - EPFL – ISIC (LPI), CRPP, ENAC (LESO) - ETHZ - TFP - EMPA – FPL - Uni Bern - Uni Genève – CUEPE - LEEE - TISO

scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required),
- not installing this share of photovoltaic cells in the electricity supply would lead to 20.8% greater non renewable primary energy consumption per capita and 16.9% greater CO_2 emission per capita
- installing the same area of photovoltaic cells but remaining with current technology (typically 15% electric efficiency) would lead to 6.0% greater non renewable primary energy consumption per capita and 4.9% greater CO_2 emission per capita

wind turbines (large & small): - for 5% of the electricity requirements: target 45% electric efficiency	- increase of rotor area by improved strength properties of rotor material (e.g. carbon fibre/epoxy) - gear box and drive train long term stability improvement - weight reduction of gearless multipole generators - improved short to mid term power prediction methodologies for grid integration - new service and maintenance concepts for O&M cost reduction
	Swiss academic 'know-how' (non exhaustive): - EPFL – ENAC (LASEN) - HEVS - EIVD - EIG

scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required),
- not installing this share of wind turbines in the electricity supply would lead to 7.4% greater non renewable primary energy consumption per capita and 5.9% greater CO_2 emission per capita
- installing the same number of wind turbines but remaining with current technology (typically 35% electric efficiency) would lead to 1.8% greater non renewable primary energy consumption per capita and 1.3% greater CO_2 emission per capita

geothermal plants: - for 3.5% of demand for room heating and based on ORC technology: 15% electric efficiency and 75% overall efficiency targets - for 1.5% of the electricity requirements with ORC technology: 18% electric efficiency target	- low cost drilling technologies - geophysical mapping and exploration - borehole activation and rock fracturing - corrosion resistant materials
	Swiss academic 'know-how' (non exhaustive): - Uni Neuchâtel – CREGE, CHYN - EPFL – ENAC (LMS) - Uni Lausanne – IG - ETHZ - IG

scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required),
- not installing such a share of geothermal in the heat and electricity supply would lead to 3.7% greater non renewable primary energy consumption per capita, and 2.9% greater CO_2 emission per capita

pumped-hydro technology: - for more efficient grid electricity supply management	- optimal design for reversible turbines - mechanical stability under unsteady phenomena - downscaling - systematic cartography of suitable sites
	Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LMH) - EPFL – ISE (LME) - EPFL – ENAC (LCH)
quantitative analysis not possible with the existing tool as based on annual energy balance	
small-scale electric storage: - for more efficient matching of electricity supply and demand on-site	- lithium batteries greater lifetime and lower cost - low temperature and pressure metal hydrides - advanced power conversion electronics
	Swiss academic 'know-how' (non exhaustive): - PSI – ENE (ECL) - EPFL – ISE (LEI), ISIC (LPI, LCIC, GGEC), IMX (LTP) - HEVS - EIVD
quantitative analysis not possible with the existing tool as based on annual energy balance	

6.3.1 Results of the first order quantitative analysis by sector

Room heating:

- Aggressive policy is put in place to reduce by half the final energy consumption in the building sector. Building standard rapidly approaches Minergie level and develops towards zero energy housing. Given an expected 25% increase of the total heated area by 2050, the average specific annual heat consumption of the whole building stock for room heating must be reduced by 75%, so that the sum of room heating and water heating is reduced by half[20]. This is achieved with advanced insulation, advanced glazing, and building system integration. As a result, and after the implementation of the other measures below, the total final energy demand for room heating is reduced by 69%, i.e. from 228.3 PJ in 2001 down to 68.8 PJ in 2050.
- Direct electric heating is banned.
- Non renewable fuel fired boilers (fuel oil and natural gas) in use within existing district heating networks are substituted with wood fired boilers, assuming advanced wood-fired boilers reach a similar heating efficiency than replaced fossil-fired installations. Finally, domestic wood boilers installed in replacement of part of the oil and gas boilers in housings located in areas with a low population density account for 4.4 PJ of final energy. Wood as a whole makes up **14.8%** of the room heating final energy demand by 2050, i.e. 10.2 PJ. This requires 11.2 PJ of wood biomass resources assuming that 10% of the wood primary energy potential is used for the conversion into a usable final feedstock, i.e. **9.2%** of the total biomass ecological potential[21].

[20] This supposes that electricity consumption in buildings is also reduced by half - out of the scope of this study as in MZ tool, electricity consumption is aggregated.
[21] See footnote 3

- A **64.4%** share of the room heating final energy demand, i.e. 44.3 PJ[22], is met with the use of integrated energy systems based on biomass fired cogeneration units coupled with compression heat pumps associated with a 4.5 average COP. Most of the cogeneration units, i.e. 95% on an energy basis, are medium scale district units associated with local district heating networks in urban areas and densely populated villages. Being large enough, such cogeneration units can be associated with gasifiers or large anaerobic digesters, which provide the required biogas/syngas from biomass feedstocks, waste in priority. Furthermore, district cogeneration units can be rather sophisticated and are therefore associated with a high average electric efficiency, i.e. 65%. Their overall conversion efficiency is however penalised by thermal losses and is of 70%. Combined cycles units based on solid oxide fuel cell and gas turbine technologies reach 70% electric efficiency, and large advanced gas engine technology reach 55% electric efficiency. The remaining 5% of the heat supplied with cogeneration is met with different types of on-site energy systems (micro-cogeneration) associated with a 25% average electric efficiency and a 95% overall efficiency. Those units can typically be ORC turbines or Stirling engines associated with wood-fired boilers and located in residential or commercial buildings in areas with a low population density, or small gas engines or fuel cells running on biogas generated by small digesters located at farm sites or waste water plants. District and on-site cogeneration units use **14.6%** of the total ecological biomass potential to meet their share of the final energy supply for room heating, assuming a 77% feedstock to biogas/syngas conversion efficiency (30% of the biomass primary energy potential is used for the conversion into a usable feedstock).
- A few housings located in less densely populated areas are heated via heat pumps driven by photovoltaics or small scale wind turbines, complemented by wood boilers in winter.
- Direct combustion of some of the available non renewable waste (2.5 PJ), direct combustion of some of the available renewable waste (2.5 PJ), available waste heat (1.3 PJ), and geothermal supply heat within urban areas via district heating (2.4 PJ) accounting for **12.6%** of the total final heat supply.
- Solar thermal accounts for **7%** of the final energy supply for room heating, i.e. 4.8 PJ, and is essentially applied in housings located in areas with a low population density in combination with wood-fired boilers to meet demand in winter. Solar thermal installations are associated with a 50% heating efficiency (final heat to useful heat ratio) and require an equivalent of 5% of the final heat delivered in the form of electricity for operation. Assuming solar panels delivering 500 kWh per m^2 and per year, about 2.7 million m^2 (or about 0.35 m^2 per capita[23]) must be installed by 2050. This is about 60'000 m^2 installed yearly in average between 2005 and 2025, and about 120'000 m^2 yearly in average between 2025 and 2050, accounting for a 20 years lifetime for the solar panels, to be compared with 35'000 m^2 currently installed every year in Switzerland[24].

[22] 30.6 PJ in the form of environment heat, and 13.7 PJ in the form of biogas/syngas which feeds the cogeneration units and from there the heat pumps with the required electricity.
[23] Assuming 7.5 millions inhabitants by 2050
[24] in terms of 'standard' capacity installed, 60'000 m^2 is equivalent to 42 MWth per year, according to the convention from the IEA Solar Heating Cooling Programme, i.e. 0.7 kWth per m^2, to be compared

	Room heating - final energy [PJ]	
	RH 2001	RH 2050
oil products	139.8	-0.0
natural gas	53.7	0.0
non renewable waste	12.2	2.5
solar - thermal	-	4.8
wood	12.3	10.2
syngas/biogas	-	13.7
renewable waste	6.6	2.5
waste heat	-	1.3
heat from environment	3.1	30.6
electricity	0.6	0.8
geothermal	-	2.4
	228.3	68.8

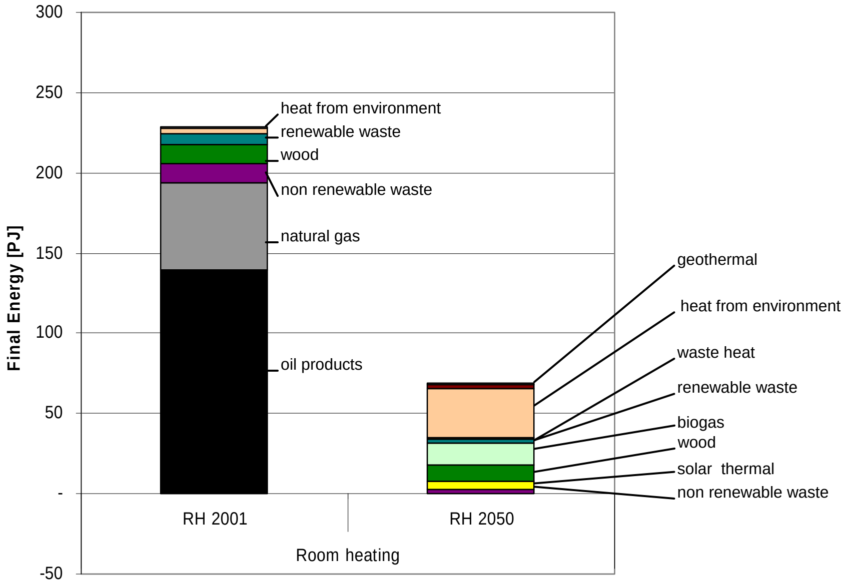


Figure 6-17 Share of the various energy sources in the room heating final energy supply (HdHfs).

<u>Water heating</u>:

- Efficiency measures reduce the specific energy demand for water heating by 12%, but an increase of the hot water consumption by 25% leads to an actual increase of the final energy demand for water heating by 10% by 2050, up to 59.7 PJ. Fuel switching measures also contribute to an additional increase of the final energy demand for water heating up to 75.8 PJ (effect of solar thermal final energy to useful energy ratio). Efficiency measures for room heating however insure that the sum of room heating and water heating demand is reduced by half.
- Non renewable fuel fired boilers (fuel oil and natural gas) in use within existing district heating networks are substituted with wood fired boilers, assuming advanced wood-fired boilers reach a similar heating efficiency than replaced fossil-fired installations. Wood as a whole makes up **10.8%** of the water heating final energy demand by 2050, i.e. 8.2 PJ. This requires 9 PJ of

with 1250 MWth of solar thermal capacity expected to be installed in the whole Europe in 2005 (www. estif.org) wood biomass resources assuming that 10% of the wood primary energy potential is used for the conversion into a usable final feedstock, i.e. **7.4%** of the total biomass ecological potential[25].

- Heat pumping based on biogas/syngas fired district cogeneration plants accounts for **23.4%** of the energy demand for water heating, i.e. 17.7 PJ (10.8 from the environment and 6.9 PJ from syngas/biogas). This requires 9 PJ of wood biomass resources assuming that 30% of the considered biomass primary energy potential is used in average for the conversion into a usable biogas or syngas, i.e. **7.4%** of the total ecological biomass potential[26].
- Solar thermal accounts for **48.9%** of the final energy demand for water heating, i.e. 37.1 PJ. It is required by rule for new housings, and is applied to single family or multi-family housings and to building clusters associated with local district heating. Solar thermal installations are associated with a 50% heating efficiency (generated heat to useful heat ratio) and require 5% of the final heat delivered in the form of electricity for their operation. Assuming solar panels delivering 500 kWh per m^2, about 15.6 millions m^2 (or about 2.2 m^2 per capita[27]) must be installed by 2050. This is about 350'000 m^2 installed yearly in average between 2005 and 2025, and about 700'000 m^2 yearly in average between 2025 and 2050, accounting for a 20 years lifetime for the solar panels, to be compared with 35'000 m^2 currently installed every year in Switzerland[28].
- Heat pump based water heaters driven by electricity generated on-site with photovoltaic cells or small wind turbines account for **11.2%** of the final energy demand for water heating, i.e. 8.5 PJ (of which 6.1 PJ come from the environment). They are associated with a 3.5 average COP.
- The rest of the demand is met with direct heating with renewable based electricity (**7.5%**).

[25] see footnote 3
[26] see footnote 3.
[27] Assuming 7.5 millions inhabitants by 2050
[28] in terms of 'standard' capacity installed, 700'000 m^2 is equivalent to 490 MWth per year, according to the convention from the IEA Solar Heating Cooling Programme, i.e. 0.7 kWth per m^2, to be compared with 1250 MWth of solar thermal capacity expected to be installed in whole Europe in 2005 (www. estif.org)

	Water heating - final energy [PJ]	
	WW 2001	WW 2050
oil products	16.4	0.0
natural gas	7.2	0.0
solar - thermal	1.2	37.1
wood	2.9	8.2
syngas/biogas	-	6.9
heat from environment	0.5	16.9
electricity	25.9	6.7
	54.2	75.8

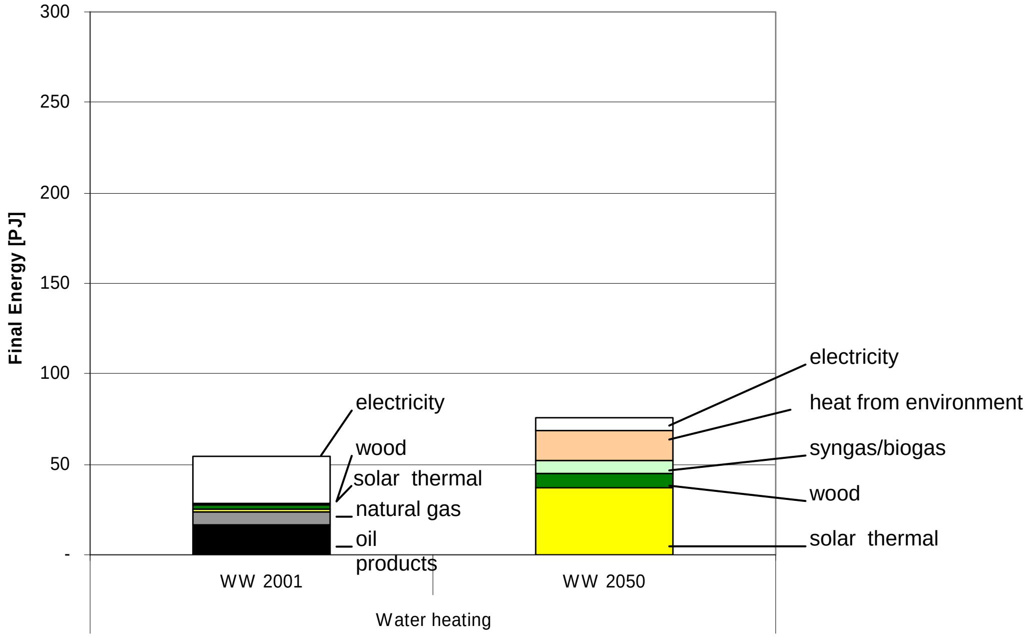


Figure 6-18 Share of the various energy sources in the water heating final energy supply (HdHfs).

Transport:

- Negotiations with car importers and policies in favour of fuel economy improvement, fuel switching, efficient driving behaviour, and modal transfer lead to a reduction of the passenger cars fleet's average fossil fuel consumption down to 3 liters of gasoline equivalent per 100 km.
- A 55% demand growth of passenger vehicles final energy demand is expected. The tank to wheel average conversion efficiency is increased by 46% and quite significant fossil fuel substitution is introduced so that the total final fossil fuel consumption of the passenger vehicle fleet is reduced from 221.3 in 2001 to 124 PJ by 2050[29]. Fossil fuel substitution is essentially obtained with the use of hydrogen generated at fuelling sites with renewable based electrolysis.
- This is achieved with:

[29] the average fuel consumption in 2001 was 8.4 liters gasoline per 100 km [Plan Directeur 2004-2007]

1) an improvement of ICE vehicles average fuel economy down to 6 litres gasoline per 100 km. Those vehicles account for 44% of the total passenger vehicles fleet.
2) an important market penetration of ICE hybrid vehicles, which are supposed to account for 44% of the new passenger cars fleet. They are considered to be running on gasoline with an average specific fuel consumption equivalent to 3 litres per 100 km.
3) a material market penetration of fuel cell vehicles running on hydrogen and associated with an average 2.5 litres gasoline equivalent per 100 km. Those are supposed to make up 11% of the fleet.
4) some pure electric urban passenger vehicles (taxi vehicles for example) associated with a 60% power train efficiency. Those make up the rest of the fleet, i.e. less than 1%.

- Heavy road vehicles, rail, and air transport final energy demands are assumed to increase by 176.7%, 82.5%, and 84.8%, respectively, compared to 2001, accounting for efficiency measures reducing the specific energy demand by 7%, 50%, and 60%, respectively.
- Oil products make up **84.7%** of the 255.5 PJ total final energy consumption for transport, i.e. 216.6 PJ.
- Hydrogen accounts for **10.9%** in the total final energy consumption for transport, i.e. 27.8 PJ. It is assumed to be produced with distributed and pressurised advanced alkaline or PEM electrolysers with a 80% conversion efficiency, requiring 46.3 PJ.
- Electricity accounts for **4.4%** in the total final energy consumption for transport, i.e. 11.2 PJ.

	Transport - final energy [PJ]	
	VK 2001	VK 2050
oil products	289.6	216.6
hydrogen from electrolysis	-	27.8
electricity	10.2	11.2
	299.7	255.5

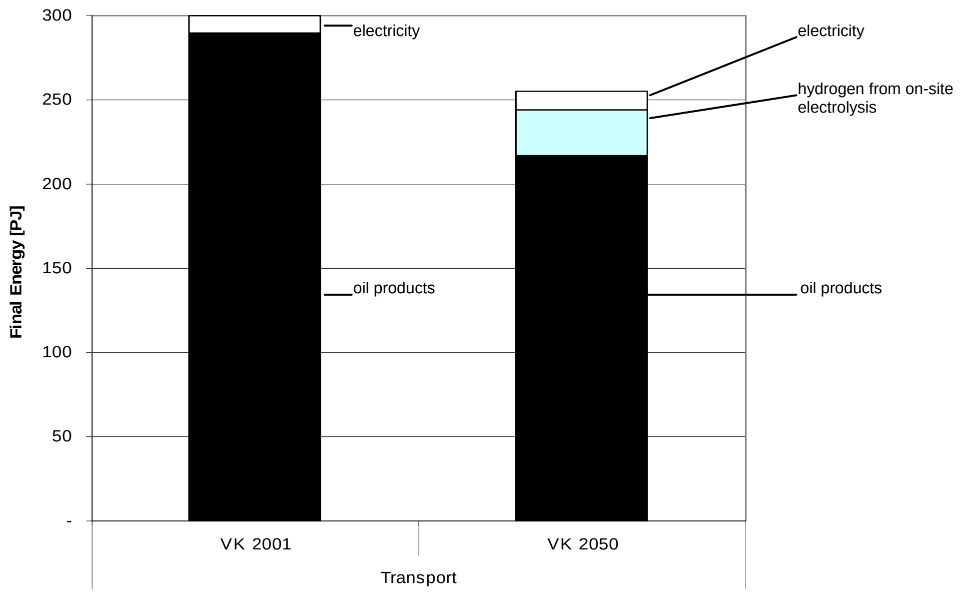


Figure 6-19 Share of the various energy sources in the transport final energy supply (HdHfs).

Process heat:

- Final energy demand for industrial process heat increases by 22.7%, i.e. from 130.6 PJ in 2001 up to 140.1 PJ in 2050, accounting for efficiency measures reducing the specific demand for process heat per unit output by 35%.
- Additional measures for a reduction of heat distribution losses are implemented, leading to a total final energy demand for process heat of 137.6 PJ.
- The replacement of a fourth of the compression chillers by absorption chillers running on waste heat reduces the share of electricity in the final energy demand for process heat.
- Industrial cogeneration running on natural gas with a 40% average electric efficiency and 95% global conversion efficiency is aggressively pursued and accounts for 42.7%, i.e. 75.2 PJ, in the final energy demand for industrial process heat. The amount of electricity generated, i.e. 22.1 PJ, exceeds internal needs for process heat and 8.7 PJ of electricity can be directed towards internal electricity final needs or exported to the grid.
- Half of the remaining oil products requirements is substituted with natural gas, leading to a **72.9%** total share of natural gas in the total final energy demand for industrial process heat.
- The rest of the demand is met with direct combustion of non renewable waste, i.e. 28 PJ, and oil fired boilers, i.e. 15.6 PJ.

	Process heat - final energy [PJ]	
	PW 2001	PW 2050
oil products	57.1	15.6
natural gas	33.5	94.0
non renewable waste	26.1	28.0
syngas/biogas	-	-
electricity	14.0	-8.7
	130.6	128.8

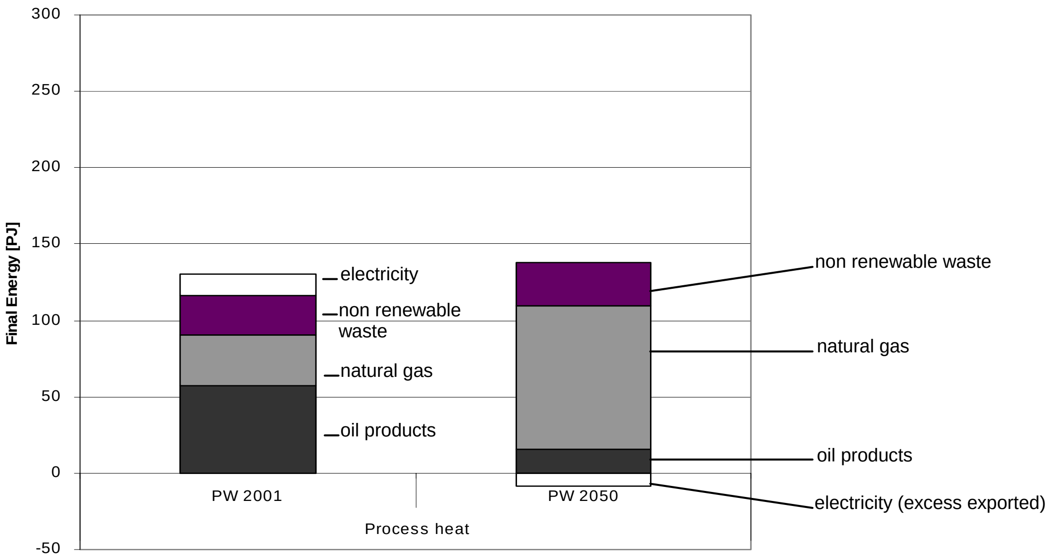


Figure 6-20 Share of the various energy sources in the process heat energy supply (HdHfs).

<u>Electricity</u>:

- Electricity requirements other than those related to room and water heating in the building sector, industrial process heat, and transport increase by 23.5%, i.e. from 141.2 PJ in 2001 up to 174.7 PJ in 2050, accounting for demand-side efficiency measures reducing the specific electricity demand by 25%. Adding electricity requirements related to room and water heating in the building sector and to transport (inc. electrolysis for hydrogen production) however leads to a total need for 250.4 PJ of which 34.9 PJ (**13.9%**) are met with distributed cogenerations units (natural gas fired in the industrial sector and biomass fired in the building sector). The remaining 215.5 PJ are met with hydro and decentralized renewable power. In 2001, 256.4 PJ were generated, out of which 191.8 PJ were supplied to domestic consumers and 43 PJ were exported, the rest being lost during transport.
- The efficiency of electricity transport and distribution via the grid is increased from 91.6% in 2001 to 95% by 2050.
- Repowering projects maintain the capacity of hydro at the same level than in 2001, therefore supplying 135.3 PJ of electricity in 2050 (after transport losses are accounted for), i.e. **54%** of the total national electricity needs. Assuming a conversion efficiency of 87% (versus 82% in 2001), this requires 155.5 PJ of water resources potential.

- Existing nuclear power plants are decommissioned and no new nuclear capacity is installed. In such a 'Future', initial capital intensive options are not favoured due to uncertainty regarding economic returns.
- Distributed medium-scale power generation plants based on biomass resources gasification supply 24.9 PJ of electricity in 2050 (after transport losses are accounted for), i.e. **9.9%** of total national electricity needs. This requires 58.3 PJ of syngas assuming a 45% conversion efficiency, and uses **62%** of the total biomass ecological potential, i.e. 75.7 PJ assuming a 77% feedstock to syngas conversion efficiency. Assuming 7'000 hours of operation annually and an average unit capacity of 50 MWe, about 20 plants are installed by 2050.
- An aggressive policy in favour of solar photovoltaic cells is put in place and those are able to account for as much as **15.7%** of the electricity supplied to domestic users, i.e. 39.4 PJ of electricity by 2050, assuming an average conversion efficiency of 25%. Assuming 200 kWh per year and per m^2, this requires about 54.7 millions m^2 in total and the installation of about 1.2 million m^2 each year in average between 2005 and 2030, and 2.4 million m^2 each year between 2030 and 2050, when considering a 20 years lifetime. Current capacity connected to the grid is of about 18 MWpeak, i.e.180'000 m^2, and about 2 MWpeak are being installed each year, equivalent to 20'000 m^2 given current average conversion efficiency (~10 m^2 per kWpeak). The maximum potential of building integrated PV in Switzerland is estimated to be 18.4 TWh per year, associated with 138 million m^2 on roofs and 52 million m^2 on facades [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005].
- Wind turbines supply 12.1 PJ of electricity by 2050 (after transport losses are accounted for), i.e. **4.8%** of total domestic electricity needs, assuming a conversion efficiency of 45%. This is far beyond the estimated maximum acceptable potential for wind farms by 2050, i.e. about 1'150 GWh per year (4.14 PJ) associated with 726 wind turbines installed among 96 different sites [Erneuerbare Energien und neue Nuklearanlagen, BFE 2005]. An important penetration of small scale wind turbines located close to the users is however considered and as a whole about 96% of the estimated wind total maximum potential is in use[30].
- Geothermal plants (not associated with district heating networks) supply 4 PJ of electricity by 2050 (after transport losses are accounted for), i.e. about **1.6%** of domestic electricity needs, assuming a conversion efficiency of 18%.

[30] another 2'850 GWh can be generated with on-site wind turbines [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005].

	Electricity supplied to the users [PJ]	
	EL 2001	EL 2050
oil products	3.5	0.0
natural gas	3.5	22.1
nuclear	68.1	0.0
water	116.7	135.3
wind	0.0	12.1
solar	0.0	39.4
biomass	0.0	37.6
geothermal	0.0	4.0
	191.8	250.4

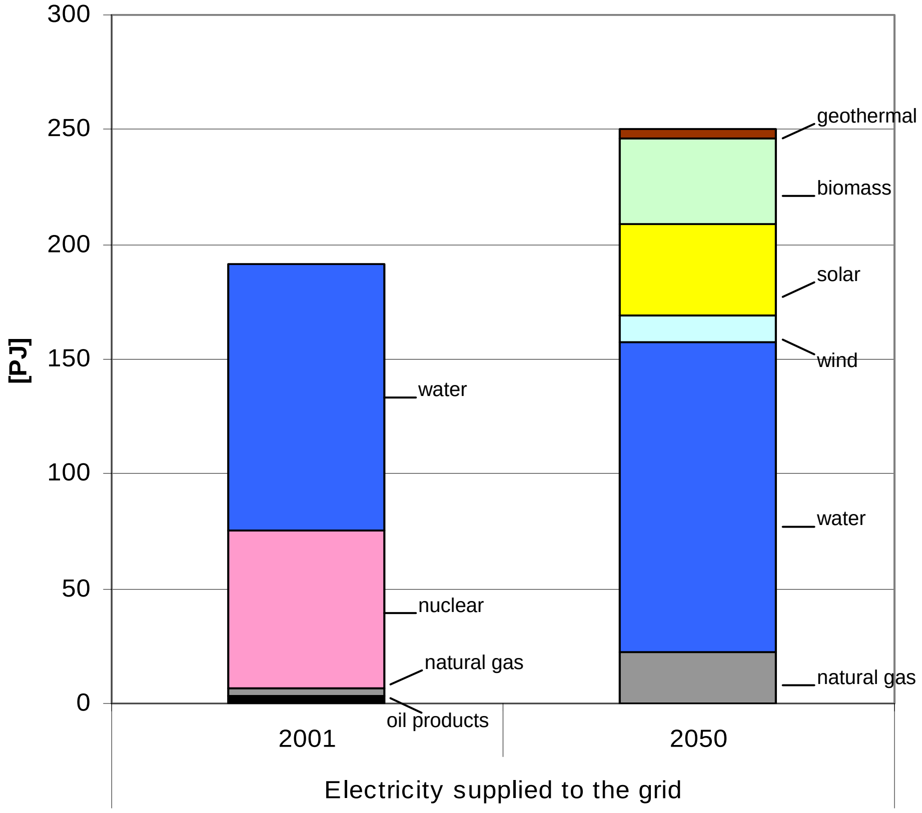
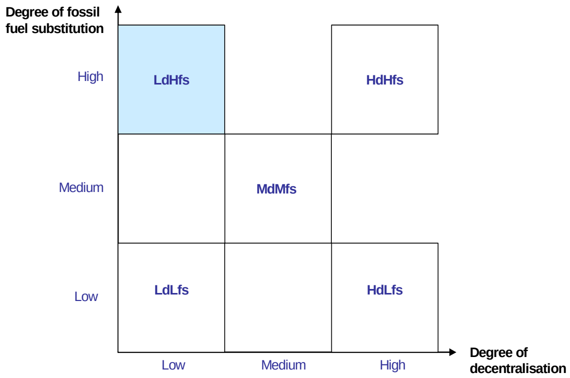


Figure 6-21 Share of the various energy sources in the electricity delivered to national users (HdHfs).

6.4 Future LdHfs: low degree of decentralization and high degree of fossil fuel substitution

Future LdHfs



- Conservative development of energy system structure
- Public support for nuclear
- High price development of fossil fuels
- Failure or limited success of liberalisation process
- Great concerns about safe and affordable energy supply

Figure 6-22: Future description and summary of the quantitative results LdHfs(for more details, see descriptions by sector)

- Aggressive policy is put in place to reduce by half the final energy consumption in the building sector. Building standard rapidly approaches Minergie level and develops towards zero energy housing. Final energy demand for room heating is reduced by 70% down to 65.3 PJ, which is lower than the final energy demand for water heating which increases by 10% up to 75.5 PJ.
- Heat pump heating driven by electricity from the grid is generalised in the building sector and covers about 66% of the room heating requirements. In this 'Future' with a high fossil fuel substitution, a strict interpretation of 'Objective a' is assumed which means that indirect use of fossil fuel for heating in the building sector is also banned - electricity imported from the grid must be 100% 'fossil free'. Although this is debatable, electricity from the grid is supposed to be 'fossil free' in such a 'Future' as enough firm power[31] is provided along the year by cumulated nuclear and biomass capacities to cover heat requirements from the building sector with enough security margin.
- Solar thermal capacity is greatly increased, mostly for water heating with a supply of more than half of the requirements (54%), but also to meet some of the room heating final energy demand (12%).
- The remaining heat demand for room and water heating requirements combined is met with about 10% of biomass resources both within district heating networks and for traditional heating (10%), and with non renewable and renewable waste (3.5%), available waste heat (1%), and geothermal (1.7%) within urban areas via district heating, and some water electric heating (3%).

[31] without seasonal dependence

- Negotiations with car importers and policies in favour of fuel economy improvement, fuel switching, efficient driving behaviour, and modal transfer lead to a reduction of the passenger vehicle fleet average fossil fuel consumption down to 3 liters of gasoline equivalent per 100 km, i.e. 124 PJ for the passenger vehicle fleet as a whole. Advanced ICE vehicles make up most of the passenger cars fleet with a 62% share. Hybrid ICE and fuel cell vehicles have a significant share with 21 and 17% respectively. Pure electric vehicles make up the rest of the fleet with less than 1%.
- Oil products still account for 76% of the total final energy consumption for transport.
- Ethanol from lignocellulosic biomass accounts for 9% of the total final energy consumption for transport. This requires close to 30% of the total biomass ecological potential.
- Hydrogen accounts for about 11% in the total final energy consumption for transport and is produced at nuclear sites with advanced high temperature electrolysis.
- Electricity accounts for 4% in the total final energy consumption for transport.
- Final energy demand for industrial process heat increases by about 20%, accounting for efficiency measures reducing the specific demand for process heat per unit output by 35%.
- Natural gas meets a large share, i.e. about 70%, of process heat requirements in the industrial sector with notably a significant role played by natural gas fired cogeneration units.
- Electricity requirements other than those related to room and water heating in the building sector, industrial process heat, and transport increase by a little less than 25% up to 174.7 PJ, accounting for demand-side efficiency measures reducing the specific electricity demand by 25%. Total electricity requirements amount to 254.5 PJ of which 22.1 PJ are met with natural gas fired industrial cogenerations units. The remaining 227.1 PJ is generated in central plants and distributed through the grid, versus 191.8 in 2001.
- Repowering projects increase the capacity of hydro to its maximum potential, i.e. 5% greater than the capacity in 2001, therefore supplying about 56% of the electricity needs.
- Existing nuclear power plants are progressively decommissioned and replaced with advanced nuclear reactors in a ‘Future’ where support for nuclear technology is gaining momentum due to major concerns about climate change. The power generation capacity from nuclear plants in 2050 is 60% of 2001 nuclear capacity and supplies 20% of national total electricity needs.
- A number of three central combined cycle power generation plants with a 350 MWe nominal capacity and based on biomass resources gasification supply close to 14% of national electricity requirements in 2050. They use close to 60% of the total biomass ecological potential.
- Wind and solar PV are moderately introduced and play a limited role in the electricity supply with 1% of total domestic electricity requirements each.
- Bottom line: such a scenario leads to a 46% renewable share in the primary energy supply, to a 4.0 kW year per year primary energy consumption per capita, and to 3.7 tons of CO_2 emissions per year and per capita.

Energy resources	Share in the Primary Energy [-]	
	2001	**2050**
oil products	0.46	0.27
natural gas	0.09	0.11
nuclear fuel	0.23	0.13
natural gas - H2	0.00	0.00
non renewable waste	0.03	0.03
water	0.16	0.19
wind	0.00	0.01
solar - H2	0.00	0.00
solar - PV	0.00	0.01
solar - thermal	0.00	0.05
biomass - wood	0.01	0.02
biomass - biogas	0.00	0.08
biomass - liquid biofuels	0.00	0.04
renewable waste	0.01	0.00
waste heat	0.00	0.00
heat from environment	0.00	0.05
geothermal heat	0.00	0.00

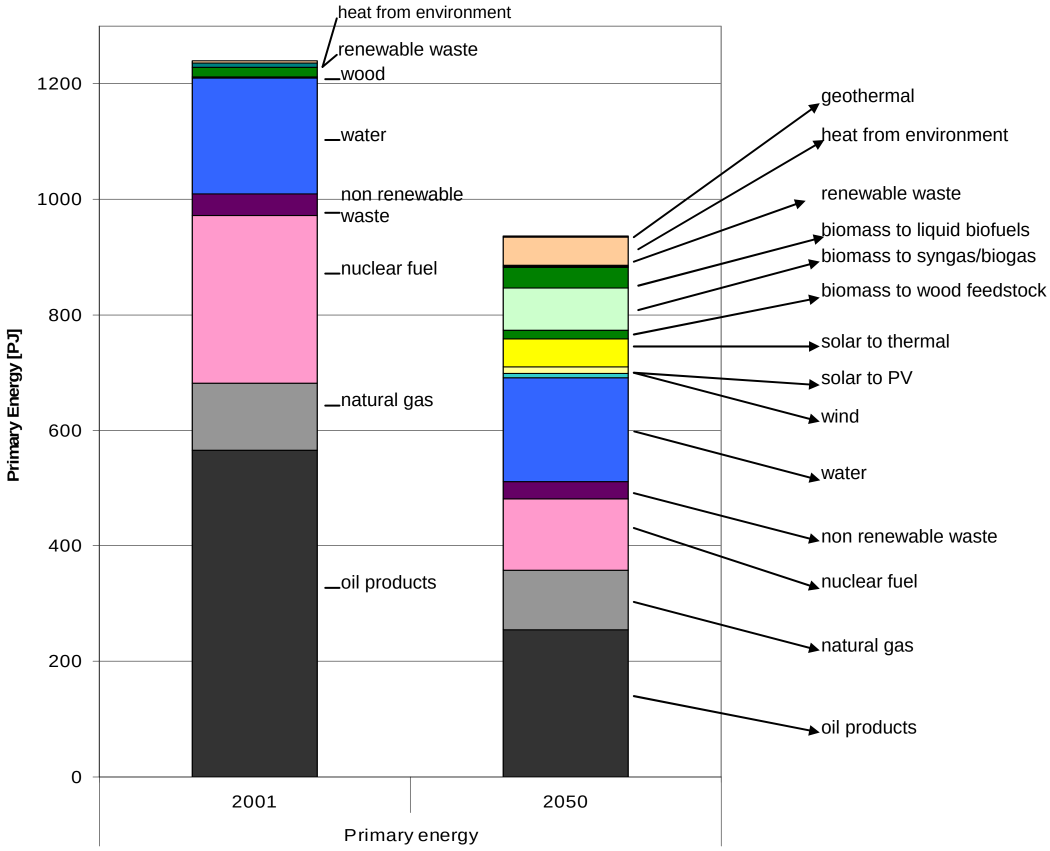


Figure 6-23 Share of the different energy resources in the primary energy supply by 2050 under a 'Future' with low degree of decentralization and a low degree of fossil fuel substitution (LdHfs).

Summary of key technologies for the domestic market in Future LdHfs and examples of related R&D needs (see technology fact sheets in Appendix for more details):

<table>
<tr><th>Technologies required for the domestic market - LdHfs</th><th>Examples of required R&D activities</th></tr>
<tr><td rowspan="2">advanced nuclear reactors and nuclear fuel cycles:

- for a total capacity equivalent to 60% of current nuclear electricity generation capacity (meets 20% of electricity requirements by 2050); 45% electric efficiency target (Gen IV)</td><td>- fuel technologies and cycles for HTR operation
- reactor physics for Gen IV concepts: Gas Cooled Fast Reactor, High Converting Light Water Reactor, LWR-Proteus,…
- repository construction technology: performance assessment criteria and methodologies for repository and benchmarking, testing and assessment of long-term behaviour</td></tr>
<tr><td><u>Swiss academic 'know-how' (non exhaustive):</u>

- PSI – NES (LSR, GaBE, LTH, LES, LWV)</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current technology for nuclear reactors (typically 33% LHV electric eff.) but assuming a similar share would lead to 7.9% greater non renewable primary energy consumption per capita
- phasing out nuclear and assuming substitution with natural gas without CCS would lead to 9.9% lower non renewable primary energy consumption per capita and 13.4% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">advanced hydropower:

- for a total hydro power generation capacity increased by 5% compared with the current level (meets 56% of electricity needs by 2050); 87% conversion efficiency target (versus 82% in 2001)</td><td>- advanced blade design for reduced cavitation problems - three dimensional modelling of turbine flow phenomena
- mechanical stability under unsteady phenomena
- advanced generators
- micro-hydro</td></tr>
<tr><td><u>Swiss academic 'know-how' (non exhaustive):</u>

- EPFL – ISE (LMH)
- EPFL – ISE (LME)
- EPFL – ENAC (LCH)</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current technology for hydro while using the same potential would lead to 2.4% greater non renewable primary energy consumption per capita and 2.3% greater CO_2 emission per capita (more gas use as lower biomass share in the power supply given a fixed biomass potential)</td></tr>
<tr><td>advanced gas turbine technology:

- for advanced gas cooled nuclear reactors (potentially meets 20% of electricity requirements by 2050); 45% electric efficiency target (Gen IV)</td><td>- advanced combustion
- advanced cooling
- system integration: IGCCs and HTRs
- alternative fuel firing – oxyfuel, hydrogen
- advanced hot gases heat exchangers, advanced heat recovery steam generators
- atmospheric pollutants abatement technology
- unfired gas turbines & new working fluids (helium,…)</td></tr>
</table>

<table>
<tr><td>- for three 350 MWe biomass fired combined cycles (14% of domestic electricity needs by 2050); 65% LHV electric efficiency target and 77% biomass to syngas conversion efficiency target

- for industrial cogeneration units running on natural gas (meets part of the 9% share in total electricity requirements); 35% electric efficiency target</td><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- EPFL – ISE (LTT, LENI, LTCM, LMF, LIN), IMX (LMCH, LTP)
- ETHZ – IET (LAV, LTNT, LSM), IFD
- PSI – ENE (CRL)
- EMPA</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- not implementing alternative fuel fired gas turbines in biomass-fired power plants and using available biomass in direct combustion plants instead (typically 45% LHV electric eff.) would lead to 5.2% greater non renewable primary energy consumption per capita and 5.4% greater CO_2 emission per capita
- not implementing industrial cogeneration would lead to 3.0% greater non renewable primary energy consumption per capita and 4.2% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">gasification technology (large scale):

- for three 350 MWe biomass fired combined cycle equipped with gasification (meets 14% of domestic electricity needs); 77% biomass to syngas conversion efficiency target

- for a central ethanol production plant based on a thermochemical preprocessing providing enough ethanol to 9% of the total final energy consumption for transport; target 70% biomass to ethanol conversion efficiency</td><td>- system reliability – tars & particulates related issues
- appropriate gas monitoring & cleaning technologies
- fuel flexible gasifiers with priority to low or negative cost feedstock such as wastes - feeding mechanisms & reactors
- feedstock quality homogenisation and standard
- advanced heat exchangers
- oxygen separation membranes
- dedicated catalyst for syngas to ethanol conversion or dedicated microorganisms for syngas fermentation</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- PSI – ENE (LSK)
- WSL
- ETHZ – IET (LTNT, PRE)
- EPFL – ISE (LTCM), ISIC (LGRC)</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- not developing gasification for central biomass-fired power plants and using available biomass in direct combustion plants instead (typically 45% LHV electric eff.) would lead to 5.2% greater non renewable primary energy consumption per capita and 5.4% greater CO_2 emission per capita
- not substituting oil products with such an amount of ethanol would lead to 4.1% greater non renewable primary energy consumption per capita and 6.8% greater CO_2 emission per capita; compliance with the 3 litres per 100 km target would require further increase of specific tank to wheel conversion efficiency or the use of hydrolysis and fermentation technology for ethanol production</td></tr>
<tr><td>advanced gas engine technology:

- for industrial cogeneration units running on natural gas (meets part of the 9% share in total electricity requirements); 55% electric efficiency target</td><td>- low irreversibility engines – advanced combustion, lower heat and friction losses, energy recovery
- adapted or dedicated alternative fuels fired engines
- affordable and robust atmospheric pollutants emission control
- system integration - mechanically coupled heat pumps, bottoming cycles</td></tr>
</table>

<table>
<tr><td></td><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- ETHZ – IET (LAV)
- EPFL – ISE (LENI)
- PSI – ENE (CRL)
- EMPA - ICEL</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current technology for gas engine district cogeneration units (typically 42% LHV electric eff.) and assuming a similar market penetration would not affect much the results given the much larger share allocated to gas turbine and solid oxide fuel cells in this scenario; however, if gas engines were assumed to cover most of the demand for those district units, remaining with current technology for gas engine units would lead to 1.1% greater non renewable primary energy consumption per capita and 1% greater CO_2 emission per capita, but a 4 times lower market penetration for similar reasons as above would lead to 13.6% greater non renewable primary energy consumption per capita and 13% greater CO_2 emission per capita
- not implementing industrial cogeneration would lead to 3.0% greater non renewable primary energy consumption per capita and 4.2% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">advanced electricity transport network:

- overall electricity transport losses reduced down to 5% (versus 8.4% in 2001)</td><td>- advanced superconductors with higher temperatures and higher inner coherence – reduced risk of resistance at grain/crystal interfaces
- advanced high voltage DC transmission concepts
- advanced AC/DC power conversion technologies
- advanced power electronics for load control</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- EPFL – ISE (LEI, LRE)
- ETHZ – EE (PES, EEH)</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current technology for hydro while using the same potential would lead to 2.7% greater non renewable primary energy consumption per capita and 1.9% greater CO_2 emission per capita (some gas need for power as fixed biomass potential)</td></tr>
<tr><td rowspan="2">advanced compression heat pumps:

- grid driven and for a 66% share of room heating requirements by 2050; target average COP 4.5

- grid driven and for a 30% share of water heating requirements; target average COP 3.5</td><td>- products for both water & room heating or for the retrofit market – new working fluids and specific components
- monitoring & control for operating strategy
- advanced compressors and cycles
- advanced heat exchangers</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- EPFL – ISE (LENI, LTCM)
- HT Basel – IE
- HT Luzern – WTT
- HT Winterthur
- HT Rapperswil - IET</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart natural gas and oil shares if required),
- assuming an average COP of 3.5 instead of 4.5 and 2.5 instead of 3.5 would lead to 1.5% greater non renewable primary energy consumption per capita and 1.6% greater CO_2 emission per capita
- remaining with current technology for heat pumps, and assuming average COP 3.5 and 3 times lower market penetration for room heating, and no material market penetration for water heating, would lead to 8.7% greater non renewable primary energy consumption per capita and 11.1% greater CO_2 emission per capita</td></tr>
</table>

<table>
<tr><td rowspan="2">advanced solar thermal, inc. storage:

- for a 54% share of water heating requirements by 2050; target 50% available heat to useful heat efficiency

- for a 12% share of room heating requirements by 2050; target 50% available heat to useful heat efficiency and seasonal storage with 40% annual efficiency</td><td>- advanced heat storage concepts
- low cost production technologies for vacuum tubular solar thermal technologies
- system integration – in-house and advanced low cost control technology</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- HT Rapperswil - SPF
- EI Vaud – IGT (LESBAT)
- EPFL – ENAC (LESO)
- Uni Genève - CUEPE</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current technology for solar thermal, and assuming similar market penetration for water heating but with 40% overall eff. and no material market penetration for room heating due to lack of satisfactory enough seasonal storage, would lead to 7.8% greater non renewable primary energy consumption per capita and 10.7% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">advanced biomass boilers:

- for district heating networks (meets most of the 9% share of wood in room heating and 10% share of water heating)</td><td>- feedstock quality homogenisation and standard
- techniques for NOx and particulate matter reduction</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- Ökozentrum Langenbruck</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- assuming that only half of the expected market penetration is achieved and the rest is met with natural gas fired boilers instead would lead to 0.7% greater non renewable primary energy consumption per capita and 0.9% greater CO_2 emission per capita</td></tr>
<tr><td rowspan="2">high temperature electrolysis and thermochemical water splitting:

- for hydrogen production at nuclear plants sites providing enough hydrogen to meet 10% of the total final energy consumption for transport; 80% electricity to compressed hydrogen conversion efficiency target</td><td>- integration within nuclear plants – safety issues (material compatibility, coolant stability,…)
- robust and low cost solid oxide technology & reversible SOFC
- thermochemical cycles</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- EPFL – ISE (LENI)
- ETHZ – MAT (NIN)
- EMPA - HPCL</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current technology for electrolysis (typically 60% electricity to compressed hydrogen conversion efficiency) would lead to 3.8% greater non renewable primary energy consumption per capita and 3.7% greater CO_2 emission per capita</td></tr>
<tr><td>polymer electrolyte fuel cell technology for transport:

- for FC passenger vehicles with on-board</td><td>- optimal system integration - heat and water on-board management
- low manufacturing cost for bipolar plates
- dedicated auxiliaries
- more robust MEAs - advanced membranes and electrodes</td></tr>
</table>

hydrogen storage (11% share in the total transport final energy demand); target 2.5 litres gasoline equivalent per 100 km , 5'000 hours lifetime	Swiss academic 'know-how' (non exhaustive): - PSI – ENE (ECL) - ETHZ – IMRT - HT Luzern - HT Biel - EI Vaud
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not developing PEM technology for FC vehicles and assuming that their share is taken up by additional ICE hybrid vehicles would not allow to comply with an average 3 litres of fossil fuel consumption per 100 km and would lead to 8.9% greater non renewable primary energy consumption per capita and 12.1% greater CO_2 emission per capita; however, enough biomass would be available for compliance to be reached with a much greater share of ethanol from biorefineries assuming either dedicated fleets or vehicles adapted to higher blends (70 PJ of ethanol required in total)	

on-board hydrogen storage: - for FC passenger vehicles with on-board hydrogen storage (11% share in the total transport final energy demand); 9% weight capacity and 2.7 kWh per litre targets	- cost reduction of storage technologies (all types) - increase of volumetric and gravimetric storage density - reduction of boil of losses of liquid hydrogen storage Swiss academic 'know-how' (non exhaustive): - Uni Fribourg - Uni Genève - EMPA – MET - EPFL – ISIC (LCOM)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not developing PEM technology for FC hybrid vehicles and assuming that their share is taken up by additional ICE hybrid vehicles would not allow to comply with an average 3 litres of fossil fuel consumption per 100 km and would lead to 8.9% greater non renewable primary energy consumption per capita and 12.1% greater CO_2 emission per capita; however, enough biomass would be available for compliance to be reached with a much greater share of ethanol from biorefineries assuming either dedicated fleets or vehicles adapted to higher blends (70 PJ of ethanol required in total)	

advanced on-board electric storage: - for ICE hybrid passenger vehicles and pure electric vehicles, with a cumulated 21% share in the total transport final energy demand; target 3 litres gasoline equivalent per 100 km for ICE, and 2 litres gasoline equivalent per 100 km for pure electric	- advanced batteries: cost reduction - advanced batteries: long term usability (increase of charging cycles) - advanced batteries: improved energy density - super-capacitors Swiss academic 'know-how' (non exhaustive): - PSI – ENE (ECL) - EPFL – ISE (LEI), ISIC (LPI, LCIC, GGEC), IMX (LTP)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for on-board batteries, and assuming 2 times lower hybrid ICE market penetration and no material pure electric market penetration as a consequence would lead to 7.4% greater non renewable primary energy consumption per capita and 7.8% greater CO_2 emission per capita and would fail to comply with an average 3 litres of fossil fuel consumption per 100 km; compliance would require a much greater tank to wheel conversion efficiency improvements for ICE engines and/or a greater ethanol use – compliance using additional ethanol only would lead to 4% greater non renewable primary energy consumption per capita and 4% greater CO_2 emission per capita	

<table>
<tr>
<td rowspan="2">advanced ICE vehicles for transport:

- for a 62% share in the total transport final energy demand; target 6 litres gasoline per 100 km for ICE and 3 litres gasoline per 100 km for hybrid ICE</td>
<td>- advanced combustion
- camless operation
- adaptive calibration of engine parameters
- in-cylinder sensing
- continuous variable transmission
- advanced injection
- advanced heat recovery
- lightweight vehicles: low cost composite structure production processes, optimisation of composite structure design, lightweight hybrid body structures (multi material sandwich structures)</td>
</tr>
<tr>
<td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- ETHZ - IET (LAV, LTNT, LSM), IFD
- EPFL – ISE (LENI)
- PSI – ENE (CRL)
- EMPA - ME
- HT Rapperswill
- HT Biel</td>
</tr>
<tr>
<td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current (new) technology for ICE vehicles (7.7 litres per 100 km) and assuming the same ratio of hybrid ICE and ICE vehicles would lead to 9.4% greater non renewable primary energy consumption per capita and 11.9% greater CO_2 emission per capita, and would fail to comply with an average 3 litres of fossil fuel consumption per 100 km; compliance would require greater hybrid ICE and/or fuel cell vehicles market penetration</td>
</tr>
<tr>
<td rowspan="2">hydrolysis & fermentation technology:

- for a central plant providing enough lignocellulosic ethanol to meet 9% of the total final energy consumption for transport; target 70% biomass to ethanol conversion efficiency</td>
<td>- greater diversity of biomass resources - multi-feedstock processing
- advanced pretreatment process - higher yield of fermentable sugars, lower or zero amount of fermentation inhibiters, chemical recycling, lower amount of residues, lower cost enzymes
- simultaneous sacharification and fermentation or direct conversion of lignocellulosic fraction into ethanol
- pentose and hexose simultaneous conversion in a same reactor</td>
</tr>
<tr>
<td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- EPFL – ISIC (LGCB), ENAC (LBE, LASEN)
- ETHZ – IB</td>
</tr>
<tr>
<td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- not substituting oil products with such an amount of ethanol would lead to 4.1% greater non renewable primary energy consumption per capita and 6.8% greater CO_2 emission per capita; compliance with the 3 litres per 100 km target would require further increase of specific tank to wheel conversion efficiency or the use of hydrolysis and fermentation technology for ethanol production</td>
</tr>
</table>

<table>
<tr>
<td rowspan="2">low energy housings: advanced insulation, glazing, lighting, and ventilation :

- for a 75% decrease of the average annual specific energy consumption per square meter for room heating

- for a 50% decrease of the average annual energy demand in the building sector</td>
<td>- vacuum insulation construction site usability
- long time integrity of vacuum
- detection technologies for ventilated vacuum panels
- vacuum glazing
- surface coating for advanced glazing
- heat recovery - system cost reduction by cost reduction of components
- energy efficient framing technologies
- switchable glazing
- improvement of heat recovery rate – advanced heat exchangers
- intelligent and robust control systems and strategy
- efficiency increase of electric motors and drives</td>
</tr>
<tr>
<td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- EMPA
- EPFL – ENAC (LESO)
- HT Winterthur
- HT Luzern
- HT Basel</td>
</tr>
<tr>
<td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- assuming that insulation, glazing, and ventilation technology only allows 50% reduction of the average annual specific energy consumption for room heating (instead of 75%) would lead to 4.6% greater non renewable primary energy consumption per capita and 6% greater CO_2 emission per capita</td>
</tr>
</table>

<table>
<tr>
<td rowspan="2">photovoltaic cells:

- for 1% of the electricity requirements: target 25% electric efficiency</td>
<td>- cost reduction by decrease of material losses in production e.g. by improved sawing technologies
- improved industrial manufacturing technologies to approach mass production efficiency to the values of lab efficiency
- cost reduction and improved reliability of balance of system components (especially inverters)
- increase of module efficiency</td>
</tr>
<tr>
<td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- Uni Neuchâtel - IMT
- EPFL – ISIC (LPI), CRPP, ENAC (LESO)
- ETHZ - TFP
- EMPA – FPL
- Uni Bern
- Uni Genève – CUEPE
- LEEE - TISO</td>
</tr>
<tr>
<td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- not installing this share of photovoltaic cells in the electricity supply would lead to 1% greater non renewable primary energy consumption per capita and 0.8% greater CO_2 emission per capita</td>
</tr>
</table>

wind turbines (large): - for 1% of the electricity requirements: target 45% electric efficiency	- increase of rotor area by improved strength properties of rotor material (e.g. carbon fibre/epoxy) - gear box and drive train long term stability improvement - weight reduction of gearless multipole generators - improved short to mid term power prediction methodologies for grid integration - new service and maintenance concepts for O&M cost reduction
	Swiss academic 'know-how' (non exhaustive): - EPFL – ENAC (LASEN) - HEVS - EIVD - EIG
scenario sensitivity analysis: the rest being unchanged (apart natural gas and oil shares if required), - not installing this share of wind turbines in the electricity supply would lead to 1% greater non renewable primary energy consumption per capita and 0.8% greater CO_2 emission per capita	
geothermal plants: - for 4% of demand for room heating and based on ORC technology: target 15% electric efficiency, 75% overall efficiency	- low cost drilling technologies - geophysical mapping and exploration - borehole activation and rock fracturing - corrosion resistant materials
	Swiss academic 'know-how' (non exhaustive): - Uni Neuchâtel – CREGE, CHYN - EPFL – ENAC (LMS) - Uni Lausanne – IG - ETHZ - IG
scenario sensitivity analysis: the rest being unchanged (apart natural gas and oil shares if required), - not installing this share of wind trubines in the electricity supply would lead to 0.2% greater non renewable primary energy consumption per capita and 0.2% greater CO_2 emission per capita	

6.4.1 Results of the first order quantitative analysis by sector LdHfs

Room heating:

- Aggressive policy is put in place to reduce by half the final energy consumption in the building sector. Building standard rapidly approaches Minergie level and develops towards zero energy housing. Given an expected 25% increase of the total heated area by 2050, the average specific annual heat consumption of the whole building stock for room heating must be reduced by 75%, so that the sum of room heating and water heating is reduced by half[32]. This is achieved with advanced insulation, advanced glazing, and building system integration. As a result, and after the implementation of the other measures below, the total final energy demand for room heating is reduced by 70%, i.e. from 228.3 PJ in 2001 down to 65.3 PJ in 2050.

[32] This supposes that electricity consumption in buildings is also reduced by half - out of the scope of this study as in MZ tool, electricity consumption is aggregated.

- Direct electric heating is banned.
- Non renewable fuel fired boilers (fuel oil and natural gas) in use within existing district heating networks are substituted with wood fired boilers, assuming advanced wood-fired boilers reach a similar heating efficiency than replaced fossil-fired installations. Wood as a whole makes up **8.7%** of the room heating final energy demand by 2050, i.e. 5.7 PJ. This requires 6.3 PJ of wood biomass resources assuming that 10% of the wood primary energy potential is used for the conversion into a usable final feedstock, i.e. **5.2%** of the total biomass ecological potential[33].
- A **66%** share of the room heating final energy demand, i.e. 43.1 PJ, is met with the use of compression heat pumps driven by electricity imported from the grid. Heat pumps in new housings become business as usual, and heat pumps dedicated to the retrofit market are importantly diffused, including units for multi-family housings in urban areas. Heat pumps are associated with a 4.5 average COP.
- New district heating networks based on some geothermal heat (2.4 PJ)[34], direct combustion of some of the available non renewable waste (2.5 PJ), direct combustion of some of the available renewable waste (2.5 PJ) and available waste heat (1.3 PJ) supply heat within urban areas, accounting for **13.3%** of the total final heat supply. Geothermal heat is supplied by cogeneration plants based on ORC technology which deliver electricity to the grid at a 15% electric efficiency and are associated with a 75% overall energy conversion efficiency.
- Solar thermal accounts for **11.8%** of the final energy supply for room heating, i.e. 7.7 PJ, and is applied to building clusters thanks to the development of appropriate seasonal storage associated with an annual efficiency of at least 40%. Solar thermal installations are associated with a 50% heating efficiency (final heat to useful heat ratio) and require an equivalent of 5% of the final heat delivered in the form of electricity for operation. Assuming solar panels delivering 500 kWh per m^2 and per year, about 4.3 millions m^2 (or about 0.6 m^2 per capita[35]) must be installed by 2050. This is about 3% of the estimated 138 million m^2 of available roof area [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005] and requires about 100'000 m^2 installed yearly in average between 2005 and 2025, and about 200'000 m² yearly in average between 2025 and 2050, accounting for a 20 years lifetime for the solar panels, to be compared with 35'000 m^2 currently installed every year in Switzerland[36].

[33] See footnote 3
[34] Assuming 6'000 hours of operation per year for room heating in the building sector, this means that between 5 and 6 plants such as the one in construction in Basel (20 MWth) are installed by 2050.
[35] Assuming 7.5 millions inhabitants by 2050
[36] in terms of 'standard' capacity installed, 200'000 m^2 per year is equivalent to 140 MWth per year, according to the convention from the IEA Solar Heating Cooling Programme, i.e. 0.7 kWth per m^2, to be compared with 1250 MW of solar thermal capacity expected to be installed in the whole Europe in 2005 (www. estif.org)

	Room heating - final energy [PJ]	
	RH 2001	RH 2050
oil products	139.8	-
natural gas	53.7	-
non renewable waste	12.2	2.5
solar - thermal	-	7.7
wood	12.3	5.7
renewable waste	6.6	2.5
waste heat	-	1.3
heat from environment	3.1	33.4
geothermal heat	-	2.4
electricity	0.6	9.7
	228.3	65.3

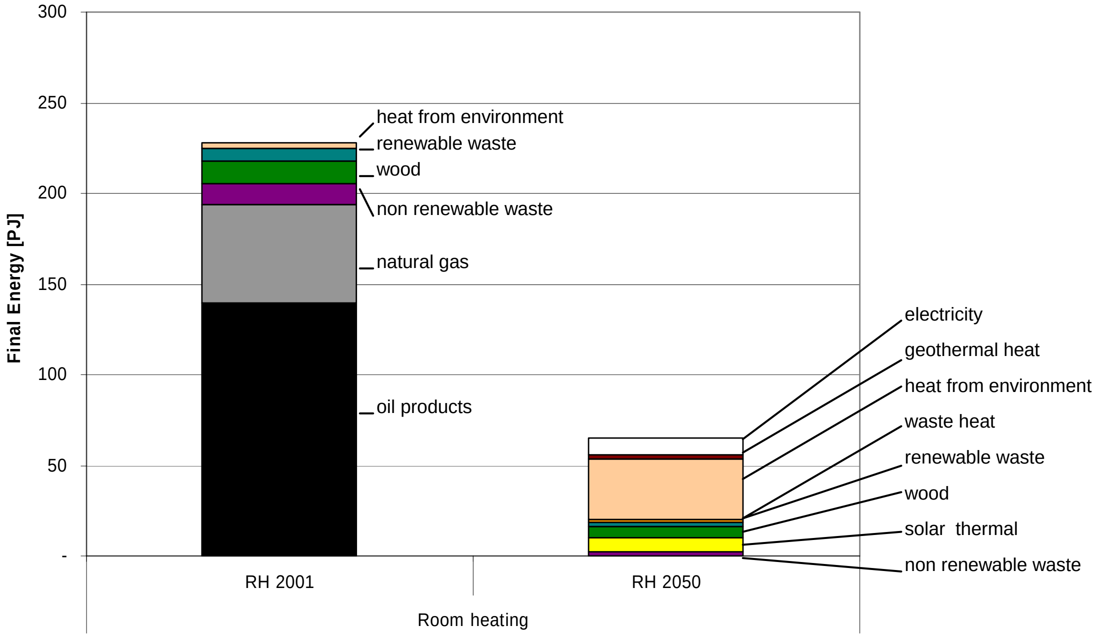


Figure 6-24 Share of the various energy sources in the room heating final energy supply (LdHfs).

<u>Water heating</u>:

- Efficiency measures reduce the specific energy demand for water heating by 12%, but an increase of the hot water consumption by 25% leads to an actual increase of the final energy demand for water heating by 10% by 2050, up to 59.7 PJ. Fuel switching measures also contribute to an additional increase of the final energy demand for water heating up to 75.5 PJ (effect of solar thermal final energy to useful energy ratio). Efficiency measures for room heating however insure that the sum of room heating and water heating demand is reduced by half.
- Non renewable fuel fired boilers (fuel oil and natural gas) in use within existing district heating networks are substituted with wood fired boilers, assuming advanced wood-fired boilers reach a similar heating efficiency than replaced fossil-fired installations. Wood as a whole makes up **10%** of the water heating final energy demand by 2050, i.e. 8.2 PJ. This requires 9 PJ or **7.4%** of the total biomass ecological potential.
- Solar thermal accounts for **54%** of the final energy demand for water heating, i.e. 40.8 PJ. It is required by rule for new housings, and is applied to single

family or multi-family housings and to building clusters associated with local district heating. Solar thermal installations are associated with a 50% heating efficiency (generated heat to useful heat ratio) and require 5% of the final heat delivered in the form of electricity for their operation. Assuming solar panels delivering 500 kWh per m^2 and per year, about 21.5 millions m^2 or about 3 m^2 per capita[37] must be installed by 2050, or about 15% of the estimated 138 million m^2 of available roof area [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005]. This requires about 480’000 m^2 installed yearly in average between 2005 and 2025, and about 960’000 m² yearly in average between 2025 and 2050, accounting for a 20 years lifetime for the solar panels, to be compared with 35’000 m^2 currently installed every year in Switzerland[38].

- Heat pump based water heaters driven by electricity imported from the grid account for **29.7%** of the final energy demand for water heating, i.e. 22.4 PJ. They are associated with a 3.5 average COP.
- The rest of the demand is met with direct heating with renewable or nuclear based electricity (**6.3%**).

[37] assuming 7.5 millions inhabitants by 2050

[38] in terms of ‘standard’ capacity installed, 960’000 m^2 is equivalent to 672 MWth per year, according to the convention from the IEA Solar Heating Cooling Programme, i.e. 0.7 kWth per m^2, to be compared with 1250 MWth of solar thermal capacity expected to be installed in the whole Europe in 2005 (www. estif.org)

	Water heating - final energy [PJ]	
	WW 2001	WW 2050
oil products	16.4	-
natural gas	7.2	-
solar - thermal	1.2	40.8
wood	2.9	8.2
heat from environment	0.5	16.0
electricity	25.9	10.5
	54.2	**75.5**

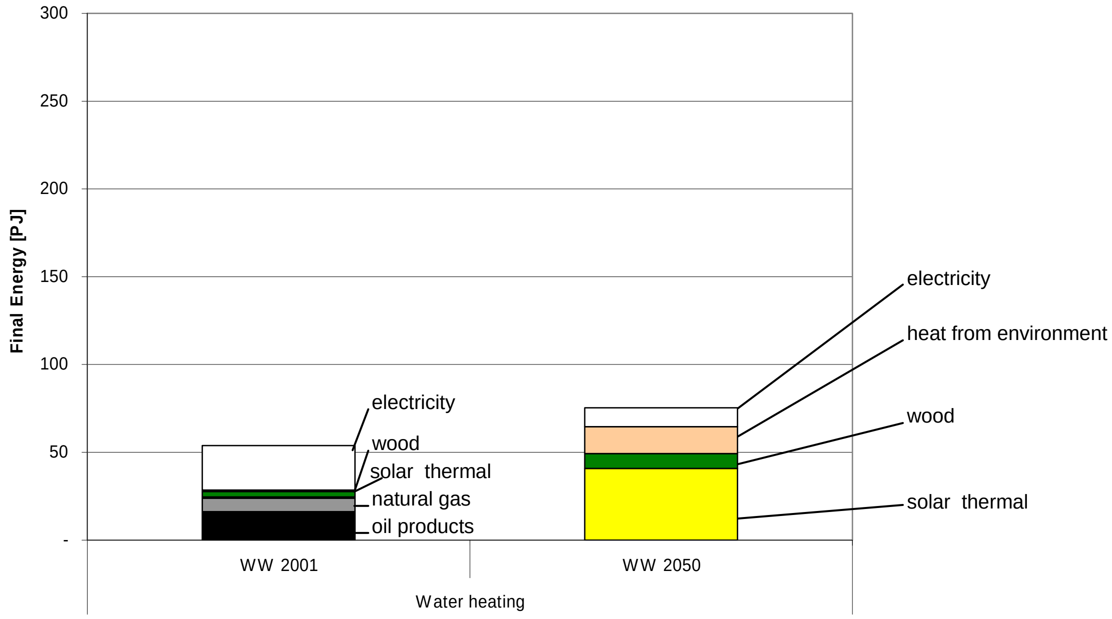


Figure 6-25 Share of the various energy sources in the water heating final energy supply (LdHfs).

<u>Transport</u>:

- Negotiations with car importers and policies in favour of fuel economy improvement, fuel switching, efficient driving behaviour, and modal transfer lead to a reduction of the passenger cars fleet average fuel consumption down to 3 liters of gasoline equivalent per 100 km.
- A 55% demand growth of passenger vehicles final energy demand is expected. The tank to wheel average conversion efficiency is increased by 37% and quite significant fossil fuel substitution is introduced so that the total final fossil fuel consumption of the passenger vehicle fleet is reduced from 221.3 in 2001 to 124 PJ by 2050[39]. Fossil fuel substitution is obtained essentially with the use of hydrogen generated from high temperature electrolysis in central production plants located at existing nuclear power generation sites and using electricity and heat delivered by advanced nuclear reactors, and with lignocellulosic ethanol.
- This is achieved with:

[39] the average fuel consumption in 2001 was 8.4 liters gasoline per 100 km [Plan Directeur 2004-2007]

1) an improvement of ICE vehicles average fuel economy down to 6 litres gasoline per 100 km. Those vehicles account for 62% of the total passenger vehicles fleet. A fraction equivalent to 20% (on an energy basis) of the gasoline used by those vehicles is replaced by ethanol from lignocellulosic biomass both as a blend and within dedicated public fleets.

2) a significant market penetration of ICE hybrid vehicles which are supposed to account for 21% of the new passenger cars fleet. They are considered to be running on gasoline with an average specific fuel consumption equivalent to 3 litres per 100 km. A fraction equivalent to 20% (on an energy basis) of the gasoline used by those vehicles is replaced by ethanol from lignocellulosic biomass both as a blend and within dedicated public fleets.

3) a significant market penetration of fuel cell vehicles running on hydrogen and associated with an average 2.5 litres gasoline equivalent per 100 km. Those are supposed to make up 17% of the fleet.

4) some pure electric urban passenger vehicles (taxi vehicles for example) associated with a 60% power train efficiency. Those make up the rest of the fleet, i.e. less than 1%.

- Heavy road vehicles, rail, and air transport final energy demands are assumed to increase by respectively 176.7%, 82.5%, and 84.8% compared to 2001, accounting for efficiency measures reducing the specific energy demand by respectively 7%, 50%, and 60%.
- Oil products make up **76.3%** of the 283 PJ total final energy consumption for transport.
- Ethanol from lignocellulosic biomass accounts for **8.9%** of the total final energy consumption for transport, i.e. 24.7 PJ. This requires 35.3 PJ of lignocellulosic biomass potential assuming a large scale processing plant[40] and a 70% overall ethanol chain conversion efficiency, i.e. **28.9%** of the total biomass ecological potential[41].
- Hydrogen accounts for **10.9%** in the total final energy consumption for transport, i.e. 30.9 PJ and is produced with advanced high temperature electrolysis with 80% conversion efficiency, requiring 18.3 PJ.
- Electricity accounts for **4.1%** in the total final energy consumption for transport, i.e. 11.5 PJ.

[40] based on hydrolysis or thermochemical preprocessing
[41] see footnote 3

	Transport - final energy [PJ]	
	VK 2001	VK 2050
oil products	289.6	216.0
liquid biofuels	-	24.7
hydrogen from electrolysis	-	30.9
electricity	10.2	11.5
	299.7	283.0

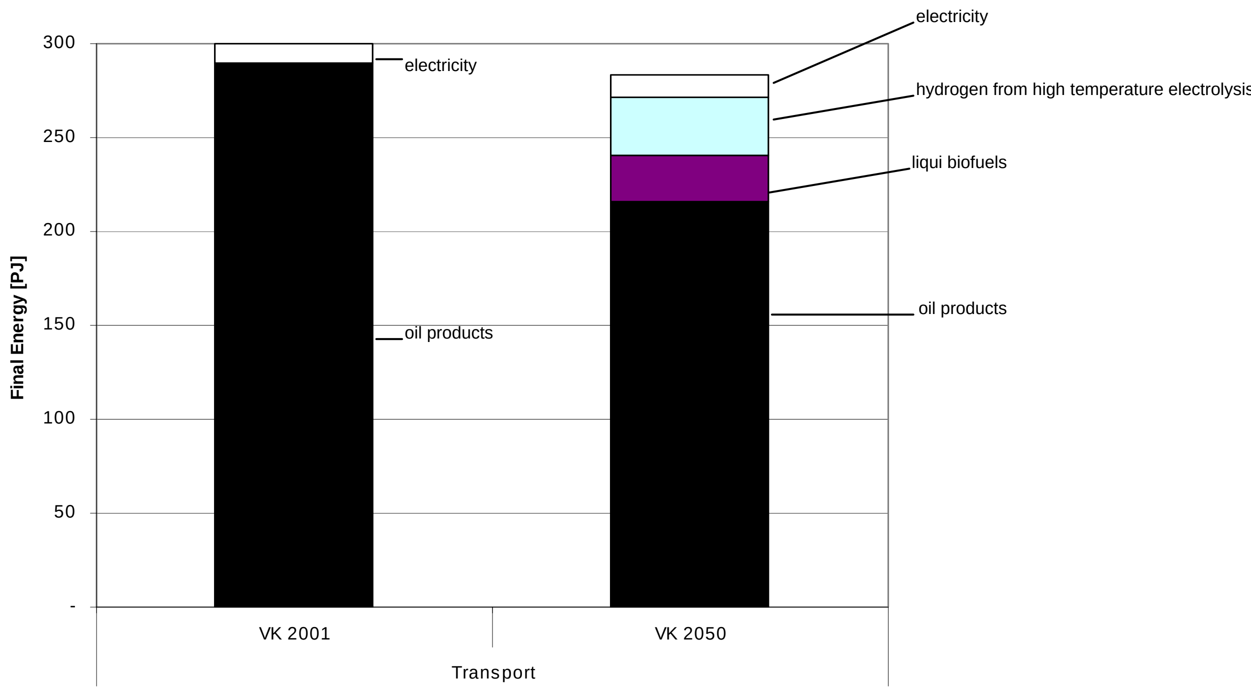


Figure 6-26 Share of the various energy sources in the transport final energy supply (LdHfs).

<u>Process heat</u>:

- Final energy demand for industrial process heat increases by 22.7%, i.e. from 130.6 PJ in 2001 up to 140.1 PJ in 2050, accounting for efficiency measures reducing the specific demand for process heat per unit output by 35%.
- Additional measures for a reduction of heat distribution losses are implemented, leading to a total final energy demand for process heat of 137.6 PJ.
- The replacement of a fourth of the compression chillers by absorption chillers running on waste heat reduces the share of electricity in the final energy demand for process heat.
- Industrial cogeneration running on natural gas with a 40% average electric efficiency and 95% global conversion efficiency is aggressively pursued and accounts for 42.7%, i.e. 75.2 PJ, in the final energy demand for industrial process heat. The amount of electricity generated, i.e. 22.1 PJ, exceeds internal needs for process heat and 8.7 PJ of electricity can be directed towards internal electricity final needs or exported to the grid.

- Half of the remaining oil products requirements is substituted with natural gas, leading to a **72.8%** total share of natural gas in the total final energy demand for industrial process heat.
- The rest of the demand is met with direct combustion of non renewable waste, i.e. 28 PJ, and oil fired boilers, i.e. 15.6 PJ.

	Process heat - final energy [PJ]	
	PW 2001	**PW 2050**
oil products	57.1	15.6
natural gas	33.5	91.2
non renewable waste	26.1	28.0
electricity	14.0	-8.7
	130.6	126.0

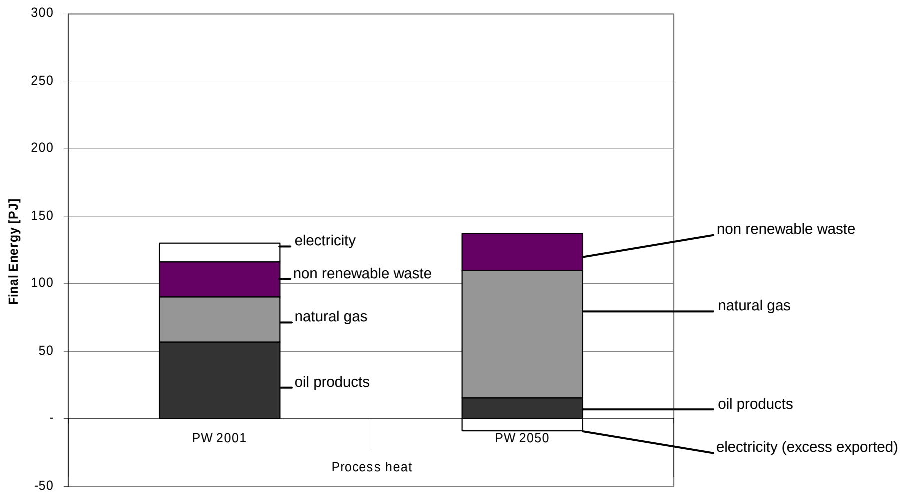


Figure 6-27 Share of the various energy sources in the process heat energy supply (LdHfs)

<u>Electricity</u>:

- Electricity requirements other than those related to room and water heating in the building sector, industrial process heat, and transport increase by 23.5%, i.e. from 141.2 PJ in 2001 up to 174.7 PJ in 2050, accounting for demand-side efficiency measures reducing the specific electricity demand by 25%. Adding electricity requirements related to room and water heating in the building sector and to transport (inc. electrolysis for hydrogen production) however leads to a total need for 254.5 PJ of which 22.1 PJ (**8.7%**) are met with natural gas fired industrial cogenerations units. The remaining 227.1 PJ is generated in central plants and distributed through the grid. In 2001, 256.4 PJ were generated, out of which 191.8 PJ were supplied to domestic consumers and 43 PJ were exported, the rest being lost during transport.
- The efficiency of electricity transport and distribution via the grid is increased from 91.6% in 2001 to 95% by 2050.
- Repowering projects increase the capacity of hydro to its maximum potential, i.e. 5% greater than the capacity in 2001, therefore supplying 142 PJ of electricity in 2050 (after transport losses are accounted for) which accounts for **55.8**% of the electricity needs. Assuming a conversion efficiency of 87% (versus 82% in 2001), this requires 163.7 PJ of water resources potential.

- Existing nuclear power plants are progressively decommissioned and replaced with advanced nuclear reactors in a 'Future' where support for nuclear technology is gaining momentum due to major concerns about climate change. The power generation capacity from nuclear plants in 2050 is 60% of 2001 nuclear capacity and supplies 50 PJ of electricity (after transport losses are accounted for) and therefore accounts for **19.6%** of the national total electricity needs.
- Central combined cycle power generation plants based on biomass resources gasification supply 34.8 PJ or **13.7%** of national electricity requirements in 2050 (after transport losses are accounted for). Assuming 7'000 hours of operation annually and an average 350 MWe unit capacity, 3 plants are installed by 2050. Assuming a 50% overall conversion efficiency for integrated gasification combined cycles (65% syngas to electricity conversion efficiency, and 77% biomass feedstock to syngas conversion efficiency), **57%** of the total biomass ecological potential is required, i.e. 69.5 PJ.
- Solar photovoltaic cells are moderately introduced and supply 2.8 PJ of electricity by 2050, assuming an average conversion efficiency of 25%. Assuming 200 kWh per year and per m^2, this requires about 3.9 millions m^2 in total and the installation of about 80'000 m^2 each year in average between 2005 and 2030, and 160'000 m^2 each year between 2030 and 2050, when considering a 20 years lifetime. Current capacity connected to the grid is of about 18 MWpeak, i.e.180'000 m^2, and about 2 MWpeak are being installed each year, equivalent to 20'000 m^2 given current average conversion efficiency (~10 m^2 per kWpeak). The maximum potential of building integrated PV in Switzerland is estimated to be 18.4 TWh per year, associated with 138 millions m^2 on roofs and 52 millions m^2 on facades [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005].
- Wind turbines supply 2.8 PJ of electricity by 2050 (after transport losses accounted for), assuming a conversion efficiency of 45%. This represents 67% of the estimated maximum acceptable potential for wind farms by 2050[42], i.e. about 1'150 GWh per year associated with 726 wind turbines installed among 96 different sites [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005].

[42] note that another 2'850 GWh could be generated but with on-site wind turbines in a Future with a high degree of decentralisation

	Electricity supplied to the users [PJ]	
	EL 2001	EL 2050
oil products	3.5	0.0
natural gas	3.5	22.1
nuclear	68.1	50.0
water	116.7	142.0
wind	0.0	2.8
solar	0.0	2.8
biomass	0.0	34.8
geothermal	0.0	0.0
	191.8	254.5

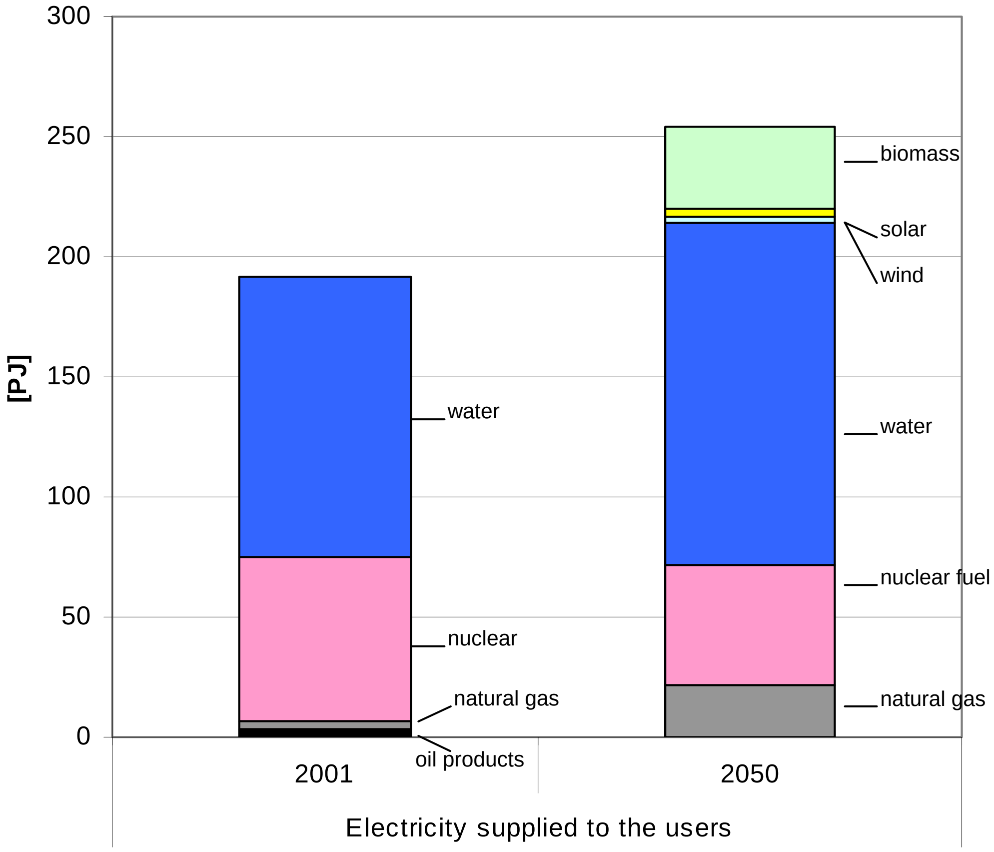


Figure 6-28 Share of the various energy sources in the electricity delivered to national users (LdHfs).

6.5 *Future HdLfs: high degree of decentralization and low degree of fossil fuel substitution*

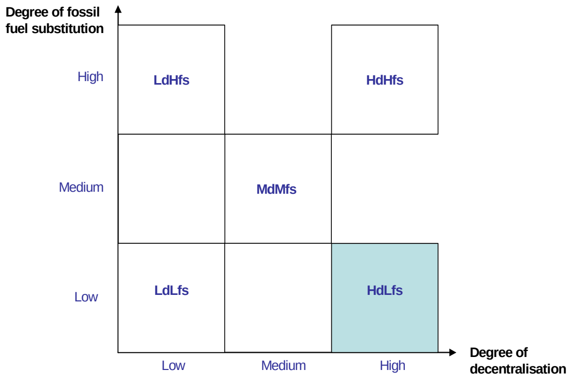
<table>
<tr><th colspan="2">Future HdLfs</th></tr>
<tr><td>
</td>
<td>Repetitive failures of energy transport & distribution networks
Strong public opposition to nuclear
Moderate price development of fossil fuels
Successful liberalisation process
Limited concerns about security of energy supply</td></tr>
</table>

Figure 6-29: Future description for LdHfs

Future description and summary of the quantitative results (for more details, see descriptions by sector)

- Aggressive policy is put in place to reduce by half the final energy consumption in the building sector. Building standard rapidly approaches Minergie level and develops towards zero energy housing. Final energy demand for room heating is reduced by 69% and becomes even slightly lower than the final energy demand for water heating which increases by 10%.
- Heat pump heating via local heating networks is generalized in densely populated areas and related electricity requirements are met with both on-site and district cogeneration units running on a mix of natural gas and syngas/biogas distributed via the gas network. In such a 'Future' where 'Objective a' is given a soft interpretation, the use of natural gas as a final energy vector in the building sector is considered to be allowed when used in cogeneration units[43]. The syngas is generated via gasification and methanation and anaerobic digestion in distributed medium scale plants and from respective suitable types of biomass feedstocks. About 67% of room heating requirements are met this way.
- Solar thermal capacity is greatly increased, mostly for water heating with a supply of more than half of the requirements (54%), but also to meet some of the room heating final energy demand (6%).
- The remaining heat demand for room and water heating requirements combined is met with about 10% of biomass resources both within district heating networks and for traditional heating (13%), and with non renewable

[43] this translates into a share of natural gas in the final energy supply of building, but it would not be fair to ban natural gas use in on-site cogeneration units delivering electricity to heat pumps when natural gas central power plants delivering electricity to heat pumps via the grid are authorized in 'Future' LdLfs'.

and renewable waste (3.5%), available waste heat (1%), geothermal (1.6%) within urban areas via district heating, and some water electric heating (3%).

- Negotiations with car importers and policies in favour of fuel economy improvement, fuel switching, efficient driving behaviour, and modal transfer lead to a reduction of the passenger vehicle fleet average fossil fuel consumption down to 3 liters of gasoline equivalent per 100 km, i.e. 124 PJ for the passenger vehicle fleet as a whole. Advanced ICE vehicles and ICE hybrids make up most of the passenger cars fleet with a 45% share each. Fuel cell vehicles have a significant share with 10%. Pure electric vehicles make up the rest of the fleet with less than 1%.
- Oil products still account for more than 87% of the total final energy consumption for transport.
- Hydrogen is produced via distributed small-scale reforming of a mix of natural gas and syngas/biogas delivered to fuelling stations via the gas network and meets about 8% of the total transport final energy demand.
- Electricity accounts for 4.5% in the total final energy consumption for transport.
- Final energy demand for industrial process heat increases by about 20%, accounting for efficiency measures reducing the specific demand for process heat per unit output by 35%.
- On-site industrial cogeneration running on the natural gas and biogas/syngas mix distributed via the gas network meets a large share, i.e. about 43%, of process heat requirements in the industrial sector.
- Electricity requirements other than those related to room and water heating in the building sector, industrial process heat, and transport increase by 23.5, accounting for demand-side efficiency measures reducing the specific electricity demand by 25%. Adding electricity requirements related to room and water heating in the building sector and to transport however leads to a total need for 219.1 PJ of which 33.3 PJ (15%) are met with distributed cogenerations units (natural gas/syngas/biogas mix fired in the industrial and building sectors). The remaining 181 PJ are met with hydro and decentralised renewable power.
- The efficiency of electricity transport and distribution via the grid is increased from 91.6% in 2001 to 95% by 2050.
- Repowering projects maintain the capacity of hydro at the same level than in 2001 and supplies 62% of the needs.
- Existing nuclear power plants are decommissioned and no new nuclear capacity is installed. In such a Future with low fossil fuel substitution and enhanced competition in a liberalised market, drivers for a nuclear capacity renewal are not dominant.
- A number of 16 distributed medium-scale power generation plants with a 100 MWe output in average and running on the mix of natural gas and syngas/biogas (two third/one third) delivered via the gas network supply close to 20% of total national electricity needs. This uses about 25% of total biomass ecological potential.
- Solar photovoltaic cells and wind turbines are moderately introduced and supply 1% of national electricity requirements each by 2050.

- Bottom line: such a scenario leads to a 46% renewable share in the primary energy supply, to a 3.5 kW year per year primary energy consumption per capita, and to 4.1 tons of CO_2 emissions per year and per capita.

Energy resources	Share in the Primary Energy [-]	
	2001	2050
oil products	0.46	0.30
natural gas	0.09	0.17
nuclear fuel	0.23	0.00
natural gas - H2	0.00	0.03
non renewable waste	0.03	0.04
water	0.16	0.21
wind	0.00	0.01
solar - H2	0.00	0.00
solar - PV	0.00	0.01
solar - thermal	0.00	0.05
biomass - wood	0.01	0.02
biomass - biogas	0.00	0.11
biomass - liquid biofuels	0.00	0.00
renewable waste	0.01	0.00
waste heat	0.00	0.00
heat from environment	0.00	0.05
geothermal heat	0.00	0.00

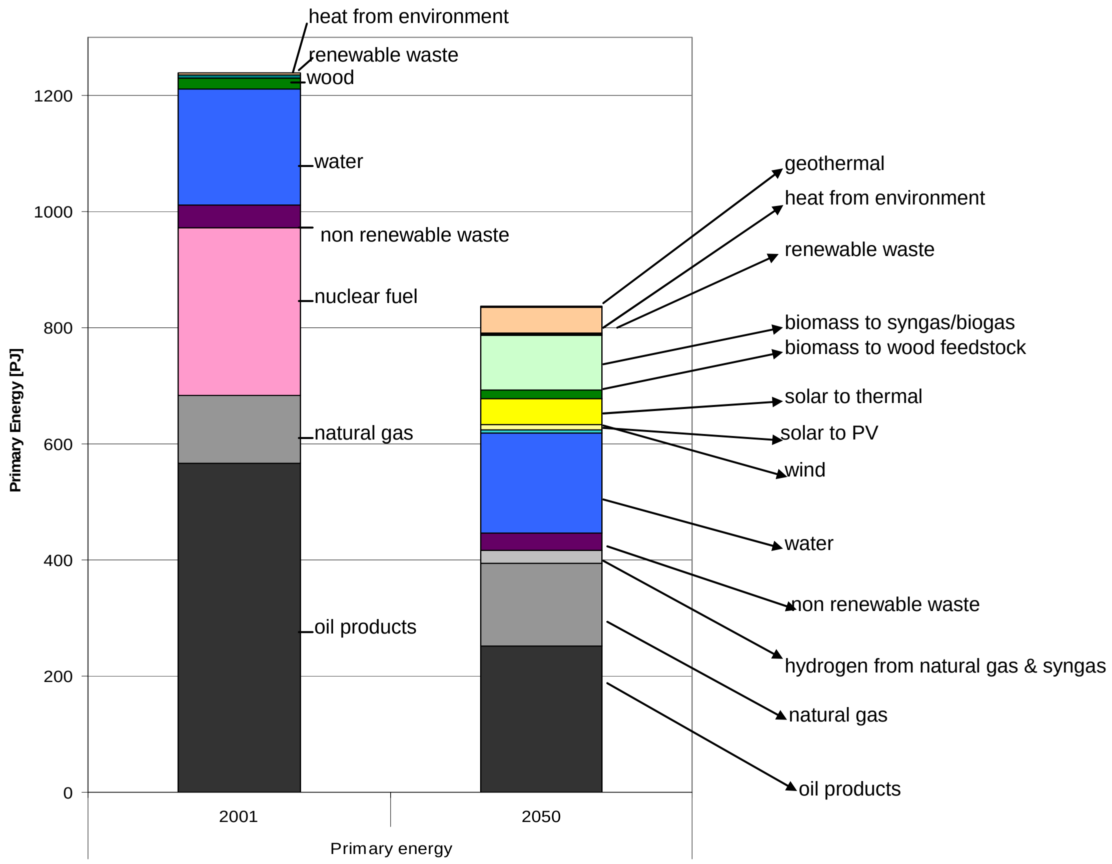


Figure 6-30 Share of the different energy resources in the primary energy supply by 2050 under a 'Future' with low degree of decentralization and a low degree of fossil fuel substitution (HdLfs).

Summary of key technologies for the domestic market in Future HdLfs and examples of related R&D needs (see technology fact sheets in Appendix for more details):

<table>
<tr><th>Technologies required for the domestic market - HdLfs</th><th>Examples of required R&D activities</th></tr>
<tr><td rowspan="2">advanced gas and steam turbine technology:

- for district combined cycle cogeneration units running on a mix of natural and upgraded syngas/biogas from the gas network, and associated with district heating networks including heat pumps (meets 40% of the 67% and 19% shares of cogeneration/HP plants in room and water heating requirements respectively); 60 to 70% electric efficiency target, and overall First Law heating efficiency between 2.5 and 3 depending on the chosen integration

- for 16 distributed GTCC power generation plants (average 100 MWe nominal output) running on a mix of natural and upgraded syngas/biogas from the gas network (meets 19% of total electricity requirements); 60% electric efficiency target

- for industrial cogeneration units running on a mix of natural gas and upgraded syngas/biogas from the gas network (meets part of the 10% share in total electricity requirements); 35% electric efficiency target</td><td>- advanced combustion
- advanced cooling
- advanced GT-ST & SOFC-GT combined cycles: system integration, advanced small-scale steam turbines, unfired gas turbines
- advanced hot gases heat exchangers, advanced heat recovery steam generators
- atmospheric pollutants abatement technology</td></tr>
<tr><td><u>Swiss academic ‘know-how’ (non exhaustive):</u>

- EPFL – ISE (LTT, LENI, LTCM, LMF, LIN), IMX (LMCH, LTP)
- ETHZ – IET (LAV, LTNT, LSM), IFD
- PSI – ENE (CRL)
- EMPA</td></tr>
<tr><td colspan="2"><u>scenario sensitivity analysis</u>: the rest being unchanged (apart from natural gas and oil shares if required),
- remaining with current technology for district combined cycle district units (typically 45% LHV electric eff.) and distributed GTCC power plants (typically 50% LHV electric eff.) but assuming a similar market penetration would lead to 2.6% greater non renewable primary energy consumption per capita and 2.2% greater CO_2 emission per capita
- given the trend towards more stringent pollution standards, remaining with atmospheric emission rates currently associated with those units could severely limit district units market penetration: a 4 times lower market penetration of those units would lead to 5.7% greater non renewable primary energy consumption per capita and 5.5% greater CO_2 emission per capita
- not implementing industrial cogeneration would lead to 4.7% greater non renewable primary energy consumption per capita and 4.6% greater CO_2 emission per capita</td></tr>
<tr><td>advanced gas engine technology:

- for district cogeneration units running on a mix of natural and upgraded syngas/biogas from the gas network, and associated with district heating networks including heat pumps (potentially meets 40% of the 67% and 18% shares of cogeneration/HP plants in</td><td>- low irreversibility engines – advanced combustion, lower heat and friction losses, energy recovery
- adapted or dedicated alternative fuels fired engines
- affordable and robust atmospheric pollutants emission control
- system integration - mechanically coupled heat pumps, bottoming cycles</td></tr>
</table>

room and water heating requirements respectively); 50 to 55% electric efficiency target, and overall First Law heating efficiency between 2 and 2.5 - for on-site cogeneration units running on a mix of natural and upgraded syngas/biogas from the gas network, and associated with district heating networks including heat pumps (potentially meets 60% of the 67% and 18% shares of cogeneration/HP plants in room and water heating requirements respectively); 45% electric efficiency target, and overall First Law heating efficiency between 2 and 2.5 - for industrial cogeneration running on a mix of natural gas and upgraded syngas/biogas from the gas network (meets part of the 10% share in total electricity requirements); 50 to 55% electric efficiency target	Swiss academic 'know-how' (non exhaustive): - ETHZ – IET (LAV) - EPFL – ISE (LENI) - PSI – ENE (CRL) - EMPA - ICEL
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for gas engine district cogeneration units (typically 42% LHV electric eff.) and for on-site cogeneration units (typically 30% LHV electric eff.) assuming a similar market penetration would lead to 0.7% greater non renewable primary energy consumption per capita and 0.5% greater CO_2 emission per capita - given the trend towards more stringent pollution standards, remaining with atmospheric emission rates currently associated with those units could severely limit district units market penetration: a 4 times lower market penetration of those units would lead to 5.7% greater non renewable primary energy consumption per capita and 6.1% greater CO_2 emission per capita - not implementing industrial cogeneration would lead to 4.7% greater non renewable primary energy consumption per capita and 4.6% greater CO_2 emission per capita	
solid oxide fuel cell technology: - for district cogeneration running on a mix of natural and upgraded syngas/biogas from the gas network, and associated with district heating networks including heat pumps (potentially meets 40% of the 67% and 18% shares of cogeneration/HP plants in room and water heating requirements respectively); SOFC-GT: 70% electric efficiency target, and overall First Law heating efficiency of about 3, SOFC: 60% electric efficiency target, and overall First Law heating efficiency of about 2.5 - for industrial cogeneration running on a mix of natural gas and upgraded syngas/biogas from the gas network (meets part of the 10% share in total electricity requirements); 50 to 55% electric efficiency target	- new designs & materials for greater mechanical and chemical stability at high operating temperature - advanced interconnects & sealants - in-situ monitoring techniques - low cost ceramic processing & manufacturing - compact & high performance gas to gas heat exchangers - advanced fuel processing & appropriate gas cleaning technology - system integration – GT/SOFC cycles, coupling with heat pumps - alternative electrolytes for lower operating temperature Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LENI) - ETHZ – MAT (NIN) - EMPA - HPCL
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for combined cycle district units (typically 45% LHV electric eff.) and	

for on-site cogeneration units (typically 30% LHV electric eff.) but assuming a similar market penetration would lead to 0.9% greater non renewable primary energy consumption per capita and 0.7% greater CO_2 emission per capita - SOFC technology is associated with very low atmospheric pollutants emission: a 4 times lower market penetration of cogeneration district units that would be due to non compliance with stricter atmospheric pollution standards when using more conventional technology would lead to 8.0% greater non renewable primary energy consumption per capita and 8.7% greater CO_2 emission per capita	
gasification technology (medium scale): - for biomass methanation plants supplying upgraded syngas to the gas network; 77% biomass to syngas conversion efficiency target	- system reliability – tars & particulates related issues - appropriate gas monitoring & cleaning technologies - fuel flexible gasifiers with priority to low or negative cost feedstock such as wastes - feeding mechanisms & reactors - feedstock quality homogenisation and standard - advanced heat exchangers - advanced catalysts Swiss academic 'know-how' (non exhaustive): - PSI – ENE (LSK) - WSL - ETHZ – IET (LTNT, PRE) - EPFL – ISE (LTCM), ISIC (LGRC)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not implementing methanation plants, assuming that natural gas is used instead, and using the corresponding available biomass in direct combustion power plants instead (typically 45% LHV electric eff.) would lead to 6.1% greater non renewable primary energy consumption per capita and 5.5% greater CO_2 emission per capita	
ORC technology: - for geothermal cogeneration plants (meets 3.5% of demand for room heating); 15% electric efficiency and 75% overall efficiency targets	- oil circulation or pressurised biomass-fired boilers - dedicated scroll turbines & pumps for small units - radial turbines for medium-scale units - suitability of alternative working fluids Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LENI)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not implementing ORC technology based geothermal cogeneration plants assuming that it would be substituted by natural gas fired boilers would lead to 0.4% greater non renewable primary energy consumption per capita and 0.5% greater CO_2 emission per capita	
advanced hydropower: - for a total hydro power generation capacity maintained at the current level (62% of electricity needs by 2050); 87% conversion efficiency target (versus 82% in 2001)	- advanced blade design for reduced cavitation problems - three dimensional modelling of turbine flow phenomena - mechanical stability under unsteady phenomena - advanced generators - micro-hydro Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LMH) - EPFL – ISE (LME) - EPFL – ENAC (LCH)

scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for hydro while using the same potential would lead to 2.0% greater non renewable primary energy consumption per capita and 1.7% greater CO_2 emission per capita (more gas use as lower biomass share in the power supply given a fixed biomass potential)	
advanced electricity transport network: - overall electricity transport losses reduced down to 5% (versus 8.4% in 2001)	- advanced superconductors with higher temperatures and higher inner coherence – reduced risk of resistance at grain/crystal interfaces - advanced high voltage DC transmission concepts - advanced AC/DC power conversion technologies - advanced power electronics for load control
	Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LEI, LRE) - ETHZ – EE (PES, EEH) - EIA-FR - EIVD
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for hydro while using the same potential would lead to 1.8% greater non renewable primary energy consumption per capita and 1.4% greater CO_2 emission per capita (more gas use as lower biomass share in the power supply given a fixed biomass potential)	
advanced compression heat pumps: - coupled with cogeneration units and for a 67% share of room heating requirements by 2050; target average COP 4.5 - coupled with cogeneration units and driven by the gird for a 23% share of water heating requirements; target average COP 3.5	- products for both water & room heating or for the retrofit market – new working fluids and specific components - monitoring & control for operating strategy - advanced compressors and cycles - advanced heat exchangers
	Swiss academic 'know-how' (non exhaustive): - EPFL – ISE (LENI, LTCM) - HT Basel – IE - HT Luzern – WTT - HT Winterthur - HT Rapperswil - IET
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - assuming an average COP of 3.5 instead of 4.5 and 2.5 instead of 3.5 would lead to 1.5% greater non renewable primary energy consumption per capita and 1.2% greater CO_2 emission per capita - remaining with current technology for heat pumps, and assuming average COP 3.5 and a three times lower market penetration for heat pump based on-site cogeneration units but no market penetration for heat pump based water heaters would lead to 9% greater non renewable primary energy consumption per capita and 9.3% greater CO_2 emission per capita	
advanced solar thermal, inc. storage: - for a 54% share of water heating requirements by 2050; target 50% available heat to useful heat efficiency - for a 6% share of room heating requirements by 2050; target 50% available heat to useful heat efficiency and seasonal storage with 40% annual efficiency	- advanced heat storage concepts - low cost production technologies for vacuum tubular solar thermal technologies - system integration – in-house and advanced low cost control technology
	Swiss academic 'know-how' (non exhaustive): - HT Rapperswil - SPF - EI Vaud – IGT (LESBAT) - EPFL – ENAC (LESO) - Uni Genève - CUEPE

scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for solar thermal, and assuming similar market penetration for water heating but with 40% overall eff. and no material market penetration for room heating due to lack of satisfactory enough seasonal storage, would lead to 0.7% greater non renewable primary energy consumption per capita and 0.7% greater CO_2 emission per capita	
advanced biomass boilers: - for district heating networks (meets 10% of wood in room heating and 6% share of water heating) - for on-site domestic biomass-fired boilers (meets 3% of room heating requirements)	- feedstock quality homogenisation and standard - techniques for NOx and particulate matter reduction Swiss academic 'know-how' (non exhaustive): - Ökozentrum Langenbruck
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - assuming that only half of the expected market penetration is achieved and the rest is met with natural gas fired boilers instead would lead to 1.0% greater non renewable primary energy consumption per capita and 1.2% greater CO_2 emission per capita	
advanced natural gas reforming technology (small- scale): - for distributed hydrogen fuelling stations providing enough hydrogen to meet 4% of total final energy transport demand: target 80% natural gas to hydrogen conversion efficiency (versus 65-70% with steam reforming currently)	- advanced catalysts - partial oxidation - autothermal reforming Swiss academic 'know-how' (non exhaustive): - ETHZ – IET (PRE) - PSI – ENE (LST, LEMC) - EPFL – ISE (LENI), ISIC (LCPM) - EMPA – MET
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current natural gas steam reforming technology would lead to 1.3% greater non renewable primary energy consumption per capita and less than 1.2% greater CO_2 emission per capita	
polymer electrolyte fuel cell technology for transport: - for FC passenger vehicles with on-board hydrogen storage (4% share in the total transport final energy demand); target 2.5 litres gasoline equivalent per 100 km , 5'000 hours lifetime	- optimal system integration - heat and water on-board management - low manufacturing cost for bipolar plates - dedicated auxiliaries - more robust MEAs - advanced membranes and electrodes Swiss academic 'know-how' (non exhaustive): - PSI – ENE (ECL) - ETHZ – IMRT - HT Luzern - HT Biel - EI Vaud
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not developing PEM technology for FC vehicles and assuming that their share is taken up by additional ICE hybrid vehicles would not allow to comply with an average 3 litres of fossil fuel consumption per 100 km and would lead to 0.5% greater non renewable primary energy consumption per capita and 1.7% greater CO_2 emission per capita; compliance would require a greater use of pure electric vehicles and/or fossil fueled vehicles greater tank to wheel conversion efficiency improvement (both with greater share of hybrid vehicles and greater specific efficiency improvement)	

on-board hydrogen storage: - for FC passenger vehicles with on-board hydrogen storage (4% share in the total transport final energy demand); 9% weight capacity and 2.7 kWh per litre targets	- cost reduction of storage technologies (all types) - increase of volumetric and gravimetric storage density - reduction of boil of losses of liquid hydrogen storage Swiss academic ‘know-how’ (non exhaustive): - Uni Fribourg - Uni Genève - EMPA – MET - EPFL – ISIC (LCOM)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not developing PEM technology for FC vehicles and assuming that their share is taken up by additional ICE hybrid vehicles would not allow to comply with an average 3 litres of fossil fuel consumption per 100 km and would lead to 0.5% greater non renewable primary energy consumption per capita and 1.7% greater CO_2 emission per capita; compliance would require a greater use of pure electric vehicles and/or fossil fueled vehicles greater tank to wheel conversion efficiency improvement (both with greater share of hybrid vehicles and greater specific efficiency improvement)	
advanced on-board electric storage: - for ICE hybrid passenger vehicles and pure electric vehicles, with a cumulated 45% share in the total transport final energy demand; target 2.5 litres gasoline equivalent per 100 km for ICE hybrids, and 2 litres gasoline equivalent per 100 km for pure electric	- advanced batteries: cost reduction - advanced batteries: long term usability (increase of charging cycles) - advanced batteries: improved energy density - super-capacitors Swiss academic ‘know-how’ (non exhaustive): - PSI – ENE (ECL) - EPFL – ISE (LEI), ISIC (LPI, LCIC, GGEC), IMX (LTP)
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current technology for on-board batteries, and assuming 2 times lower hybrid ICE market penetration and no material pure electric market penetration as a consequence would lead to 6.7% greater non renewable primary energy consumption per capita and 7.2% greater CO_2 emission per capita and would fail to comply with an average 3 litres of fossil fuel consumption per 100 km; compliance would require a much greater tank to wheel conversion efficiency improvements for ICE engines and/or a greater fuel cell vehicles market penetration	
advanced ICE vehicles for transport: - for a 44% share in the total transport final energy demand; target 5 litres gasoline per 100 km for ICE and 2.5 litres gasoline per 100 km for hybrid ICE	- advanced combustion - camless operation - adaptive calibration of engine parameters - in-cylinder sensing - continuous variable transmission - advanced injection - advanced heat recovery - lightweight vehicles: low cost composite structure production processes, optimisation of composite structure design, lightweight hybrid body structures (multi material sandwich structures)

	Swiss academic 'know-how' (non exhaustive): - ETHZ - IET (LAV, LTNT, LSM), IFD - EPFL – ISE (LENI) - PSI – ENE (CRL) - EMPA - ME - HT Rapperswill - HT Biel
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - remaining with current (new) technology for ICE vehicles (7.7 litres per 100 km) and assuming the same ratio of hybrid ICE and ICE vehicles would lead to 12.4% greater non renewable primary energy consumption per capita and 12.7% greater CO_2 emission per capita, and would fail to comply with an average 3 litres of fossil fuel consumption per 100 km; compliance would require greater hybrid ICE and/or fuel cell vehicles market penetration	
low energy housings: advanced insulation, glazing, lighting, and ventilation : - for a 75% decrease of the average annual specific energy consumption per square meter for room heating - for a 50% decrease of the average annual energy demand in the building sector	- vacuum insulation construction site usability - long time integrity of vacuum - detection technologies for ventilated vacuum panels - vacuum glazing - surface coating for advanced glazing - heat recovery - system cost reduction by cost reduction of components - energy efficient framing technologies - switchable glazing - improvement of heat recovery rate – advanced heat exchangers - intelligent and robust control systems and strategy - efficiency increase of electric motors and drives
	Swiss academic 'know-how' (non exhaustive): - EMPA - EPFL – ENAC (LESO) - HT Winterthur - HT Luzern - HT Basel
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - assuming that insulation, glazing, and ventilation technology only allows 50% reduction of the average annual specific energy consumption for room heating (instead of 75%) would lead to 4.6% greater non renewable primary energy consumption per capita and 6% greater CO_2 emission per capita	
photovoltaic cells: - for 1% of the electricity requirements: target 25% electric efficiency	- cost reduction by decrease of material losses in production e.g. by improved sawing technologies - improved industrial manufacturing technologies to approach mass production efficiency to the values of lab efficiency - cost reduction and improved reliability of balance of system components (especially inverters) - increase of module efficiency

	Swiss academic 'know-how' (non exhaustive): - Uni Neuchâtel - IMT - EPFL – ISIC (LPI), CRPP, ENAC (LESO) - ETHZ - TFP - EMPA – FPL - Uni Bern - Uni Genève – CUEPE - LEEE - TISO
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not installing this share of photovoltaic cells in the electricity supply would lead to 1.3% greater non renewable primary energy consumption per capita and 1.0% greater CO_2 emission per capita	
wind turbines: - for 1% of the electricity requirements: target 45% electric efficiency	- increase of rotor area by improved strength properties of rotor material (e.g. carbon fibre/epoxy) - gear box and drive train long term stability improvement - weight reduction of gearless multipole generators - improved short to mid term power prediction methodologies for grid integration - new service and maintenance concepts for O&M cost reduction
	Swiss academic 'know-how' (non exhaustive): - EPFL – ENAC (LASEN) - HEVS - EIVD - EIG
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not installing this share of wind turbines in the electricity supply would lead to 1.3% greater non renewable primary energy consumption per capita and 1.0% greater CO_2 emission per capita	
geothermal plants: - for 3.5% of demand for room heating and based on ORC technology: 15% electric efficiency and 75% overall efficiency targets	- low cost drilling technologies - geophysical mapping and exploration - borehole activation and rock fracturing - corrosion resistant materials
	Swiss academic 'know-how' (non exhaustive): - Uni Neuchâtel – CREGE, CHYN - EPFL – ENAC (LMS) - Uni Lausanne – IG - ETHZ - IG
scenario sensitivity analysis: the rest being unchanged (apart from natural gas and oil shares if required), - not installing such a share of geothermal in the heat and electricity supply would lead to 0.9% greater non renewable primary energy consumption per capita, and 0.7% greater CO_2 emission per capita	

6.5.1 Results of the first order quantitative analysis by sector

Room heating:

- Aggressive policy is put in place to reduce by half the final energy consumption in the building sector. Building standard rapidly approaches Minergie level develops towards zero energy housing. Given an expected 25% increase of the total heated area by 2050, the average specific annual heat consumption of the whole building stock for room heating must be reduced by 75%, so that the sum of room heating and water heating is reduced by half[44]. This is achieved with advanced insulation, advanced glazing, and building system integration. As a result, and after the implementation of the other measures below, the total final energy demand for room heating is reduced by 69%, i.e. from 228.3 PJ in 2001 down to 70.8 PJ in 2050.
- Direct electric heating is banned.
- Fuel oil in use within existing district heating networks is substituted with wood fired boilers, assuming advanced wood-fired boilers reach a similar heating efficiency than replaced fossil-fired installations. Finally, domestic wood boilers installed in replacement of part of the oil boilers in housings located in areas with a low population density (where a connection to the natural gas network does not make economic sense) amount for 2.1 PJ of the final energy demand for room heating. Wood as a whole makes up **12.7%** of the room heating final energy demand by 2050, i.e. 9 PJ. This requires 9.1 PJ of wood biomass resources assuming that 10% of the wood primary energy potential is used for the conversion into a usable final feedstock, i.e. **7.5%** of the total biomass ecological potential[45].
- A **67.1%** share of the room heating final energy demand, i.e. 47.5 PJ[46], is met with the use of integrated energy systems based on distributed cogeneration units coupled with compression heat pumps associated with a 4.5 average COP. Those cogeneration units are either on-site units (40% on en energy basis) or district units associated with a district heating network (60%). All of them are connected to the natural gas network which supplies a mix of two thirds natural gas and one third upgraded biogas/syngas. District cogeneration units can be rather sophisticated and are therefore associated with a high average electric efficiency, i.e. 65%. Their overall conversion efficiency is however penalized by thermal losses and is of 70%. Combined cycles units based on solid oxide fuel cell and gas turbine technologies reach 70% electric efficiency, and large advanced gas engine technology reach 55% electric efficiency. On-site cogeneration units are gas engine or fuel cell based units associated with an average 45% average electric efficiency and a 95% overall

[44] This supposes that electricity consumption in buildings is also reduced by half – a detailed analysis of this point is out of the scope of this quantitative analysis as in this existing tool, electricity consumption is aggregated.

[45] In the way the existing tool is designed, the energy required for the conversion of a biomass resource into usable final feedstock and for its transportation to the point of use is supposed to be fully provided by the biomass resource itself; this is the most optimistic case and not likely in practice. Authors recommend a more sophisticated modeling tool to be developed that takes into account interactions between the various primary energy resources among the different applications.

[46] 29.7 PJ in the form of environment heat, and 11.7 PJ in the form of natural gas and 5.4 in the form of biogas/syngas feeding the cogeneration units and from there the heat pumps.

efficiency. District and on-site cogenerations units together use **5.7%** of the total ecological biomass potential in the form of upgraded biogas/syngas injected in the natural gas network to meet their share of the final energy supply for room heating, assuming a 77% feedstock to biogas/syngas conversion efficiency and that 10% of the biomass primary energy potential is used for the conversion into a usable feedstock.

- New district heating networks based on some geothermal heat (2.4 PJ)[47], direct combustion of some of the available non renewable waste (2.1 PJ), direct combustion of some of the available renewable waste (2.1 PJ) and available waste heat (1.3 PJ) supply heat within urban areas, accounting for **11.1%** of the total final heat supply for room heating. Geothermal heat is supplied by cogeneration plants based on ORC technology which deliver electricity to the grid at a 15% electric efficiency and are associated with a 75% overall energy conversion efficiency.
- Solar thermal accounts for **6.2%** of the final energy supply for room heating, i.e. 4.4 PJ, and is applied to building clusters thanks to the development of appropriate seasonal storage associated with an annual efficiency of at least 40%. Solar thermal installations are associated with a 50% heating efficiency (final heat to useful heat ratio) and require an equivalent of 5% of the final heat delivered in the form of electricity for operation. Assuming solar panels delivering 500 kWh per m^2 and per year, about 2.4 millions m^2 (or about 0.3 m^2 per capita[48]) must be installed by 2050. This is about 2% of the estimated 138 million m^2 of available roof area [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005] and requires about 60’000 m^2 installed yearly in average between 2005 and 2025, and about 100’000 m² yearly in average between 2025 and 2050, accounting for a 20 years lifetime for the solar panels, to be compared with 35’000 m^2 currently installed every year in Switzerland[49].
- Existing natural gas fired district heating now operates with a mix two third natural gas and one third biogas/syngas, and account for 2.1 PJ, i.e. **3%** of the total final heat supply for room heating, with 1.4 PJ of natural gas and 0.7 PJ of upgraded biogas/syngas.

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[47] Assuming 6’000 hours of operation per year for room heating in the building sector, this means that between 5 and 6 plants such as the one in construction in Basel (20 MWth) are installed by 2050.

[48] Assuming 7.5 millions inhabitants by 2050

[49] in terms of ‘standard’ capacity installed, 100’000 m^2 per year is equivalent to 70 MWth per year, according to the convention from the IEA Solar Heating Cooling Programme, i.e. 0.7 kWth per m^2, to be compared with 1250 MW of solar thermal capacity expected to be installed in the whole Europe in 2005 (www. estif.org)

	Room heating - final energy [PJ]	
	RH 2001	RH 2050
oil products	139.8	-0.0
natural gas	53.7	13.1
non renewable waste	12.2	2.1
solar - thermal	-	4.4
wood	12.3	9.0
biogas/syngas	-	6.2
renewable waste	6.6	2.1
waste heat	-	1.3
heat from environment	3.1	29.7
geothermal heat	-	2.4
electricity	0.6	0.8
	228.3	70.8

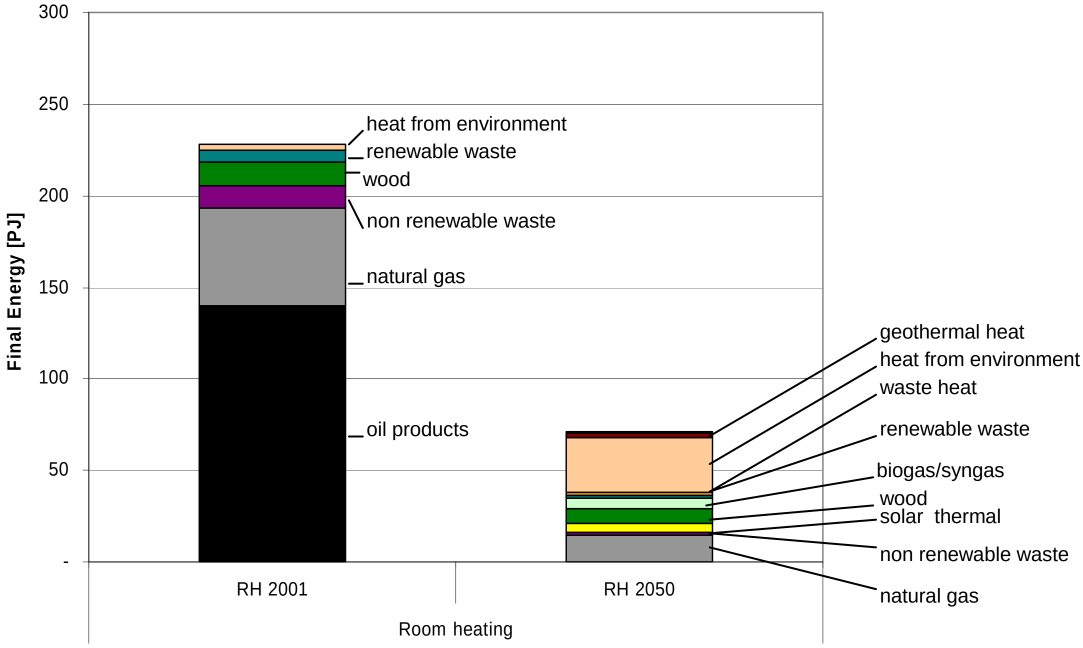

Figure 6-31 Share of the various energy sources in the room heating final energy supply (LdLfs).

Water heating:

- Efficiency measures reduce the specific energy demand for water heating by 12%, but an increase of the hot water consumption by 25% leads to an actual increase of the final energy demand for water heating by 10% by 2050, up to 59.7 PJ. Fuel switching measures also contribute to an additional increase of the final energy demand for water heating up to 75.7 PJ (effect of solar thermal final energy to useful energy ratio). Efficiency measures for room heating however insure that the sum of room heating and water heating demand is reduced by half.
- Fuel oil in use within existing district heating networks is substituted with wood fired boilers, assuming advanced wood-fired boilers reach a similar heating efficiency than replaced fossil-fired installations. Wood as a whole makes up **6.1%** of the water heating final energy demand by 2050, i.e. 4.6 PJ. This requires 5 PJ of wood biomass resources assuming that 10% of the wood

primary energy potential is used for the conversion into a usable final feedstock, i.e. **4%** of the total biomass ecological potential[50].

- Solar thermal accounts for **53.9%** of the final energy demand for water heating, i.e. 40.8 PJ. It is required by rule for new housings, and is applied to single family or multi-family housings and to building clusters associated with local district heating. Solar thermal installations are associated with a 50% heating efficiency (generated heat to useful heat ratio) and require 5% of the final heat delivered in the form of electricity for their operation. Assuming solar panels delivering 500 kWh per m^2 and per year, about 21.5 millions m^2 or about 3 m^2 per capita[51] must be installed by 2050, or about 15% of the estimated 138 million m^2 of available roof area [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005]. This requires about 480'000 m^2 installed yearly in average between 2005 and 2025, and about 960'000 m^2 yearly in average between 2025 and 2050, accounting for a 20 years lifetime for the solar panels, to be compared with 35'000 m^2 currently installed every year in Switzerland[52].
- Heat pump based water heaters driven by distributed cogeneration units account for **17.8%** of the final energy demand for water heating, i.e. 13.5 PJ[53]. They are associated with a 3.5 average COP.
- Heat pumped based water heaters driven by imported electricity from the grid account **11.3%** of the final energy demand for water heating, i.e. for 8.5 PJ [54]. They are associated with a 3.5 average COP.
- Existing natural gas fired district heating now operates with a mix two third natural gas and one third biogas/syngas and accounts for 0.6 PJ, i.e. **0.7%** of the total final heat supply for water heating, with 0.4 PJ of natural gas and 0.2 PJ of upgraded biogas/syngas.
- The rest of the demand is met with electric heating (**10%**).

[50] see footnote 3
[51] assuming 7.5 millions inhabitants by 2050
[52] in terms of 'standard' capacity installed, 960'000 m^2 is equivalent to 672 MWth per year, according to the convention from the IEA Solar Heating Cooling Programme, i.e. 0.7 kWth per m^2, to be compared with 1250 MWth of solar thermal capacity expected to be installed in the whole Europe in 2005 (www. estif.org)
[53] 7.5 PJ from the environment, 5.8 PJ from natural gas, and 2.7 PJ from biogas/syngas
[54] 6.1 PJ from the environment, 2.4 from imported electricity

	Water heating - final energy [PJ]	
	WW 2001	WW 2050
oil products	16.4	0.0
natural gas	7.2	6.4
solar - thermal	1.2	40.8
wood	2.9	4.6
biogas/syngas	-	2.9
heat from environment	0.5	14.3
electricity	25.9	6.8
	54.2	75.7

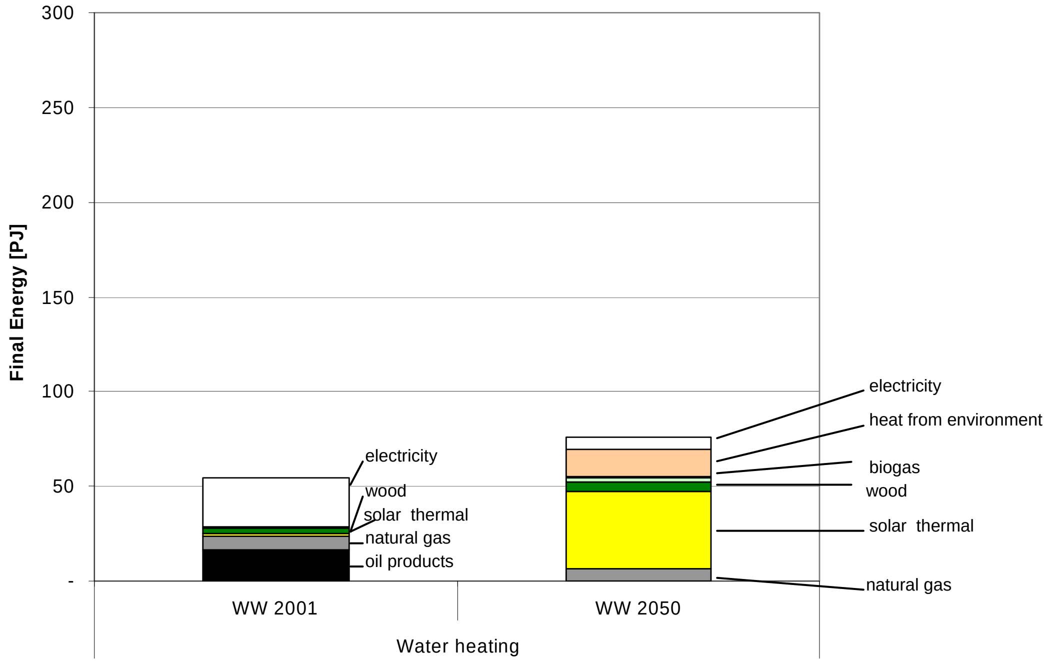

Figure 6-32 Share of the various energy sources in the water heating final energy supply (HdLfs).

Transport:

- Negotiations with car importers and policies in favour of fuel economy improvement, fuel switching, efficient driving behaviour, and modal transfer lead to a reduction of the passenger cars fleet average fuel consumption down to 3 liters of gasoline equivalent per 100 km by 2050.
- A 55% demand growth of passenger vehicles final energy demand is expected due to greater comfort requirements. The tank to wheel average conversion efficiency is increased by 56% and some fossil fuel substitution is introduced so that the total final fossil fuel consumption of the passenger vehicle fleet is reduced from 221.3 in 2001 to 124 PJ by 2050[55]. Fossil fuel substitution is obtained essentially with the use of hydrogen from syngas/biogas reforming.
- This is achieved with:

  1) an improvement of ICE vehicles average fuel economy down to 5 litres gasoline per 100 km. Those vehicles account for 45% of the total passenger vehicles fleet.

[55] the average fuel consumption in 2001 was 8.4 liters gasoline per 100 km [Plan Directeur 2004-2007]

2) an important market penetration of ICE hybrid vehicles which are supposed to account for 45% of the new passenger vehicles fleet. They are considered to be running on gasoline with an average specific fuel consumption equivalent to 2.5 litres per 100 km.

3) a significant penetration of fuel cell vehicles running on hydrogen and associated with an average 2.5 litres gasoline equivalent per 100 km. Those are supposed to make up 10% of the fleet.

4) some pure electric urban passenger vehicles (taxi vehicles for example) associated with a 60% power train efficiency. Those make up the rest of the fleet, i.e. less than 1%.

- Heavy road vehicles, rail, and air transport final energy demands are assumed to increase by respectively 176.7%, 82.5%, and 84.8% compared to 2001, accounting for efficiency measures reducing the specific energy demand by respectively 7%, 50%, and 60%.
- Oil products make up **87.6%** of the 244.4 PJ total final energy consumption for transport.
- Hydrogen accounts for **8%** of the total final energy consumption for transport, i.e. 19.5 PJ. It is produced with an 80% efficiency by on-site reforming of the mix of two third natural gas and one third biogas/syngas distributed to fuelling stations via the gas network.
- Electricity accounts for **4.4%** in the total final energy consumption for transport, i.e. 10.8 PJ.

	Transport - final energy [PJ]	
	VK 2001	VK 2050
oil products	289.6	214.2
hydrogen from nat. gas and snygas	-	19.5
electricity	10.2	10.8
	299.7	244.4

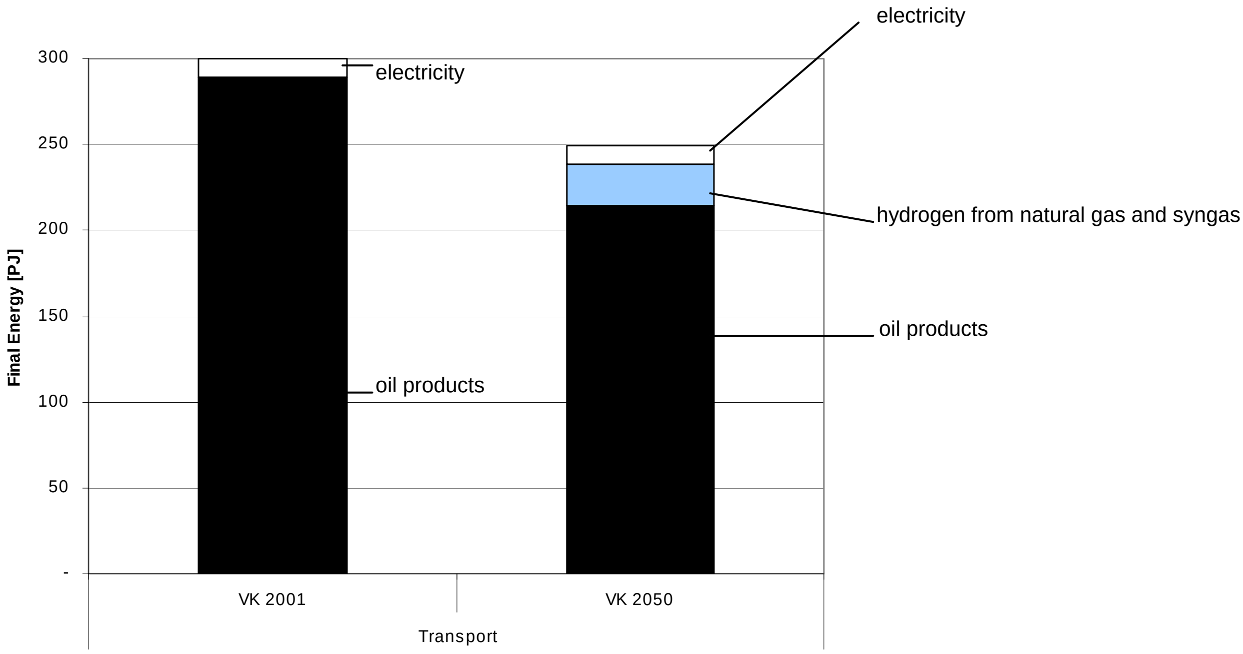

Figure 6-33 Share of the various energy sources in the transport final energy supply (HdLfs).

Process heat:

- Final energy demand for industrial process heat increases by 22.7%, i.e. from 130.6 PJ in 2001 up to 140.1 PJ in 2050, accounting for efficiency measures reducing the specific demand for process heat per unit output by 35%.
- Additional measures for a reduction of heat distribution losses are implemented, leading to a total final energy demand for process heat of 137.6 PJ.
- Measures such as the replacement of a fourth of the compression chillers by absorption chillers running on waste heat reduce the share of electricity in the final energy demand for process heat.
- Cogeneration running on a mixture of natural gas and syngas/biogas with a 40% average electric efficiency and 95% global conversion efficiency is aggressively pursued and accounts for 42.7%, i.e. 55.1 PJ, in the final energy demand for industrial process heat. The amount of electricity generated, i.e. 22.1 PJ, exceeds internal needs for process heat and 8.7 PJ of electricity can be directed towards internal electricity final needs or exported to the grid.
- Half of the remaining oil products requirements are substituted with a mix of natural gas and syngas/biogas, leading to a 47.4% total share of natural gas (61.1 PJ) and a 25.6% total share of syngas/biogas (32.9 PJ) in the total final energy demand for industrial process heat.
- The rest of the demand is met with direct combustion of non renewable waste, i.e. 28 PJ, and oil fired boilers, i.e. 15.6 PJ.

	Process heat - final energy [PJ]	
	PW 2001	PW 2050
oil products	57.1	15.6
natural gas	33.5	61.1
biogas/syngas	-	32.9
non renewable waste	26.1	28.0
electricity	14.0	-8.7
	130.6	128.8

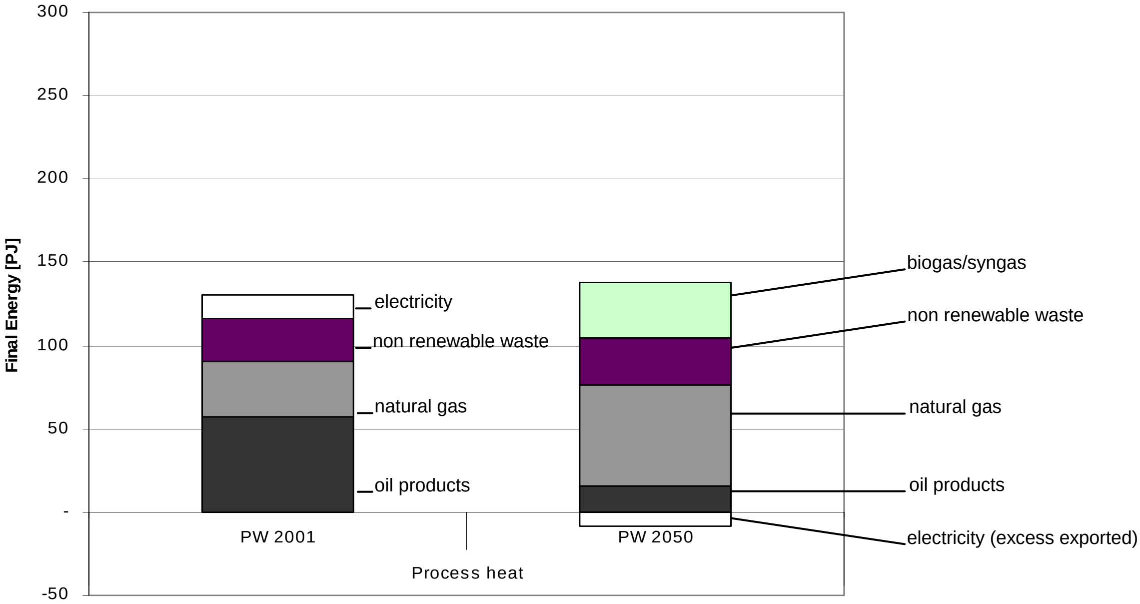

Figure 6-34 Share of the various energy sources in the process heat energy supply (LdLfs).

<u>Electricity</u>:

- Electricity requirements other than those related to room and water heating in the building sector, industrial process heat, and transport increase by 23.5%, i.e. from 141.2 PJ in 2001 up to 174.7 PJ in 2050, accounting for demand-side efficiency measures reducing the specific electricity demand by 25%. Electricity requirements related to room and water heating in the building sector and to transport however lead to a total need for 219.1 PJ of which 33.3 PJ (**15.2%**) are met with distributed cogenerations units (natural gas/syngas/biogas mix fired in the industrial and building sectors). The remaining 181 PJ are met with hydro, natural gas/syngas/biogas mix fired distributed power plants, and decentralized renewable power. In 2001, 256.4 PJ were generated, out of which 191.8 PJ were supplied to domestic consumers and 43 PJ were exported, the rest being lost during transport.
- The efficiency of electricity transport and distribution via the grid is increased from 91.6% in 2001 to 95% by 2050.
- Repowering projects maintain the capacity of hydro at the same level than in 2001, therefore supplying 135.3 PJ of electricity in 2050 (after transport losses accounted for), i.e. **61.9%** of the needs. Assuming a conversion efficiency of 87% (versus 82% in 2001), this requires 155.7 PJ of primary energy from water resources.

- Existing nuclear power plants are decommissioned and no new nuclear capacity is installed. In such a Future with low fossil fuel substitution and enhanced competition in a liberalised market, drivers for a nuclear capacity renewal are not dominant.
- Distributed medium-scale GTCC power generation plants running on the mix of natural gas and syngas/biogas (two third/one third) delivered via the gas network supply 40.8 PJ of electricity in 2050 (after transport losses are accounted for), i.e. **18.6%** of total national electricity needs. This requires 23.9 PJ of syngas assuming a 60% conversion efficiency, and uses **25.4%** of total biomass ecological potential, i.e. 31 PJ assuming a 77% feedstock to syngas conversion efficiency. Assuming 7'000 hours of operation annually and an average unit capacity of 100 MWe, about 16 plants are installed by 2050.
- Solar photovoltaic cells are moderately introduced and supply 2.3 PJ or **1.1%** of national electricity requirements by 2050, assuming an average conversion efficiency of 25%. Assuming 200 kWh per m^2 and per year, this requires about 3.2 millions m^2 in total and the installation of about 70'000 m^2 each year in average between 2005 and 2030, and 140'000 m^2 each year between 2030 and 2050, when considering a 20 years lifetime. Current capacity connected to the grid is of about 18 MWpeak, i.e.180'000 m^2, and about 2 MWpeak are being installed each year, equivalent to 20'000 m^2 given current average conversion efficiency (~10 m^2 per kWpeak). The maximum potential of building integrated PV in Switzerland is estimated to be 18.4 TWh per year, associated with 138 millions m^2 on roofs and 52 millions m^2 on facades [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005].
- Wind turbines supply 2.3 PJ or **1.1%** of national electricity requirements by 2050 (after transport losses accounted for), assuming a conversion efficiency of 45%. This represents 56% of the estimated maximum acceptable potential for wind farms by 2050[56], i.e. about 1'150 GWh per year associated with 726 wind turbines installed among 96 different sites [Erneuerbare Energien une neue Nuklearanlagen, BFE 2005].

[56] note that another 2'850 GWh could be generated but with on-site wind turbines in a Future with a high degree of decentralisation

	Electricity supplied to the users [PJ]	
	EL 2001	EL 2050
oil products	3.5	0.0
natural gas	3.5	52.2
nuclear	68.1	0.0
water	116.7	135.3
wind	0.0	2.3
solar	0.0	2.3
biomass	0.0	27.1
geothermal	0.0	0.0
	191.8	219.1

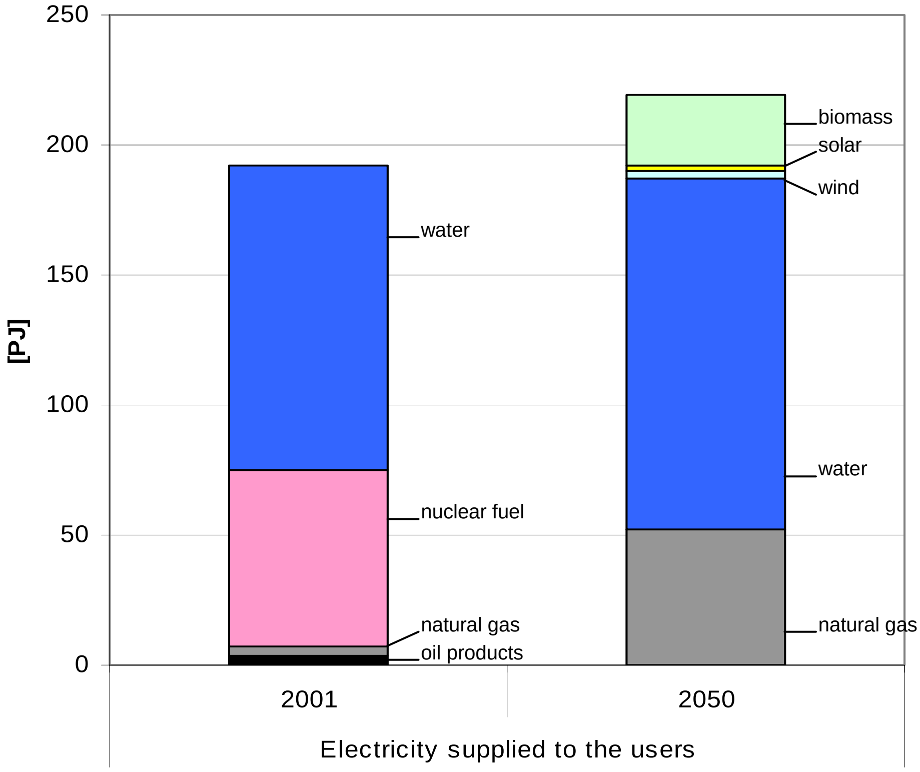

Figure 6-35 Share of the various energy sources in the electricity delivered to national users (HdLfs).

7 Reflection of the 'Futures' and the corresponding technology selections against industry views and capabilities

7.1 Patent analysis

7.1.1 Methodology of the patent analysis

Patents are usually considered as legal documents that should guarantee to its owner a temporary protection for the commercial use of an invention. This temporary protection is compensated by the publication of a detailed description of the invention, which should stimulate other inventors and enterprises to produce further new developments. Overall, this should promote the technical and scientific progress.

Since electronic patent databases have been provided, not only individual patent documents can be viewed, but also large scale statistical analyses of patent documents can be performed. Due to the large scientific interest in patent statistic data, the OECD has published a handbook for the use of patent statistic data (OECD, 1994). More recently developed methods of the patent analysis can be found e.g. in Moed et al. (2004).

Even though the use of patent indicators has proven successful, Schmoch and Gauch (2004) point out that there are methodological limitations which should be taken into account. Patents aim at the commercial use of inventions. Hence they are useful to mirror the results of the research and development activity of individual industrial companies. Different to this the reflect only to a much lesser extent research and development activities of universities and other non-industrial research institutions. This fact however can also be viewed as an advantage for the purpose that is followed with the patent analysis in this study, as the patent analysis is primarily used as a tool to investigate the industrial research and development capabilities in Switzerland.

Not all technological inventions are filed as a patent, because alternative options for safeguarding the commercial use inventions can be used such as confidentiality or the temporal lead over the competitors at relevant markets. Furthermore, there are differences in the tendency to apply for patents amongst technology fields and economic sectors, that make it difficult to compare across those fields and sectors. Diverging national laws and patent strategies make it crucial to choose an adequate patent office for the statistical analysis of patents.

Usually, patent applications are filed to the domestic patent offices as the national patent secures the domestic production and commercialisation and as domestic patents raise limited costs only. Of the domestic patents, only part are also registered abroad because depending on the target country, the costs may be significantly higher. In Europe, there is the alternative to file a patent application via the central procedure of the European Patent Office (EPO). Patents granted by the European Patent Office are transferred into national patents, by consequence a patent application at the EPO leads to several national property rights.

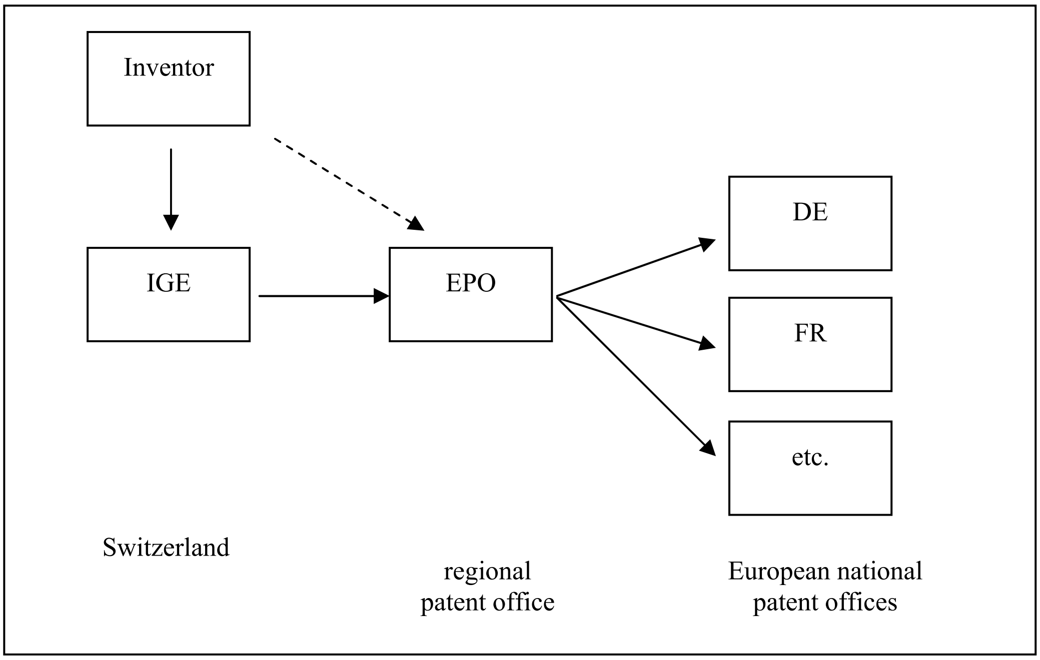

Figure 7-1: Procedure of patent application via the European Patent Office from a Swiss perspective, excluding the applications via the WIPO/PCT. Source: Schmoch (1990), adapted.

From a Swiss perspective, not only the national patents or a patent application at the EPO can be useful but also an application at the German patent office (Deutsches Patent- und Markenamt, DPMA). There the costs are substantially lower than at the EPO and the German market is a key market to many Swiss companies. Another alternative for patent protection abroad constitutes in the procedure following the Patent Cooperation Treaty (PCT), through which the application for patents in up to 123 country can be performed centrally. An advantage of the PCT procedure lies in the long time span of 30 months after the first application via the PCT before the decision about the transfer to regional and national patents has to be performed. This transfer generates high costs to the applicants especially in comparison to the initial application via the PCT. Hence applicants make use of this time span to further investigate the commercial viability and relevance of the inventions described in patents applications to the PCT before taking the costly decision of transfer into national patents.

In order to reach a coverage as complete as possible of the Swiss inventions, obviously an analysis on the basis of applications to the Institut für geistiges Eigentum (IGE) could be performed. Due to the publication policy of the IGE this approach is problematic though. Different to the publication policy of e.g. the EPO, the IGE does not follow a strict procedure of publishing all patent applications after a time span of 18 months. Instead, only those granted patents are published that have undergone a formal and technical examination. Even more, the publication can be delayed upon request of the applicant. Due to these procedures of the IGE, the time of publication of an application is uncertain. Unsuccessful applications or withdrawn applications aren't published at all. By consequence, the published patents of the IGE can not really be considered as a suitable database for measuring patent related research activity.

The result of the statistical analysis is further influenced by the criterion which is used to allocate a country of origin to an invention. One option for the allocation is to use the country of first application the so-called priority country. Doing so means assuming that the first application usually is performed at the domestic patent office.

For the Swiss case however, this approach seems not be suitable as Swiss companies could apply directly to the EPO or even to the German patent office as the Swiss market is of limited size only. Especially for those inventions, where a large market potential is viewed right away, the patent applications are usually filed directly to the European Patent Office. When doing so, Switzerland is named as one of the destination countries in the patent application and Europe or Germany respectively is named as priority country.

Most databases also contain the information about the country of residence of the inventor and of the location of the applying company. Using the registered office of the applying company is equally not fully suitable to determine the origin of an invention, as often in larger companies the registered office of the central unit is stated in the patent applications. On top, there is no generally accepted rule which office to use, when larger companies with offices at several locations file patent applications. By consequence, the criterion viewed as most appropriate for the identification of the Swiss patents is the country of residence of the inventor.[57]

For the analysis performed in this study, the patent applications filed or transferred to the EPO are taken as basis. There are three ways how an application can reach the EPO:

- filed directly by the applicant
- transferred to the EPO by a European national patent office
- transfer of PCT patent applications

In order to found the analysis on a coherent database the temporal implications of the three procedures have to be taken into account. When filed directly by the applicant, the patent application appears 18 months after the date first of application (priority date) in the database of European Patent Office. Applications that reach the EPO via a national patent office have to be filed there the latest 12 months after the priority date. As the EPO publishes 18 months after the priority date, patent applications originating from national patent offices are published with the same time lag as patents that were filed directly to the EPO. Patent applications filed through the PCT procedure may reach the EPO with a greater time lag. The PCT, as already indicated above, grants a period of up to 30 months before the decision of the transfer to national or regional patent offices has to be taken. Hence a patent application may have priority date reaching up to 30 months back when arriving at the EPO. Such applications are then published without further formal time lag by the EPO.

Methodologically, the time lag of the applications reaching the EPO when originating from the PCT requires some additional adjustments in order to perform patent analyses for the most recent available years. For these patents from the most recent years, in a first round, all the patent applications that have reached the EPO directly are counted. Further, all the applications that have reached the EPO via the PCT are counted for a time series of historical years where the transfer has been completed already. Together with the total number of applications that have reached the PCT, the additional transfer of applications from the PCT to the EPO can be estimated for the more recent years.

For the analyses within this study, the specialisation of the Swiss industry in relevant technology fields will be used. The specialisation which is calculated as described

[57] Using this selection is not free of error either, as persons cited as inventors residing in Germany may very well live abroad. Schmoch (2004) indicates that this is especially the case for the region of Basel, where many people employed in the Swiss chemical industry live in Germany. Comparable cases also occurred for companies in the region of Geneva, where employees live in France.

below can be viewed as s suitable indicator because it is independent of the absolute number of patents within the area under investigation and also independent of the overall patent activity in the technology field. The specialisation (RPA_{ij}) is calculated as follows:

$$RPA_{ij} = 100 \tanh \ln [(PAT_{ij} / \sum_i PAT_{ij}) / (\sum_j PAT_{ij} / \sum_{ij} PAT_{ij})]$$

With PAT_{ij} being the number of patents of a country i in the technology field j. Employing the logarithm provides for a symmetrical field of data around the value 0. In order to limit the values to a range of values reaching from -1 to +1 instead of stretching out to infinity, the hyperbolic tangent is used. Multiplying by 100 finally stretches the range to ±100, thus simplifying the graphical representation and improving the readability. The specialisation RPA_{ij} is not a hard measure, however when taking into account tolerances for error, index values larger than +15 can be interpreted as a significant above-average specialisation in the concerned technology field. Index values below -15 in turn can be interpreted as significant below-average specialisation in the concerned technology field.

Before going into the description of the results obtained from the patent analysis some remarks with respect to the interpretation should be given. The patent analysis reflects the intensity of patent applications in specific technology fields. These technology fields have to be identified in the international patent classification (IPC) by which the databases at the patent offices are organised. Especially for cases such as the analyses performed for this study with a limited time budget, there are chances that not all patent applications that are actually meant for a certain technological purpose could be identified. This may be caused for example either by unexpected classes to which applications could be allocated or by intentional hiding of patents by the applications. Such a strategy is partly pursued by applicants, who do not describe the main purpose and technological characteristics in their applications explicitly in order not to draw the attention of competitors to their R&D results. Identifying these patents requires extensive research work in the field of patent applications and granted patents as well as in the technological domain in order to get to know all the researchers, research institutions and industrial companies that could come into play.

Further it should be kept in mind that the patent analysis is one way of many others to characterise industrial (and partly academic) research and development and activities. The fact that the patent activity between certain branches or technology fields differ does not have to mean that the R&D efforts differ proportionally, because there are distinct differences in general patent activities of branches. These mainly originate from the suitability of the patent protection for the technology developments that are concerned in the respective branches. In some branches confidentiality may be more appropriate to safeguard the economical benefit of R&D efforts or in other simple temporal advance and head time in market penetration of the resulting products.

7.1.2 Results of patent analysis

In general, the Swiss position with respect to patent activity indicates a super-proportional specialisation in a high number of technology fields among the group of advanced technology and high technology as revealed in a study by Schmoch, 2004. The technology specific analysis carried out within this study leads to a more differentiated picture. First of all it has to be noted that the investigations proved to be more difficult than expected mainly because the number of patents in the individual technology groups that have been exemplarily analysed proved to be very small. This fact limits the significance of the quantitative results produced with the patent analysis in these technology fields.

Nevertheless, certain conclusions can be drawn. First of all, the results from the patent analysis indicate that there are significant differences in the patent related research among the examined technology fields in Switzerland (compare Figure 7-2). On a technology level the following interpretation can be made:

Most clearly observable is the fact that Switzerland shows a continuous high specialisation in the field of **thermal turbo-machines**. This high degree of specialisation is maintained over the entire period of fifteen years that have been analysed. Compared on an international level, the patent related research in Switzerland shows the highest degree of specialisation (see Appendix 2). Also when looking at absolute numbers, the strong position of the Swiss industry is clearly visible. From 1989 to 2003 in average 25 patents originating from Switzerland were filed to the EPO, which is almost as much as Japan (27 applications in average) and more than France (21) or Great Britain. This means that the Swiss turbo-machine research reaches a comparable success rate than the research activities of much larger industrialised countries.

The patent analysis for **PEM fuel cells** being carried out on a temporal segmentation of three four-year intervals showed a distinct positive specialisation of Swiss patent related research in the time from 1991 to 1998. In the period from 1998 to 2002 however, the specialisation changed to a neutral values. The main reason for this lies in the fact that worldwide the intensity of patent applications increased substantially at the end of the 1990s whereas the patent activity in Switzerland remained more or less constant.

In the technology field of **electricity transmission, distribution and switching** Switzerland reaches a high degree of specialisation as well. There however, a development from an average level of patent applications in the first five year period analysed to a high degree of specialisation in the period from 1994 to 2003 can be observed. The cross-country comparison for the electricity transmission, distribution and switching technologies shows that besides Switzerland also France and Germany and to a slightly lower degree also Italy and Sweden are highly specialised in this field.

With respect to patent activity in **nuclear fission** technologies the Swiss industries show a significant sub-proportional specialisation. This is the case although with the research in the ETH-Domain a first class academic research basis is available. It should be noted though that the degree of specialisation is low for France with its very strong nuclear industry as well. One explanation of these results could lie in the possibility that some patent applications relevant for nuclear technologies could not be identified with the selected patent classes. The overall positive specialisation of the EU-25 that is observable is probably caused be a comparatively high rate of patent applications for nuclear technologies originating from the new member states of the European Union. With respect to the patent applications for nuclear technologies the absolute number of patents with Swiss origin is very low (between 0 and 1 patent application per year since 1995). So, the statistical significance is limited, but it still can be concluded that the high academic activity is not reflected in a comparable industrial activity.

The number of patent applications for **solar PV** technologies grew significantly over the analysed period from 1989 (111 patent applications to the EPO originating from worldwide sources) to 2003 (255 patent applications in total). The development of patent activity in Switzerland shows an overall growing trend as well. Even so, the level of specialisation has evolved from an significant sub-proportional specialisation in the first five year period to a range in the average only. If looking to the international picture, one can observe however that only Japan (and Belgium in the last five year period) shows a significant positive specialisation. So, it can be assumed that the high level of semiconductor research activity in Japan is influencing the solar PV domain as well. The analysis of the patent statistics should however not draw the attention away from the fact that Swiss research has a prominent position in the several fields PV cell research.

For **wind turbine** technologies the very low number of patent applications in most of the countries analysed – among them Switzerland – make the calculation of specialisation index change in direction almost erratically. Within the entire period from 1989 to 2003 only five patent applications for wind-turbine technologies from Switzerland have been filed to the European patent office. Nevertheless, the strong position of the German and also of the Danish[58] wind industry can be clearly observed in the patent statistics.

In the technology field of **solar collectors**, Switzerland shows a constant positive specialisation across the entire analysed time period. This is even more interesting as the market penetration and absolute market size in Switzerland is much lower than for example in Austria or Germany. Hence, it could be concluded on the one hand that the industrial research and development base in Switzerland should probably be able to lay the foundations for a more stringent market penetration. On the other hand, the comparatively simple technology of solar collectors probably is not always protected by patents and hence, the patents do not reflect the technology development as well as in other technology fields.

Although **heat pumps** play a very important role in the domestic building sector of single family houses in Switzerland, only a very sparse patent activity can be observed. Over the entire period analysed only 9 patent applications for heat pumps for domestic heating filed from Switzerland could be counted. As now the overall number of patents in this field is very low, Switzerland is showing a positive specialisation still. This is a result, which should be interpreted with care because of the low statistical significance. Especially in this field with a comparatively strong market and a low number of patents in the corresponding classes, one could suspect that the patents are filed in other classes that could not be identified within limited time available for the process of the patent analysis, Another possible explanation could be that the overall patent activity of system manufacturers of heat pumps systems is comparatively low.

The absolute number of patents for **gasification technologies** is larger than e.g. the number of patents for heat pumps for heating purposes. Even so, there is no very clear picture with respect to the specialisation of Swiss patent related research and development in this field. In the period from 1989 to 1993, Switzerland shows an average activity in this technology field with neither super-proportional specialisation nor sub-proportional specialisation. In following time period from 1994 to 1998, a significant super-proportional specialisation of Swiss patent related research and development activity could be observed. From 1999 to 2003 however, the super-proportional specialisation goes back to an index value of some 26, which is just

[58] Because of the the strong position of the Danish wind industry, the wind-turbine patents originating from there were analysed as well. In some years, the Danish and the German patent applications make up three quarters of the total number of applications at the EPO.

above the generally accepted level of significance of 15to 20. It should be noted further, that although the absolute number of patents in this field is not the smallest among the technologies analysed, the results are varying strongly also for other countries and that there are only two countries with continuous high positive specialisation (Netherlands and Finland).
In the technology field of **combustion engine** research, Switzerland shows a significant sub-proportional specialisation. This is a remarkable result as there is a tradition of motor engine development in Switzerland. The low specialisation possibly could be explained by the absence of a large car manufacturer in Switzerland. These large manufacturers seem to outweigh any other player due to the need for a high innovation rate coupled with high numbers of produced units, which together result in substantial research and development activity. Interestingly, also the United States show a continuous sub-proportional specialisation.
With respect to **hybrid drive-train technologies**, only Japan shows a strongly super-proportional specialisation over the entire time period analysed. In contrast to this, the Swiss patent applications indicate sub-proportional specialisation. Among the countries analysed, only Sweden reaches a significant positive specialisation in the third five-year period analysed. It should be noted also, that the intensity of patent related research in this field strongly increased over the three five-year periods. While in the first one some 250 patent applications have reached the EPO, the number has more than tripled to some 850 in the time span from 1999 to 2003.

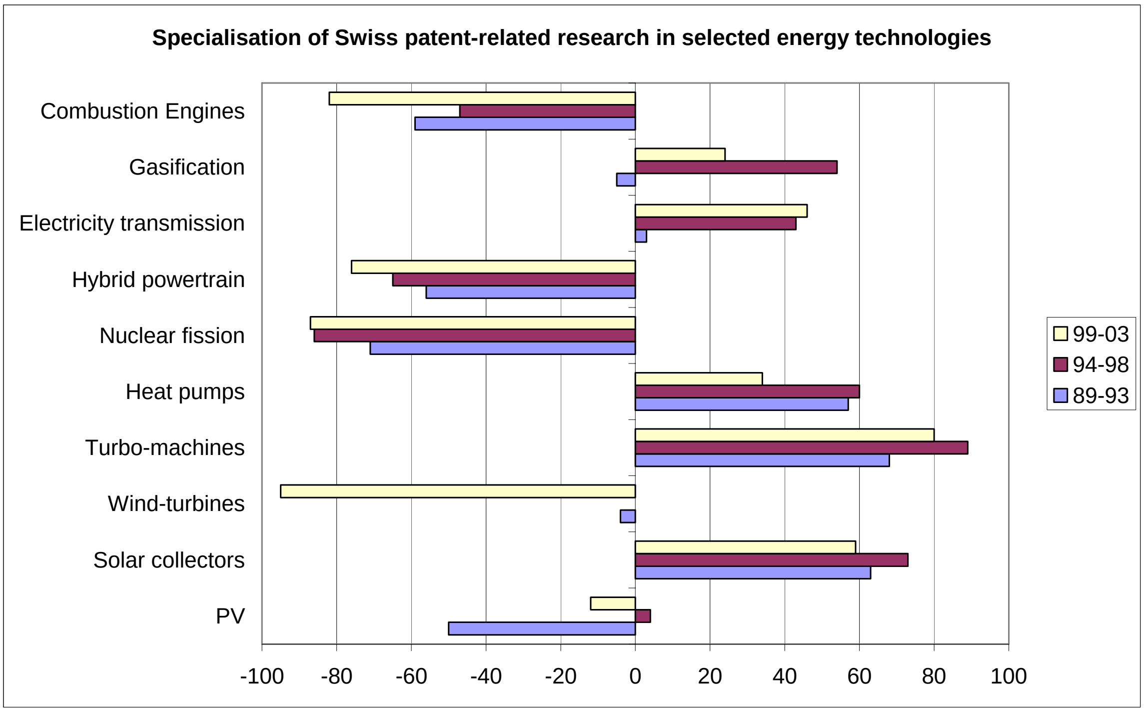

Figure 7-2: Specialisation of Swiss patent related research in energy technologies (to be compledted)

7.2 Position of a large electricity supplier: Axpo

Axpo supplies together with the NOK and final distributors about 3 million people in Switzerland and hence is an important actor in the Swiss energy industry. The published prospective views of this company can thus provide some insights into the possible 'autonomous' future development of a part of the energy system under the conditions of an unchanged political and economical framework.

7.2.1 Framework Conditions of the Axpo-perspectives:

- From the year 2020 on, the contracts for electricity imports with the EDF will run out covering a volume of roughly the equivalent of 2 nuclear power stations or 16 to 17 TWh.
- The end of production of the first nuclear power plants is foreseeable around this period of time as well.

Axpo concludes that resulting from the change in production capacity and the projected growth in demand, Switzerland will be confronted with a rapidly growing gap in electricity supply. Facing this situation, Axpo has mandated a perspectives study focussing on the year 2020.

7.2.2 Projections on electricity demand

For the study, two scenarios ("High" and "Low") have been created based on an ex-post analysis of the development from 1970 until today. In this past period, the growth of electricity demand showed to be super-proportional to the growth of the real GDP. For a 1% growth of the real GDP, 2% growth of electricity were observed according to the Axpo study.
Scenario "High" assumes:

- 2 % annual growth of electricity demand until 2010
- 1.5 % growth from 2011 until 2030
- 1 % growth from 2031 until 2050

resulting in an electricity demand of roughly 44 TWh in 2020 and 60 TWh in 2050.
Scenario "Low" assumes:

- 1 % annual growth until 2010
- 0.5 % growth until 2050

resulting in an electricity demand of roughly 37 TWh in 2020 and 43 TWh in 2050.
Mirrored against the declining production and import capacities, a supply gap between 10 and 21 TWh is projected for the winter half year 2030/2031. Depending on the demand scenario, the Axpo perspectives indicate the possibility that gaps in supply could occur already in the winter months between 2012 and 2019.
On the basis of these findings, the Axpo perspectives formulate the need to develop new production and acquisition strategies in order to close the supply gap in a reliable, cost efficient and as environmentally friendly manner as possible and doing this in due time.

New Renewable energies:
According to the Axpo perspectives, the long term (2050) theoretical potential for electricity production from new renewable energies lies in the order of 20 TWh excluding geothermal electricity generation, 38 TWh including geothermal energy[59]. These potentials are given on the assumption that no constraints due to landscape protection, permitting or costs are made. In the Axpo perspectives, it is also stated that 5 TWh of electricity generation by new renewable energy sources by 2030 would be discussed as possibly politically realisable.

[59] The geothermal electricity potential involves a higher degree of uncertainties than the other new renewable energies according to the Axpo scenarios.

Table 7-1: Renewable electricity generation potentials and cost ranges for Switzerland according to the Axpo perspectives

	Theoretical Potential for electricity generation after 2050 (TWh)[60]	Minimum production costs for electricity (Rp/kWh)	Maximum production costs for electricity (Rp/kWh)
Small hydro	6	10	90
Geothermal	18	9	26
Biogas	3.5	15	38
Solid Biomass	2	15	67
Wind	4	7	33
PV	5.5	54	open

The potentials for renewable electricity generation partly come to lie in the same order as the ones assessed by a recent BFE-study (BFE, 2005). For small hydropower and for wind power, the potentials are more or less the same whereas the potentials identified by Axpo are substantially lower for solid biomass based electricity and PV electricity.

Concerning the costs the Axpo study states that the new renewable energies have generation costs being 3 to 15 times higher in average than today's generation costs of conventional sources. It is further pointed out that additional costs for reserve capacity would arise for wind and PV power.

7.2.3 Conclusions of the Axpo-perspectives

The Axpo study concludes that new renewable energy sources could cover realistically a share of maximally 6% of the electricity demand up to the year 2030. This is a substantial difference to the results obtained in the most advanced scenario of this study, where a penetration of 33 % of new renewables in electricity generation has been obtained for 2050 with help of the quantitative tool developed in the preceding study. Nevertheless, Axpo would start significant investments (according to its terms) in these energy sources as of today. In addition to this, the additional potential for generation with large hydro plants is estimated to be 2%.[61]

In the Axpo perspectives the conclusion is drawn from the above mentioned findings that only with a supplementary combination of fossil fuelled (gas- and oil-fired) power plants and/or nuclear power plants the problem of the supply gap could be resolved. Attention is drawn to the following implications of this strategy:

- With a strategy relying on gas-based generation only, Switzerland would be exposed to a substantial risk of rising gas prices and additional costs for CO_2 emissions. Moreover, there would be the risk that Switzerland could not meet its obligations from the Kyoto-Protocol.
- A strategy involving coal fired power stations could come only into play, if the generation would be performed abroad. On top, such a strategy would depend strongly on future costs for CO_2 emissions.

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[60] The figures for the theoretical potential without geothermal generation do not add up to the total 20 TWh that are stated as total potential in the text. Some error may have occurred from interpreting the graphically representation in the Axpo-perspectives study.

[61] At this point the Axpo perspectives remain unclear whether the 2% relate to the actual generation of large hydropower plants or whether they relate to the total demand.

- The risks associated with nuclear generation are seen in the very high need for capital and the long lasting capital lockup. Further risks are seen in the social and political acceptance, which is strongly related to the open question of the disposal of radioactive wastes.
- According to the Axpo perspectives the nuclear variant offers the best solution if measured in terms of costs only. Further, the very low dependency on supply from abroad is pointed out.

For the analysis of a new production and acquisition strategy, Axpo states the goal for security of supply as the most important, followed by the need for commercial and financial viability. In view of these goals, the Axpo perspectives formulate a strategy of diversification:

- Total investment of 5 billion CHF until 2050
- Investment into new renewables of 100 million CHF until 2010
- Investment of 1 to 2 billion CHF for extension and refurbishment of its large hydro plants within the next 10 years (~until 2015)
- Planning for the construction of domestic gas fired combined cycle power plants as well as for the import of electricity generated in gas- and coal-fired plants as well as in nuclear plants from neighbouring states.
- In a further step, the generation of electricity in a new domestic nuclear power plant is planned, that should be realised with (domestic) partners
- Support for the rational use of electricity and own measures for energy efficiency such as reduction of peak load demand, reduction of transmission and distribution losses, increase of the efficiency of power plants. Energy services such as contracting and energy consulting should be extended.

The future generation portfolio[62] of Axpo is envisaged as follows:

Table 7-2: Generation portfolio of Axpo according to the Axpo perspectives

	Future portfolio	Present portfolio
Nuclear power	49 % (domestic and import)	74 %
Hydro power	25 %	26 %
Gas fired generation	10 %	
Imported (gas and coal)	10 %	
New renewable energies	6 %	

[62] No specific date is given for the date by when this portfolio should be developed.

7.2.4 Reflection of the analysed futures with the Axpo-perspectives

Table 7-3: Electricity generation portfolio of Axpo according to the Axpo perspectives in comparison with the origin of the electricity supplied to the users in the four 'Futures' investigated in this study

	Future portfolio	'Future LdLfs'	'Future HdHfs'	'Future LdHfs'	'Future HdLfs'
Nuclear power	49 % (domestic and import)	-	-	20%	-
Hydro power	25 %	63%	54%	56%	62%
Gas fired generation	10 %	15% (from centralised power plant and decentralised cogeneration)	9% (decentralised cogeneration only)	9% (decentralised cogeneration only)	24% (decentralised cogeneration only)
Imported (gas and coal)	10 %	-	-	-	-
New renewable energies	6 %	22%	37%	15%	14%

When comparing the results of the Axpo scenario to the results obtained in the analysis of the futures in this study, it should be kept in mind that the scenarios for the 'Futures' faced a much larger degree of restrictions due to the set of goals for all energy sectors, which had to be met simultaneously. In general one could characterise the Axpo scenario as a further development of a centralised electricity system, which will rely on surprisingly low amount of renewable energies, including hydro. With the continued use of nuclear energy, the Axpo scenarios implicitly assume public acceptance for this technology that is translated into supportive political decisions. With 10 % of gas fired generation, which apparently is not considered to be connected to CO_2 capture and storage strategies, the Axpo scenario leaves the path of almost CO_2 free electricity generation. This is also the case for the imported electricity from gas and coal based generation. Here, the emissions possibly could simply be transferred to the neighbouring countries, if there, CO_2 capture and storage wasn't implemented either.

Lastly, when interpreting the results of Axpo, it should be kept in mind, that the view of this electricity utility is one example among diversified industrial views and is not to be considered representative for the entire Swiss industry and also not for the energy industry either. For the latter, it would be interesting to get to incorporate the views of the gas industry. Unfortunately to the knowledge of the authors there has been no long-term vision made publicly available from this branch so far.

7.3 Innovation activity in the Swiss economy according to literature results

Within the series “Strukturberichterstattung”, the Swiss secretariat of state for economy has mandated an analysis of the results of the innovation survey conducted in Switzerland in the year 2002. Arvantis et al. (2004) have reported in the study “Innovationsaktivitäten in der Schweizer Wirtschaft” (innovation activity in the Swiss economy) about the results of their analysis.
The report is divided in the following sections:

- Innovation survey 2002: description of the questionnaire, of the sample and of ways handling problems with the questionnaire
- Innovation activity in the period from 2000 to 2002: concept of measuring innovation activity; simple qualitative indicators for innovation activity; selected quantitative indicators for innovation activity, aggregated appraisal of the innovation activity of branches.
- Development of the innovation activity since beginning of the 1990ies
- Barriers to innovation
- International comparison.
- Summary and conclusions

In the conclusions Arvantis et al (2004) point out that the innovation activity of the Swiss economy today were – despite of a stabilisation in the recent years – substantially lower than in the early 1990ies. This finding is mirrored against the fact that the bulk of the barriers to innovation from regulatory side have lost importance according to the surveyed companies. Reasons for this development are at first the longer lasting poor economic situation, which made financial resources for (high risk) innovation projects being sparsely available only. Amongst European countries Switzerland still holds a leading position with respect to its innovation activity. The strong lead against other innovative economies such as the Swedish economy or the Finnish economy has been lost however.
The analysis of the innovation activity of branches is carried out on the statistical level of sub-sections (“Unterabschnitte”, i.e. DK – Maschinenbau/machinery). This level detail in the analysis has been chosen suitable by the authors of the study for the scope of an analysis of the innovation activity of the entire economy. For a comparative analysis of the innovation activity and R&D capabilities of Swiss companies with respect to different energy conversion technologies and energy efficiency technologies, the level of detail is not sufficient however. The technologies in focus could be located in the branches:

- Manufacture of chemicals and chemical products
- Manufacture of Rubber and Plastic Products
- Manufacture of fabricated metal products (by analysing basic metals and fabricated metal products separately, the study goes beyond the level of sub-sections at this point)
- Manufacture of machinery and equipment
- Manufacture of office equipment, data processing devices, electronic technology, precision machinery and optical equipment
- Manufacture of transport equipment
- Electricity, gas and water supply
- Construction

For the qualitative analysis, the authors differentiate between product-oriented innovations and process-oriented innovation. Both types of innovation may play a role for the appraisal of the innovation capabilities of companies dealing with energy conversion and energy efficiency technologies. The need for more efficient energy conversion technologies at first requires product innovations that could be e.g. more efficient gas turbines with higher inlet temperature or even new types of nuclear reactors of the fourth generation. However attaining these technology goals or the goal of cost reduction for these technologies could often mean that process innovations are necessary. These could be e.g. better sawing procedures to produce thinner and by this less costly solar PV cells by using fewer amounts of raw material.
Among the sub-sectors investigated by Arvantis et al (2004), the sectors electronics/instruments, machinery and chemicals are characterised as super-proportionally innovative with respect to products. Interestingly the sector energy/water is characterised as under-proportionally innovative with respect to products as well as with respects to processes. On the one hand this could be explained as in the Swiss electricity market, the momentum for product-oriented innovation is probably quite limited still because the market has not been liberalised so far. On the other hand, it could be expected that the discussion about the future electricity supply (compare Axpo-perspectives) and also about climate change and emissions reductions should act as driving forces for process innovations. These process innovations could be the increase of generation efficiency or the development of electricity generation capacity from new renewable energies.

7.4 Reflection of the study results against industry views and capabilities

The analysis of the Swiss industry views and capabilities do not add up to a fully coherent picture. Nevertheless, the patent analysis gives some directions about strong areas of Swiss industrial R&D and thereby also reconfirms expectations about this matter such as the strong position in turbomachinery patents. There are also more unexpected results such as the high specialisation in the field of solar thermal collectors. In total the patent analysis as performed for a choice of technologies does not support to choose one ‘Future’ among the analysed ‘Futures’ as being best represented by the industrial R&D activities.
The position of Axpo gives a more clear indication. With a comparatively strong focus on nuclear energy electricity generation and on natural gas combined cycle electricity generation, this vision is most similar to a combination of the ‘Futures’ LdLfs and LdHfs. The ‘Future’ LdLfs would reflect the view of a future gas based electricity generation and the strategy with nuclear energy fits to the ‘Future’ LdHfs. All together it can be said clearly that Axpo does not show a tendency to restructure the electricity system to a more decentralised system. With respect to the research strategy under development of CORE, this fact has to be considered carefully. In case a research strategy leading to a more decentralised electricity system were to be adopted, special care should be taken in order to convince industrial actors such as Axpo of the viability and the economic chances of such a strategy.

8 Reflection of the technology selections according to the Futures against the framework of academic competences and strategies

8.1 Energy research strategy of the ETH-Domain

The institutions of the ETH-Domain have elaborated a joint energy research report. Within the report a roadmap for energy research is formulated basing on a set of strategic targets in view of the most important challenges of the 21st century:

- Securing the settlement of energy demand in the industrialised as well in the developing world
- Mitigation of climate change, especially the minimisation of CO_2 emissions into the atmosphere
- Reduction of the dependency on unreliable supply and of the import of limitedly available primary energy resources
- Minimisation of energy related local and regional air pollution ("zero-emissions systems")
- Reduction of the costs for the energy system by increase of efficiency

8.1.1 Research topics within the energy research strategy of the ETH-Domain

Based on existing competences in the institutions within the ETH-Domain, the research strategy formulates an extensive list of research topics, by which a contribution should be made to cope with the core challenges of the 21st century stated above.

For **Hydropower** the ETH Research strategy sees the following challenges to be worked on:

- improving the reliability of hydro-turbines,
- adaptation of hydro-turbines to frequent changes in operation mode,
- development of advanced fluid instrumentation and mechanical instrumentation, computation and fluid mechanics.
- investigation of complex unsteady phenomena of rotor-stator interaction in large hydro turbines.
- development of predictive tools for the behaviour of hydro turbines.
- fundamental and applied research in cavitation.
- research on off-design operating conditions of hydro turbines.

For the more special case of pumped storage, the research topics laid out are:

- development of variable speed motors generators.
- investigation of fundamental phenomena such as wake transport and dissipation, detachments with adverse pressure gradients, structure vibration effects on fluid boundary layers

With respect to dams investigation and management of sedimentation in dams are considered;

In the domain of **geothermal energy** the following research topics are formulated**:**
Drilling:

- development of improved, economic drilling technologies for geothermal wells. This implies the visionary goal of developing an electric drilling robot;
- advancing the understanding of operations in high temperature geothermal applications;
- development and evaluation of new high-temperature components to accelerate the drilling process;
- provision of borehole information during and after drilling.

For the conversion of geothermal energy the strategy states the aim of direct heat to electricity conversion: development direct converter with high power, acceptable efficiency and operation mode across a wide range of temperatures, especially also at low temperatures. The idea points at reducing the gap e.g. between achievable efficiencies of electricity generation and theoretical Carnot-efficiencies.

The technology field of **wind energy** is seen as relatively mature, with the main remaining challenges of the reduction of material use and costs, avoiding material fatigue, engineering of load and power management and especially frequency conversion. The research report indicates that the institutions of the ETH-Domain will not pursue the research of wind energy technologies.

The potential for **biomass** is stated as being estimated to 120 PJ/a. The main research topics stated in the strategy of the ETH-Domain are:

- development of processes for the simultaneous fermentation of multi-source agricultural renewable material;
- research on hydrothermal gasification (conversion of feedstock with high water content into methane in supercritical water)

Within the domain of **solar energy** the research report states as well the research and the development of photovoltaic technologies as well as the research and development of solar concentrating technologies:
The research on PV is concentrated on silicon based thin film technology and on dye injection cell technology.
For solar thermal energy conversion the following topics are stated:

- integrated Solar Combined Cycle Systems;
- solar driven thermo-chemical cycles (e.g. reduction of Zn, with subsequent generation of hydrogen;)

Nuclear Energy – Fission
In the energy report of the ETH-domain, four major R&D topics are formulated:

- Research on neutronics and core behaviour aiming at: greater fuel utilisation, reliable prediction of nuclear power plant behaviour (combining neutronic and thermo-hydraulic behaviour)
- Thermal hydraulic modelling: understanding conditions of severe accidents, development of passive safety systems for decay heat removal under accident situations
- Material aging phenomena: lengthening the exposure time of core materials, development of aging control technologies. Improve the reliability of life-time modelling predictions, reduce uranium use. (Eddy current techniques for

assessment of concentration of embrittled hydrides, micro-magnetic for assessment of prior-crack development)

- Probabilistic safety assessment: Holistic research on nuclear power plants as complex human-technical system. Development of methods for estimating probabilities of human actions, for integrating equipment and operator responses in safety assessments.

Further Switzerland engages in the joint cooperative research for the so-called Generation IV nuclear systems. The Swiss participation is executed through the PSI with an engagement in the research on the gas-cooled fast reactor. Research topics worked on in the ETH-Domain are the characterisation of materials for high temperature applications under irradiation and the understanding of basic mechanisms in gas-cooled reactors as well as the control of their behaviour. Further work is performed in development of numerical tools for safety analysis of Generation IV fast reactors.

Besides the research on nuclear fission technologies, the research strategy of the ETH-Domain also comprises the research on **nuclear fusion technologies** with research topics such as the development and construction of a first fusion reactor producing significant amounts of fusion power and fusion pulses of significant duration or the research on and the development of materials for fusion reactors withstanding high neutron fluxes;

In the field of **transmission and distribution of electricity** he following research topics are formulated:

- power electronic research for load control: linking distributed generation and storage systems. Further development of Flexible AC Transmission Systems and of their deployment strategies;
- active filtering to cope with sensibility of electrical networks to distortions;
- long-term scenarios for transmission and distribution: concept and design of new switching principles (e.g. matrix switch)

Research topics concerning **energy storage** stated in the strategy are**:**

- Short term electricity storage: supercapacitors (electrode materials)
- Energy storage by electrolytic hydrogen production: development of Solid Oxide Electrolyser Cells (material improvement for long term stability and corrosion reduction)

With respect to the research on **hydrogen and hydrogen-rich fuels**, the research strategy of the ETH-Domain focuses on the following topics concerning production technologies:

- improvement of fossil fuel-based hydrogen production by research on new chemical reactions; new catalysts for steam reforming, partial oxidation processes.
- catalyst research for methane reforming
- hydrogen production by direct solar photolysis of water
- direct conversion of concentrated solar heat via ZnO-reduction (see solar energy description)
- hydrogen production from nuclear energy via high temperature electrolysis or thermochemical cycles

Concerning the storage, transport and distribution of hydrogen, the different existing technology options are discussed in the research report pointing out the knowledge and experience on hydrogen storage in metals and alloys of these present in the ETH-Domain. Further the need for comprehensive system analysis research on hydrogen based energy systems is referred to.

In the field of **technologies for energy conversion to useful energy** the research report of the ETH-domain formulates several research topics and goals:
The reduction of locally and regionally acting pollutants by near zero emissions combustions.

- advanced computational methods for combustion modelling such as direct numerical simulation of reactive flows;
- extension of flamlet models to near-extinction conditions;
- advanced experimental methods and combustion diagnostics: non-intrusive optic sensors, laser based diagnostic methods

Among the energy conversion technologies the **turbomachinery research** is given special emphasis with topics such as:

- research on thermo-acoustic instabilities and their control in gas turbine combustion
- research on non-premixed flame instabilities and their control
- improving the quality of the fuel-air mix in burners
- catalytic combustion
- high performance cooling techniques of gas turbine components to allow higher working fluid temperatures and reduction of cooling air needs
- advanced compressor concepts for higher mass flows and higher pressure ratios
- fluid structure coupling, rotor-stator-interactions to reduce tip-loss, to avoid blade vibrations

In the field of **direct heat to electricity conversion** (DEHC), the research report of the ETH-domain focuses on efficiency increase, on cost reduction of the employed technologies, and on reduction of weight and size of the converters. The research work aims at identifying novel materials for the direct heat to electricity conversion with high stability, a high Seebeck coefficient, good electrical and low thermal conductivity.

With respect to the research on **hydrogen and hydrogen-rich fuels**, the research report of the ETH-Domain focuses on the following topics concerning production technologies:

- improvement of fossil fuel-based hydrogen production by research on new chemical reactions; new catalysts for steam reforming, partial oxidation processes.
- catalyst research for methane reforming
- hydrogen production by direct solar photolysis of water
- direct conversion of concentrated solar heat via ZnO-reduction (see solar energy description)
- hydrogen production from nuclear energy via high temperature electrolysis or thermochemical cycles

Concerning the storage, transport and distribution of hydrogen, the different existing technology options are discussed in the research strategy pointing out the knowledge and experience present in the ETH-Domain on hydrogen storage in metals and alloys of these. Further the need for comprehensive system analysis research on hydrogen based energy systems is pointed out.

In the domain of **fuel cells**, the research strategy of the ETH-Domain lists both, the high temperature fuel cell research, low temperature fuel cell research.
Among the high temperature fuel cell technologies, SOFC research is described with the challenges of:

- material research for efficiency increase;
- adaptation to carbon-based fuels and the development of fuel conversion systems;
- increase of operational reliability;
- improvement of system and component durability.

Meeting these challenges involves among others research work on charge transport, on interfacial reactions at gas exposed surfaces, materials interactions and research on oxygen membranes.
The following challenges for low-temperature fuel cells (especially PEM fuel cells for transportation) are seen:

- cost reduction;
- day to day reliability;
- convenience of operation;
- availability of fuel.

One prime research topic for meeting the cost reduction target consists in the seek for electro-catalysts with reduced platinum contents. Further work is carried out in the reduction of parts per repeat unit in a fuel cell stack, the flow optimization in fuel cell stack.

Within the domain of **building energy** needs, a series of topics has been addressed by the authors of the research report of the ETH-Domain. However it has to be noted that they also pointed out the fact that the basic technologies for energy efficient buildings were available. Further developments are described for all segments of the building energy use: thermal insulation of the building envelope (i.e. vacuum insulation), glazing systems (i.e. electro-chromic glazing), ventilation and air quality as well as heating and cooling systems and lighting.

For **heat pump technologies** for low temperature heat the following research activities are listed:

- development of heat transfer flow base correlation for in-tube boiling and condensation
- demonstration of high performance two-stage heat pumps for domestic purposes
- demonstration of an intermediate vapour injected scroll compressor
- investigation of direct electrically driven high speed oil-free two stage refrigerant compressor concepts with gas bearings

The **transport system** imposes substantial challenges especially as not only technological problems but also behavioural structures have to be addressed in order to achieve a significant reduction in transport energy demand. Research should focus on:

- car choice modelling and psychology of car purchase decision making

- simulation of technical characteristics of future generations of passenger cars and their market penetration
- identification of first mover markets and early adapters.
- development of innovative public transport systems such as autonomously operating vehicles

Among the available and near to medium-term envisageable technology options for drive trains, the research strategy states natural gas hybrid engines and fuel cell vehicles as most promising for achieving technology based energy efficiency improvements.

With respect to the fuel cell drive train the following challenges are stated:

- decrease of manufacturing costs of the fuel cell system by a factor of approximately 20;
- improvement of reliability and ease of use of fuel cell vehicles;
- development of a fuel cell infrastructure of sufficient geographic extension and sufficiently small mesh size of the supply network.

8.1.2 Priorities of the Roadmap for Energy Research of the ETH-Domain

When considering the priorities of the roadmap it should be kept in mind that the energy research of the ETH-Domain has a worldwide scope.

1. Decrease the **transformation losses especially of thermal conversion processes** with the key action of increasing of process temperatures
2. Transition of the electricity generation system from coal to natural gas and ultimately to **CO_2 free electricity generation concepts**. Intermediate electricity generation system states with CO_2 capture and storage may play a role
3. **Decarbonisation of the low temperature heat sector** (buildings predominantly): Supply side with: heat pumps, modern biofuels, supported by solar thermal. Demand side low-energy-demand housing, being a mature technology.
4. R&D devoted to major **efficiency increases in transportation technology** and to decarbonisation of the transport system
5. **R&D on biofuels and synfuels** to support carbon free conversion cycles paralleled by transitional strategies for co-firing of biomass with fossil fuels.
6. R&D on **more efficient use of materials**, strategies for additional recycling of energy intensive materials
7. Long-term fundamental and systems oriented research to investigate and depict a **hydrogen economy**.

8.1.3 Key scientific disciplines according to the Roadmap for Energy Research of the ETH-Domain

- Material science: e. g heat resistance, high mechanical stability; light weight, nano-manufactured
- Reactive flows: complex coupling of timescales of physical flows and of chemical reactions
- Membrane science and biotechnology for the substitution of thermal separation processes
- Catalyst development: less noble metals, alternative processes with lower input energy, solvents and by-products

- Computational methods for simulations on various scales (atomic level to energy system level)
- Sensor technologies for in-situ monitoring, diagnostics and remote control

8.1.4 Main conclusions from the research strategy of the ETH-Domain for the CORE roadmap:

The research strategy of the ETH-Domain builds on comparable overriding goals of a sustainable, secure and affordable energy system and thereby puts special emphasis on the challenge of climate change. Concerning the research needs for achieving the large scale goals, the strategy offers an extensive list of research fields and actual activities of research and technology development. The strategy does however not provide a technological vision of the long-term development of the Swiss energy system, which could be suitable to meet the goals. Instead, the authors of the strategic sections of the report have formulated a hierarchy of priorities of the challenges that should be tackled most urgently. With this structure the research report of the ETH-Domain does not provide an alternative roadmap to the CORE roadmap but it is very well suitable to verify the target setting. The ETH roadmap is further very helpful to assess conclusions on the next steps of research that could be drawn by the CORE with help of the roadmaps.

General remarks on technologies independent of the different futures analysed in this study:

- The ETH Domain pursues nuclear fusion research. This research is viewed as part of the energy research activity and equally represented in the priorities for future research. However, given the long time scale estimated to reach a market entry of nuclear fusion energy technologies, a contribution to meet the CORE targets for 2050 can not be expected. Hence, the research activities in the field of fusion could also be viewed as fundamental research with a direct vision for the energy domain.
- The technology research and development on gas turbines envisaged by the ETH-Domain is mostly concentrating on a further-development of the presently employed routes of fired systems based on natural gas or possibly hydrogen. In the field of system analysis, system integration and optimisation it also aims at the research on unfired gas turbine systems or on complex systems with other working fluids such as CO_2 with recirculated flue gases.
- The research strategy of the ETH-Domain puts a strong emphasis on the reduction of the energy demand for low temperature heat and the decarbonisation of the associated energy supply chains and is by this fully in line with the CORE goals. This statement also holds true for the assessment result that energy efficiency technologies for low energy buildings are available and that the most important challenge lies in implementing successful strategies for a fast market penetration of these technologies.
- The required R&D for efficiency improvement in transport is weakly represented in ETH-Domain research activities compared with progress necessary that is assumed in the investigated ‘Futures’.

8.1.4.1 Comparison of the future HdHfs technology portfolio to the ETH-research strategy

Conclusions of the assessment of future HdHfs in view of the research portfolio and strategy of the ETH-Domain

The technologies in the research report of the ETH-Domain cover most of the set of technologies that are likely to make a substantial contribution to a highly decentralised energy system with a high substitution of fossil fuels. Nevertheless it should be noted that the ETH-report puts an emphasis on the importance of a continued use of centralised technologies in order to maintain a CO_2 free electricity generation and advocates to pursue nuclear fission and nuclear fusion technology research. Further, some technology elements seen as important for a development towards a decentralised energy system basing largely on non-fossil fuels are actually not represented in the ETH research portfolio such as decentralized gasification technologies and gasification technologies using waste as feedstock or solid-biomass fired micro-cogeneration (based on ORC or Stirling engine technology), or advanced small scale electrolysis.

Elements of where current ETH-research is aiming in the same direction as identified as important for meeting the CORE targets in the Future HdHfs	Elements where current ETH-research is aiming not directly in the same direction as identified as important for meeting the CORE targets in the Future HdHfs
• the research strategy on advanced PV cells in the ETH-Domain fits to the needs of a decentralised energy system • heat pump technology research • strong position in gas turbine research in the ETH-Domain with the small limitation of focusing on presently applied system configurations • hydrogen storage technologies are part of the research in the ETH-Domain, but concentrated to storage in hydrides • PEM fuel cell technology • advanced hydropower • Solid Oxide fuel cell technology research • gas engines for stationary applications	• the ETH-strategy envisages a substantial contribution of centralised energy supply technologies (especially nuclear electricity generation) • gasification technology research in the ETH-Domain focuses on centralized systems applied to methanation • wind energy research is seen as mature technology in the ETH-Domain • small scale electrolysis • solar thermal heat generation • ORC-technologies • research on internal combustion engines for vehicles is part of the ETH-research portfolio but covering a section of the technology domain • research activities on electricity storage technologies at the ETH-Domain are focused to supercapacitors, other technologies such as lithium batteries apparently are not part of the portfolio.

8.1.4.2 Comparison of the future HdLfs technology portfolio to the ETH-research strategy

Conclusions of assessment of future HdLfs in view of the research portfolio and strategy of the ETH-Domain

The technologies in the research portfolio of the ETH-Domain also covers most of the set of technologies that are likely to make a substantial contribution to a highly decentralised energy system with a continued use of fossil fuels. As for the future HdHfs it should be noted for the future HdLfs as well that the ETH-strategy puts an emphasis on the importance of a continued use of centralised technologies in order to maintain a CO_2 free electricity generation and advocates to pursue nuclear fission and nuclear fusion technology research. Further, some technology elements seen as important for a development towards a decentralised energy system basing largely on non-fossil fuels are pursued with a different focus in the actual research portfolio of the ETH-domain. The present focus of gasification technology research to more centralised solutions is one example for this.

Elements of where current ETH-research is aiming in the same direction as identified as important for meeting the CORE targets in the Future HdLfs	Elements where current ETH-research is aiming not directly in the same direction as identified as important for meeting the CORE targets in the Future HdLfs
• gas engine research • strong position in gas turbine research in the ETH-Domain with the small limitation of focusing on presently applied system configurations • heat pump technology research • Solid oxide fuel cell technology research • advanced hydropower research • electricity transport and distribution technology research • PEM fuel cell technology research • small-scale reforming technology • hydrogen storage technologies are part of the research in the ETH-Domain, but concentrated to storage in hydrides	• The ETH-strategy envisages a substantial contribution of centralised energy supply technologies (especially nuclear electricity generation) • gasification technology research in the ETH-Domain focuses centralized systems applied to methanation • research on internal combustion engines for vehicles is part of the ETH-portfolio but covering a section of the technology domain only • research activities on electricity storage technologies at the ETH-Domain are focused to supercapacitors, other technologies such as lithium batteries apparently are not part of the portfolio. • solar thermal heat generation

8.1.4.3 Comparison of the future LdLfs technology portfolio to the ETH-research strategy

Conclusions of assessment of future LdLfs in view of the research portfolio and strategy of the ETH-Domain

Although showing coherence in many technology fields, the research portfolio and strategy of the ETH-Domain and the vision of a centralised energy system with continued use of fossil fuels do not match in the important segment of electricity generation. Here the ETH-strategy gives the distinct recommendation to pursue a CO_2-free electricity generation by using hydropower, new renewable energies and nuclear energy. The ETH-study further points out the high likeliness that CO_2 capture and storage could play a role on a worldwide basis. Within the current research portfolio however, there is not yet a distinct focus on the technology chain for CO_2 capture and storage. Certainly, several research fields as for example gas turbine research already form parts of the required technology research fields. However there is still the risk that a technology gap could evolve, if fossil fuel based electricity generation with CO_2 capture and storage had to take over the part of nuclear generation. On the other hand there are indications that ETH researchers are extending the work towards an integrated strategy on CO_2 capture and storage.

Elements of where current ETH-research is aiming in the same direction as identified as important for meeting the CORE targets in the Future LdLfs	Elements where current ETH-research is aiming not directly in the same direction as identified as important for meeting the CORE targets in the Future LdLfs
• strong position in gas turbine research in the ETH-Domain with the small limitation of focusing on presently applied system configurations • heat pump technology research • advanced hydropower research • PEM fuel cell technology research • hydrogen storage technologies are part of the research in the ETH-Domain, but concentrated to storage in hydrides • hydrolysis & fermentation technology for liquid biofuels • electricity transport and distribution technologies research	• carbon capture and storage is discussed as a probably important option in the ETH-strategy but there is no integrated research activity within the ETH Domain so far • research activities on electricity storage technologies at the ETH-Domain are focused to supercapacitors, other technologies such as lithium batteries apparently are not part of the portfolio. • research on internal combustion engines for vehicles is part of the ETH-strategy but only covering a section of the technology domain • solar thermal heat generation

8.1.4.4 Comparison of the future LdHfs technology portfolio to the ETH-research strategy

Conclusions of assessment of future LdHfs in view of the research portfolio and strategy of the ETH-Domain

The coherence between future LdHfs and the research portfolio and strategy of the ETH-domain is probably the highest amongst the four futures analysed. The ETH-portfolio offers technology options for the most important processes of energy conversion and energy use that would play a role in such a future centralised energy system where the presently used fossil fuels were highly substituted. Certainly, the research topics actually pursued in the ETH Domain would not be entirely sufficient to generate the complete set of technologies that were identified as important in such a future right away. For example, the research activities undertaken for the generation four reactors in Switzerland would hardly be sufficient on their own to develop a production-ready reactor technology. These fields would have to be covered continuingly in international co-operation as they are today. The diverging elements identified are of comparatively small number and could also be viewed as a result of different appraisal of technology pathways.

Elements of where current ETH-research is aiming in the same direction as identified as important for meeting the CORE targets in the Future LdHfs	Elements where current ETH-research is aiming not directly in the same direction as identified as important for meeting the CORE targets in the Future LdHfs
• strong position in gas turbine research in the ETH-Domain with the small limitation of focusing on presently applied system configurations • heat pump technology research • advanced hydropower research • PEM fuel cell technology research • hydrogen storage technologies are part of the research in the ETH-Domain, but concentrated to storage in hydrides • hydrolysis and fermentation technologies for liquid biofuels • high temperature electrolysis • hydropower technology research • electricity transport and distribution technologies research • research on advanced gas engines for stationary applications	• electricity storage technologies in focus of the research at the ETH-Domain are limited to supercapacitors; it is likely that for successful application of hybrid cars other storage technologies will be needed as well. • research on internal combustion engines for vehicles is part of the ETH-strategy but only covering a section of the technology domain

8.2 Pre-study for a 2000 Watt society

The pre-study for a 2000 Watt per capita society is organised in five chapters (plus two chapters for references and for a glossary). Following an introduction (chapter 1) and the presentation of the objectives of the study (chapter 2), a methodological chapter gives details about the employed methods and basic assumptions of the analysis. The fourth chapter presents the aggregated results on a sectoral basis, on the level of cross-cutting issues and on the behavioural level. In the fifth chapter finally conclusions of the analysis and the derived recommendations are given. An appendix provides detailed results on a level of technologies, processes and industry branches.

8.2.1 Main findings and recommendations of the pre-study

In the pre-study the following set of concluding findings is given:

- Solely the presence of a technology with an energy-saving potential does not promote reaching the goals of the 2000 Watt per capita society unless there is a potential for its use in the framework of behavioural demands and unless the technology is broadly marketed and finally broadly employed;
- concentrating energy-related R&D on efficiency improvements of energy conversion technologies in the transformation sector and the final energy sector will not be sufficient. R&D has to be extended to develop strategies and technologies for the reduction of the transformation losses from useful energy to energy services; for a more efficient use of energy-intensive materials and substitution with less energy-intensive materials; for organisational solutions in order to increase the rate of use of goods by offering services instead of owning these goods and for integrating system aspects such as avoiding wasteful and unproductive exergy losses and or unproductive demand for mobility;
- the length of re-investment cycles in some applications necessitates early action from policies to implement strategies in these fields as early as possible;
- the broadness of the R&D areas requires international co-operation of researchers and in turn a close monitoring in order to identify the most promising and advanced areas that would also be the most fruitful ones for Swiss R&D and could contribute to maintain the comparative advantage of the Swiss research and innovation system;
- additional R&D will be needed in order to compensate a growth in demand for energy consuming services in private households and in the field of passenger transport.

General recommendations:

- R&D policy in the field of energy and material efficiency should be understood as material part of innovation policy towards sustainable development not only on a domestic but on a global level and organised as such with international exchange of knowledge.
- Research has to be implemented as interdisciplinary research on technological, economical and behavioural aspects is necessary to make progress towards a 2000 Watt per capita society.
- With help of a more detailed study, potentials of a 2000 Watt per capita society, promising technologies and research groups and institutions should be identified.

Specific recommendations:

- Buildings: the largest expected savings will be realised by improving the **energy efficiency of space heating** by better insulation, air tightness, controlled ventilation with heat recovery and by more efficient energy conversion technologies. Incorporating also the stock of existing buildings into the strategy for efficiency improvements is seen as crucial.
- Industry: develop and implementation of **substitutes for energy-intensive processes** and improving process design where no substitution is possible
- Transportation: **efficiency improvements of passenger cars** such as by weight reduction, by the optimisation of internal combustion engines, by car design measures are considered as of highest importance. Further, **substitutes for short-distance air traffic** basing on high-speed magnetic levitation technology trains should be developed soon.

- Energy conversion: Most important is sustained R&D in **high temperature energy conversion processes** (advanced co-generation, gas turbines, fuel cells) as well as R&D in inexpensive **integrated systems** with high exergetic efficiency (heat pumps, micro-gas turbines, cooling, district heating)
- Biomass: Harvesting the large natural potential for biomass should be supported with **highly efficient conversion technologies for biomass** in various applications.
- Integrated systems: **zero-emission plants**, energetic autonomous systems and CO_2 capture and storage should be covered with adequate research
- **Behavioural sciences** research and **innovation** research should be performed in order to improve decision-making processes, knowledge building and professional training.

8.2.2 Main conclusions from pre-study for a 2000 Watt society for the CORE roadmap

Expectedly, the results presented obtained in this work are generally in line with the findings of the pre-study for a 2000 Watt per capita society, as the principal CORE goals were derived from the needs of a 2000 Watt per capita society. It should be noted though, that the pre-study takes a position with a broader view also addressing challenges and prospects for energy efficiency in the industry sector, where substitution of energy intensive processes is considered as the principally best suited route for substantial reduction in energy requirements. The pre-study has also a broader scope with respect to the transport system, where all modes of transport are considered and thus pointing at the special challenge of (short-distance) air transport.
High importance is given to the research needs in high-temperature processes in energy conversion, irrespective of the system setting in a centralised or a decentralised set-up. The pre-study is not decisive on the question of the use of nuclear fission energy either, but at least does not count the development of new reactor technologies as high priority topic.
In the field of renewable energies, only biomass use is estimated as one of the high priority R&D fields. The more detailed technology appraisal analyses biomass technologies and hydropower whereas technologies for the use of wind energy, geothermal energy and solar energy are not dealt with in the appendices. The research on these renewables is considered as being of second order importance and related only to the economics. This appraisal is not fully in line with the results for the 'Future' HdHfs, where renewable energy technologies play a pivotal role in the energy system. Also in view of the fact that the Swiss potential for renewable energy sources is limited especially for wind, also efficiency of energy conversion plays a role. It should be noted though that the pre-study for a 2000 Watt per capita society did not develop a vision uniquely for the Swiss context but also for the global context. On a global perspective the potential for many renewable energy sources is less critical.

9 Reflection of the technology selections according to the three Futures against the EU-Strategy

The European Union performs the priority setting and the allocation of research budgets in the field of energy technologies under the rule of two treaties, one being the general treaty of the European Union and the other the EURATOM treaty. Research work in all energy fields except nuclear energy is mandated by the general European Union treaty, whereas EURATOM is responsible for the nuclear energy research.
The sixth framework programme has a planned budget of 16270 MEuro for all research fields and the sixth framework programme of EURATOM has a budget of 1230 MEuro.

Within the basket of thematic priorities, the energy research of the FP6 has been organised as part of the sustainable development, global change and ecosystems research. In this field, sustainable energy systems form one of three major fields with the topics:

- Technological development and integration of renew-able energy sources in the energy system, including storage, distribution and use.
- Energy savings and energy efficiency.
- Development of alternative motor fuels.
- Development of fuel cells and their application, in particular for transport and hydrogen storage.
- Reduced use and clean burning of fossil fuels, especially coal.

The seventh framework programme (FP7) actually under discussion states nine thematic priorities for research among them being energy research. Hence, energy research will probably play a more important role in FP7 than it actually plays in FP6. Within the thematic priority “energy” of FP7, eight research fields (plus an overriding field of knowledge building for energy policy making) have been defined. At the actual state of the discussion, the research fields are described as follows:

- **Hydrogen and fuel cells** aiming at new concepts and technologies to improve energy efficiency and savings for buildings, services and industry. The hydrogen and fuel cell field should be closely interlinked to the research on energy efficiency and renewable energy fields.
- **Smart energy networks** research should strengthen the safety and reliability of electricity and gas systems and improve the integration of large volumes of distributed renewable energy sources.
- **Renewable electricity generation** research should increase the overall conversion efficiency of renewable electricity generation, reduce the cost of electricity generation from indigenous renewable energy sources as well as contribute to the development and demonstration of regionally adapted technologies.
- The field **renewable fuel production** should lead to the development of integrated conversion technologies for cost efficient production of solid, liquid and gaseous fuels including hydrogen. A strong focus is put on the domain of biofuels for transport

- **Renewables for heating and cooling** is aiming at efficiency increase, cost reduction and regional adaptation of heating and cooling technologies employing renewable energy sources.
- **Energy savings and energy efficiency** research should cover the sectors buildings, services and industry with new concepts and technologies to improve energy efficiency. Besides the integration of efficiency concepts and technologies with the use of renewable energies, a focus is put on energy demand management strategies and technologies.
- **CO_2 capture and storage** technologies for zero emission power generation.
- **Clean coal technologies** should substantially improve the efficiency of energy conversion of coal (and lignite), improve reliability of plants and reduce costs through further-development and demonstration of advanced coal technologies.

The envisaged budget for the energy research is in the order of 2.58 billion Euro for the time period from 2007 to 2013. With this budget, the entire direct non-nuclear energy research budget would still lower than the EURATOM budget which is planned to reach an amount of some 3 billion Euro for the time period from 2007 to 2011 only.

Conclusions from the present status of the planned seventh framework programme for the CORE roadmaps.

With the eight research fields formulated for the seventh framework programme, most of the research topics and challenges are covered that have been equally identified as important in this study. With a strong focus on **renewable energy research** aiming at the electricity sector, the transport sector and also at the building sector, technologies could be developed that will fit well into the needs imposed by the requirements of the CORE objectives. The existence of energy efficient and cost efficient renewable fuel production technologies will be of high importance for meeting the targets set by the CORE for Switzerland. The same holds true for the building sector, where renewable energy sources in connection with CO_2 free electricity will have to take over the contribution actually made by fossil fuels.

Hydrogen and fuel cell research as proposed in the plans for FP7 should aim at building energy demand, the service sector and at industry. The technology needs identified in this study would not fully suit to this focus of hydrogen research as for Switzerland, the use of hydrogen in the transport sector would be very important e.g. in the future HdHfs and also in the future LdHfs.

The technological results of the research on **smart energy networks** could be beneficial in the all analysed futures but especially in the one with a high degree of decentralisation and a high fossil fuel substitution. In this HdHfs future, the technologies for integrating large volumes of (intermittent) renewable energy sources into the electricity grid could contribute to the energy system needs that would evolve also in Switzerland

The research field of **energy savings and energy efficiency** in the buildings, services and industry sector would be fully in line again with the needs resulting from the CORE goals for these sectors. It should be noted though, that the general structure of FP7 does not foresee a section of efficiency research in the transport sector. This could lead to the situation that the efficiency improvements required from this sector would have to rely largely on the activities of the Member States of the EU and probably even more on the industrial research activities.

The research on **CO_2 capture and storage** planned within FP7 has a more dominating role than it has within the research and technology development needs identified within the framework of the futures analysed except for the LdLfs future. Here Switzerland would probably need to make use of this option to reach the CORE targets. The stronger focus on CO_2 capture and storage within the EU research programme originates from the important role of coal in the electricity system of many member states and from the needs of the oil and gas industry especially in the North Sea region.

Clean coal technologies will most likely be of no importance for Switzerland as there is no tradition of coal use in the Swiss energy system. However, the option of importing electricity from the EU and the presence of technology manufacturers in Switzerland that could contribute to advanced clean coal technologies (IGCC or if becoming technologically mature also pressurised fluidised bed coal technologies in connection with brayton cycles) could lead to a some beneficiary involvement of Swiss research and development in this field.

10 Conclusions

Energy research roadmapping is highly dependent on the assumptions made for the energy system framework conditions. In order to reflect this dependency in the presented work, different visions of "Futures" have been developed, which may realise according to the materialisation of the driving forces exerted from the framework conditions. In theory, the probability of occurrence of the four different 'Futures' investigated can be identified in a 'world of possible' limited to those four 'Futures' when associating a probability to the different driving forces considered. The relative importance of R&D activities related to the various technologies considered can then be derived.

The tree diagrams given in Figure 10-1 and Figure 9-2 represent two possibilities to represent outcomes from quantitative and qualitative investigation of the four 'Futures' depending on whether the degree of acceptance of nuclear energy or the degree of success of the liberalisation process is seen as the dominant driving force. Other trees can of course be drawn with different appreciations dependent on what driving forces are dominant.

As allocating actual probabilities to the different driving forces is hardly achievable in practice, a simplified approach can rely on successive debates conducted at each node of the tree diagram, therefore focusing on specific driving forces, in order to try to agree on whether a branch is more likely than another.

10.1 Exemplary priorisation with a decisions tree method

As an example, when considering that the degree of acceptance of nuclear energy is the dominant driving force followed by the degree of success of the liberalisation process and finally by the other driving forces, the following procedure can be conducted in order to identify the most probable 'Future'- see Figure 10-1 for an easier understanding.

Supposing that public support for nuclear energy is more likely than public opposition, then 'Future LdHfs' and its corresponding technologies are of primary importance for a sustainable energy supply by 2050. And among those technologies, R&D activity should preferentially focus on technology fields, where it can contribute the most as was identified by the quantitative analysis. If no agreement can be achieved, then an equivalent priority should be given to 'Future LdHfs' technologies and the most likely of the other 'Futures' technologies. And finally, supposing that nuclear is rather likely to face public opposition, then public R&D resources should be prevented from being allocated towards technologies associated with such a 'Future' only.

In the latter case, if the liberalisation process of the electricity sector is not expected to lead to more competition on the field in the longer term due to the occurrence of an oligopolistic market in replacement of a monopolistic market, and/or if utilities follow a conservative path for the development of the energy structure, then 'Future LdLfs' and its corresponding technologies should be given the priority. If no agreement can be achieved regarding the outcomes of the liberalisation process, then an equivalent priority should be given to 'Future LdLfs' technologies and the most likely other 'Futures' technologies. Finally, if the liberalisation process is commonly expected to be successful, then public R&D resources should be prevented from being allocated towards technologies associated with such a 'Future' only.

In the latter case, if a development to high prices of fossil fuels and/or high concerns of security of energy supply is commonly expected, then 'Future HdHfs' and its corresponding technologies should be given the priority. If no agreement can be achieved regarding the evolution of fossil fuel prices and/or the perception of resource concentration and rarefaction, then an equivalent priority should be given to 'Future HdHfs' technologies and the 'Future HdLfs' technologies. Finally, if high fossil fuel prices and great concerns about security of energy supply are commonly expected, then public R&D resources should be prevented from being allocated towards technologies associated with 'Future HdLfs' only.

Overall, if no clear path(s) can be identified to be more likely than others, then all 'Futures' could be given an equal occurrence probability. In such a case, and because not all technologies, even with a limitation to those with the greatest contributions, can be investigated giving the limited R&D budget, then a possible approach is to consider technology fields, which show a high contribution in all or at least several 'Futures'.

Various cases are discussed below, starting with the situation where no agreement can be reached defining whatever path(s) are most likely.

10.2 Case 1: no clear path(s) can be identified to be more likely than others, and thus all 'Futures' are given an equal probability of occurrence.

10.2.1 Technologies with a very substantial contribution to the CORE targets

The 'Objective' of a reduction by half of the energy consumption in the building sector requires a drastic reduction of the specific energy demand in buildings, and in particular a 75% reduction of room heating specific energy requirements. Technology for **low energy housings** makes therefore a central contribution to meet the CORE's targets. For example, a sensitivity analysis shows that a reduction of room heating requirements by 'only' 50% instead could lead to a 5% higher in non-renewable primary energy demand per capita and 6% greater CO_2 emissions per capita. Already available technologies can however achieve most of the task if largely and rapidly implemented as for example emphasised in the energy research roadmap of the ETH Domain (Boulouchos et al. 2005, section C. p 92). Focus is therefore the rapid diffusion of these technologies into the market.
Unfortunately the attempted patent analyses on low energy building technologies proved not to show the required validity. In this very inhomogeneous technology field it was not possible so far, to identify and assess statistically all but only the concerned patents. By consequence, this analysis method does not provide further insight in the Swiss industry capacity in this technology field.

Both, the targeted reduction of energy consumption and the ban of direct fossil fuel heating in the building sector expressed by two of the four CORE's 'Objectives' lead towards a general use of **heat pumps** in all 'Futures' investigated, whether powered by electricity from the grid or part of a more decentralised energy supply based on integrated energy systems. Heat pumping appears therefore to be a 'must' technology to comply with CORE's definition of a sustainable future energy supply. R&D for advanced compression heat pumps is mainly related to the achievement of greater

coefficient of performance and seasonal performance factor (reduction of exergetic losses in compression and expansion processes, or within heat exchangers, and development of advanced cycles such as multi-stage heat pumps), to the development of systems allowing the use of new working fluids such as CO_2, NH_3 or hydrocarbons (propane, propylene), and to better system integration and control strategy.
A sensitivity analysis shows that a market penetration for room heating, which would be only a third of the one assumed and no material market penetration for water heating could lead to up to 11% greater non-renewable primary energy consumption per capita and 16% greater CO_2 emissions per capita. Note that an increase of the average COP that would not be followed by large market diffusion has a limited impact on the overall non-renewable primary energy consumption and CO_2 emission rate by 2050 (between 1.5 and 2.5%) due to the required drastic reduction of specific heat demand, which makes room heating less energy intensive than other services. R&D funding directed towards measures and technology development favouring diffusion across the whole building stock is of special interest, with for example an increase of heat pump based room heating for urban multi-family housings and heat pump based water heaters.
The low number of overall patent applications in the field of heat pumps for heating applications makes it hardly possible to draw firm conclusions on Swiss industrial innovation with respect to this technology field. With some care in drawing conclusions, one could interpret the data in the way, that the Swiss industry shows some degree of specialisation in this field.

Advanced **internal combustion engine** (ICE) and **hybrid internal combustion engine** vehicles play an important role in all investigated 'Futures' with between 44 and 62% of the total final energy demand for transport. Related technologies have therefore a considerable impact on the overall primary energy consumption and CO_2 emission rate by 2050 whatever the 'Future' considered. A sensitivity analysis shows for example that the market penetration of hybrid vehicles that would be limited to half of what is expected in the various 'Futures' investigated due to inappropriate technology leads to a 7 to 8% higher non-renewable primary energy demand per capita and a 7 to 27% higher CO_2 emissions per capita depending on the 'Future' considered[63]. And remaining with current new technology for ICE vehicles would lead to between 8 and 15% greater non-renewable primary energy demand per capita and between 8 and 40% greater CO_2 emissions per capita depending on the 'Future' considered and while assuming the same ratio between ICE and hybrid ICE vehicles[64].
Switzerland does not host car manufacturing industry but can take part in a material way to efficiency improvement with its academic and industrial 'know-how' in advanced combustion research, on-board energy storage and power electronics. On-board battery technology for example is currently a barrier to large hybrid vehicles' market penetration; lithium-ion batteries are among the most promising options but still face challenges due to excessive cost, insufficient lifetime, low abuse tolerance,

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[63] Note that compliance with the 3 litres per 100 km target being in such a case insured with a greater liquid biofuel share, and that the higher bound of the impact on CO_2 emissions per capita is due to the fact that less biomass is then available for centralised biomass-fired power plants, which benefit from a very high impact when associated with carbon capture and sequestration (Future LdLfs with CCS for large biomass-fired power plants and their 'negative' emission rate).
[64] idem note 1

and low temperature performance. Also, power electronics currently widely in use requires cooling, and consumption for ancillary power is high.
Combustion engine research and hybrid drive train research were comparatively well represented with patent applications at the European Patent Office. As expected, the Swiss industry showed an under-proportional patent activity in the field of combustion engine research. This is most probably a result of the absence of a large car or motor engine manufacturer in Switzerland. Equally, the Swiss industry shows a sub-proportional specialisation in patent related research and development activity for hybrid power trains in vehicles. In this technology field, only Japanese industries show a continued positive specialisation.

The requirement of a full use of the biomass' ecological potential together with the induced generalised use of heat pumps due to constraints imposed by 'Objectives' a and b make **gasification** another key technology in all 'Futures' investigated.
On the one hand, heat pumping translates a large share of the heat demand into an electricity demand. Moreover, fuel switching in the transport when based on electrolytic hydrogen fuelled vehicles and on pure electric vehicles also contributes to an increase of the electricity demand.
On the other hand, although liquid biofuels do play a material role in 'Futures' with a low degree of decentralisation of the energy supply for meeting CORE's 'Objective' of a 3 litres per 100 km average fossil fuel consumption of passenger vehicles, it is still essentially met with improved tank to wheel efficiency, and with some significant use of mostly electrolytic or natural gas reforming based hydrogen. This leaves most of the biomass potential available for other sectors, and in particular for room and water heating, but mostly through heat pumps, and for overall electricity requirements. Biomass to electricity chains are therefore of great importance to comply with the given set of constraints, and gasification if reliable enough is shown to be of great interest in that regards as it allows multiple types of downstream electricity technologies and is potentially associated with greater biomass to electricity conversion efficiencies (combined cycles) than direct combustion. The introduction of reliable gasification technology on the market within large centralised power plants (IGCCs) or within more distributed district units is shown to possibly lead to between 5 and 12% lower non-renewable primary energy demand per capita and between 5 and 13% lower CO_2 emissions per capita depending on the 'Future' considered compared with a use of corresponding available biomass in direct combustion plants.
R&D on gasification technology has been going on for several decades now, however greater reliability and lower cost need to be achieved for a successful large-scale commercialisation.
Major R&D requirements are technologies for gas cleaning to reduce the impacts of various contaminants on the down stream technology used for the conversion of syngas into heat, power or biofuels, in particular tars removal or cracking (hot gas clean up, catalytic reforming followed by scrubbing, or wet scrubbing)[65], delivery of more homogenous and standardised feedstock, or on the contrary the development of more fuel flexible gasifiers for the use of alternative feedstock (feeding, corrosion, or fouling issues related to the use of low or negative cost feedstock such as waste).

65 an alternative to costly gas cleaning process is the use less sensitive downstream technology such as biomass boilers associated with steam turbines, indirect firing gas turbines, or ORC cycles but this is associated with lower conversion efficiencies.

Pollution control technology and understanding of the impact of the various contaminants released within the gasification process on the kinetics and catalyst beds performance is an important field in which Swiss academics are involved. Swiss academia is also conducting in hydrothermal gasification and methanation activities.
There is no industrial involvement for large commercialisation of this technology so far in Switzerland but the country hosts several small providers of small-scale gasifiers.
Swiss industries filed a limited absolute number of patent applications in the field of gasification technologies. However even so, a moderately super-proportional specialisation could be observed for this field within the last decade analysed. This indicates that the worldwide efforts on gasification have not been very intense with respect to technologies close to the market that would be patented. It further indicates that the Swiss industries still could have a comparatively good position with the status of their technologies and research activities.

Advanced gas turbine technology plays a central role in all 'Futures' investigated, although within different applications and capacities, and therefore with different R&D focus, depending on the considered 'Future'. Overall however, R&D activities aim at improving energy efficiency, allowing operation with alternative fuel firing or alternative working fluids, and maintaining high reliability and availability while complying with stricter and stricter pollution legislation at lower costs. It involves higher gas turbine cycle thermal efficiency via advanced blade design, materials and cooling techniques, ultra-low NOx emissions without post-treatment technology (stable ultra-lean premix combustion or catalytic combustion), advanced system integration for combined cycles with or without integrated gasification, options such as gas recirculation, oxygen separation and chemical looping for plants associated with CO_2 capture, and gas cooled advanced nuclear reactors.
Switzerland is particularly well placed regarding gas turbine technology development. It hosts a main international system developer and provider and related technology developers for this technology, and has a long tradition of innovation in this field as shown by the patent analysis. Furthermore, Swiss academic institutions are involved in many of the research fields mentioned above. The Swiss industry shows constantly the highest degree of super-proportional specialisation among all analysed countries' industries. This indicates that a high share of the overall Swiss patent related research efforts is allocated to this field. The strong dedication to this field can also be observed when looking at absolute numbers of patents, where the Swiss industry reaches the same level as the industries of much larger countries such as France, Great Britain or Japan.
In 'Futures' with a high degree of decentralisation in the energy supply, gas turbines with greater conversion efficiencies in itself do neither improve that significantly the overall primary energy consumption nor the CO_2 emissions per capita (between 1.5 and 3%). However, a limited market penetration of district plants based on cogeneration units that would be induced by technology, which could not cope with stricter and stricter legislation on atmospheric pollutants or which could not prove to be competitive on the market would have a significant impact. A market penetration reaching only one fourth of the market diffusion assumed decentralised 'Futures' would lead to between 6 and 14% greater non-renewable primary energy demand per capita and between 6 and 15% greater CO_2 emissions per capita.
In a 'Future' based on centralised energy supply and with a low degree of fossil fuel substitution, remaining with current conversion efficiency would lead to 3.5% greater

non-renewable primary energy demand per capita and 4.5% greater CO_2 emissions per capita. Furthermore, not developing gas turbine technology adapted to IGCC plants would lead to 9% greater non renewable primary energy per capita and 12% greater CO_2 emissions per capita, assuming the use of corresponding available biomass in direct combustion plants.
Finally, in a 'Future' based on advanced nuclear reactors, innovative gas turbine technology for alternative working fluids such as helium at high temperature is a requirement for the option of gas-cooled reactors to be available. Such a technology would lead to 8% lower non-renewable primary energy consumption per capita compared with the use of current nuclear reactor technology for the share of nuclear assumed by 2050 in the investigated 'Future', and to 10% lower non-renewable primary energy demand per capita and 13% lower CO_2 emissions per capita compared with a situation, where the assumed nuclear energy share is replaced by natural gas combined cycle technology without CCS.

Although not necessarily associated with the greatest contribution to meeting CORE's targets in all 'Futures', **gas engine technology** does potentially have a material impact in all 'Futures' via district cogeneration plants and/or industrial cogeneration applications. As shown by achievements such as those from the SwissMotor project, Switzerland has proven to host good academic 'know-how' in that field. Furthermore, Switzerland hosts several stationary ICE manufacturers, which can serve as a good basis for the development of gas engines industry, if changes in boundary conditions make it an interesting market.
Although there are engine manufacturers in Switzerland, the Swiss industry has still shown an under-proportional patent activity in the field of combustion engine research. This is most probably a result of the absence of a large car or motor engine manufacturer in Switzerland.
R&D activities in the field of stationary gas engines deal with emission control, efficiency improvement, fuel flexibility, operating and maintenance cost reduction, and reliability and lifetime improvement. The challenge is to improve conversion efficiency while coping with the evolution towards stricter and stricter legislation on atmospheric pollutants emissions at moderate costs in order to achieve the expected market penetration. This involves notably R&D activities related to combustion efficiency and knock phenomena (multiple site spark ignition, innovative combustion chamber designs, direct in-cylinder water injection, alternative cycle such as Miller cycle), ultra-low NOx engines (lean air-fuel ratio and selective catalytic reduction, or stochiometric engines with high level of recirculation and three way catalysts), advanced turbo-charging (advanced turbine design and multi-stage compressor with intercooling), advanced upstream gas cleaning technology and catalysts (compatibility with pollutants from alternative fuels), slow combustion rate at low temperature, and heat and friction losses (new materials and lubricants, and thermal barriers).
If technical improvements were limited in such a way that market penetration would reach only one fourth of the market diffusion assumed in the investigated 'Futures', then between 4 and 13% greater non-renewable primary energy demand per capita and between 6 and 13% greater CO_2 emissions per capita depending on the 'Future' considered could be observed.

PEM fuel cell passenger vehicles with on-board hydrogen storage make a large contribution in three of the four 'Futures' investigated. Not introducing those vehicles would lead to between 9 and 12% greater non-renewable primary energy demand per capita and between 11 and 13% greater CO_2 emissions per capita depending on the 'Future' considered, and assuming that their share is taken up by hybrid ICE passenger vehicles. Switzerland does not host car manufacturing industry and Swiss industry involvement in that technology is low both for transport and stationary applications. However, there is internationally recognised academic 'know-how' in hydrogen storage in Swiss research, and ongoing academic activities in the field of polymer electrolyte fuel cells.

The Swiss industry activity resulted in a super-proportional patent activity in the field of PEM fuel cell technology in the 1990ies. At the beginning of the present decade however, the degree of specialisation declined owing to the fact that the worldwide activity increased whereas the number of Swiss patent applications remained more or less constant.

R&D activities pursued in the field of polymer electrolyte technology are mainly lifetime improvement, cost reduction and system integration including water management, cooling system and fuel processing (conversion and cleaning). Greater power density and electric efficiency are also pursued as they lead to more compact systems.

This implies the development of new electrolyte membranes allowing operation at higher temperature and lower relative humidity, advanced electrodes that require lower amounts of noble catalysts, the understanding and prevention of MEAs poisoning and degradation caused by contaminants such as CO, H_2S, SO_2, NH_3 (sputtered Pt/C films, nanostructured catalyst layers, alternative oxygen reduction catalysts, CO tolerant Pt-Ru anodes,…), advanced bipolar plates (carbon-based composites, or coated or uncoated metal and organic bipolar plates), modelling of reactants distribution and products evacuation, advanced sealing, and advanced system integration.

Hydrogen storage related R&D activities aim at reaching suitable energy storage density at affordable cost in order to allow appropriate ranges for hydrogen-fuelled vehicles. Liquid hydrogen storage is investigated and improvements for such an option rely on limitation of boiling losses and more efficient liquefaction process. But R&D activities essentially involve material science for the development of very high-pressure compressed hydrogen systems (carbon composite vessels), reversible metal hydrides, chemical hydrides (such as sodium borohydrides), or physical absorption (such as high surface carbon structures). Swiss academic 'know-how' focuses on those last three options. Further there are R&D activities towards liquid hydrogen storage systems, where main challenges lie in reduction of heat transfer and system design of storage containments.

Solid oxide technology can potentially play an important role in two of the four 'Futures', and a material contribution in a third one. Associated with low atmospheric pollutants emission rate and with silent operation, solid oxide fuel cells could contribute to a significant market penetration of decentralised cogeneration units, if cost and reliability targets, including meeting these targets under operation with syngas or biogas, can be reached. Assuming that market penetration of distributed cogeneration (district and on-site) based on more conventional technology was limited to a fourth of what is considered in the two decentralised 'Futures' and that solid oxide fuel cell technology was able to meet the requirements, the introduction of this technology could lead to between 8 and 15% lower non-renewable primary energy per capita and between 8 and 14% lower CO_2 emissions per capita.

In a 'Future' based on nuclear energy, solid oxide technology can also potentially be of interest for high temperature electrolysis. The introduction of such a technology would lead to 3.8% lower non-renewable primary energy demand per capita and 3.7% lower CO_2 emissions per capita compared with conventional electrolysis.
Until the very recent decision of closing down activities related to solid oxide fuel cell technology, Switzerland hosted a leading industrial player for small-scale distributed cogeneration systems. The industrial basis for the development of such a technology is therefore not clear at the moment. However, Swiss academic sector does have interesting activity on solid oxide technology.
R&D main activities in the field of solid oxide technology involve lifetime improvement, cost reduction and system integration including new stack designs, as well as combined cycles for larger units. Two main routes are pursued: some developers bet on the achievement of acceptable performance at lower temperature (< 700 C) in order to allow the use of more conventional materials and therefore reduce significantly the manufacturing cost, others bet on system integration, which benefits from maintaining the current high operating temperature. For low temperature SOFC technology, research currently focuses on the development of new electrodes, new designs, and alternative electrolytes. For high temperature SOFC technology, new designs leading to greater fuel utilisation rates and better heat and flow management are of primary importance for small-scale systems. The development of advanced coatings for metallic alloys interconnects which are oxidation resistant, and electrically conductive would contribute to improved lifetime and performance (reduction of oxide growth and increase of specific resistance over time), and reduce the cost by allowing the use of conventional materials for interconnects. Another option is to develop resistant stainless steel interconnects with surface treatment. New materials for sealants (glass ceramics, mica) would reduce linkages and increase mechanical stability. Finally, advanced manufacturing techniques are another R&D topic, which aims to contribute to substantial cost reduction by allowing thin ionic conductivity electrolytes (electrochemical vapour deposition, plasma spraying, or physical vapour deposition).

10.2.2 Second order technologies with a material role in all futures

Following technologies are not associated with greatest contribution to CORE's targets in any of the investigated 'Futures' but do play a material role in all of them.

Remaining with current **electricity transport and distribution** technology could lead to between 1.5 and 2% higher non-renewable primary energy demand per capita and between 1.5 and 3% greater CO_2 emissions per capita depending on the 'Future' considered compared with expectations.
Expected reduction of transport power losses rely on some of the following options: advanced superconductors with higher temperatures and higher inner coherence, advanced high voltage DC transmission concepts, advanced AC/DC power conversion technologies, and advanced power electronics for load control.
Switzerland hosts a major player in that field and hosts substantial academic research activities. With respect to patent application, there is a positive specialisation observable for the decade until 2003, whereas in the years before, no significant deviation from the international activity level in this field could be observed. The increase in activity can also be observed in absolute figures, where the number of applications rose from 10 to 20 in the early 1990s to 25 to 35 in the more recent years.

Hydropower meets a significant share of electricity requirements in all ‘Futures’. Remaining with current technology could lead to between 1.5 and 2% higher non-renewable primary energy per capita and between 1.5 and 3% greater CO_2 emissions per capita depending on the ‘Future’ considered compared with expectations.

Although hydro power is a mature technology, improvement of the average conversion and reduction of maintenance requirements are considered to be achievable via R&D activities essentially dealing with the development of advanced generators (variable speed), the understanding of unsteady phenomena (mechanical stability), the reduction of cavitation with advanced blade design, and improved reversible turbines for pumped-hydro schemes. Switzerland benefits from a very solid academic and industrial basis in that field based on a long history of research and development, and its ‘know-how’ is internationally recognised.

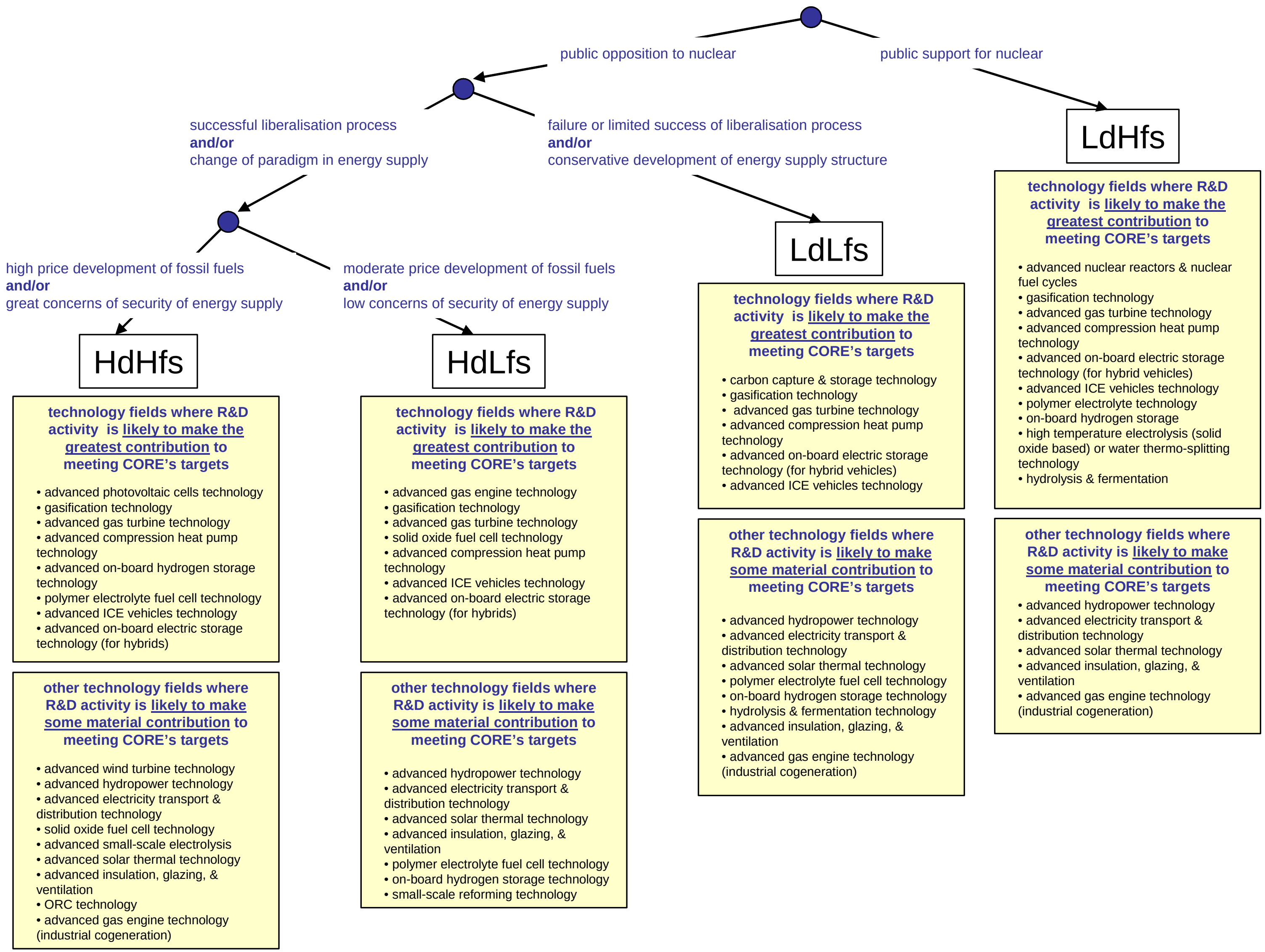

Figure 10-1: **Summary of qualitative and quantitative analysis of the four investigated 'Futures' (note again that this is the tree diagram in a 'world of possible' limited to those four 'Futures' only) – approach when considering that the degree of acceptation of nuclear energy is the dominant driving force.**

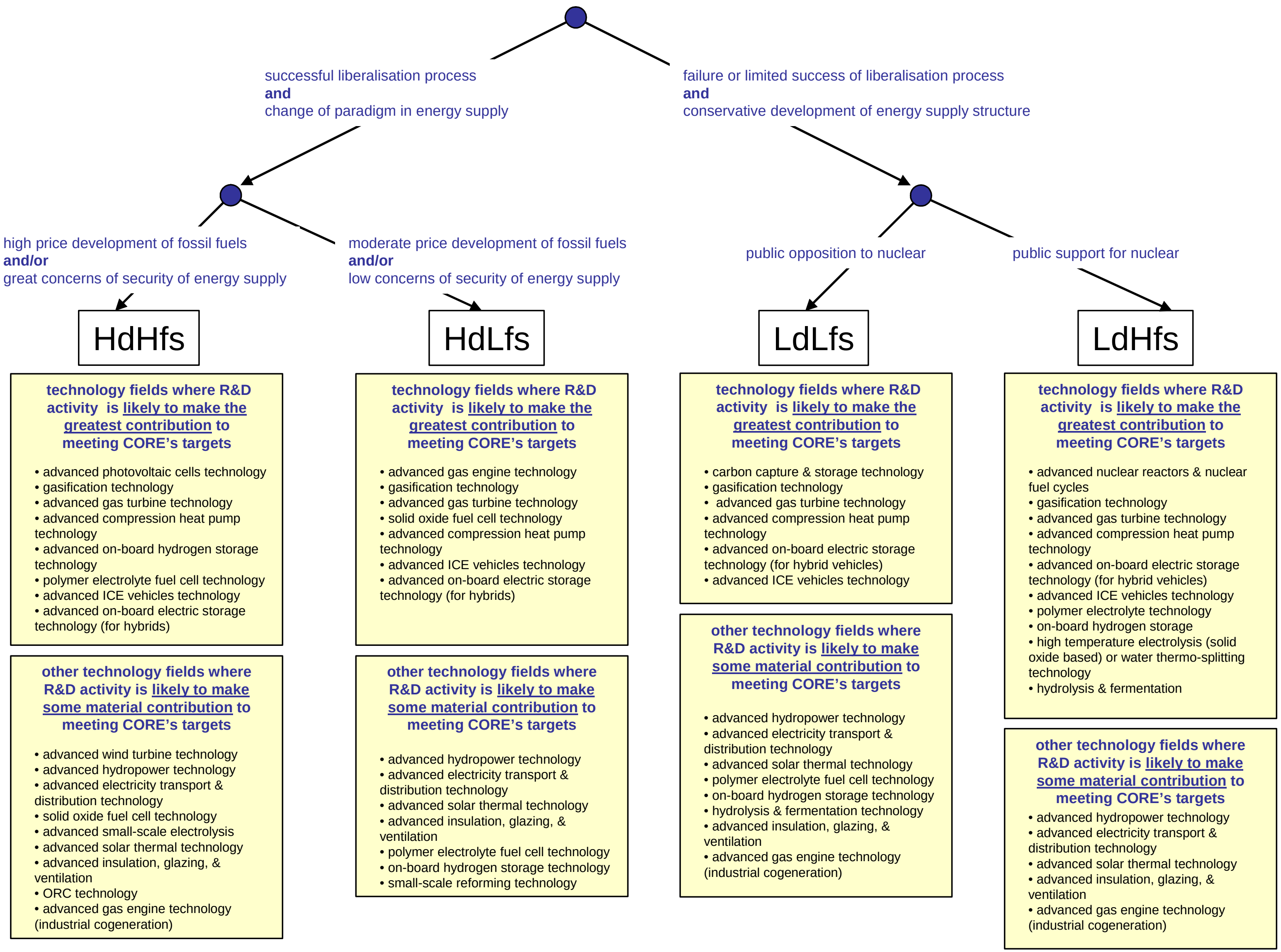

Figure 10-2: Summary of qualitative and quantitative analysis of the four investigated 'Futures' (note again that this is the tree diagram in a 'world of possible' limited to those four 'Futures' only) – approach when considering that the degree of success of the liberalisation process is the dominant driving force.

10.3 Case 2: consensus is reached on the conclusions that 'Future' LdHfs is the most likely

Assessment result that leads to the ´Future´ LdHfs:

It is believed that in the considered time frame, there is high probability for nuclear energy to gain public support in the context of climate change mitigation, that the liberalisation process is likely to have limited or no success in diversifying the energy supply portfolio, and that a high price development of fossil fuels and great concerns about security of energy supply are expected.

In such a case, conclusions discussed under case 1 apply, in addition to the three following technology fields.

In a 'Future' where nuclear energy plays a continuing role in electricity generation, the contribution from this energy source would be about 50 PJ or some 20 % of the Swiss electricity demand. By 2050 the actually operating reactors would have been replaced by advanced nuclear reactors.

Efficiency increase does not play such an important role in the research and development for **advanced nuclear reactors**. Instead, safety, reliability, nuclear waste reduction and non-proliferation are issues of equally high importance. Among the reactor concepts currently under review, Swiss research institutions engage in research on advanced high temperature gas cooled reactors. Major issues for high temperature reactors are material research on corrosion resistant alloys or flow modelling of coolant streams. The research for other generation IV reactor concepts such as for example gas core reactors involves further challenges such as high temperature uranium chemistry, pumping chemistry or wall corrosion chemistry of fission product induced reactions.

Switzerland shows an under-proportional specialisation in nuclear patents, which is all the more surprising as there is substantial academic research in nuclear technologies in Switzerland. So, possibly the research results have been protected by patents that could not be identified due to e.g. unexpected classification or even maybe strategies of intentional hiding the purpose of the patented technology development.

Hydrogen plays an important role in such a 'Future' and the sensitivity analysis shows that advanced options for greater conversion chain efficiency could lead to about 4% reduction in both non-renewable primary energy consumption per capita and CO_2 emissions per capita compared with conventional electrolysis for a same nuclear capacity installed. High temperature steam electrolysis based on solid oxide technology or thermochemical water splitting are options worth to be investigated in this context in association with high temperature nuclear reactors.

Major R&D issues with **high temperature steam electrolysis** are durability and reliability of thin solid oxide electrolytes and sealing, electrodes corrosion resistance, scalability, and system integration. Swiss 'know-how' in this field so far oriented towards fuel cell technology could also be directed towards electrolysis applications.

Thermochemical water splitting R&D essentially relies on the development of materials sustaining high temperatures and corrosive environments, separation membranes, and system integration. Many different cycles have been investigated so far with sulphur-iodine often cited as the most promising one. Swiss research is currently involved in the field of thermochemical cycles but essentially applied to concentrated solar heat rather than nuclear heat so far.

As shown in the quantitative analysis, in such a 'Future' a significant share of biomass resources can be directed towards transport applications and ethanol is given a material role. Not introducing the expected ethanol share in the investigated 'Future' could lead to 4% greater non-renewable primary energy consumption per capita and to 8% greater CO_2 emissions per capita. In such a case, compliance would have to be met with greater share of hydrogen or greater tank to wheel efficiency.

Technology for ethanol production from sugar or starch crops is mature but limited agricultural land available for those types of dedicated crops would not allow the production of large volumes of such conventional ethanol in Switzerland. R&D activity in Switzerland currently mostly concentrates on multiple feedstocks processing to allow the use of various fermentable wastes simultaneously. In the timeframe considered and in order to reach the expected share of ethanol, producing ethanol via hydrolysis and fermentation or via thermochemical processing is however an option worth looking at in such a 'Future' in order to make use of available lignocellulosic biomass resources. Major R&D issues regarding hydrolysis and fermentation routes relate to improvement of preprocessing (higher yields of fermentable sugars, low or zero fermentation inhibiters, chemical recycling), simultaneous sacharification and fermentation (thermo-tolerant fermentation microorganisms), the development of new enzymes for simultaneous fermentation of pentose and hexose (genetic modification), or the development of new microorganisms for direct conversion of lignocellulosic fraction into ethanol.

R&D for thermochemical routes focus on the development of new catalysts for the catalytic conversion of syngas or the development of microorganisms for syngas fermentation.

The concept of biorefineries based on either of those two routes is of great interest with the co-production of power, liquid biofuels, and chemicals being a promising option for improving economic viability. The importance of the chemical industry in Switzerland could be a good basis for the development of such a technology.

Note that given the sustained increase of the diesel share observed in Europe, Fischer-Tropsch processing of lignocellulosic biomass could be an interesting alternative, however Switzerland has been focusing on ethanol so far in the context of a major on-going project.

10.4 Case 3: consensus is reached on the conclusions that 'Future' LdLfs is the most likely

Assessment result that leads to the ´Future´ LdHfs:

It is believed that in the considered time frame, there is high probability for strong opposition to nuclear energy, that the liberalisation process is likely to have limited or no success in diversifying the energy supply portfolio, that a low price development of fossil fuels is expected, and that concerns about security of energy supply are likely to be limited.

In such a case, conclusions discussed under case 1 apply, in addition to the three following technology fields.

CO_2 capture and storage could offer the option to switch a part of the electricity generation to natural gas combined cycle units while maintaining a largely CO_2 free electricity system. With the possibility to capture and store even CO_2 emissions from biomass conversion processes even a negative emissions balance could be reached, meaning that technically CO_2 would be withdrawn from the atmosphere.
The three main routes for CO_2 capture currently under discussion impose different research issues. The post combustion is probably the closest to a possible technical realisation. Still, there are substantial R&D challenges starting from efficiency increase of the entire process to concerns about reliability of the capture technologies in connection with flue gases with a significant amount of impurities. Reaching satisfying technical properties involves research on solvents (MEA), on system concepts and integration as well as on advanced concepts such as with flue gas recirculation increasing the partial pressure of the CO_2 in the flue gas. The pre-combustion route requires efficiency improvements and cost reduction of natural gas reforming technologies, improvements on CO_2 separation with physical solvents or alternatively membrane separation processes. Further gas turbine research is needed in order to cope with hydrogen as fuel for gas turbines or alternatively gas turbine processes with CO_2 as working fluid and flue gas recirculation. Oxy fuel concepts demand for efficiency improvements in air separation – which could possibly be reached via membrane processes. There are however doubts whether air separation with membrane processes will be possible at all. Further research on the combustion with high oxygen concentrations has to be performed in order to achieve optimal control of the process parameters.
Besides the research on capture technologies, the options for geological storage have to be explored. This is a topic involving issues such as: reservoir exploration and characterisation, cap-rock investigation and especially cap rock behaviour under influence of CO_2 at reservoir conditions. Further flow modelling and dispersion predictions of the CO_2 have to be performed.

Large scale **natural gas steam reforming** is a mature technology in use for the supply of hydrogen required in various industrial applications with oil refining among them. The main improvement in this field is the introduction of CO_2 capture, using the technologies described above. Once CCS is applied, some further improvements can be expected but with limited effect on non-renewable primary energy consumption and CO_2 emissions in the 'Future' considered here. A more extensive use of hydrogen as a transport fuel in a 'Future' with low fossil fuel substitution would justify more R&D around this technology, with notably the development of advanced catalysts and separation processes, and process integration including heat recovery and the combination of steam reforming and partial oxidation.

10.5 Case 4: consensus is reached on the conclusions that 'Future' HdLfs is the most likely

Assessment result that leads to the ´Future´ HdLfs:

It is believed that in the considered time frame, there is high probability for strong opposition to nuclear energy, that the liberalisation process is likely to have success in *diversifying the energy supply portfolio, and that a low price development of fossil fuels is expected, and that concerns about security of energy supply are likely to be limited.*

In such a case, conclusions discussed under case 1 apply, in addition to the following technology field.

In a decentralized 'Future' with low fossil fuel substitution, hydrogen is produced at fuelling sites from natural gas via small-scale reformers. This is viewed as an attractive near to mid-term solution for the development of hydrogen as a transport fuel (transition phase). Up-scaling of reformers currently in development for the stationary applications of low temperature fuel cells is the most probable path. R&D activities in that field relate notably to faster start-up, catalyst life-time, and seals for conventional types of reactors, membrane cost and life-time for membrane reactors, low cost purification technology for partial oxidation reactors, autothermal reforming, and novel concepts such as sorbent enhanced reforming, ion transport membrane reforming, and thermal plasma reforming.

10.6 Case 5: consensus is reached on the conclusions that 'Future' HdHfs is the most likely

<u>*Assessment result that leads to the ´Future´ HdLfs:*</u>
It is believed that in the considered time frame, there is high probability for strong opposition to nuclear energy, that the liberalisation process is likely to have success in diversifying the energy supply portfolio, that a high price development of fossil fuels and great concerns about security of energy supply are expected.

In such a case, conclusions discussed under case 1 apply, in addition to the technology fields of new renewable energy technologies for solar radiation electricity, wind power and geothermal energy as well as to small scale electrolysis.

In a future with a highly decentralised energy system basing on a low share of fossil fuels, the new renewable energy technologies will play a very important role. With 16 % of the primary energy demand being supplied by solar PV technologies and 4% of the primary energy demand being supplied by solar thermal heat technologies, the decentralised use of solar radiation energy by itself already makes up 20% of the primary energy demand. Further, biomass technologies contribute 12% to the primary energy consumption, wind contributes 3% as well as geothermal heat technologies (3%). So overall, the contribution of new renewables sums up to a share of 38% of the primary energy demand. Instead, small scale electrolysis basing at least partly on renewables may come into play.

The R&D needs for **photovoltaic cell technologies** are especially cost reduction for the cells as well as for the balance of system components, the efficiency increase of organic and dye sensitized cells as well as of thin film PV cells but also of crystalline cells. For the new solar PV technologies, also the long-term stability is a topic. For advanced PV cells with crystalline technology, the cost reduction is the most important issue. This could be reached by an even continued reduction of waver thickness and thus by reduction of the amount of employed material. An improvement of production techniques

is necessary to approach the efficiency of bulk production cells to the efficiencies of laboratory products (several percentage points of difference). For the group of thin film solar cell technologies, increase of efficiency is a major issue with a large set of material science and production technology issues such as grain boundary passivation, increase of deposition crystallization speed or light trapping. The group of dye sensitized cells and organic cells – although showing a considerable market growth of first mover customers – requires efforts in nano-technology research and developments in production technologies in order to meet the industry standards of PV-technologies (lifetime, temperature resistance, UV-radiation resistance). The Swiss patent activity in the field of PV shows no significant specialisation. In view of the international picture, where only Japan shows a continuous positive specialisation and many countries show a continuous negative specialisation, the Swiss position can be interpreted as comparatively good.
Remaining with current photovoltaic cells technology while assuming the same 16% share in electricity generation could lead to 6% greater non-renewable primary energy demand per capita and 5% greater CO_2 emissions per capita.

Wind turbine research follows the need to make the best use of each individual site available for the placement of wind turbines. This means that the size of the rotor area is increased as well as the height of the wind turbine towers. Further the long-term reliability of wind turbines is in focus of the research. The main specific research topics derived from these objectives are research on composite materials for increased size and duration of rotor blades and the weight reduction of rotor blades. With respect to drive trains, the research focuses on the reliability improvement and weight reduction by investigation of reasons for failure and strategy development for improvement. Work on multipole generators aims at reduction of weight and size as well. With respect to patents, Swiss research shows a significant under-proportional specialisation. Like the market in Europe, the patent activity is dominated by the leading countries there: Denmark, Germany and The Netherlands. The sometimes strongly changing patent specialisation in the field of wind turbines is a result of the very low number of patents in these areas.
Remaining with current wind technology while assuming the same 5% share in electricity generation could lead to 2% higher non-renewable primary energy demand per capita and 1.5% greater CO_2 emissions per capita.

Although the production of **geothermal heat and electricity** involves technologies that are in principle well developed and mature in that sense, a future efficient and cost effective geothermal energy production involves a large set of research needs. In the chain of activities associated with the development of geothermal energy sources, the improvement of geophysical methodologies and techniques for site assessment prior to drilling are the first requirement. With respect to drilling the cost reduction by improved drilling bit technologies and mud suspensions are in focus as well as the reduction of the risk of failure of drilling by improved surveillance technologies and equally by new mud suspensions reducing the risk of collapsing boreholes. Further, technologies fort the stimulation of boreholes in general and the rock material of hot dry rock environments form part of the research topics. The long time success of geothermal energy production also requires research and development of highly corrosion resistant materials for tubes

and casings as well as pumping technologies with high efficiencies and equally high corrosion resistance.
Not installing the geothermal capacity of heat and electricity generation assumed in this 'Future' could lead to 4% higher non-renewable primary energy demand per capita and 3% greater CO_2 emissions per capita.

The high share of partially fluctuating new renewable energy sources creates the necessity on the one hand for an optimised electricity transportation and distribution network and on the other hand for conversion of electricity into hydrogen in order to balance the fluctuating energy input and in order to provide hydrogen for transport applications. Among the available technologies for electrolysis, the PEM fuel cell electrolysis and the alkaline fuel cell electrolysis are relatively new technologies with significant headroom for improvements by further research, while the classical alkaline electrolysis offers presently the highest efficiencies. The main research challenges and task for **PEM electrolysis** lie in the cost reduction for the fuel cell system and in the efficiency increase. Being a comparable technology as the PEM fuel cells aimed at electricity generation, the research topics are of the same nature as faced there. Research challenges for reversible alkaline fuel cells for electrolysis are the development of electrode materials alternatives to noble metals that are corrosion resistant and of lower costs.

10.7 Final Remarks

The analysed 'Futures' represent extreme materialisations of the future energy system as it could possibly evolve. In all of them, the targets formulated by the CORE roadmaps working group are met. Besides these four 'Futures' other configurations of the Swiss energy system by 2050 can be imagined that equally meet the CORE targets and thereby stand for an approach towards a 2000 Watt per capita society.
The presented analysis deliberately does not give recommendations about the probability of one of the 'Futures' nor does it provide a decision about setting research priorities. Instead the results should be understood as an additional means for priority setting in a research agenda under development by the CORE. If being employed as such the developed methodology could help to structure the discussion and decision making process while the collected technical information and the derived quantitative data could elucidate the possible consequences of the options under discussion by the CORE.
Actual R&D funding allocation must answer also further fundamental questions, which are not dealt with in this short study, such as: what minimum level of funding is necessary for the Swiss research community to likely have an actual significance in the development of a given technology in light of the overall funding allocated worldwide to this technology? Given the comparatively modest Swiss R&D budget an investigation at a deeper level of details is advisable, where the prospects of individual technologies could be set into relation with the available research budget.

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Appendix 1

Technology fact sheets

Polymer Electrolyte Fuel Cells Fact Sheet (1)

• fuel cell technology of choice for transport applications and suitable for stationary applications – synergies, technology transfer between different markets, more actors involved

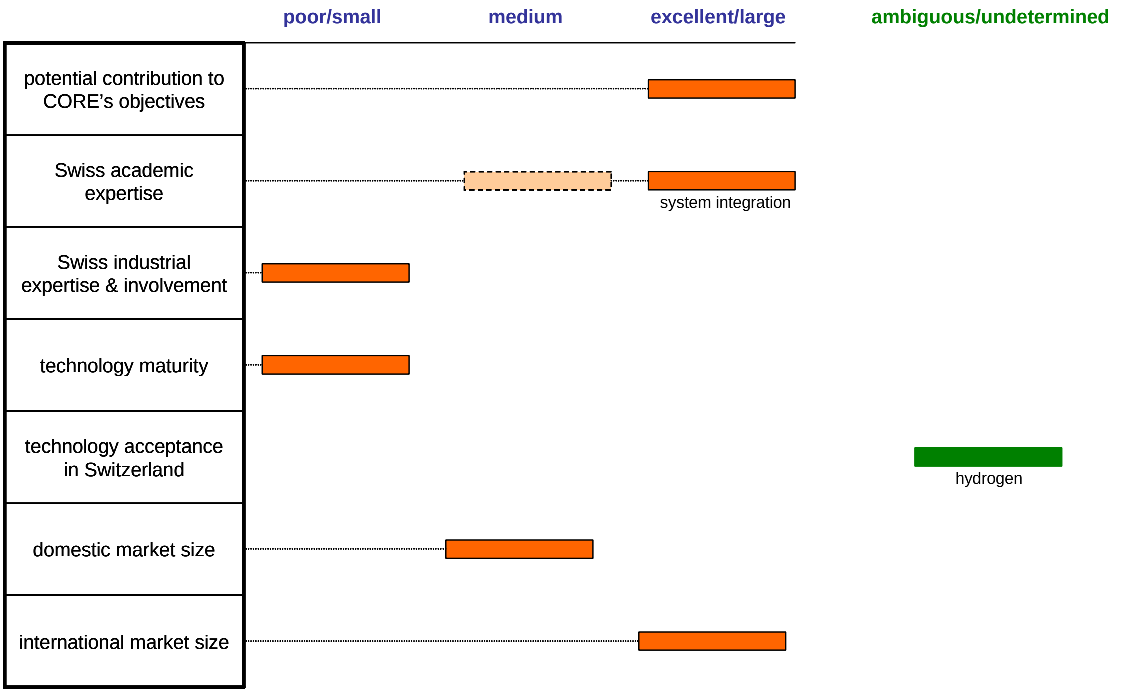
• some good Swiss academic expertise; however, very little Swiss industrial involvement so far

• recent breakthrough in membrane technology may greatly facilitate the development of viable systems

• fuel cell vehicle can be more than twice as efficient than conventional ICE vehicles on a tank to wheel basis; although lower efficiency gains on a well to wheel basis compared to hybrid vehicles, very high diversity of sources exist to provide hydrogen in the longer term, including carbon neutral ones

• quite large domestic market potential in a 'Future' with highly decentralised energy supply

• very large worldwide export market potential



Polymer Electrolyte Fuel Cells Fact Sheet (2)

Status: 2005	2010 2020 2030 2040	Prospects: 2050
• most funded fuel cell technology worldwide • current demonstrated lifetime is typically up to 2’000 hours • current cost 2’000 to 10’000 euros per kWe • small-scale cogeneration units: numerous manufacturers, no Swiss industrial actor, ~1 to 10 kWe, ~30 to 35% LHV electric efficiency • medium-scale cogeneration units (~10 to 250 kWe): very few manufacturers, Alstom was involved at one point but program aborted • transport: all major car manufacturers involved; two small Swiss companies for niche market of ultra-light vehicles • small-scale natural gas or other hydrocarbon stationary reformers with ~65% conversion efficiency • on-board reforming abandoned by most developers	• develop more robust MEAs • develop alternative bipolar plates • develop more reliable auxiliaries • improve system integration (heat and water management, fuel processing) • achieve large volumes of production – high economies of scale in manufacturing • reduce material cost	• lifetime: stationary ~40’000 hours, transport ~5’000 hours • cost: small-scale stationary ~ 1’000 euros per kWe, medium to large scale stationary ~ 800 euros per kWe, transport ~50 euros per kWe (30 for the stack) • small-scale cogeneration units: 50 to 60% LHV electric efficiency • new MEAs: high operating temperature up to ~200 C, low or no water requirements, and CO tolerant • metal or polymer bipolar plates • freeze start -30 C • stack volumetric density ~2’500 W per litre (transport applications)

Objectives

- reduce cost: 10 fold for stationary, 200 fold for transport
- increase lifetime: about 2 to 3 fold for transport, 20 fold for stationary
- enlarge workable domain: operate at higher temperature, start at very low temperatures
- increase electrical efficiency
- develop more compact systems
- increase stack power density
- fuel processing and availability

Research topics

development of advanced membranes: high operating temperature, high CO tolerance, low or no humidification, low degradation rate, low cost	Nafion (Dupont) was so far the best compromise; however, recent breakthroughs may lead to improvement
development of alternative bipolar plates: improvement of carbon-based plates (composites), development of coated or uncoated metal or conducting polymer plates,…	bipolar plates make up an important share of the final cost; metal plates allow better conductivity, more compact systems and cheaper manufacturing; polymer plates allow channels manufacturing by moulding
new designs for reactant distribution and reaction product removal	better reactant access to active sites; increase fuel utilisation rate
development of alternative electrodes: high surface catalyst support (nanostructured catalyst layers), low Pt loading electrodes, alternative oxygen reduction catalysts (alloys such as Pt-Ni or Pt-CO), CO tolerant anodes (Pt-Ru),…	better utilisation of a given amount of Pt; reduced degradation rate due to poisoning
development of advanced reformers and gas cleaning techniques: new catalysts, POX, ATP, PSA, activated carbon,…	can benefit from the development of small reformers for the industrial sector
better system integration and development of dedicated auxiliaries: air and water management systems	current generating set around the stack can represent half of the system volume and consume 25% of the power generated
in-situ monitoring techniques	better understanding of degradation mechanisms
integration with on-board H_2 storage	for R&D on H_2 storage, see related slide

Compression Heat Pumps Fact Sheet (1)

• technology which makes the most environmentally effective use of local renewable energy resources in the building sector

• first class expertise in both the academic and the industrial sector in Switzerland; however, so far lack of components manufacturers

• technology well diffused in new housings in Switzerland

• technology already quite mature and economically viable today for the new building standards, and which can therefore be rapidly put in place and generalised in the given timeframe

• large domestic market if technology adapted to the existing building stock

• worldwide export market potential is very large

Compression Heat Pumps Fact Sheet (2)

Status: 2005

- ~7'000 units sold per year in new single family housings (<20 kWe) - ~60% market share and >10% annual growth rate
- ~2'000 units sold for retrofit of single family housings
- ~10'000 heat pumps annually in single family housings versus 16'000 gas fired boilers and 17'000 oil fired boilers
- heat pump current capacity range: standard 5 to 500 kWth, special up to 30 MWth
- Carnot efficiency ranges from 0.3 to 0.5 for small units (average COP ~3.5), and reaches 0.5 to 0.7 for large units
- source type in Switzerland: air-water 55%, ground-water 42%, water-water 3%
- decent number of Swiss heat pump systems providers
- no Swiss manufacturer for key components

2010 2020 2030 2040

- achieve industrial scale: > 20'000 units per year, including standardisation of larger scale units
- increase penetration in the retrofit market
- develop products for both water and room heating
- improvement of the Carnot efficiency for similar cost, especially for small units
- increase penetration in the urban environment – scale up: ground-water heat pumps for large buildings and water (lake)-water district heating plants
- increase seasonal performance factor (SPF)
- possibly reduce heat pump technology induced environmental impact, but actually already very low
- system integration with cogeneration units

Prospects: 2050

- heat pumps in the vast majority of single family housings
- water-water heat pumps in all district heating plants supplying an important share of the urban building stock in cities near lakes
- ground heat pumps in the majority of large commercial buildings which are not connected to a district heating network
- Carnot efficiency > 0.6 for small units (average COP ~4.5)
- Carnot efficiency > 0.7 for large units (district heating plants)
- overall First Law heating efficiency between 1.5 and 3 , depending on the scale and the technology delivering the energy required by the compression

Objectives

- reduce cycle exergy losses: in current heat pumps, ~50% of exergy losses during compression process, ~30% during expansion process, and ~15% within heat exchangers
- increase penetration in the retrofit market and develop systems for both water and room heating : need for systems with higher operating temperature
- increase overall energy conversion efficiency: system analysis
- increase seasonal performance factor: prolong the domain of usability (greater annual operating factor)
- reduce operating cost for a given design: optimise operation
- develop more compact systems:
- reduce heat pump technology related environmental impact: no more use of global warming inducers

Research topics

advanced compressors: oil-free scroll compressors, high-speed turbo-compressors, variable-speed, other working fluids	first class Swiss know-how in aerodynamics but current lack of Swiss manufacturers for small compressors
high performance heat exchangers, gas coolers (CO_2)	compact systems
multi-phase turbines	major barriers such as large volume expansion factor, delay of vaporisation due to nucleation, and non adapted speed versus compressor
advanced cycles: intermediate injection, two-stage small-scale units, multi-stage large scale units	greater complexity is an issue for small-scale units; oil migration between stages must be solved
alternative working fluids: natural fluids (CO_2, NH_3, propane, propylene), other synthetic fluids	natural fluids require development of specific components (for example gas cooler, compressors and seals for greater pressure with CO_2); for new synthetic fluids, difficult to find better compromise than current working fluids
in-situ monitoring and control strategy: heat storage and electricity price profile	some material benefits at low implementation cost
integrated energy systems: electric or mechanical coupling with cogeneration units either on-site or within district heating plants; synergies with efficiency measures in buildings	greater complexity and cost is an issue for small-scale units; particular issue to deal with is emission of atmospheric pollutants in case of coupling with fossil-fired units

Chemical Heat Pumps Fact Sheet (1)

• technology which can make effective use of waste heat, and solar and biomass resources in the building sector for heating or cooling, in a silent manner and potentially at lower cost and with lower maintenance than cogeneration units coupled with compression heat pumps or chillers in small-scale decentralised applications, and without noticeable increase of the overall electricity demand

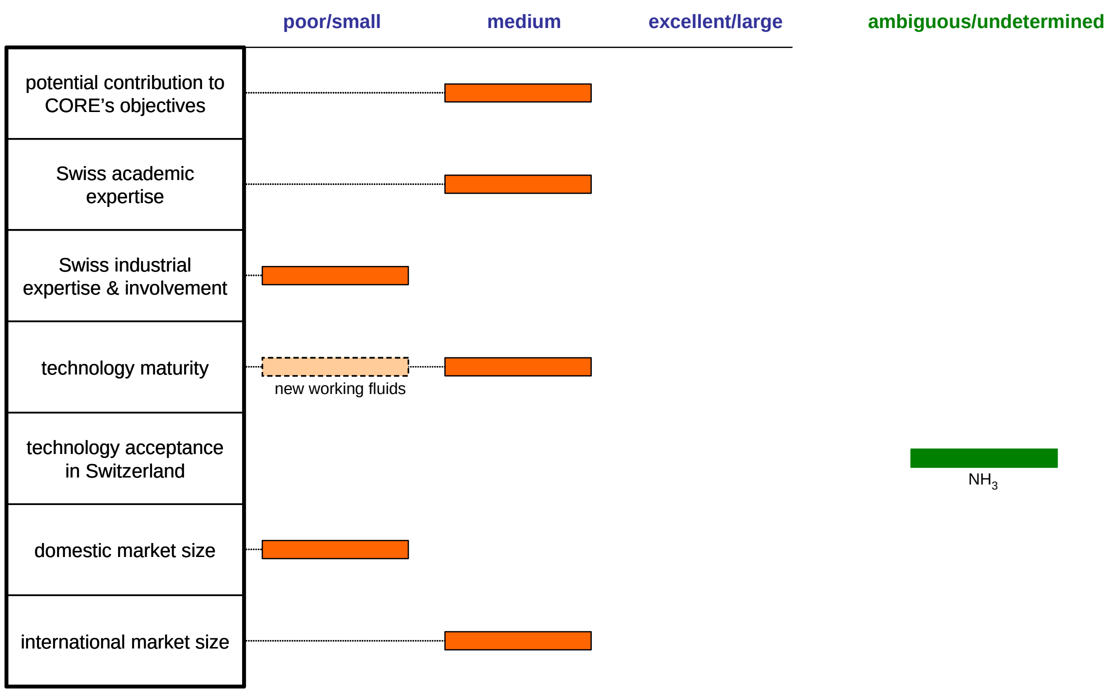
• absorption technology with LiBr-H_2O or NH_3-H_2O couples already quite mature and which can therefore be rapidly put in place and generalised in the given timeframe

• in a 'Future' with highly decentralised energy supply, interesting synergies between metal hydride or gas-liquid heat pumps and solar thermal due to energy storage properties; in a 'Future' with highly centralised energy supply, metal hydride heat pumps also potentially of interest for hydrogen production from nuclear heat water splitting (heat transformer and hydrogen storage)

• first class academic knowledge in metal hydrides in Switzerland; however, low industrial activity so far

• potentially quite large market in Switzerland, including growing cooling demand and use of waste heat in industrial processes (heat transformers with large temperature domains)

• very large worldwide export market potential, especially in countries with fast rising air conditioning demand



Chemical Heat Pumps Fact Sheet (2)

Status: 2005 | **2010 2020 2030 2040** | **Prospects: 2050**

Status: 2005

- low academic and industrial activity in Switzerland around chemical heat pumps, but activities in energy storage which is closely related
- commercialised technology (H_2O-LiBr, or NH_3-H_2O) associated with much lower COP than compression technology; typically between 1.3 and 1.6 for heating, 0.7 and 1.5 for cooling
- most commercial products for cooling; for heating, a few large H_2O-LiBr and NH_3-H_2O heat pumps; for small-scale, essentially NH_3-H_2O heat pumps so far
- hot source temperature domain: H_2O-LiBr, 80 to 150 C depending on design (half, simple, double effect); NH_3-H_2O,
- performance of alternative working pairs so far lower than conventional pairs
- for stand-alone units, usually only competitive when heat source is 'free' due to much lower COP and greater investment cost than compression technology; however, some exceptions for which direct-fired is justified

2010 2020 2030 2040

- develop advanced multi-effect systems for conventional working pairs; enlarged suitable domain and increase efficiency
- increase storage capacity, thermal stability, thermal conductivity, heat and mass transfer coefficients, sorption and desorption kinetics, specific power output, transportability of new working pairs
- decrease specific volume, corrosion potential, toxicity, viscosity, and surface tension for new working pairs
- coupling of solid or liquid sorption systems of different types (cascading)
- develop renewable sources driven chemical heat pumps or chillers and investigate synergies with energy storage requirements
- develop various options for integration within cogeneration plants
- investigate applications for heat/cold management in the transport sector

Prospects: 2050

- decentralised small-scale solar thermal and/or biomass-fired boilers driven absorption units for heating and/or cooling supply – heating COP > 1
- commercial heat pumps with energy storage properties collateral benefits for solar thermal driven system (metal hydride, zeolite-water, …) – heating COP > 0.8
- air-cooled chemical heat pumps
- coupling with cogeneration units within district heating plants with overall First Law heating efficiency between 1.0 and 1.5, depending on the scale and the technology
- commercial chillers with COP up to 2
- coupling with micro to medium size gas turbines for average efficiency improvement with inlet air cooling
- metal hydride heat transformers, notably for hydrogen production from water thermal splitting in nuclear plants and its storage

Objectives

- enlarge workable domain or safety: limited solubility issue with H_2O-LiBr absorption units suffer from limited solubility; toxicity issue with NH_3-H_2O
- reduce cycle exergy losses
- increase overall heating efficiency
- increase reliability and lifetime
- develop more compact systems
- develop renewable driven systems: biomass direct-fired or thermal solar

Research topics

investigation of new working pairs' basic properties: zeolite-water, salts-ammonia, activated carbons, metal hydrides, solid sorption…	difficult to achieve greater performances than classical working pairs; however, of interest for some specific applications with different temperature and pressure working domains such as heat transformers for nuclear based water thermal splitting (hydrogen production and storage)
improve half-effect cycle for conventional working pairs	allows use of temperature sources < 80 C; for example commercial buildings on-site absorption cooling from district heating network - better utilisation rate over the all year
develop advanced cycles for conventional and alternative working pairs: multi-effect cycles and cascading	GAX cycle, triple-effect heat pumps and chillers, …
high performance heat exchangers	sompact systems
develop better in-situ monitoring and control	alleviate any crystallisation issues over the whole load range
integrated energy systems: heat supply from cogeneration units heat recovery, gas turbines inlet air cooling, solar driven heat and cold supply and storage,…	biomass direct-fired absorption heat pumps for small-scale on-site heat supply; upgrade of low temperature solar thermal for heating; solar cooling

Solid Oxide Fuel Cells Fact Sheet (1)

- potentially the fuel cell technology of choice for stationary applications due to its high operating temperature which can allow internal reforming, good ionic conductivity, fast reaction kinetics, high output voltage, but also provides opportunities for system integration (bottoming cycles, chemical heat pumps,…)

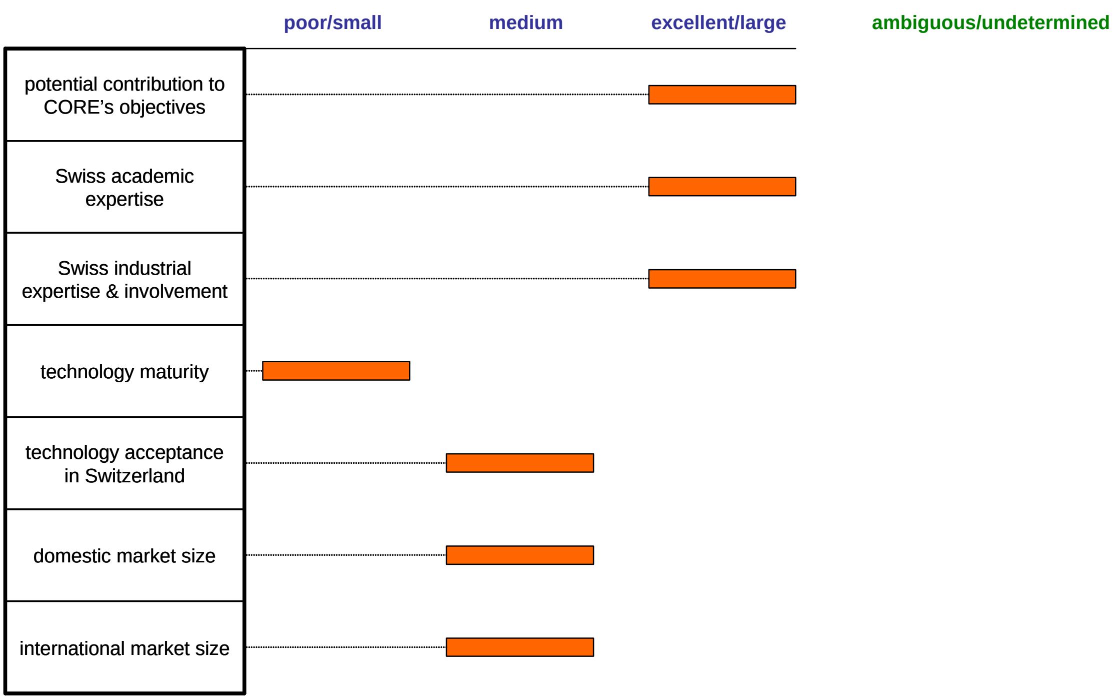
- potential application in the transport sector as APUs for large trucks and buses (engine idling elimination)

- first class academic and industrial expertise for small-scale applications; however, Swiss leading industrial player in that field very recently closed down its program

- fewer system and stack providers than PEFCs worldwide; less competition, but on the other hand less mature technology and smaller market

- quite large domestic market potential in a 'Future' with highly decentralised energy supply

- the worldwide export market potential is large



Solid Oxide Fuel Cells Fact Sheet (2)

Status: 2005

- second most investigated technology; but few stack providers in Europe ~10
- a leading company in Switzerland for the development of small-scale SOFC units
- current demonstrated lifetime of one example of planar technology: ~10'000 hours lifetime with a 3% per 1'000 hours degradation rate at 850 C
- current cost > 20'000 euros per kWe
- small-scale cogeneration units: ~25 to 30% LHV electric efficiency; Sulzer: ~100 units installed with 1 million hours cumulated in real conditions
- medium and large scale applications: 3 major industrial players (no Swiss)
- atmospheric pressure & natural gas unit : 126 kWe, 100 kWth, 47% LHV electric efficiency, 80% First Law global efficiency (Siemens)
- pressurised hybrid SOFC/gas turbine units in early demonstration at 200 and 300 kWe power output

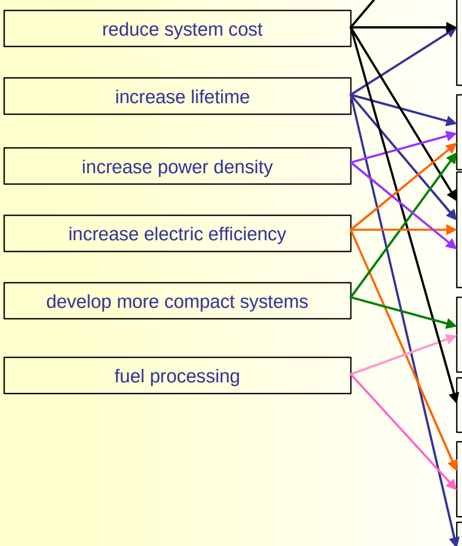
2010 2020 2030 2040

- increase mechanical stability at high operating temperature
- solve transient operation issues
- achieve acceptable performance at lower operating temperature, OR develop new design and integration for current operating temperature
- produce large volumes – high economies of scale in manufacturing
- system integration: hybrid cycles, coupling with compression or absorption heat pumps

Prospects: 2050

- lifetime: ~40'000 hours or more
- cost: small-scale stationary ~ 1'000 euros per kWe, medium to large scale stationary ~ 800 euros per kWe
- small-scale cogeneration: 50 to 55% LHV electric efficiency
- medium & large-scale cogeneration: 55% LHV electric efficiency for 250 kWe, 60% for 1 MWe, 70% for 3MWe and above
- integrated energy systems with overall First Law heating efficiencies up to 3 (coupling with compression or chemical heat pumps)

Objectives



Research topics

development of new electrolyte materials: perovskites, ceria,… achieve similar ionic conductivity than YSZ at lower temperature (< 700 C)	allows use of conventional materials for interconnects
development of alternative anodes: Ni-precious metal alloys,…greater tolerance to oxy/red cycles, greater sulphur tolerance (up to 50 ppm), tailored catalytic activity (hydrocarbon on-cell reforming)	so far, few alternatives have shown high activity and high performance
new designs modelling & testing: reactant distribution and product removal, and for heat management	increased fuel utilisation rate, reduced parasitic losses, and less stress related to temperature difference
advanced interconnects and sealants: new coatings or surface treatment for metallic interconnects oxidation resistant, electrically conductive; sealants based on glass ceramic or mica	delay increasing specific resistance over time (reduce oxide growth)
compact and high performance gas to gas heat exchangers, development of advanced reformers, & gas cleaning tech.	more effective internal reforming and gas cleaning technologies
advanced manufacturing techniques for thin electrolytes	electrochemical vapour deposition, plasma spraying, … – very expensive
better system integration and auxiliaries: reduce parasitic losses and synergies	atmospheric cogeneration units, pressurised hybrid cycles, coupling with compression or absorption heat pumps,…
in-situ monitoring techniques	better understanding of degradation mechanisms

Gasification Technology Fact Sheet (1)

• key technology for a more diverse use of local biomass resources available but reliability issues remain to be solved

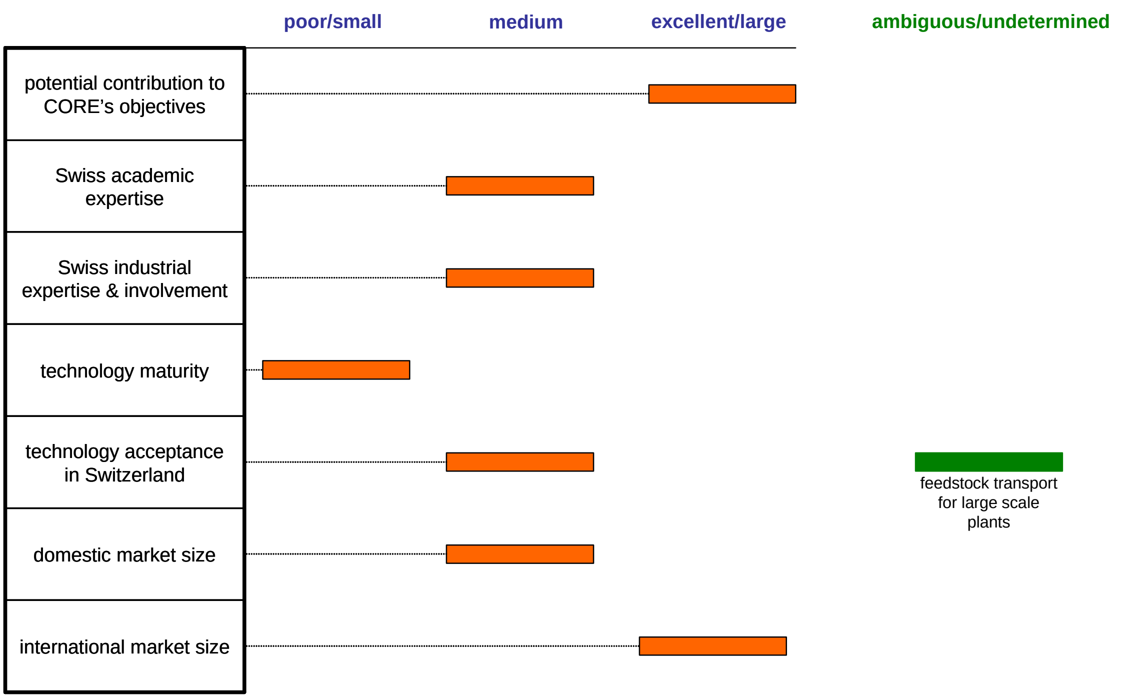
• suitable for a great diversity of biomass resources, end-use technologies and applications – combined power and heat generation or alternative transport fuels production

• complexity and cost makes it unsuitable for micro-scale applications

• some very good academic expertise, and a few Swiss industrial providers

• material domestic market potential in a 'Future' with highly decentralised energy supply in association with medium scale cogeneration units and district heating (especially for waste disposal), or in a 'Future' with centralised energy supply in the context of alternative transport fuel production (FT liquids or upgraded syngas), but limited on the supply side by the relatively low amount of biomass resources collectable in a sustainable way

• very large worldwide export market due to the great variety of applications and large amount of biomass and coal resources



Gasification Technology Fact Sheet (2)

Status: 2005

- various technologies in the considered capacity range: downdraft technology up to 1 MWth, updraft and fluidised bed between 1 and 50 MWth, atmospheric and pressurised circulating fluidised bed beyond
- more than 60 GWth installed worldwide; ~450 gasifiers, but only a small share for biomass; a few Swiss providers and demonstration plants up to 200 kWe (downdraft technology)
- biomass conversion efficiency is typically 60 to 95% depending on size and feedstock
- gasifiers for biopower commercialised by several manufacturers but no full guarantee yet due to low cumulated operating hours and experience; so far, performance of prototypes usually significantly lower than theoretical potential
- power generation from biomass gasification: current overall efficiency ~25-30% LHV (gas engines)
- gas cleaning in large plants currently based on wet scrubbing (water, organic solvent) – does not meet level required by many downstream technologies

2010 2020 2030 2040

- improve system reliability in order to develop industrial scale manufacturing – in particular, solve tar and particulates related issues
- develop fuel flexible gasifiers (feeding mechanism and reactor) or establish feedstock quality homogenisation and standard, or both
- develop appropriate and affordable gas cleaning technologies or investigate system integration with less sensitive downstream technologies, or both
- give priority to low or negative cost feedstock gasification systems, i.e. wastes
- system integration with downstream power generation cycles
- develop affordable downstream methanation process for fungibility with natural gas usage (injection into natural gas network or delivery trucks)
- develop affordable and resistant catalyst for production of FT liquids (bioFT-diesel)
- develop various concepts for biorefineries: co-generation of power, hydrogen or liquid biofuels, and chemicals from biomass resources

Prospects: 2050

- wastes, residues and wood & grasses oxygen blown pressurised gasifiers for advanced combined cycle power generation units; typically ~100-150 MWe, electric efficiency ~40-55% LHV depending on scale and downstream technology, < 1'500 euros per kWe, possibly carbon CS
- wastes, residues and wood & grasses gasifiers for advanced urban cogeneration units associated with heat pump based district heating; typically ~50 MWe, overall First Law heating efficiency between 1.5 and 3 , depending on scale and downstream technology, < 2'000 euros per kWe
- wood gasification plants for methane or hydrogen production: best compromise to find between economies of scale and feedstock transport distance, ~0.07 euros per kWh of CH_4 or H_2 (wood price ~0.02 euros per kWh)
- biorefineries ; best compromise to find between economies of scale and feedstock transport distance; ~0.07 euros per kWh of FT products (wood at ~0.02 euros per kWh, elec. co-generated sold at 0.04 euros per kWh)

Objectives

- reduce system and operating costs
- increase reliability and lifetime
- increase fuel flexibility
- increase conversion efficiency
- reduce environmental impacts
- increase diversity of applications

Research topics

development of feedstock preparation based on quality standard	homogenous feedstock, low-cost briquetting, advanced dewatering, …
development of advanced hot gas heat exchangers: corrosion and fouling resistant	reduce O&M cost; collateral benefits for and from other applications and sectors
improvement of existing types of gasifiers: advanced materials, new feeding systems (dry or slurry), ceramic coating for refractory systems, …	water cooled refractory or new materials for refractory life extension, process without refractory needs (for highly corrosive feedstock), catalysts for enhanced gasification,…
development of advanced feed injectors	new materials for lifetime improvement, efficient load adjustment,…
development of new types of gasifiers: supercritical gasification,…	interest for new designs may emerge from on-going modeling activities
development of pollutants measuring techniques and of new gas/ashes cleaning technologies: catalytic reforming, hot gas cleaning for pressurised systems,…	tar (hydrocarbon compounds) removal or cracking, heavy metals removal from ashes (evaporation), NH_3 and sulfur clean up in warm gases, particulates …
understanding of the impact of alkali and other contaminants on catalyst lifetime	reduce O&M cost; compatibility with gas cleaning technologies
identification of suitable markets for by-products	characterisation and beneficiation of ashes and slag, CO_2,, NH3,…
system integration: air separation, syngas upgrading or conversion, downstream power generation cycles, biorefineries,…	oxygen and hydrogen separation membranes, PSA, catalyst for FT liquids, multiple output plants (power, H_2, FT liquids, upgraded syngas, chemicals),…

Gas Engines Fact Sheet (1)

• most mature technology for medium scale cogeneration applications; economically viable today, and therefore can be rapidly put in place and generalised in the given timeframe with appropriate adaptation to biomass firing

• first class academic and industrial expertise in Switzerland

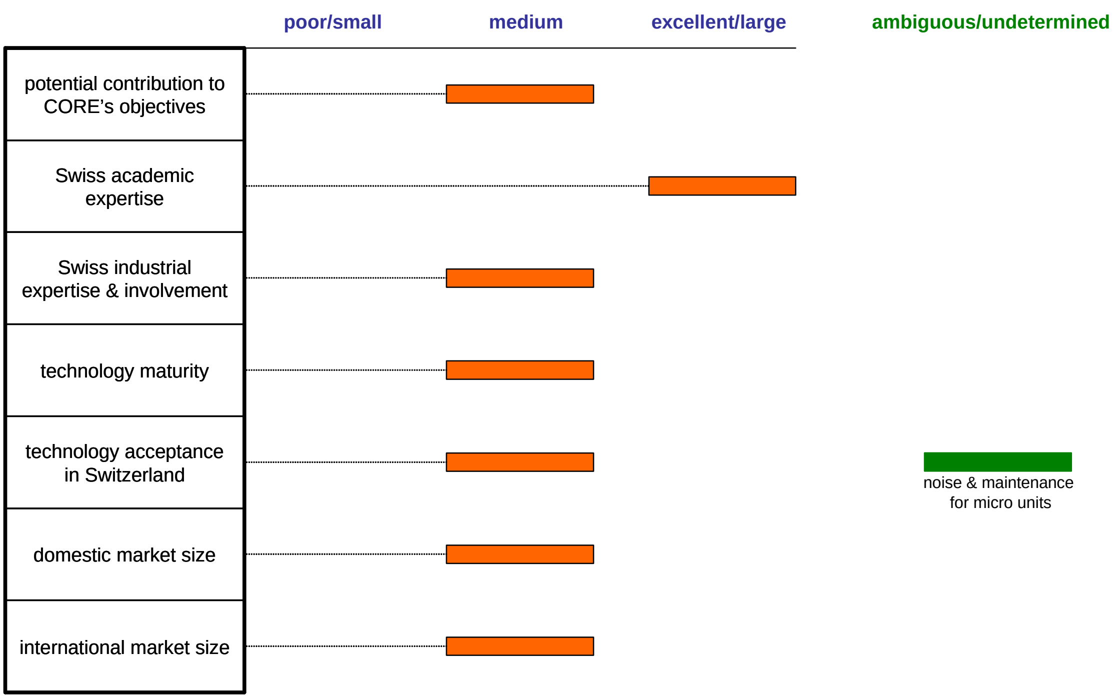
• best compromise so far between initial investment cost and conversion efficiency

• large domestic market in a ‘Future’ with highly decentralised energy supply if gas cleaning technology and pollution control can follow stringent requirements at affordable costs

• potential synergies with activities in the transport sector with ICEs conversion to natural gas

• quite large domestic market potential in a ‘Future’ with highly decentralised energy supply

• worldwide export market potential is large



Gas Engines Fact Sheet (2)

Status: 2005

- current electric efficiency for stationary applications: 28% (small-scale stoichiomteric units < 100 kWe) to 42% LHV (large lean burn units ~5 MWe)
- exhaust catalysts in advanced lean burn stationary engines allows 50 ppmv @ 15% O_2 (dry basis)
- stationary engines optimised for efficiency emit up to twice NOx emissions than engines tuned for lowest emissions; which show 1 or 2 points lower efficiency
- cogeneration system cost: 900 to 1400 euros per kWe depending on the size
- maintenance cost ~0.08 euro per kWh
- several Swiss manufacturers of stationary engines; 190 kWe engine with exhaust gas recirculation and three way-catalyst commercialised with 40% LHV electric efficiency, and demonstrated for 5'000 hours with biogas at 37% LHV electric efficiency
- prechamber ignition instead of direct ignition technically demonstrated with biogas at 36% LHV electric efficiency and with compliance with norms

2010 2020 2030 2040

- achieve affordable atmospheric pollutants emission control
- improve conversion efficiency while complying with emission's legislation
- reduce operating and maintenance cost
- improve reliability and lifetime
- fuel flexibility: adaptation to alternative fuels (biogas, bio-oil)

Prospects: 2050

- electric efficiency: 45 % LHV (small-scale units) to 55% LHV (large-scale units)
- small-scale stoichiometric with EGR and three way catalyst
- medium to large scale lean burn with or without SCR
- cogeneration system cost: 700 to 1000 euros per kWe depending on the size
- maintenance cost ~0.01 euro per kWh
- NOx emission rate < 10 ppmv @15% O_2 (dry basis) without exhaust treatment
- gas engine for mechanically coupled heat pumps, or coupling with chemical heat pumps

Objectives

- reduce environmental impacts
- increase reliability and lifetime
- increase conversion efficiency (reduce exergy losses)
- increase fuel flexibility
- reduce system cost

Research topics

address knock (explosive auto-ignition) limitations: multi-spark ignition, novel designs for combustion chamber (turbulence enhancement), water injection	leads to greater power density and thus less friction losses (more compact systems) and higher efficiency
reduce friction and heat losses: new materials, and thermal barriers coating	currently, friction losses~10% of fuel energy content, exhaust gases heat losses ~25%, other heat rejection ~25%, incomplete combustion ~2%
advanced turbo-charging: turbine design, multi-stage compressor with intercooling,…	currently, turbo-charging efficiency ~55%; can be increased up to 65% and more
better understanding of dilute mixture combustion and ignition	combustion stability
reduce NOx emission and understand other emissions such as particulates : in-cylinder water injection, ultra lean-air combustion, catalysts,…	two main options are stoichiometric with EGR and three way catalyst, or lean burn with or without SCR
alternative fuels: catalysts with high tolerance for contaminants, lean burn with prechamber, advanced gas cleaning…	current catalyst degrade with contaminants from biofuels; 3 way catalyst does not function with oxygen excess
in-situ monitoring and control: advanced sensors	critical to maintain stability of ultra-lean combustion
alternative cycles: Miller cycle,…	Miller cycle commercialised by Mitsubishi (expansion ratio > comnpression ratio)
system integration: bottoming cycles, exhaust heat internal recovery,…	ORC as bottoming cycle allows a jump in efficiency improvement but must be available at affordable cost

Gas Turbines Fact Sheet (1)

- technology of choice for the upper range of medium scale cogeneration applications; economically viable today, and therefore can be rapidly put in place and generalised in the given timeframe with appropriate adaptation to biomass firing

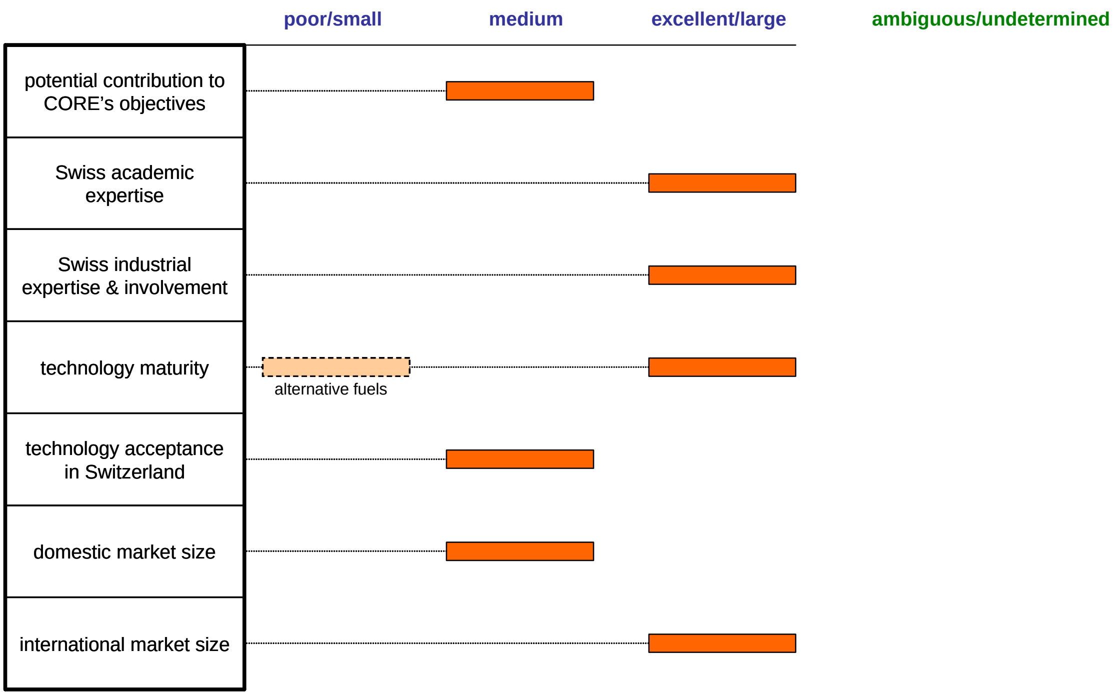
- also technology of choice in alternative transport fuel production plants for on-site power and steam generation requirements

- first class academic and industrial expertise for upper capacity range in Switzerland

- highly suitable for system integration as bottoming or topping cycle

- large domestic market in a 'Future' with highly decentralised energy supply if gas cleaning technology and pollution control can follow stringent requirements at affordable costs, or in a 'Future' with centralised energy supply if carbon capture and sequestration proves to be viable

- worldwide export market potential is very large, especially when gasification technology for coal and biomass becomes available



Gas Turbines Fact Sheet (2)

Status: 2005

- current electric efficiency: small-scale units (~500 kWe to 1 MWe) <25% LHV; medium scale units ~30 to 35% LHV, large scale units (>100 MWe) > 35% LHV
- NOx emissions < 3 ppmv @15% O_2 (dry basis); dry low NOx for large scale units
- cogeneration system cost: 1 MWe units, ~2000 euros per kWe; 40 MWe units, ~700 euros per kWe
- maintenance cost ~0.004 euro per kWh
- one major international technology developer in Switzerland, currently focusing on large scale units (>50 MWe)
- commercialised large scale gas turbine/steam turbine combined cycles with electric efficiency up to 60% LHV

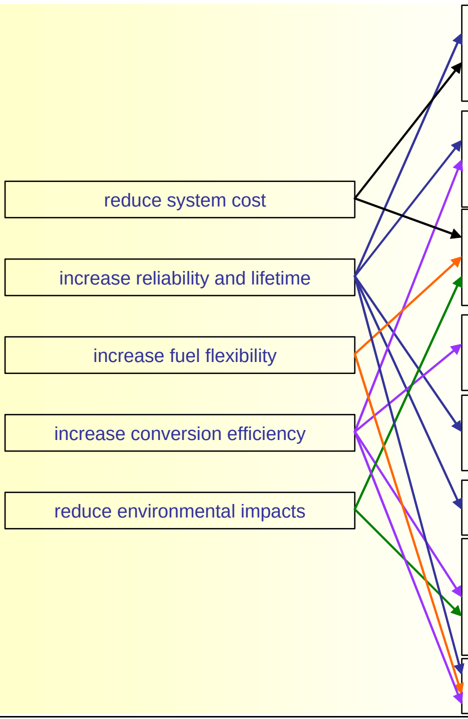
2010 2020 2030 2040

- achieve less costly atmospheric pollutants emission control for small to medium size units
- improve conversion efficiency while complying with emission's legislation
- reduce operating and maintenance cost
- downscaling of large scale advanced technology for smaller scale units
- fuel flexibility: adaptation to alternative fuels (biogas, bio-oil)
- advanced cycles with internal heat recovery, gas recirculation, alternative working fluids…
- system integration: combined cycles with gas turbine as topping or bottoming cycle, with advanced options (oxygen separation, gas recirculation, water injection,…)

Prospects: 2050

- electric efficiency: ~5 MWe units ~35 % LHV ; ~40 MWe units ~40% LHV ; ~100 MWE and above: similar to current efficiency for gas turbine, focus on combined cycle efficiency
- cogeneration system cost: ~5 MWe units, 800 euros per kWe; ~40 MWe units, 600 euros per kWe; above, < 500 euros per kWe
- maintenance cost ~0.005 euro per kWh
- NOx emission rate < 3 ppmv @15% O_2 (dry basis) without exhaust treatment
- combined cycle units with electric efficiency up to 70% LH
- 'zero emissions plants' and fuel flexible gas turbines
- gas turbines adapted to fuels with low heating values for integration with gasification technology

Objectives



Research topics

advanced blade design and cooling: internal cooling, surface protection layer,…best compromise between inlet temperature and extracted gas mass flow	better understanding of heat and mass transfer & affordable down-scaling of concepts applied for large scale units
advanced materials: super alloys, coatings, monolithic or composite ceramics…	higher inlet temperature at affordable cost requires the identification of materials with both high strength at high temp. and suitable manufacturability
advanced combustion: ultra lean-premix combustion, catalytic combustion, combustion of alternative fuels (biofuels, hydrogen),…	ultra-low NOx without post-treatment techniques; 1.4 MWe catalytic comb. gas turbine commercialised with less than 3 ppm (Kawasaki)
advanced compressor and turbine designs & advanced generators: aerodynamic efficiency, electric efficiency,…	greater pressure ratio allows greater specific power output, advanced generators,…
understanding of sustained oscillating combustion	air fuel ratio coming closer and closer to stability limit due to a trend towards high degree of premixing
non destructive inspection methods and repair or refurbishing techniques	greater operating factors
advanced cycles and system integration: internal heat recovery, inlet air cooling, combined cycles, exhaust gas recirculation, oxygen separation, CO_2 post capture, zero emission plants,…	multitude of options for integration; modeling and optimisation methods can help identifying most promising options under various boundary conditions
development of advanced hot gas heat exchangers	corrosion and fouling resistant

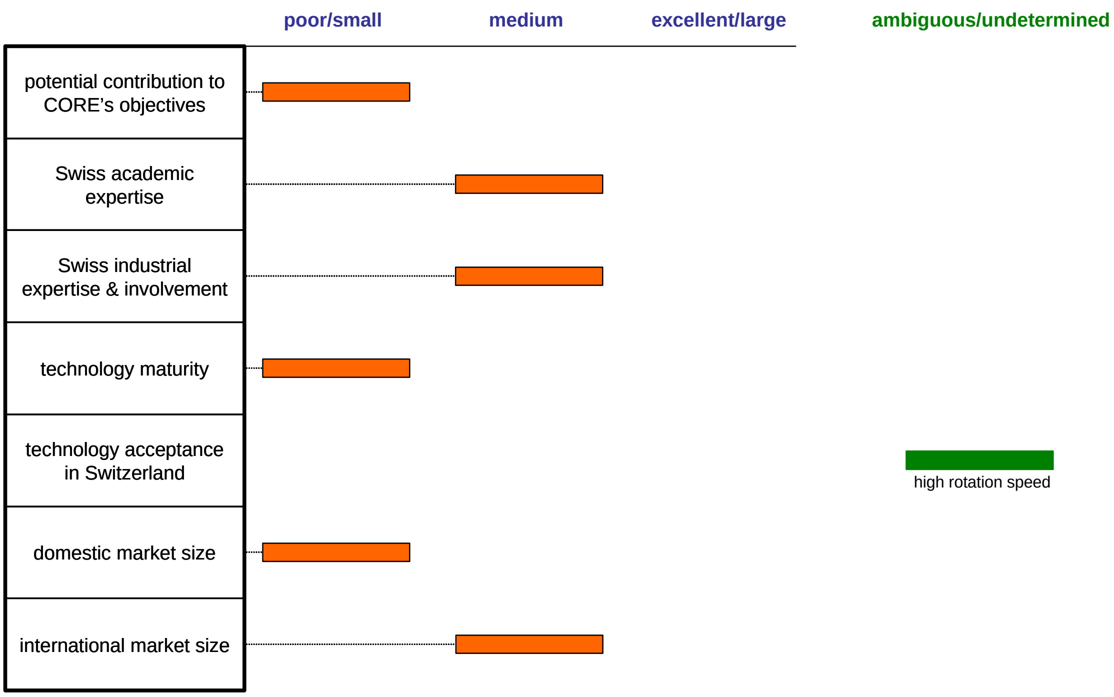
Microturbines Fact Sheet (1)

• candidate for micro-cogeneration due to potentially lower maintenance than gas engines and lower cost than fuel cell technology

• first class academic and industrial expertise in Switzerland for large gas turbines may be downscaled; good expertise in power conversion electronic devices

• quite large domestic market in a ‘Future’ with highly decentralised energy supply if gas cleaning technology and pollution control can follow stringent requirements at affordable cost

• worldwide export market potential is potentially rather large



Microturbines Fact Sheet (2)

Status: 2005	2010 2020 2030 2040	Prospects: 2050
• current electric efficiency : ~30 kWe units, ~25% LHV; ~100 kWe units, ~ 28% LHV (cycle with heat recovery) • NOx emissions: ~30 kWe units, ~15 ppmv LHV; ~100 kWe units, ~ 40 ppmv (@15% O_2, dry basis) • cogeneration system cost: ~100 kWe units, 1700 ; ~30 kWe units, 2600 euros per kWe • maintenance cost ~0.02 to 0.01 euro per kWh	• achieve affordable atmospheric pollutants emission control • improve conversion efficiency while complying with emission's legislation • reduce operating and maintenance cost • fuel flexibility: adaptation to alternative fuels (biogas, bio-oil)	• electric efficiency: >34% LHV • cogeneration system cost: < 1250 euros per kWe • maintenance cost ~0.01 euro per kWh • NOx emission rate < 3 ppmv @15% O_2 (dry basis) without exhaust treatment • gas turbines adapted to fuels with low heating values for integration with gasification technology

Objectives

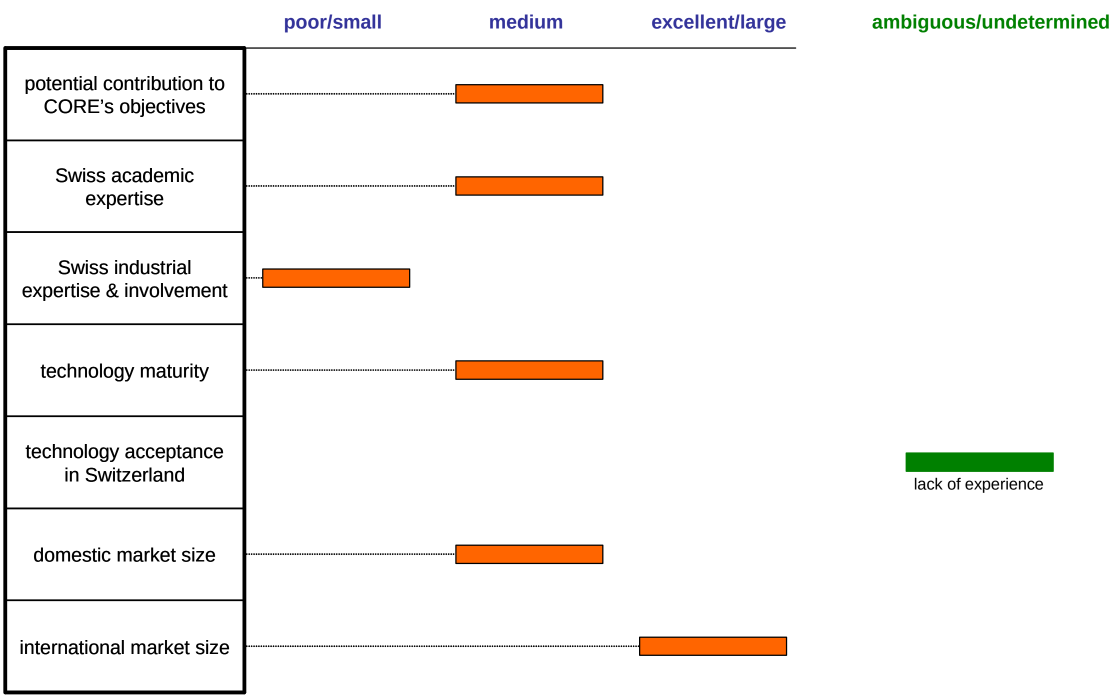
- increase reliability and lifetime
- increase fuel flexibility
- increase conversion efficiency
- reduce environmental impacts
- reduce system cost

Research topics

downscaling of cooling techniques: internal cooling, surface protection layer	achieve greater inlet temperature with less expensive materials; manufacturability at small scale is an issue
advanced materials: super alloys, coatings, monolithic or composite ceramics…	higher inlet temperature at affordable cost requires the identification of materials with both high strength at high temp. and suitable manufacturability
advanced combustion: ultra lean-premix combustion, catalytic combustion,…	allows ultra-low NOx without post-treatment techniques; downscaling of larger scale equipment
development of advanced hot gas heat exchangers	corrosion and fouling resistant recuperator
new radial turbine design or intercooled cycle (two radial compressors) for greater pressure ratio	allows greater inlet temperature while keeping low enough temperature at the entrance of the recuperator
advanced bearings: advanced air bearings or magnetic bearings	allows suppression of oil supply and filtering system – numerous starts is however an issue due to metal to metal contact
advanced power conversion electronics: high frequency generators, AC-AC converters, filters,…	both stand alone and grid connected modes with smooth transition, control of transient operation,…

Organic Rankine Cycles & Stirling Engines Fact Sheet (1)

- large ORC units are suitable for the use of low temperature geothermal energy sources
- small ORC units and Stirling engines are technologies of choice for on-site biomass-fired boilers cogeneration units
- ORC and Stirling technologies allow the use of biomass resources without costly gasification and gas cleaning technologies
- very good academic know-how; lack of industrial involvement so far
- large domestic market potential for ORC units in a ‘Future’ with highly decentralised energy supply, given the suitability for many types of energy sources, including the large amount of unexploited low temperature waste heat
- very large worldwide market potential for both ORC and Stirling, including use of concentrated solar heat



Organic Rankine Cycles & Stirling Engines Fact Sheet (2)

Status: 2005

• large scale ORC technology (>2 MWe) is mature and commercialised for low enthalpy geothermal sources (100-300 C); hydrodynamic turbines; elec. efficiency ~20%; 1'500 euros per kWe; few manufacturers; no Swiss activities so far

• medium scale ORC units (~300 kWe to 2 MWe): commercialised for solid biomass or biogas fired cogeneration and waste heat recovery; hydrodynamic turbines elec. efficiency ~10-17%; 2'000 euros per kWe; few manufacturers; no Swiss activities so far

• micro to small scale ORC units (~1 to 50 kWe): cycle technically demonstrated, notably at EPFL; not commercialised yet; scroll turbines (converted compressors); elec. efficiency ~10% for single stage cycle, ~17% for two-stage cycle; ~2'500 euros per kWe @ 20-50 kWe; ~3'500 @ 1-5 kWe; some Swiss activities

• Stirling engines: commercialised from ~5 kWe to 50 kWe; applied for high temperature solar thermal, solid biomass or biogas fired cogeneration, and waste heat recovery; efficiency ~15-30%; ~3'000 euros per kWe; some Swiss

2010 2020 2030 2040

• large scale ORC units: reduce cost with larger manufacturing volumes

• medium scale ORC units: improve reliability of boilers with oil circlation, develop pressurised biomass-fired boilers, efficiency improvement with radial turbines, reduce cost with large manufacturing volumes

• micro to small scale ORC units: develop oil circulation boilers (downscaling), manufacture dedicated turbines and pumps, demonstrate technology in-situ, and reduce cost with larger manufacturing volumes

• all ORCs: investigate suitability of alternative working fluids

• Stirling engine: reduce cost with large manufacturing volumes

• ORCs and Stirling: investigate various option for system integration with renewable sources and with cogeneration units (bottoming cycles)

Prospects: 2050

• large scale ORC units: low enthalpy geothermal sources, > 20% elec. efficiency, < 1'000 euros per kWe

• medium scale ORC units: pressurised biomass-fired boilers, two-stage cycle, radial turbines, ~25% elec. efficiency, < 800 euros per kWe

• small scale ORC units: ~20 to 50 kWe, pressurised biomass-fired boilers, two-stage cycle, ~20-25% elec. efficiency, 1'000 euros per kWe

• micro scale ORC units: ~1 to 5 kWe, solid biomass or biogas fired boilers with oil circulation, bi-serial turbine single stage cycle, ~15-20% elec. efficiency, 1'000 euros per kWe

• Stirling engines: ~1 to 5 kWe, >35% elec. efficiency, 1'000 euros per kWe

Objectives

- increase conversion efficiency
- increase fuel flexibility
- reduce system cost
- reduce environmental impacts

Research topics

develop dedicated small ORC scroll turbines	allows greater pressure ratio than with converted scroll compressors
develop small pressurised biomass-fired boilers	avoids intermediary loop; certification issues
develop small oil circulation biomass-fired boilers	downscaling of current existing biomass-fired boilers
develop dedicated pumps for micro ORC units: small mass flow, high pressure ratio, and low viscosity fluid	increased efficiency and significant cost reduction with developing market
Investigate alternative working fluids: CO_2, water, new synthetic fluids,…	alleviate fluids with impact on climate; greater thermodynamic performance; safety issues with natural hydrocarbons
radial turbines in replacement of axial turbines for medium scale ORC units	expansion process efficiency improvement
new materials and seals for Stirling engines	reduce friction and heat losses, and increase hot-end temperature: efficiency improvement
system integration: investigate and demonstrate various options for system integration with renewable sources and with cogeneration units (bottoming cycles)	demonstrate competitiveness in a diversity of application to reach large market volumes and manufacturing economies of scale

Hydrogen from Advanced Nuclear Fact Sheet (1)

- in a 'Future' with centralised energy supply, technology of choice for hydrogen production independent from fossil resources and without CO_2 emissions through water-splitting via high temperature electrolysis or thermochemical process, under the imperative conditions of both greater social acceptance and viable solution for waste disposal

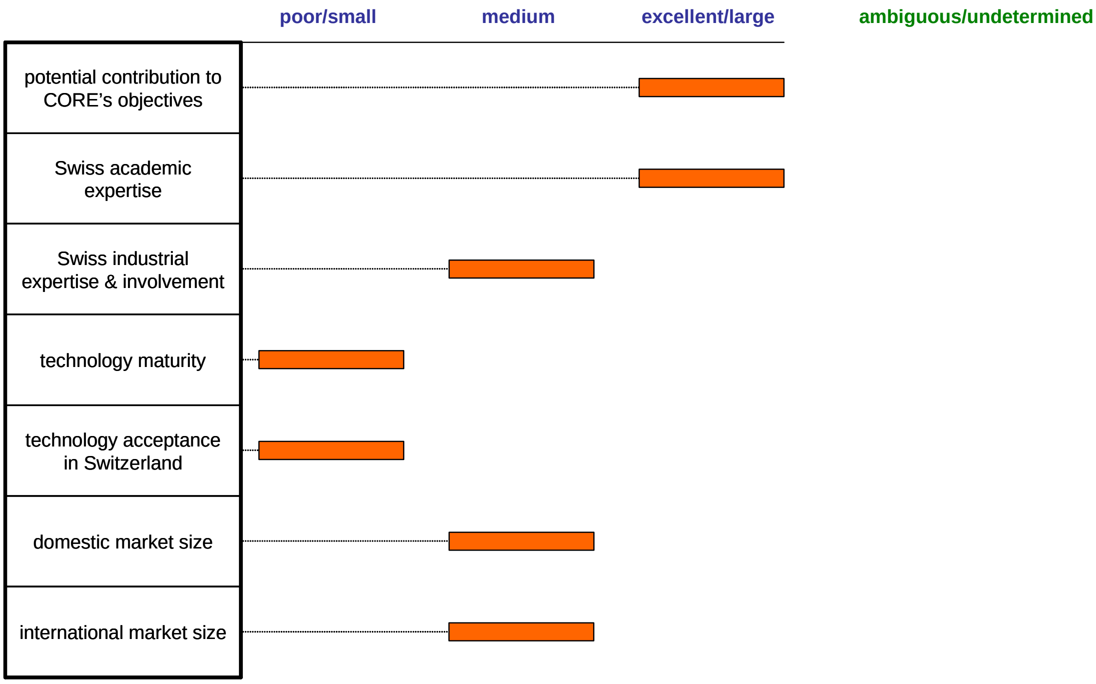
- Swiss power utilities are very familiar with nuclear technology

- Swiss academic know-how on nuclear waste disposal issues and advanced materials for high temperature reactors; first class academic industrial know-how on large gas turbines which is the technology of choice for high temperature nuclear reactors; first class academic know how on thermochemical cycles; first class academic and industrial know-how on solid oxide fuel cell technology which can be redirected towards high temperature electrolysers

- advanced nuclear technology is capital intensive

- domestic market potential is constrained in practice by the existing nuclear power plant sites

- worldwide market is potentially large but public concerns about waste disposal, widespread devastation in case of accidents, and nuclear proliferation is likely to seriously limit its growth



Hydrogen from Advanced Nuclear Fact Sheet (2)

Status: 2005	2010 2020 2030 2040	Prospects: 2050
• current route: hydrogen from conventional electrolysis based on current fission reactors technology (high temperature; conventional alkaline electrolysers, overall conversion efficiency ~25-30% , hydrogen cost ~ 3-4 euros per kg • high temperature electrolysis is investigated but advanced fission reactors and advanced electrolysers not available yet • integration of advanced fission reactors with methane steam reforming plants is investigated • thermo-chemical water splitting in development with the investigation of a great diversity of possible cycles (more than 1'300); sulfur-Iodine and copper-chlorine cycles perceived as most promising – temperature required > 800 C (except copper-chlorine > 550 C) • main focus is now on sulfur-iodine with laboratory scale experiments; extensive investigation of calcium-bromine-iron (UT-3) cycle produced disappointing results so far • first class Swiss academic know-how on high temperature chemical cycles (but so far focus on Zn/ZnO and concentrated solar)	• development of advanced electrolysers: PEM or solid oxide technology • investigate integration with methane steam reforming • experimental verification of promising thermo-chemical cycles • investigate integration with various possible advanced fission reactors (see advanced nuclear power generation fact sheet): material compatibility, coolant stability, operating pressure, safety… • investigate heat transformers (see chemical heat pumps fact sheet) for temperature upgrading • identify markets for co-produced oxygen • assess uranium supply by 2050 • when hydrogen vehicles enter the market, demonstrate feasibility with successive prototypes associated with gradually increasing daily production capacity	• hydrogen from conventional electrolysis based on advanced fission reactors technology: PEM or large advanced alkaline electrolysers, overall conversion efficiency ~35% • integration of advanced nuclear fission reactors with high performance methane steam reforming plants; overall conversion efficiency >70% (but not CO_2 free) • hydrogen from high temperature electrolysis using electricity and heat of advanced fission reactors: solid oxide electrolysers; overall conversion efficiency ~40-50% • hydrogen from thermo-chemical water splitting using heat from advanced fission reactors and water as only inputs: overall heat to hydrogen conversion efficiency ~40-60% (50% @ 900 C for sulfur- Iodine); hydrogen cost between 1.0 and 2 euros per kg (if oxygen is sold, could compete against hydrogen from natural gas with today's cost and without accounting for a CO_2 penalty); typical plant: 2'400 MWth, 200 tons per day of hydrogen; investment cost ~300 euros per kWth; O&M cost: ~8 euros per MWthh

Objectives

- increase safety, reliability, and lifetime
- increase conversion efficiency
- enlarge workable domain

Research topics

development of advanced materials for mechanical and chemical stability at high temperature: refractory metals, ceramics,…	sulfur-iodine case: temperature as high as 900ºC; many of the chemicals employed are strong oxidizers; extremely corrosive environment
development of advanced membranes for hydrogen and oxygen separation	robust membranes suitable for the rapid, selective removal of hydrogen or oxygen from high-temperature, high-pressure gas streams, while remaining resistant to chemical impurities
heat transformers for temperature upgrading: metal hydrides,…	allows integration with lower temperature reactors
development of advanced hot gas heat exchangers	corrosion and fouling resistant
development of advanced catalyst or inorganic membranes	allows use of lower operating temperature reactors or higher conversion rates
investigation of various possible chemical processes and establishment of flowsheet: reactive or extractive distillation,…	efficiency of thermochemical process and of integrated hydrogen production system can differ significantly
extensive investigation of all safety issues	definition of possible accident chains for the nuclear-chemical integrated system
development of advanced electrolysers	large scale advanced alkaline electrolysers or small scale PEM electrolysers; solid oxide electrolyser for high temperature electrolysis – see electrolysers fact sheet

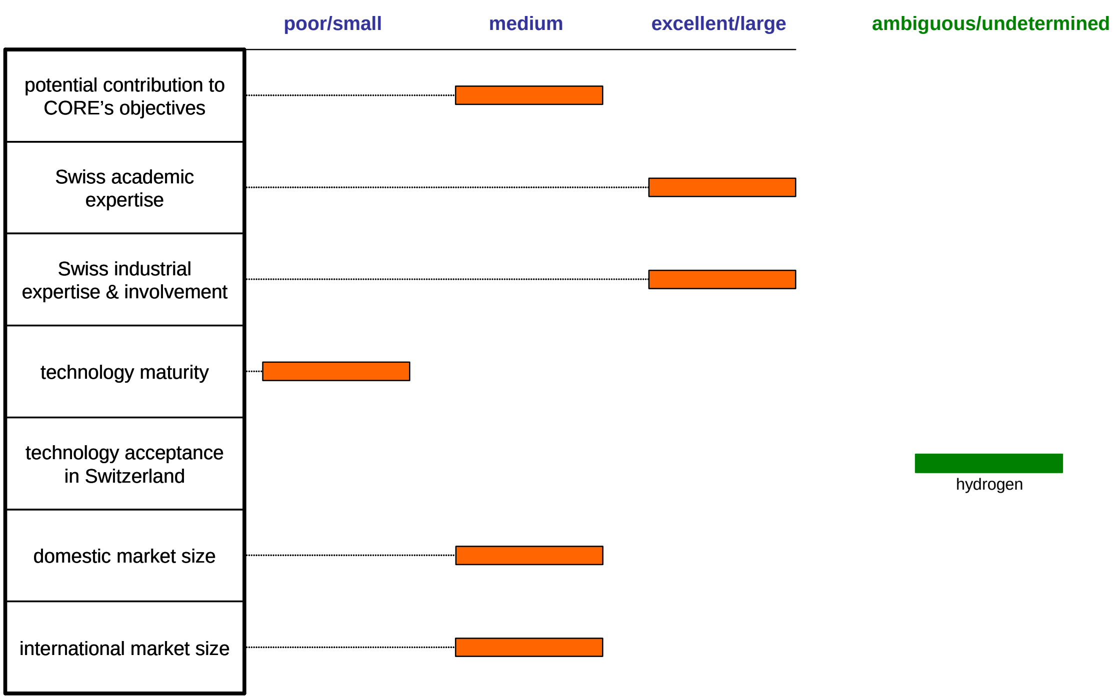
Advanced Electrolysis Fact Sheet (1)

• PEM or pressurised alkaline electrolysers are the technologies of choice for distributed hydrogen production based on electricity generated on-site or in a centralised way by renewable sources, and therefore without CO_2 emissions, although with a low overall chain efficiency; first class industrial know-how in alkaline technology; good academic knowledge on PEFC technology can be redirected towards electrolysis

• in a 'Future' with a central energy supply, solid oxide technology is the technology of choice for carbon neutral hydrogen from high temperature steam electrolysis at the location of advanced nuclear power plants; very good academic and industrial know how on SOFC technology can be redirected towards high temperature electrolysis

• domestic market potential is large when hydrogen vehicles are readily available and if concerns about security of energy supply becomes of first priority, or if carbon sequestration and capture does not prove to be a viable option

• worldwide export market potential is very large in the longer term when most of the hydrogen is fossil free



Advanced Electrolysis Fact Sheet (2)

Status: 2005

- currently two technologies commercially available: alkaline (atmospheric or pressurised) and polymer membrane electrolyers (less mature)
- alkaline: typically 0.5 to 10'000 Nm³/h; operating pressure: up to 25-30 bars; water to H_2 conversion efficiency 80-95%; overall system (inc. purification) up to 70% LHV; ~1'000 euros per kWe; several Swiss developers
- PEM: 0.5 to 100 Nm3/h; high H_2 purity; operating pressure: up to 200 bars; overall system up to 65% LHV; ~2'000 euros per kWe
- based on electricity bought from the grid, large systems (~1'000 kg H_2 per day), ~ 4 euros per kg; electricity cost is the main factor in the total hydrogen production cost
- based on electricity bought from the grid, for small systems (~20 kg H_2 per day) ~ 20 euros per kg, and refuelling stations (~100 kg H_2 per day) ~8 euros per kg; capital cost is more significant than electricity cost in the hydrogen production cost
- high pressure alkaline electrolysers in development; solid oxide and photo electrolysers in early development – existing Swiss know-how in all of those

2010 2020 2030 2040

- centralised option: upscaling and high pressure alkaline electrolysers - 10 to 100 times today's capacity
- centralised option: develop solid oxide electrolysers for high temperature electrolysis; increase mechanical stability at high operating temperature, solve transient operation issues, achieve acceptable performance at lower operating temperature than current SOFCs,…
- distributed option: develop more robust MEAs, alternative bipolar plates, more reliable auxiliaries,…for PEM electrolysers; economies of scale: production of large volumes, synergies with PEFCs
- investigate further photo-electrolysis
- integration with intermittent energy sources

Prospects: 2050

- distributed electrolysis with PEM electrolysers; system efficiency >70% LHV; system cost ~150-300 euros per kWe for 250 kg H_2 per day; H_2 production cost ~2.5 euros per kg
- micro-scale distributed electrolysis with photoelectrolysers; stabilised solar to hydrogen direct conversion efficiency ~10-15% to be competitive with distributed conventional electrolysis
- centralised electrolysis with advanced alkaline or solid oxide electrolysers; ~2 euros per kg H_2
- high temperature electrolysis with solid oxide electrolysers and nuclear heat @ 700 C: ~40-50% overall conversion efficiency
- part load as low as 10% nominal load
- advanced control allowing frequency control and load management of systems with high intermittent renewable energy share

Objectives

- reduce system cost
- increase reliability and lifetime
- increase conversion efficiency

Research topics

PEM technology: development of advanced membranes, alternative bipolar plates, new designs for oxygen and hydrogen evacuation, reversible cells…	membranes for high operating temperature, and with low degradation rate; coated or uncoated metal or organic plates; low Pt loading electrodes – synergies with PEFCs development (see PEFCs fact sheet)
solid oxide technology for high temperature steam electrolysis: development of new electrolyte materials, alternative anodes, new designs for oxygen and hydrogen evacuation, advanced interconnects and sealants, high temperature heat exchangers, reversible cells, …	use of conventional materials for interconnects, coatings or surface treatment for metallic interconnects oxidation resistant, Cr retaining, electrically conductive; sealants based on glass ceramic or mica – synergies with SOFC development (see SOFCs fact sheet)
advanced alkaline technology: pressurised electrolysis	conversion efficiency improvement, hydrogen purity improvement, wide range of load variability, load change speed,…
photoelectrolysis technology: development of highly efficient corrosion resistant photoelectrode materials, bandgap shifting and surface chemistry modification (doping, dye sensitisation), anode-cathode matching, new reactor designs, thin-film mass production, …	improve conversion efficiency (light absorption rate, catalytic activity, reactor design) and device stability (protective layers) – synergies with PV research
system integration	part-load control when associated with highly intermittent energy sources, electric load buffer: frequency control, load management, …

Concentrated Solar Fact Sheet (1)

• good candidate for the use of an abundant renewable energy source wherever wind is not a viable option

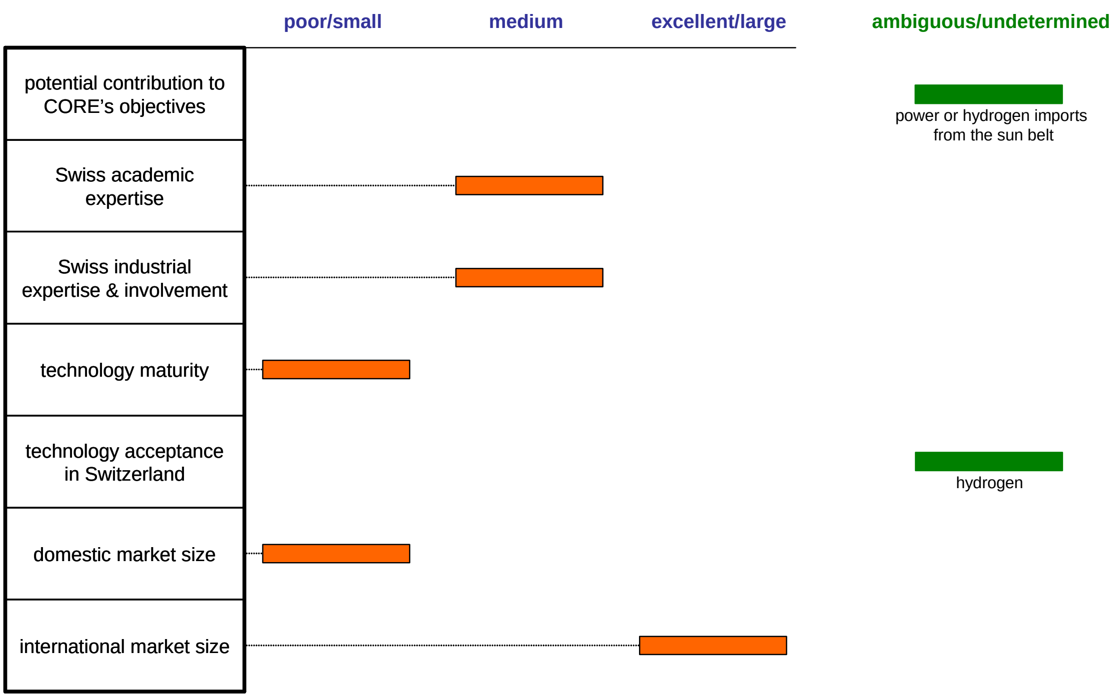
• high cost and high sensitivity to economies of scale tend to lead towards large central systems in the 'sun belt' regions for power generation, hydrogen or other chemical production; but technology also suitable at smaller scale for the energy supply of isolated sites (solar through and ORC, or parabolic dish and Stilring)

• when applied for direct power generation, technology dependent on advanced thermal storage; hybrid cycles are good candidates in the mean term; other applications such as solar chemistry is an alternative or complementary option

• good Swiss academic know-how in solar through technology; first class Swiss academic know-how in thermochemical cycles for hydrogen production with solar chemical reactors and in fossil fuels reforming and cracking

• domestic market potential is low

• worldwide export market potential is large on the longer term for power generation, solar decarbonisation of fossil fuels, and hydrogen production



Concentrated Solar Fact Sheet (2)

Status: 2005

• power from solar concentration: typically 50 MWe plant, ~200 millions euros with 50% share for solar field components (4'000 euros per kWe); ~3 GWe demo plants in the pipeline worldwide (> 10 millions m² of solar collectors) for a total 4.5 billion euros investment with most of them to begin operation in 2010

• solar concentrators: parabolic through up to 400 C, parabolic dish up to 600 C, central tower up to > 2500 C; optical efficiency ~70-98%; solar radiation to thermal energy nominal conversion efficiency ~70 to 95%

• overall power generation nominal efficiency: thermal engine with parabolic dish ~29%; other types ~20%; generation cost ~15-20 cts per kWh

• hydrogen from concentrated solar: direct thermal dissociation of water (> 2000 C), thermochemical water splitting (> 500 C), thermal reduction of metal oxides, hydrocarbons thermal cracking, and hydrocarbons steam reforming; first class Swiss academic know-how

2010 2020 2030 2040

• more detailed resource assessment: link solar radiation levels with land use and topography

• performance improvement: increase optical efficiency under wind loads and thermal efficiency

• component cost reduction: new designs and materials, up-scaling, manufacturing of large volumes of collectors (use of optical components in other markets), …

• greater operating factors: advanced storage devices (molten salt,…), rapid start-up and shutdown procedures, more reliable components (mechanical stability), …

• system integration for greater nominal and average annual overall conversion efficiency; hybrid cycles, combined cycles, high temperature conversion devices (gas turbines, SOFCs,…)

• lower temperature thermochemical processes or water splitting: new thermochemical cycles or new catalysts

• investigate synergies with other industrial applications: non biodegradable waste disposal, production of chemical commodities, water desalination,…

Prospects: 2050

• ~100 to 200 MWe central towers power generation plants; < 1'500 euros per kWe; ceramic receivers with pressurised air as the heat carrier for downstream dual fuel gas turbine or SOFC based combined cycles; output temperature > 800 C; solar share 20 to 50%; electricity generation cost ~5 cts per kWh

• solar upgrading of hydrocarbons by steam reforming in specific receivers in association with large scale combined cycles

• solar through (with direct steam generation in case of small scale applications ~up to 10 MWe); annual solar to electric efficiency > 20%; < 2'000 euros per kWe

• ~1 to 5 MWe advanced (hybrid) dish/Stirling plants; < 2'000 euros per kWe

• hydrogen production plants from thermochemical water splitting at high (~900 C) or medium (~550 C) temperature, and from hydrcarbon thermal cracking

• metal and hydrogen co-production plants (zinc & hydrogen plants with ZnO/Zn cycle)

Objectives

- reduce system and operation cost
- increase reliability and lifetime
- increase conversion efficiency (reduce exergy losses)
- increase operating factor, solar share, domain of usability

Research topics

investigate stress induced by wind loads on large parabolic collectors	optimise collector design – reduce amount of materials needed
develop advanced metal tube and central receivers: selective coatings	maximise absorption of incident solar radiation; minimise radiation losses – smaller solar fields, lower O&M, higher tempearture
develop alternative mirror designs: thin-glass and non metallic structural elements	lower material cost
investigate alternate heat carriers: molten-salt,…	allows higher temperature (> 500 C) – lower thermal storage cost and greater power generation efficiency
develop solar through with direct steam generation	avoids intermediate loop
upscaling of central tower technology based on Rankine cycle and	economies of scale
alternative advanced central tower receiver technology: ceramic coating,…	achieve higher temperature and pressurised systems for gas turbine operation while maintaining acceptable lifetime
system integration: hybrid cycles, advanced thermal storage, combined cycles,…	achieve high solar share and high power generation efficiency
investigate non power applications: hydrogen production, hydrocarbons reforming, upgrading or cracking,….	thermochemical cycles, catalysts,…

Lignocellulosic Ethanol Fact Sheet (1)

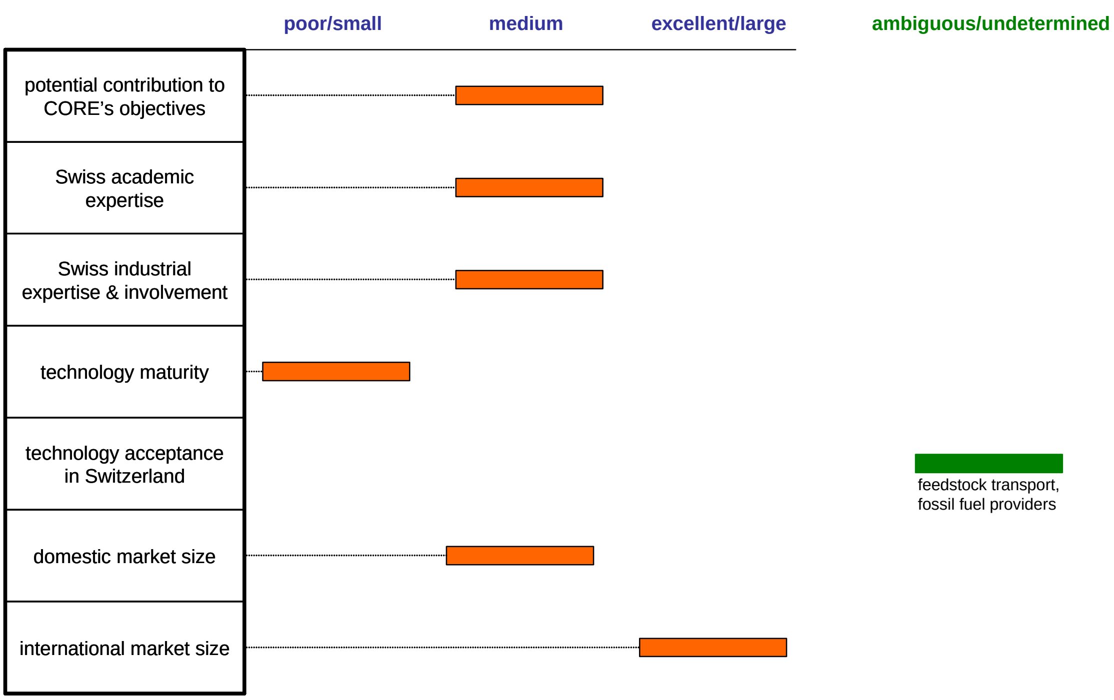
• good candidate in the medium term for the transport sector, while hydrogen vehicles and 'clean' hydrogen are not readily available yet on the market

• good Swiss academic know-how in fermentation and some in enzymatic hydrolysis; as downstream technology is similar (fermentation, distillation, dehydration), recent industrial involvement in more conventional ethanol production technology can be a good support for lignocellulosic ethanol to gain momentum in Switzerland

• some good academic know-how in gasification technology is a good basis for further investigation of lignocellulosic ethanol from thermochemical processes, although focus has been on upgraded syngas so far

• domestic market is limited on the supply side by the relatively low amount of biomass resources collectable in a sustainable way and by potentially much cheaper imported ethanol

• worldwide export potential market is large, not for the ethanol produced for the reasons mentioned above, but possibly for the technology related to thermochemical processing, or downstream side of hydrolysis and fermentation routes, including process residues handling



Lignocellulosic Ethanol Fact Sheet (2)

Status: 2005

- technology for the conversion of lignocellulosic biomass into ethanol is emerging; few providers on the point to deliver lignocellulosic ethanol on the market
- acid hydrolysis pretreatment: dilute acid hydrolysis, sugar yields ~60-80%, fast reaction (allows continuous process), high capital cost (corrosiveness, high temp. ~200 C, high pressure), formation of fermentation inhibiters; concentrated acid hydrolysis, very high sugar yields >90%, low cot materials (low temp. ~40 C & pressure), slow process, costly acid and acid recovery system; combined dilute & concentrated, two-stage process, yield ~95%
- enzymatic hydrolysis pretreatment: high temp. & pressure milling, solvent, or acid or alkaline partial hydrolysis as preprocessing, sugar yields ~80%, relatively low energy requirements, long process (5-7 days) and costly enzymes
- thermochemical pretreatment is being investigated

2010 2020 2030 2040

- reduce production cost: less energy intensive and shorter processes
- investigate a greater diversity of biomass resources; multi-feedstock processing
- investigate further processes with simultaneous sacharification and fermentation – thermo-tolerant fermentation microorganisms
- develop new microorganisms for direct conversion of lignocellulosic fraction into ethanol
- develop new enzymes for fermentation of pentose and hexose simultaneously in a same reactor (genetic modification of baker yeast,…)
- improve pretreatment process: high yield of fermentable sugars, low or zero amount of fermentation inhibiters, chemical recycling, low amount of residues, low cost - investigate alternative acid hydrolysis schemes, identify and demonstrate less costly enzymes, improve gasification reliability and financial viability for thermochemical routes

Prospects: 2050

- lignocellulosic ethanol production cost < 0.05 euros per liter
- lignocellulosic ethanol production from hydrolysis process plants: agricultural residues, wood, and grasses; power and steam required generated from non fermentable products; surplus of electricity sold to the grid; feedstock to ethanol conversion efficiency ~40-55% LHV depending on capacity and feedstock composition; total process efficiency ~55-70% LHV taking into account power and steam produced on-site
- lignocellulosic ethanol production from thermochemical process plants: agricultural residues, wood, and grasses gasification and syngas fermentation with dedicated microorganisms, or gasification and conversion to ethanol with catalytic reaction

Objectives

- reduce system & operation cost
- increase conversion efficiency
- reduce environmental impacts

Research topics

investigate advanced pretreatment techniques: mild alkaline extraction and weak acid hydrolysis in pressurised hot water,…	production of fermentable sugars at lower cost
optimise enzymatic hydrolysis with currently available enzymes	better use of given amount of enzymes; however, cost of currently used enzymes may well remain prohibitive
develop new enzymes	10 fold reduced enzyme cost to reach ethanol production cost from starch
develop new microorganisms for simultaneous hydrolysis and fermentation	low or no added acid pretreatments with advanced ethanol-producing microorganisms represents a significant step towards lowering conversion cost
genetic modification of baker yeast, or development of anaerobic, thermophilic bacteria	fermentation of both 5-carbons and 6-carbons
investigate thermochemical processes: syngas production, catalysts or dedicated microorganisms	integration with gasification process – see gasification fact sheet
investigate new techniques for process integration and residues disposal	reduce water use (currently 4 times the amount used by ethanol from starch processes), co-generation of power and steam with non fermentable materials,…
investigate biorefinery concepts and identify markets for by-products	increase revenues through the co-production of valuable chemicals from the biomass feedstock

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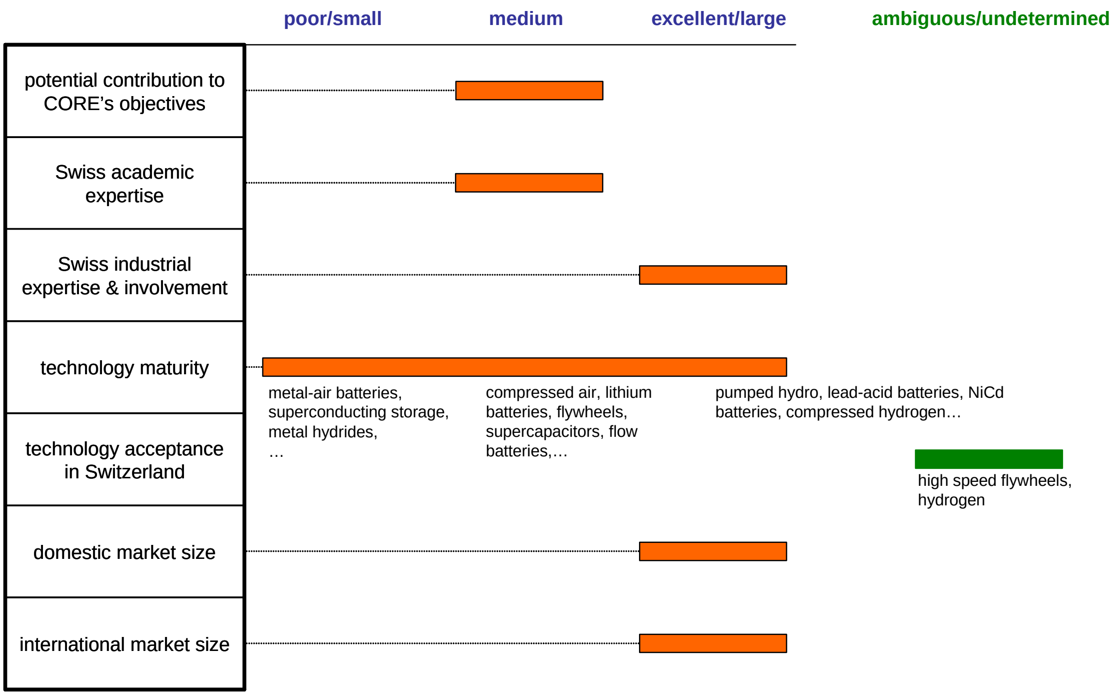
Electricity Storage (Stationary Applications) Fact Sheet (1)

• electricity storage technology is crucial in 'Futures' with high fossil fuel substitution for both centralised or decentralised energy supply

• a significant share of intermittent renewable capacity will require large scale storage facilities at production sites to insure grid stability and improve economics; pumped hydro is obviously the best candidate in Switzerland for such a market due to first class Swiss know-how, high storage efficiency and suitable topography; gas turbine technology first class Swiss know-how can be used for export markets related to compressed air large scale storage

• the installation of new power lines is more and more of a long process – distributed storage allows lower grid capacity for the same electricity consumption ; there is a market for stationary small to medium scale electricity storage even in a 'Future' with centralised energy supply; first class academic Swiss know-how in metal hydrides and superconductivity; very good Swiss academic and industrial know-how in power electronics (converters,…)

• small scale electricity storage is crucial for a viable use of distributed renewable energy sources in isolated sites; the Swiss market of unconnected housing is rather low (mountain housings), but worldwide export market potential is large



Electricity Storage (Stationary Applications) Fact Sheet (2) – medium to large scale

Status: 2005

- large scale storage (~25 MWe and far beyond): pumped hydro and compressed air are most suitable mature technologies
- pumped hydro ~1'000-2'000 euros per kWe, ~50-200 euros per kWh, and 70-85% storage eff.; 90 GW installed worldwide, several in Switzerland
- compressed air 500-800 euros per kWe, ~40-100 euros per kWh, 70-80% eff.(storage only), only a few installations so far, Alstom involved in a large plant project in Ohio
- medium scale storage (~100 kWe to 25 MWe): lead acid, NiCd or NaS batteries are currently the most mature technologies
- lead acid less expensive (~300 to 800 euros per kWe and ~200-1'000 euros per kWh, versus ~500-2'500 euros per kWe and similar stored energy cost for others), but lower lifetime and volume densities; storage eff. (new): lead-acid ~75%, NiCd ~65%, NaS ~85%

2010 2020 2030 2040

- identify suitable sites for new large pumped hydro and compressed air
- investigate compressed gas hydrogen storage for diversification of applications; improve storage efficiency – see also fuel cells & electrolysers fact sheets
- for medium scale applications, improve and further demonstrate redox flow batteries (Vanadium, Zinc bromine), compressed hydrogen storage, superconducting storage, high energy flywheels, and small compressed air systems
- investigate hybrid storage systems and integration with renewable or nuclear energy sources, e.g. storage capacity/wind farm capacity optimisation, …achieve high capacity factors
- improve power electronics for more efficient conversion

Prospects: 2050

- optimal design and operation of large wind/hydro (>90% eff) or wind/compressed air systems
- high pressure medium scale compressed air systems: ~10 to 25 MWe during 3 to 5 hours, > 80% eff, < 500 euros per kWe
- hydrogen storage: compressed gas associated with advanced electrolysis and fuel cells; >45% eff
- redox flow batteries: ~10 to 25 MWe during 3 to 5 hours, > 80% eff, 150 euros per kWh, 15 years lifetime
- large magnetic bearing & high energy low speed (~5'000 t per min) flywheels: >90% eff, > 800 Wh per kg, ~200-500 euros per kWh @ 100-300 kWh capacity
- magnetic storage systems with high temperature superconductors with high critical current densities: >90% eff,

Objectives

- increase storage efficiency
- increase reliability and lifetime
- enlarge domain of usability
- reduce storage cost

Research topics

improve reversible hydro turbines: specific optimal design, advanced generators, understanding of unsteady phenomena	improved pumped hydro storage efficiency and reliability, and turbine lifetime; downscaling for capacities < 10 MWe
systematic cartography of high head and steep topography sites; identify repowering opportunities	high head reduces required size (lower capital cost) and steep topography allows short water passages ; repowering makes use of existing infrastructure
optimisation techniques, inc. real time, for optimal design and management of integrated storage/renewables systems	best use of variation of boundary conditions - critical to commercial viability of storage schemes
advanced flow batteries: improve chemical stability of separators, electrodes, and electrolytes, optimise hydraulic balance - pump energy management and electrolyte distribution, …	optimised flow geometry avoids local electrolyte starvation, recyccling and advanced manufacturing of electrolyte reduces cost, oxidation resistant materials,…
develop affordable high strength materials	affordable upscaling of high energy flywheels
develop affordable high temperature (60-70 K) superconductors with high critical current densities	use of liquid nitorgen instead of helium for superconducting magnetic energy storage; affordable upscaling; synergies with flywheels magnetic bearings
compressed air systems downscaling	high pressure vessels; small scale gas turbine technology
develop advanced power electronics	reach greater power conversion efficiency at lower cost; more reliable auxiliaries

Electricity Storage (Stationary Applications) Fact Sheet (3) – micro to small scale

Status: 2005

• small-scale storage (~10 kWe to 100 kWe): lead acid, NiCd, sodium nickel chloride (zebra), or lithium batteries and conventional speed flywheels are currently the most mature technologies

• lead-acid batteries: high storage eff. ~80-90%, low cost ~100 euros per kWh, but high degradation rate and low energy densities ~35-40 Wh per kg and 100 Wh per l

• NiCd batteries: greater lifetime than lead-acid but much more expensive, Cd toxicity (future ban?)

• lithium batteries: very high storage eff. ~90-98% (new) for slightly higher cost than lead-acid

• micro-scale storage – power quality or domestic applications (<10 kWe): lead acid, NiCd, and metal-air batteries, supercapacitors, and flywheels are currently the most mature technologies

• metal air batteries: low stored energy cost ~20-40 euros per kWh, high weight and volumetric energy densities ~80-120 Wh per kg and 60-80 Wh per l, but low eff. ~50-60%

• supercapacitors and flywheels are ideal candidates for the power quality market

2010 2020 2030 2040

• improve lifetime, efficiency and recycling methods of lead-acid batteries

• improve lifetime and cost of LI-ion batteries and efficiency of metal-air batteries; reduce discharge rate for both types

• investigate compressed air/oil systems

• improve efficiency of hydrogen storage: high pressure gas or metal hydrides – see also fuel cells & electrolysers fact sheets

• for micro scale applications, improve batteries lifetime, improve and further demonstrate supercapacitors, advanced metal-air batteries, and advanced metal hydrides for hydrogen storage

• improve power electronics for more efficient conversion

• investigate hybrid storage systems and integration with distributed renewable energy sources; control algorithms

Prospects: 2050

• long life and cycle life lead-acid batteries @ ~50 euros per kWh

• lithium batteries: lifetime equivalent to PV modules (~20 years), >95 eff. (new); 150 euros per kWh (high energy), 35 euros per kWe (high power)

• metal-air batteries: > 70% eff. (new), < 50 euros per kWh

• small scale compressed air/oil isothermal systems: >60% eff.

• hydrogen storage: associated with advanced electrolysis and fuel cells; >40 % eff

• magnetic bearing & high sped (> 30'000 t per min) flywheels: >90% eff.

• small scale high speed flywheels

• magnetic storage systems with high temperature superconductors with high critical current densities: >90% eff,

Objectives

- increase storage efficiency
- increase reliability and lifetime
- enlarge domain of usability
- reduce system cost

Research topics

optimisation techniques, inc. real time, for optimal design and management of integrated storage/renewables systems	best use of variation of boundary conditions - critical to commercial viability of storage schemes
lead-acid batteries: new active material formulation and separators for greater lifetime and cycle life	reach typically 2'000 cycles @ 20C & 100% DOD (x 4 versus today's performance)
lithium batteries: new oxide materials for Li-ion, increased ionic conductivity and stability of electrolyte for Li-polymer	improve lifetime significantly to typically reach 3'000 cycles @ 20C & 100% DOD (x 3 versus today's performance)
metal-air batteries: development of new catalysts and high surface area electrodes	improve efficiency; bi-functional air electrodes (for possible electric recharging) or fast mechanical recharging
downscaling of compressed air systems	
investigate new metal hydrides & hydrogen chemical storage	requires advanced electrolysers and affordable and reliable fuel cell technology
develop ultra-high strength materials and safety standards: advanced composite materials,…	distributed high speed flywheels; certification issue
develop affordable high temperature (60-70 K) superconductors with high critical current densities	use of liquid nitorgen instead of helium for superconducting magnetic energy storage; synergies with flywheels magnetic bearings
develop advanced power electronics	reach greater power conversion efficiency at lower cost

Insulation Technologies fact sheet (1)

- very good thermal insulation
- reduction of space demand for high efficiency insulation
- problems of thermal bridges can be avoided
- long term integrity of vacuum insulation can be expected
- positive characteristics for building design
- research and development capacity in Switzerland

Insulation Technologies Fact Sheet (2)

2005	2010 2020 2030 2040	2050
status		**prospects**

status (2005)

- technology in demonstration projects and niche market applications.
- efficiency about factor 10 to conventional insulation materials.
- no long term experience with long term integrity of vacuum.
- planning tools and handling manuals under development.
- technology costs are not yet known.
- unsatisfying technologies for air intrusion detection and replacement of vented panels
- academic R&D performed in Switzerland
- no industrial production identified in Switzerland

2010 2020 2030 2040

- application of vacuum insulation in zones of limited space availability
- application of vacuum insulation for special constructive elements i.e. doors and window framing
- application of vacuum insulation in the high-price building sector (commercial buildings in city centres)
- enforced professional training of construction personnel in handling of vacuum technologies
- mass production of prefabricated vacuum panels and constructive elements

prospects (2050)

- vacuum insulation is a proven long term stable technology
- vacuum insulation has a good market diffusion in the field of elaborated building design
- vacuum technologies are state of the art in office buildings
- the option to realise elaborated building design with the availability of low thickness, high efficiency vacuum insulation generates professional and public acceptance for far reaching building standards
- with good cost reductions, large market share can be expected
- potential reduction of 38 PJ (2kW-study)

Objectives

- reduce risk of damaging:
- increase durability of vacuum:
- avoid risk of long term undetected failure of vacuum insulation
- improved exchangeability of damaged panels
- reduce costs of vacuum insulation panels

Research topics

Development of sandwich design elements and prefabricated façade elements for variable application	simple panels are easily damaged at construction sites Reduced risk of damaging has a high impact on the usability of vacuum insulation
Investigate long term behaviour of seal materials	lifetime of 30 or more years has to be reached for a wide applicability
Further development of adhesives for sealing of panels	Trade of between tightness and durability of aluminum based sealing foils an their high thermal conductivity
Low cost thermal scan technologies for buildings	
development of adapted sealing foils for different climate conditions	
development of detection technologies for vented panels	

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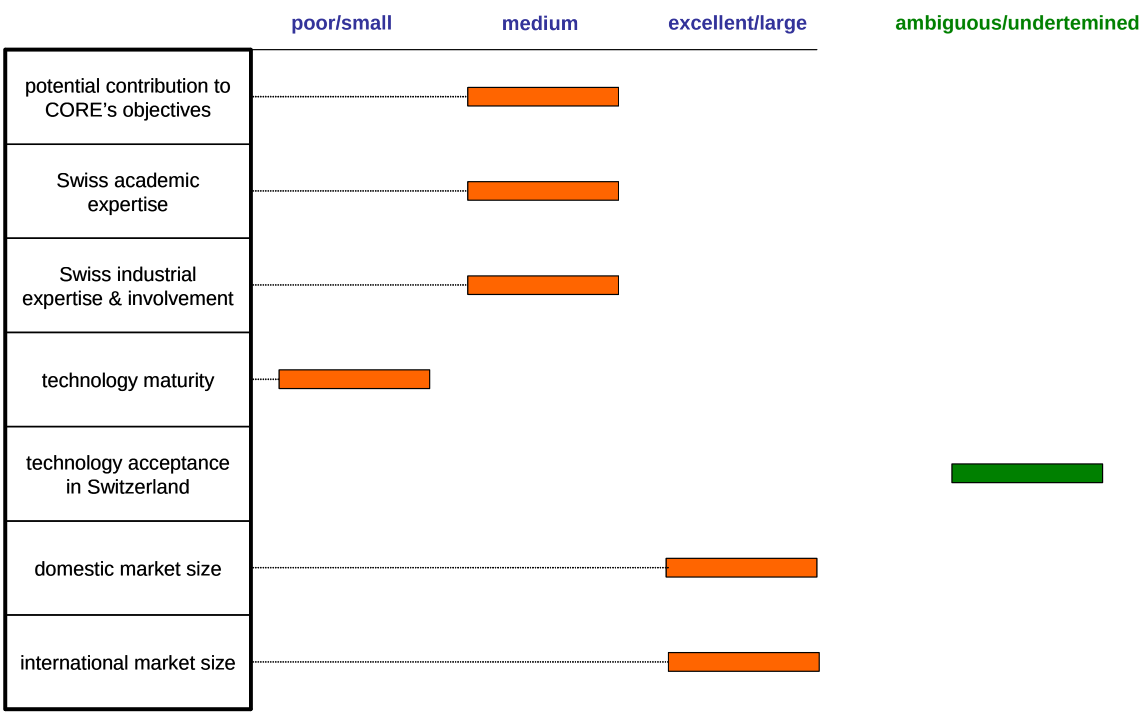
Advanced window technologies: switchable glazing Fact sheet (1)

- improvement of indoor room quality
- improvement control of indoor energy balance
- reduction of cooling demand
- extended usability of daylight lighting
- avoidance of moving parts of conventional shading elements and by consequence lower risk of failure and lower maintenance cost
- allowing the use of low central control technologies and thus user independent strategies for improved indoor climate control



Advanced window technologies: switchable glazing Fact Sheet (2)

2005 status	2010 2020 2030 2040	2050 prospects
• product stage for Particle Dispersed Liquid Crystal technologies (PDLC) • pilotproduction for electrochrome glazing and gaschrome glazing technologies • laboratory status and prototypes for photo-electrochrome, thermochrome and thermotrope technologies • cost information not yet available • possible further development of successful Swiss products of high insulation window technologies	• development of market ready products with different switchable glazing technologies • cost reduction with increasing production • increase of size of single window sheets	• wide application as durable and reliable shading system • application in autonomous (i.e. photochrome glazing) or automated building management (i.e. electrochrome glazing) • reduction of space cooling energy demand by reliable and efficiently managed switchable glazing technologies

Objectives	Research topics
Increase difference between switched states	
reduce energy demand in electrochrome glazing	
reduce costs for switchable glazing	
increase size of panels	

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Mechanical Ventilation technologies fact sheet (1)

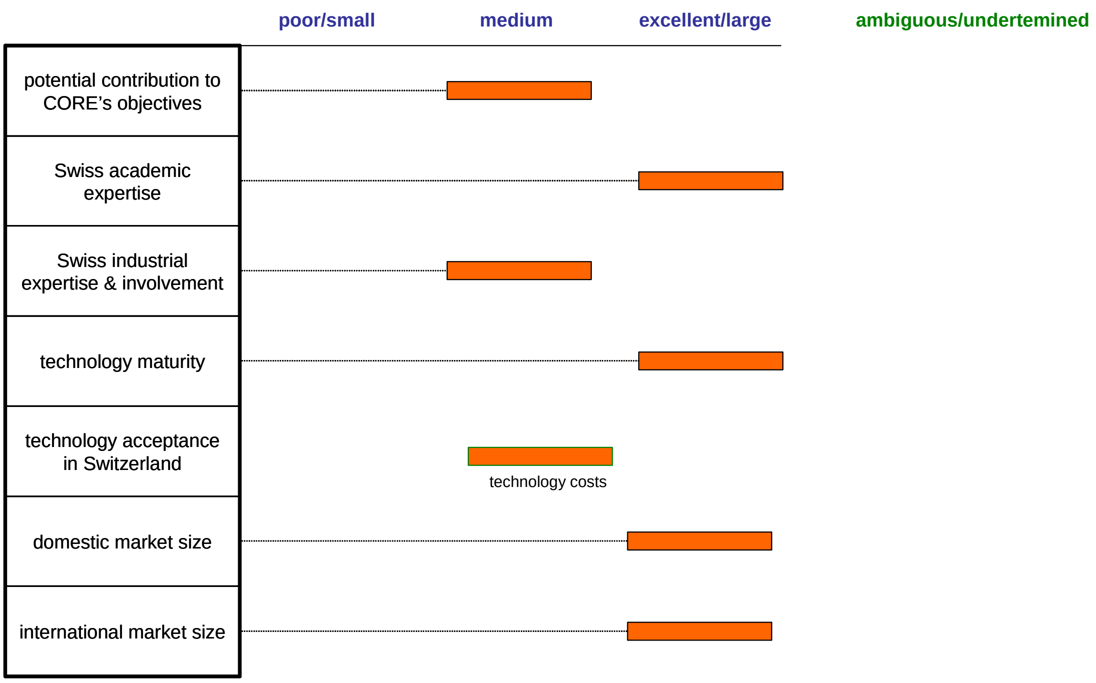
• Mechanical ventilation technologies allow fulfilling high air quality standards while avoiding unrecoverable heat losses

• large unharvested potential for efficiency improvement in the residential building sector

• mature technologies are already available on the market

• headroom for technology improvement is still available (e.g. counterflow heat exchangers)

• industrial expertise and high quality production of large scale ventilation systems



Mechanical Ventilation Fact Sheet (2)

2005 status	2010 2020 2030 2040	2050 prospects
• controlled ventilation makes up 12% of final energy consumption (2kW) • ventilation with heat recovery in only 5% of the households • implementation problems such as pressure drops, air leakage, noise problems, vibrations • increased penetration of energy efficient controlled ventilation could save 31 PJ/a • advanced ventilation obsolete due to low overall standards of building energy efficiency	• improved implementation of controlled ventilation in buildings with higher energy efficiency standard • increased penetration of controlled ventilation in the residential building sector • increased penetration in the commercial sector • improved efficiency of heat recovery systems • improved performance of applied electrical motors and drives • improved control technologies and interplay with variable speed drives	• controlled ventilation is broadly deployed in the residential and commercial building sector • efficient heat recovery is state of the art in buildings (eff. > 80%) • control systems interacting efficient motors and drives allow with minimum electricity need for ventilation

Objectives

- Reduce thermal energy losses by ventilation:
- Reduce costs of ventilation systems
- Improve energy efficiency of ventilation system technology: reduce electricity demand for ventilation
- Improve comfort of controlled ventilation technologies

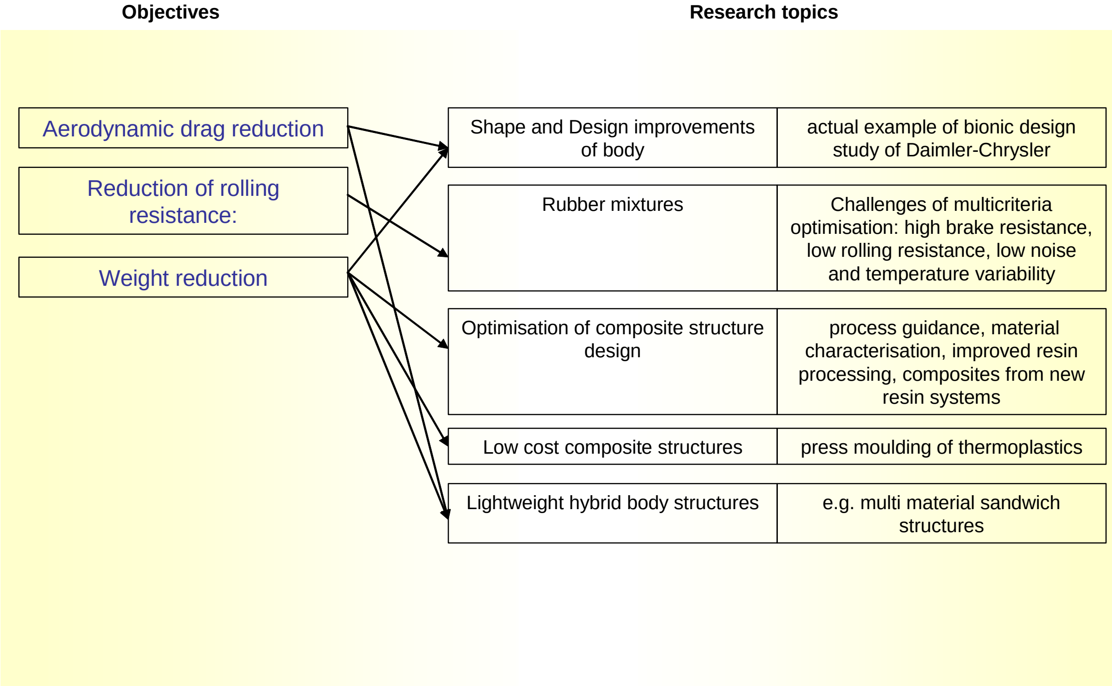
Research topics

Improved heat recovery systems: low pressure drop counterflow heat exchangers	actual state of the art are crossflow heat exchangers
Adaptation of energy efficient motors for ventilation purposes	
Controlled ventilation systems with variable speed drives	Realisation of demand controlled ventilation strategies
Air quality sensing technologies and control algorithms	Realisation of demand controlled ventilation strategies
Failure proof noise avoidance technologies and system integration strategies strategies	

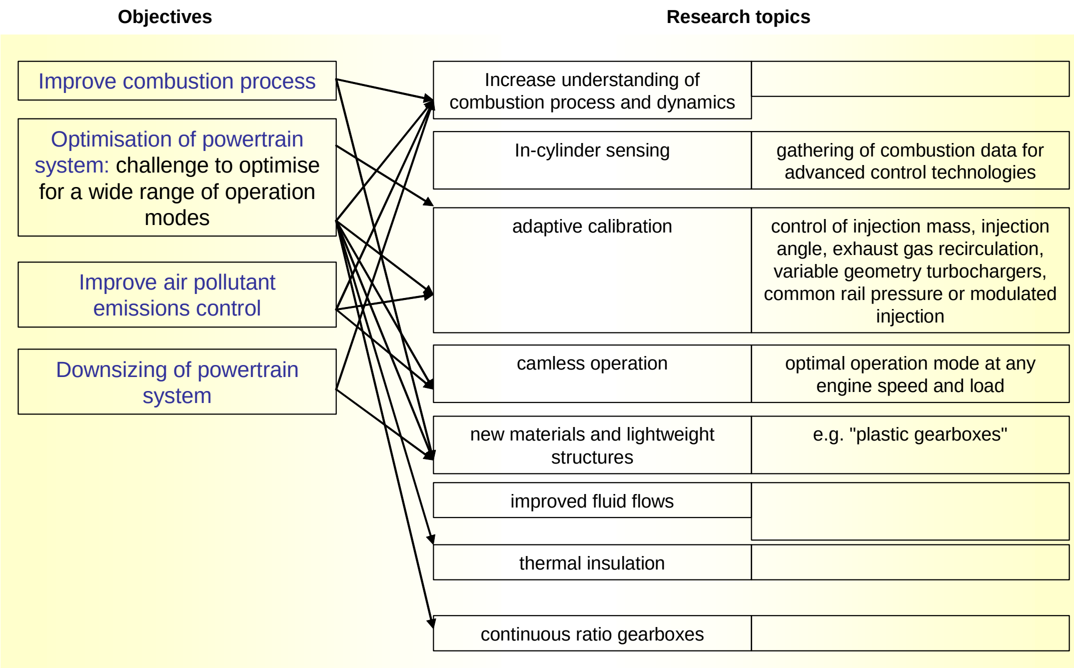
Efficient Passenger Car Fact Sheet (Part 1)

- large efficiency improvement potential
- passenger cars likely to maintain important role in modal split safeguarding a large market for efficient transport technologies
- Economic parameters for efficiency technologies likely to improve due to probable price increase of transport fuels

Efficient Passenger Car Fact Sheet (Part 2) – Body and Tires



Efficient Passenger Car – Conventional Drive Train



Hydrogen storage in vehicles – compressed hydrogen: Fact sheet (1)

- high amount of operational experience with pressurised gas storage
- low cost solution (in comparison to other storage options)
- practicability and usability
- reliable storage system
- no boil-off effects

Hydrogen storage in vehicles – compressed hydrogen Fact Sheet (2)

2005	2010 2020 2030 2040	2050
status		**prospects**

2005 – status

- technology of compressed gases is state of the art today in passenger vehicles
- tank cost about 1500 CHF for 150 kWh of hydrogen
- cylindrical tanks out of steel, aluminium or composite materials
- 350 bar pressure is commercially available
- 700 bar tanks are under development

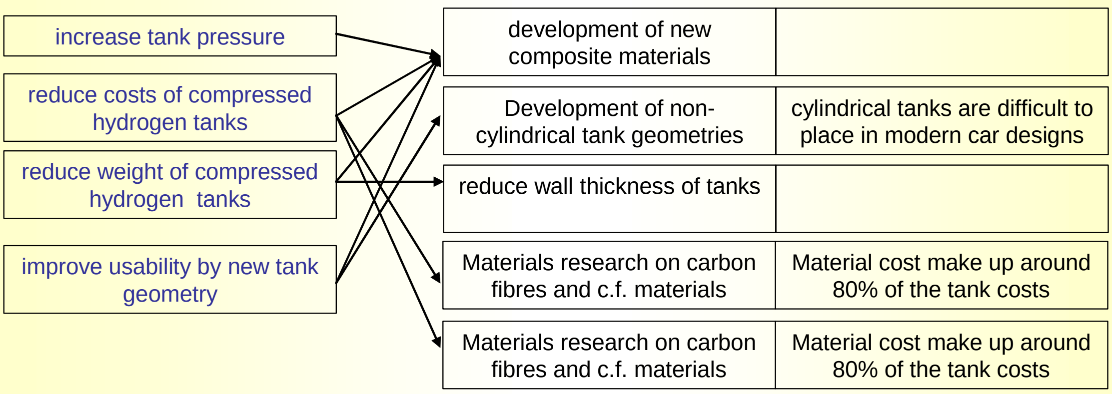
2010 2020 2030 2040

- increase of tank pressure
- cost reduction achieved by mass production and wider ranger of manufacturers on the market

2050 – prospects

- high pressurized tanks allow suitable driving range for high comfort personal vehicles
-

Objectives | **Research topics**



Hydrogen storage in vehicles – liquid hydrogen: Fact sheet (1)
• high volumetric density of hydrogen stored • reasonably high gravimetric density of hydrogen stored • avoidance of high pressured gases improves inherent safety • operational experience with hydrogen at least existent from special applications (e.g. space crafts) • prolonged storage without boil-off (~2 weeks) can be reached already

Hydrogen storage in vehicles – Liquid hydrogen storage Fact Sheet (Part 2)

2005 status	2010 2020 2030 2040	2050 prospects
• liquid hydrogen storage tanks are employed in test vehicles (BMW, GM) • tanks for liquid hydrogen in cars are not produced in series production • cost data for liquid hydrogen tanks not yet known	• development of automated production processes • increased market size and manufacturer's competition	• liquid hydrogen tanks used as safe, reliable solution for hydrogen storage in fuel cell vehicles

Objectives

- reduce boil off
- increase gravimetric storage density
- increase volumetric storage density
- reduce tank costs

Research topics

reduce conductive losses in tank wall materials	
reduction of wall material thicknesses	
automated production processes to reduce manual labour share	targets for tank costs reduction are in the order of factor 10 to 20.
advanced multistage cooling of hydrogen tanks	first tank designs are available liquefying air with boil of hydrogen and using this liquid air as additional cooling stage

Electricity storage in vehicles – lithium batteries: Fact sheet (Part 1)
• favourable gravimetric and volumetric energy density • good gravimetric power density • high amount of charging cycles • Academic research capacity • Industrial research

Electricity storage in vehicles – lithium batteries: Fact Sheet (Part 2)

2005 | **2010 2020 2030 2040** | **2050**

status

- widespread application in portable applications
- application in niche markets for transportation
- high costs of electricity (CHF 800 to 1300/kWh)
- Energy density
  80-200 Wh/kg
  300-400 Wh/l
- Charging cycles: 600-1000

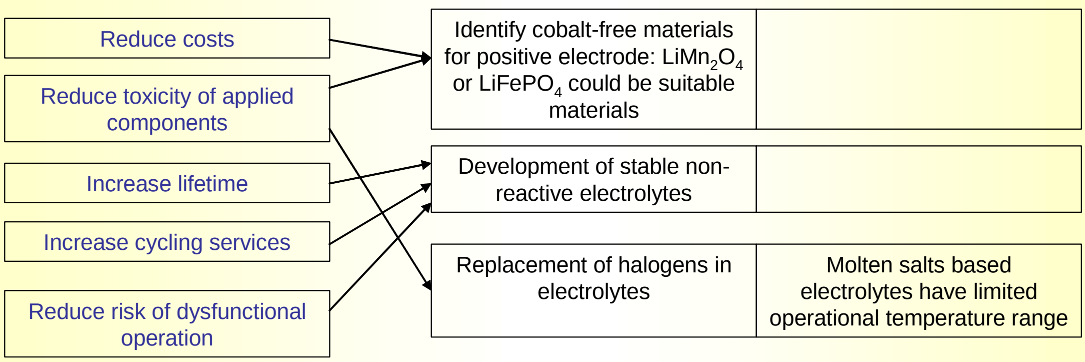
2010 2020 2030 2040

- application in hybrid vehicles starting from niche markets (today) to mass markets

prospects

- substantial reduction of costs
- > 3000 charging cycles
- reduction of energy costs by 80% to 90%
- widespread application of lithium batteries in hybrid vehicles in urban regions

Objectives | **Research topics**



Electricity storage (in vehicles) – supercapacitors: Fact sheet (1)

- extremely high gravimetric power density
- extremely high amount of charging cycles
- research capacity in Switzerland: ABB, PSI, SME's

Electricity storage (in vehicles) – supercapacitors: Fact sheet (2)

2005 | 2010 | 2020 | 2030 | 2040 | 2050

status

- applied for power storage for power quality
- high technology costs (CHF 70 to 220/Wh)
- Energy density 5-10 Wh/kg
- power density 100- 5000 W/kg
- Charging cycles: 100k to 500k

- application to balance short term fluctuating power production of renewable energy sources

prospects

- substantial reduction of costs
- improvement of energy density
- application for flattening peak demand and supply fluctuations in vehicles with electrical drive train

Objectives

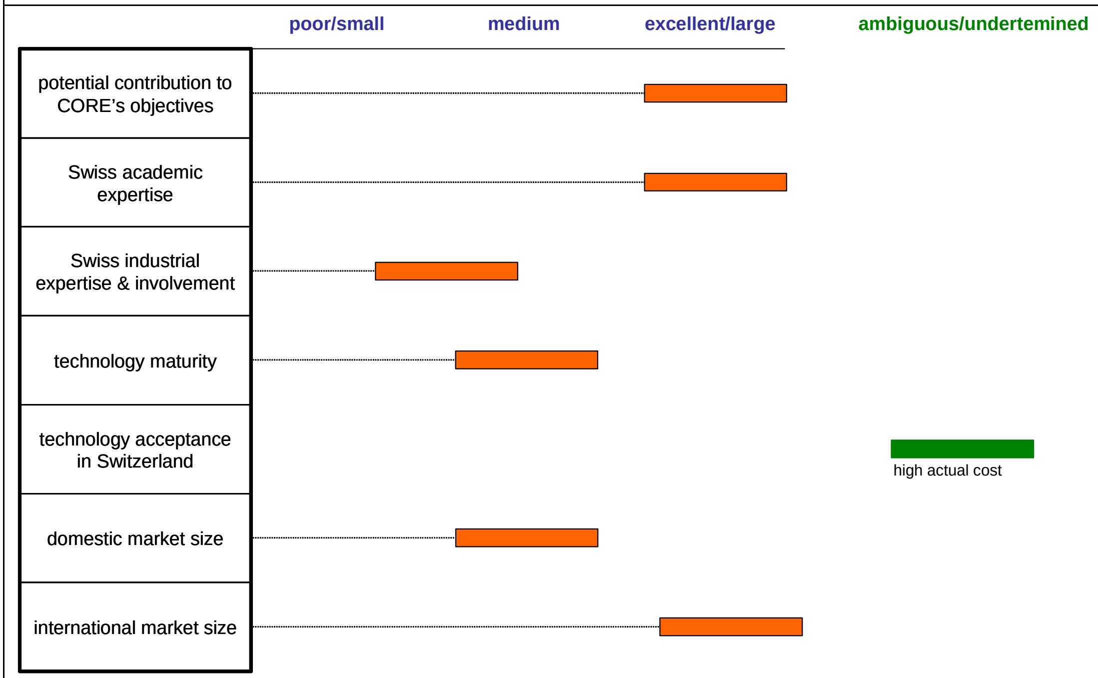
- Reduce costs: carbon, electrolyte and separator field
- Improve energy density
- Increase lifetime

Research topics

- Decrease particle size of carbon in order to increase surface area
- Increase voltage of capacitors by use of organic electrolytes
- Design improvements of electrode structure

PV technologies: Fact sheet (1)

- large potential for solar energy use
- modular application
- strong learning effects observed in the past and anticipated for the future
- crystalline silicon cells are state of the art technology
- variety of alternative PV technologies (thin film crystaline, thin film amorphous, thin film CIS, organic solar cells, dye sensitized solar cells) with high potential for future application resulting from potential for significant cost reduction due to low cost materials and more simple production technologies



PV technologies: Fact sheet (2)

2005 | 2010 2020 2030 2040 | 2050

status

- Electricity generation costs in the order of 0.3 to 0.8 CHF/kWh
- Module lifetime ~20-25 years
- Module efficiencies in the order of 15% (multi -crystalline) 17% (mono-cryst.)
- demand in waver material 14g of silicon per Wp (cryst.)
- Crystalline cells make up 95% of world production
- Swiss market size ~ 1.7 to 2.5 MWp/year (1998 to 2004)
- advanced technologies in view with good prospects in efficiency and costs

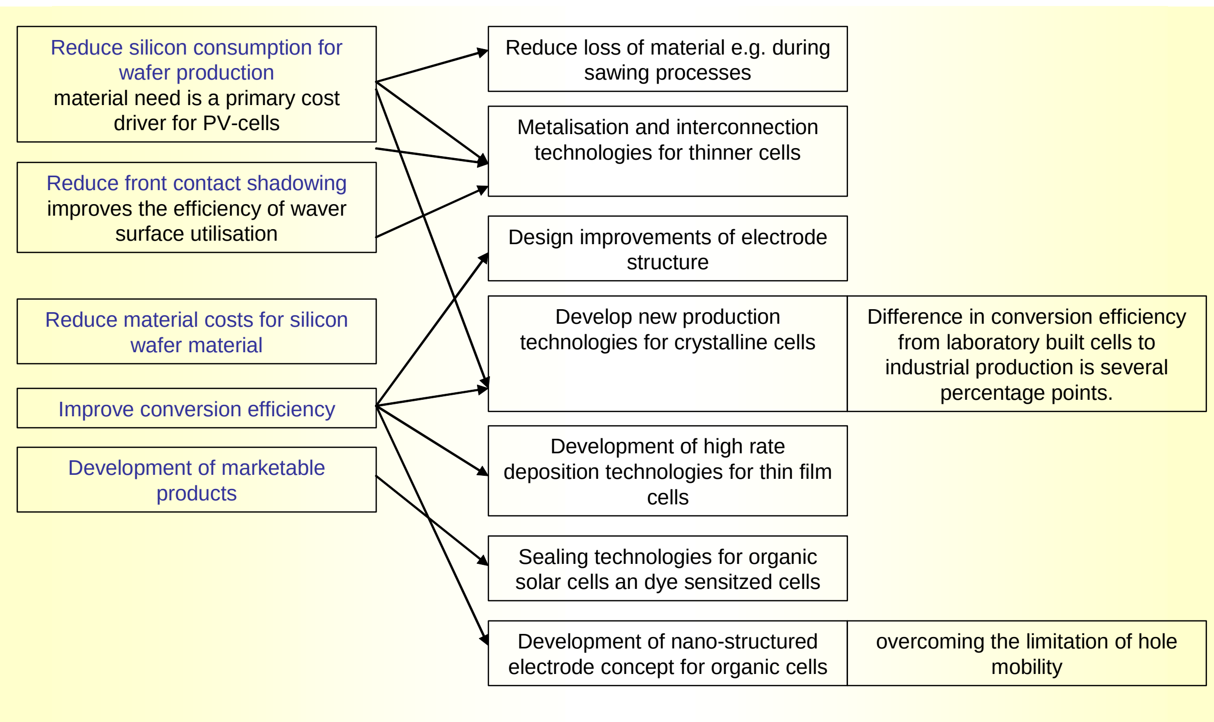
2010–2040

- stepwise reduction of module cost by improvements in production processes and low cost feed-stock material
- improvement of conversion efficiency by approaching industrial production processes to laboratory standards
- starting market penetration of low cost cells with advanced technologies

prospects

- reduction of crystalline silicon solar PV electricity costs to < 0.15 CHF/kWh
- module lifetime >40 years
- module efficiencies 25% or above
- silicon waver demand < 8g/Wp
- PV cells for large scale window and façade integration

Objectives | **Research topics**



Geothermal technologies: Fact sheet (1)

Geothermal technologies: Fact Sheet (2)

2005 — **2010 2020 2030 2040** — **2050**

status (2005)

- geothermal heat pumps are state of the art technology in residential housing however with a limited market penetration in the space heating market
- Different systems of heat exchange from very shallow earth collectors to medium depth ground water heat exchangers
- Hydrothermal geothermal energy use for heat generation is in the transition phase from demonstration phase to full commercial phase (limited market size still)
- Hydrothermal geothermal electricity generation is in transition from demonstration to commercial phase with substantial regional differences. In regions with high enthalpy sources (e.g. Italy, hydrothermal electricity can be seen as fully commercial)
- Enhanced geothermal systems (hot dry rock [HDR] and hot fractured rock [HFR]) are in transition from R&D phase to Demonstration phase

2010 2020 2030 2040

- Improved exploration technologies reduce the risk of failure for drilling campaigns
- cost reduction for drilling technologies and drilling campaigns
- Improvements of stimulation procedures for enhanced geothermal systems
- Increased penetration of geothermal energy use allows better statistical risk assessment and thereby allows insuring the drilling risk

prospects (2050)

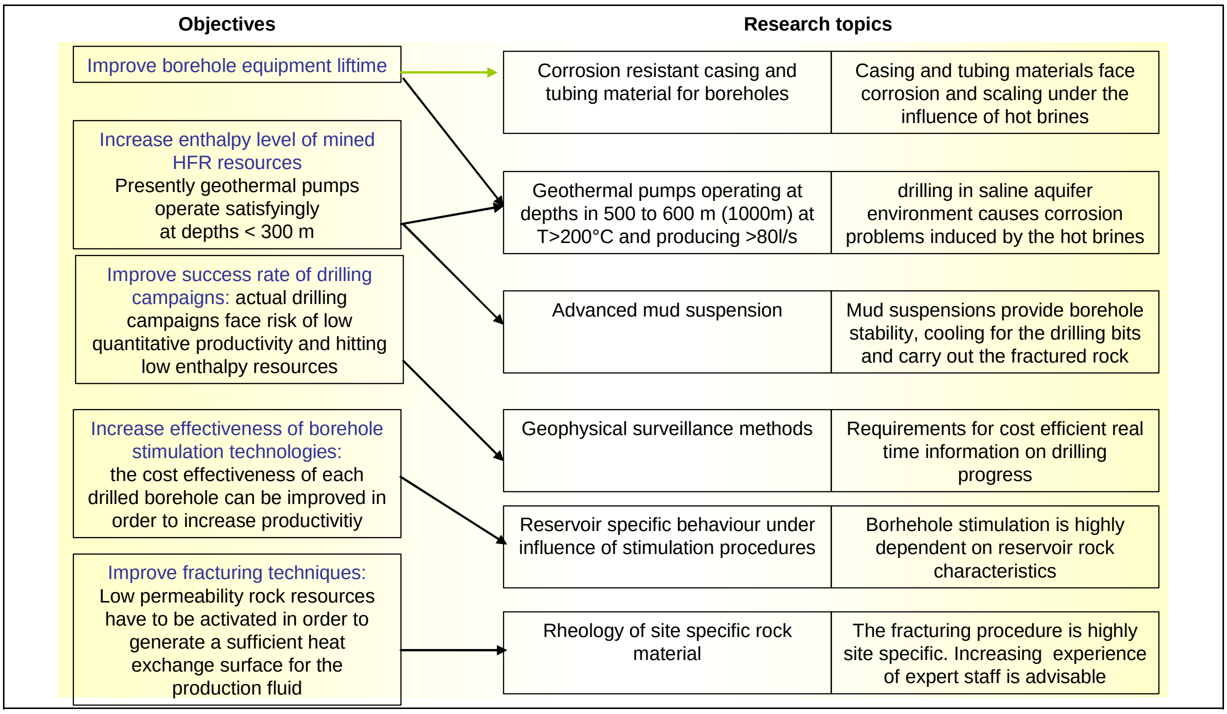
- geothermal heat pumps supply a large share of the residential and commercial heat demand
- hydrothermal geothermal energy supplies small to medium scale district heating systems and provides medium temperature process heat for industrial and tertiary sector applications
- hydrothermal electricity generation is state of the art in combination of integrated heat use
- Enhanced geothermal systems provide a significant (substantial) contribution to meeting the electricity demand and make up the dispatchable backbone of the renewable electricity supply.

Objectives

- Reduce drilling costs: drilling costs make up a considerable part of overall plant costs
- Reduce risk of drilling failure: boreholes face the risk of collapsing
- Improve success rate of drilling campaigns: actual drilling campaigns face risk of low quantitative productivity and hitting low enthalpy resources
- Increase effectiveness of borehole stimulation technologies: the cost effectiveness of each drilled borehole can be improved in order to increase productivitiy
- Improve fracturing techniques: Low permeability rock resources have to be activated in order to generate a sufficient heat exchange surface for the production fluid

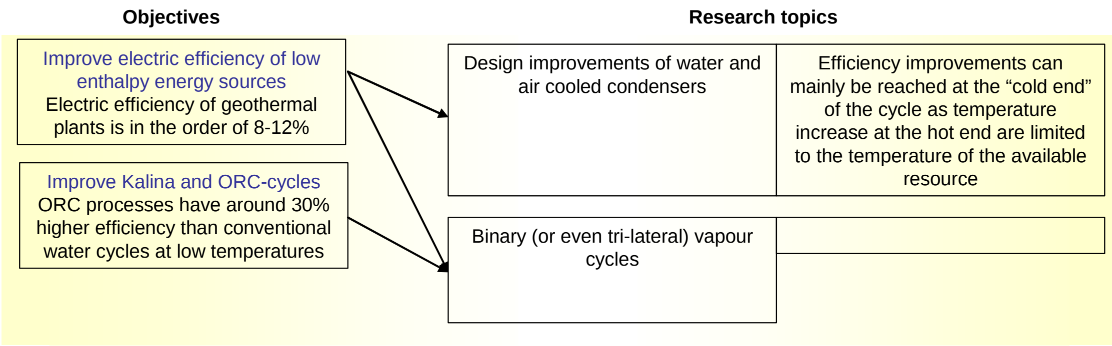
Research topics

Improve drilling bit durability	The durability of the drilling bits controls the required intervals for time consuming drilling bit exchange
Develop new corrosion protection materials for drilling equipment	drilling in saline aquifer environment causes corrosion problems induced by the hot brines
Advanced mud suspension	Mud suspension fulfill the task to carry out the fractured material, to support the borehole walls against collapsing and to cool the drilling bits
Geophysical surveillance methods	Requirements for cost efficient real time information on drilling progress
Reservoir specific behaviour under influence of stimulation procedures	Borhehole stimulation is highly dependent on reservoir rock characteristics
Rheology of site specific rock material	The fracturing procedure is highly site specific. Increasing experience of expert staff is advisable


Objectives
Research topics
Improve borehole equipment liftime
Increase enthalpy level of mined HFR resources
Presently geothermal pumps operate satisfyingly at depths < 300 m
Improve success rate of drilling campaigns: actual drilling campaigns face risk of low quantitative productivity and hitting low enthalpy resources
Increase effectiveness of borehole stimulation technologies: the cost effectiveness of each drilled borehole can be improved in order to increase productivitiy
Improve fracturing techniques: Low permeability rock resources have to be activated in order to generate a sufficient heat exchange surface for the production fluid
Corrosion resistant casing and tubing material for boreholes
Casing and tubing materials face corrosion and scaling under the influence of hot brines
Geothermal pumps operating at depths in 500 to 600 m (1000m) at T>200°C and producing >80l/s
drilling in saline aquifer environment causes corrosion problems induced by the hot brines
Advanced mud suspension
Mud suspensions provide borehole stability, cooling for the drilling bits and carry out the fractured rock
Geophysical surveillance methods
Requirements for cost efficient real time information on drilling progress
Reservoir specific behaviour under influence of stimulation procedures
Borhehole stimulation is highly dependent on reservoir rock characteristics
Rheology of site specific rock material
The fracturing procedure is highly site specific. Increasing experience of expert staff is advisable

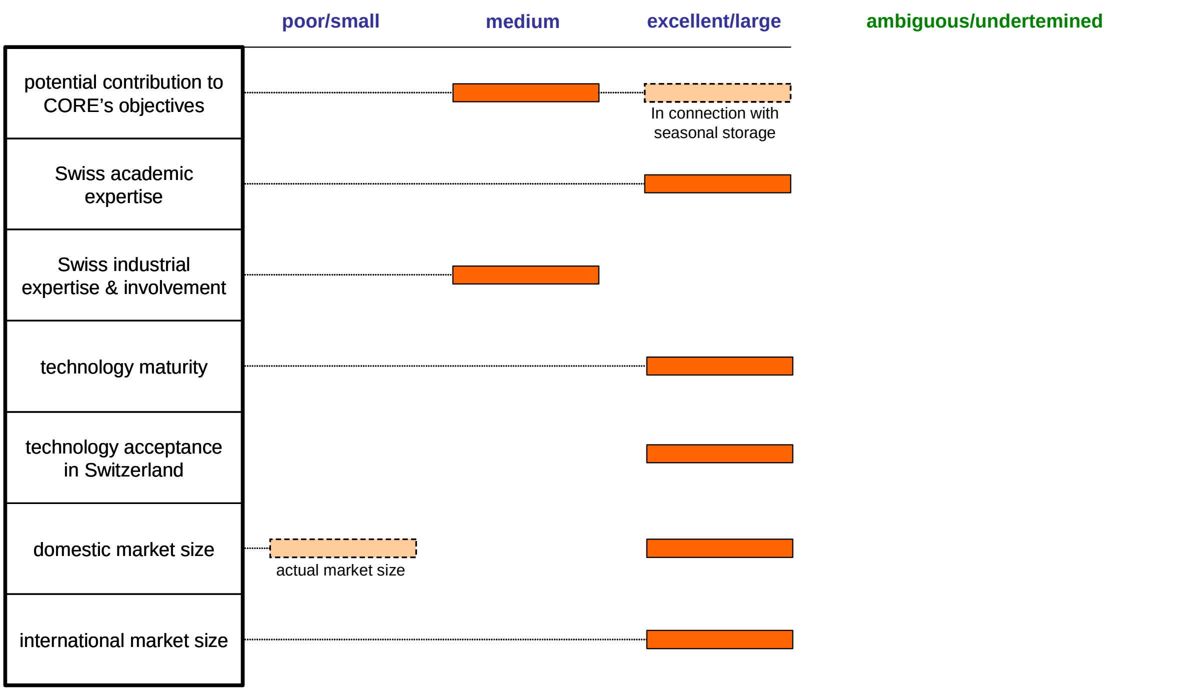
Geothermal Electricity Generation: Fact sheet (1)

Geothermal Electricity Generation: Fact Sheet (2)



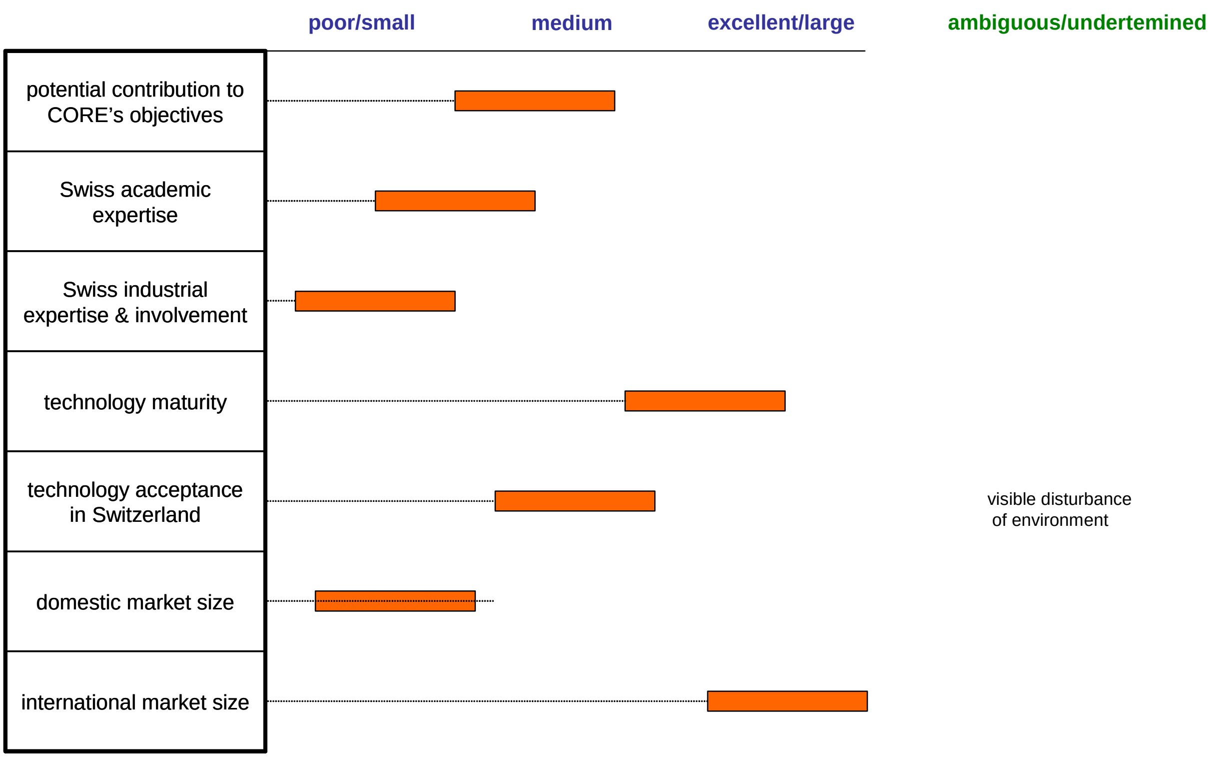
Solar thermal collectors: Fact sheet (1)

- technology is well developed already today
- no constraints in public acceptance
- wide range of applications
- large freedom in dimensioning applications



Solar thermal collectors were found to be a largely mature technology. In the literature, no specific research fields and activities could be identified. The market is dominated by SME, where product development is not performed in specific research departments.

Wind Energy Fact Sheet (1)



Wind Energy Fact Sheet (2)

2005	2010 2020 2030 2040	2050
status		**prospects**
• Wind energy production 2004 6.4 GWh • Wind turbine capacity 2004 below 10 MW • Wind capacity costs 1300 to 1800 CHF/kW	• increasing penetration of wind turbines • continued adaptation of turbines to the continental wind regime	• Potential contribution of 1.6 TWh • Wind power capacity costs between 1000 and 1400 CHF/kW

Objectives

- Increase rotor area
- Improve rotor area to rotor weight ratio
- Improve long term endurance of rotor blades
- Improve reliability of drive trains
- Reduce weight of drive train and generator
- Improved grid integration

Research topics

material development for lightweight, high endurance, cost effective blades	Glass fibre epoxy is state of the art compromise between costs and material properties. Carbon fibre epoxy actually not yet cost efficient
Investigation of gear transmission failure reasons (poor lubrication, wrong use of roller bearings)	
Development of modeling and calculation tools for wind turbine gear design	
Weight and size reduction of multi-pole generators	multi-pole generators not yet competitive with traditional drive trains with mechanical gears
Improved prediction tools for wind power generation	

Generation IV reactor technologies: Fact sheet (1)

• Nuclear energy conversion provides reliable energy supply

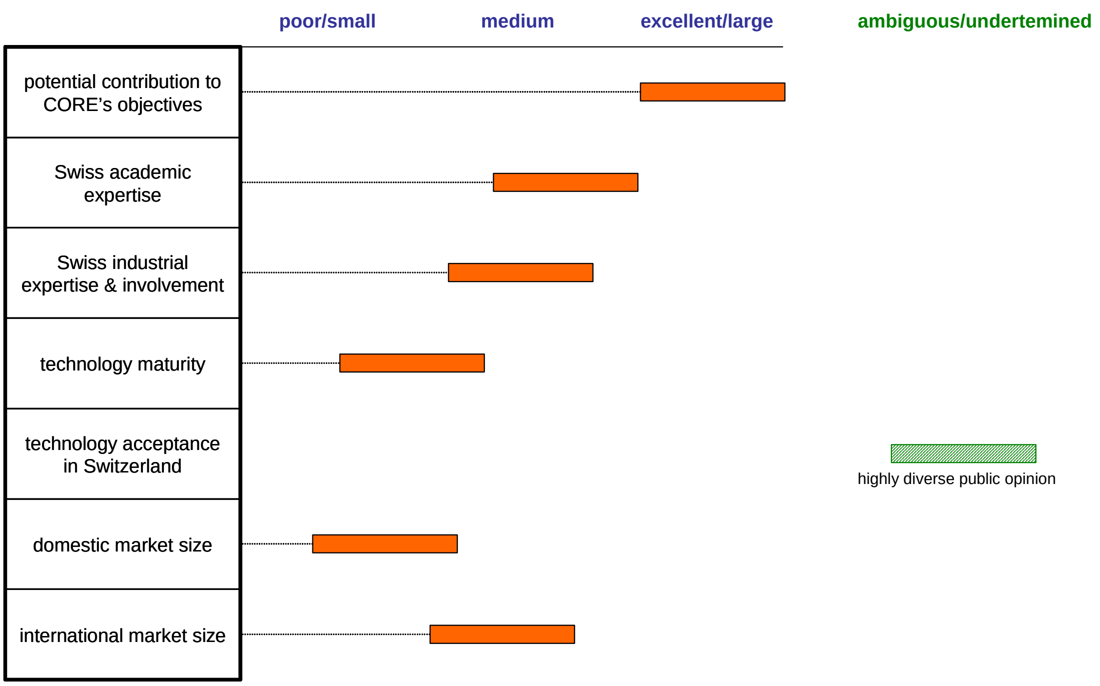
• Generation IV concepts allow improving the inherent safety of nuclear reactors

• Reduced amount of nuclear waste in Gen. IV reactors

• Reduction of enrichment needs achievable

• Risk of proliferation could be minimised

• Generation of multiple energy carriers possible (electricity, h.t. heat, hydrogen)



Generation IV reactor technologies: Fact Sheet (2)

2005 | **2010 2020 2030 2040** | **2050**

status

- Generation III reactors in development and construction of plants in planning (Finnland)
- Generation IV reactor concepts re-evaluated on international level

Possible path

- positive evaluation of one or more generation IV concepts
- development of acceptable nuclear waste disposal strategies
- settlement of nuclear waste disposal dispute
- choice of pilot plant concept
- proof of concept in pilot plant

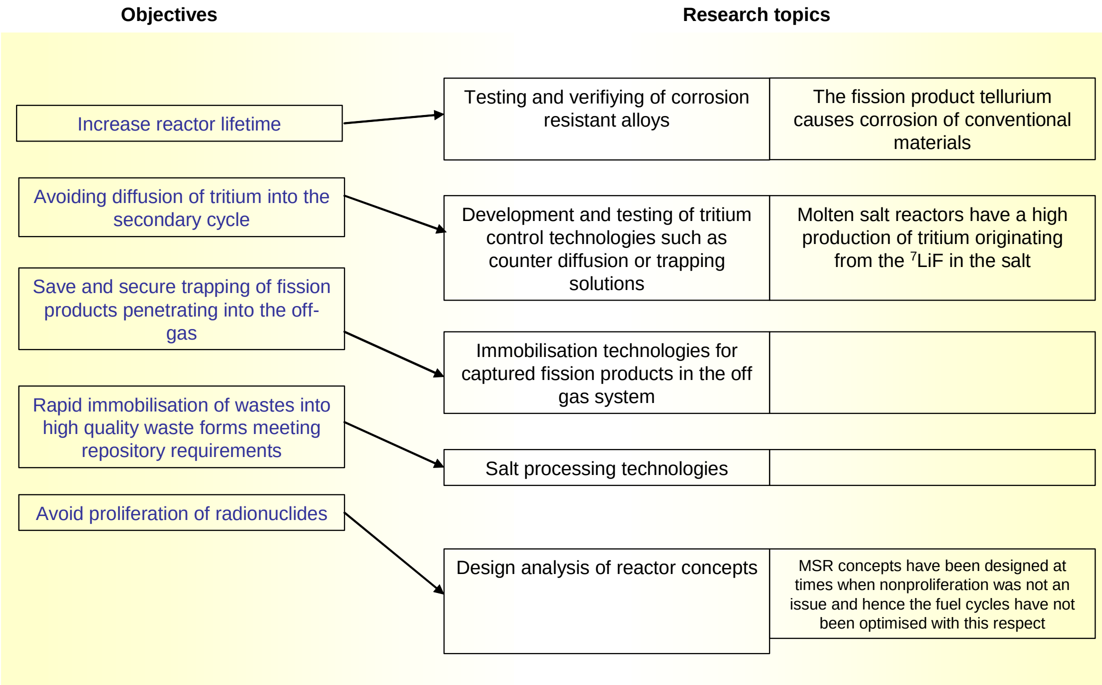
prospects

- significant contribution to the settlement of electricity demand (~25%)
- contribution to transport energy demand by production of hydrogen (i.e. ~12%)
- possible production of high-temperature heat for industrial processes

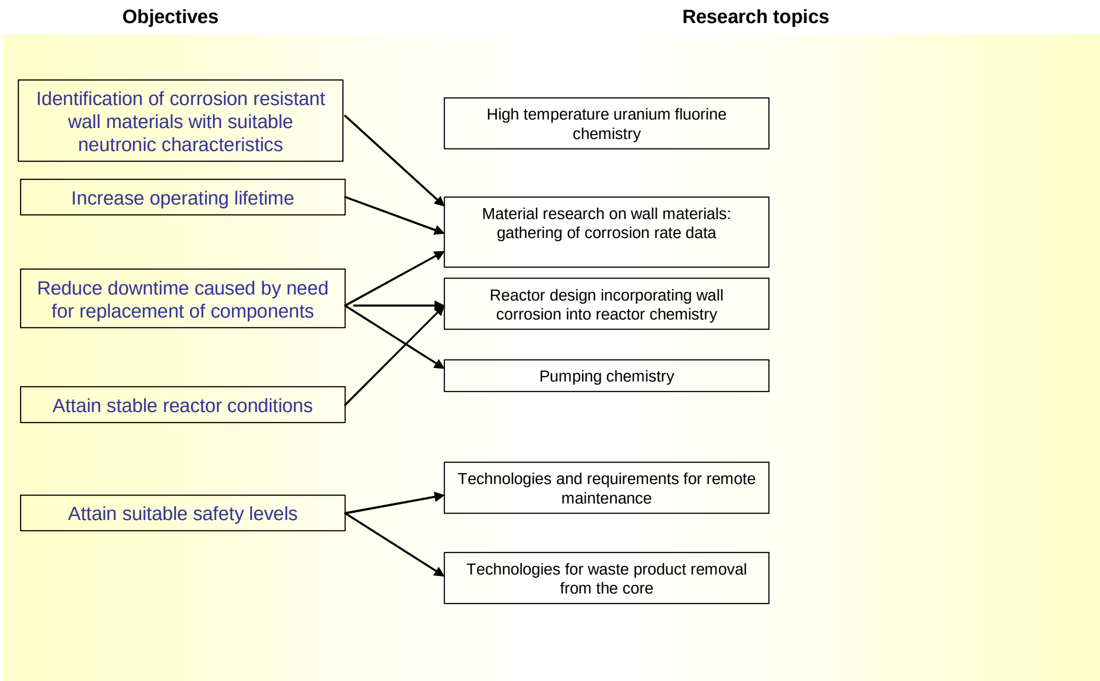
Molten Salt reactors: research objectives and topics

Objectives	Research topics	
Increase reactor lifetime	Testing and verifiying of corrosion resistant alloys	The fission product tellurium causes corrosion of conventional materials
Avoiding diffusion of tritium into the secondary cycle	Development and testing of tritium control technologies such as counter diffusion or trapping solutions	Molten salt reactors have a high production of tritium originating from the ^{7}LiF in the salt
Save and secure trapping of fission products penetrating into the off-gas	Immobilisation technologies for captured fission products in the off gas system	
Rapid immobilisation of wastes into high quality waste forms meeting repository requirements	Salt processing technologies	
Avoid proliferation of radionuclides	Design analysis of reactor concepts	MSR concepts have been designed at times when nonproliferation was not an issue and hence the fuel cycles have not been optimised with this respect

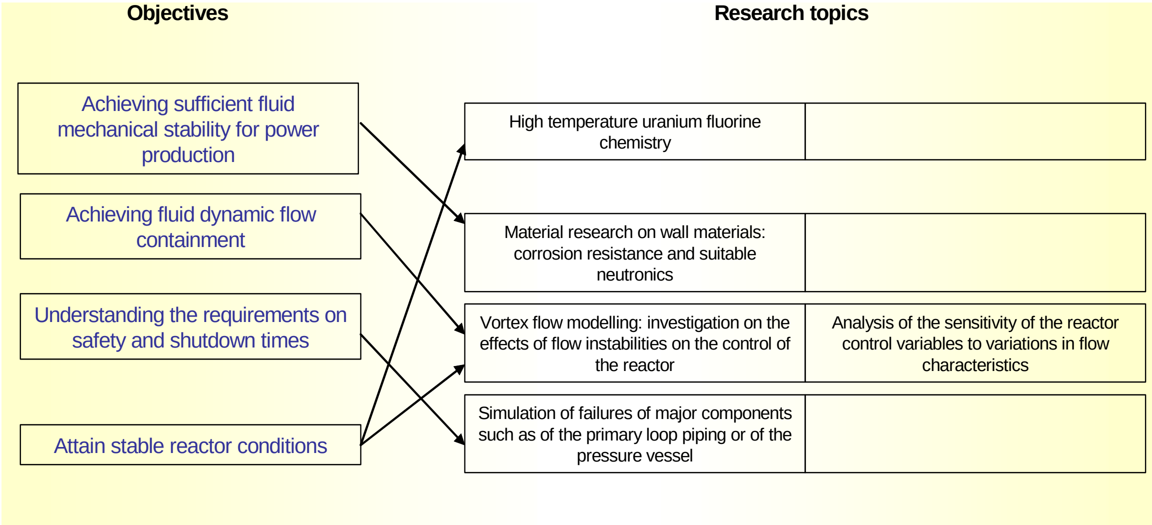
Gas Core Reactors (U-C-F-Type): research objectives and topics



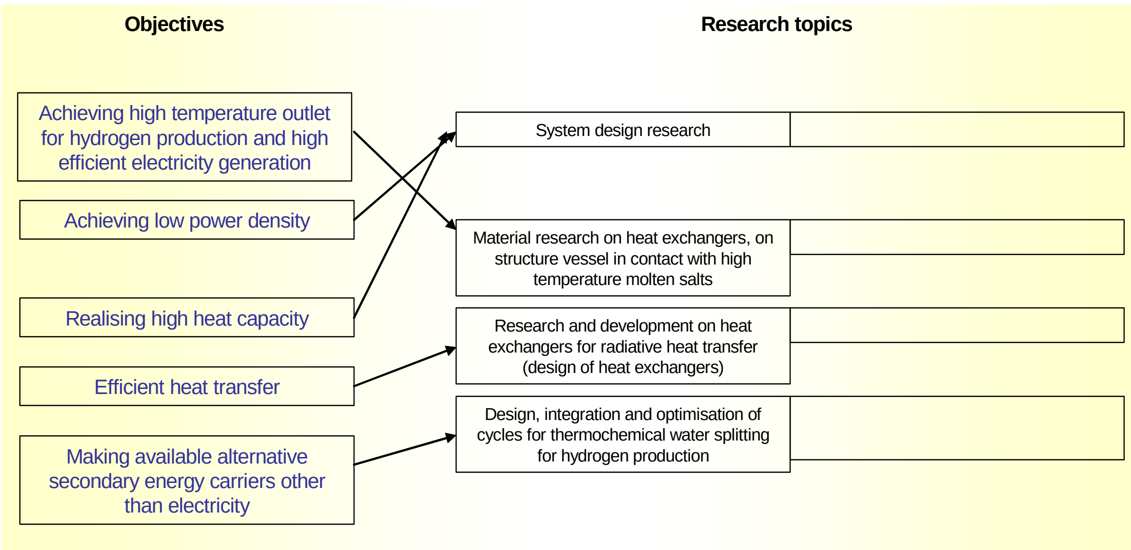
Gas Core Reactors (UF6-Type): research objectives and topics



Plasma Vortex Flow Gas Core Reactors: research objectives and topics



Molten salt cooled graphite-matrix-fuel advance high temperature reactor (AHTR) – research objectives and topics

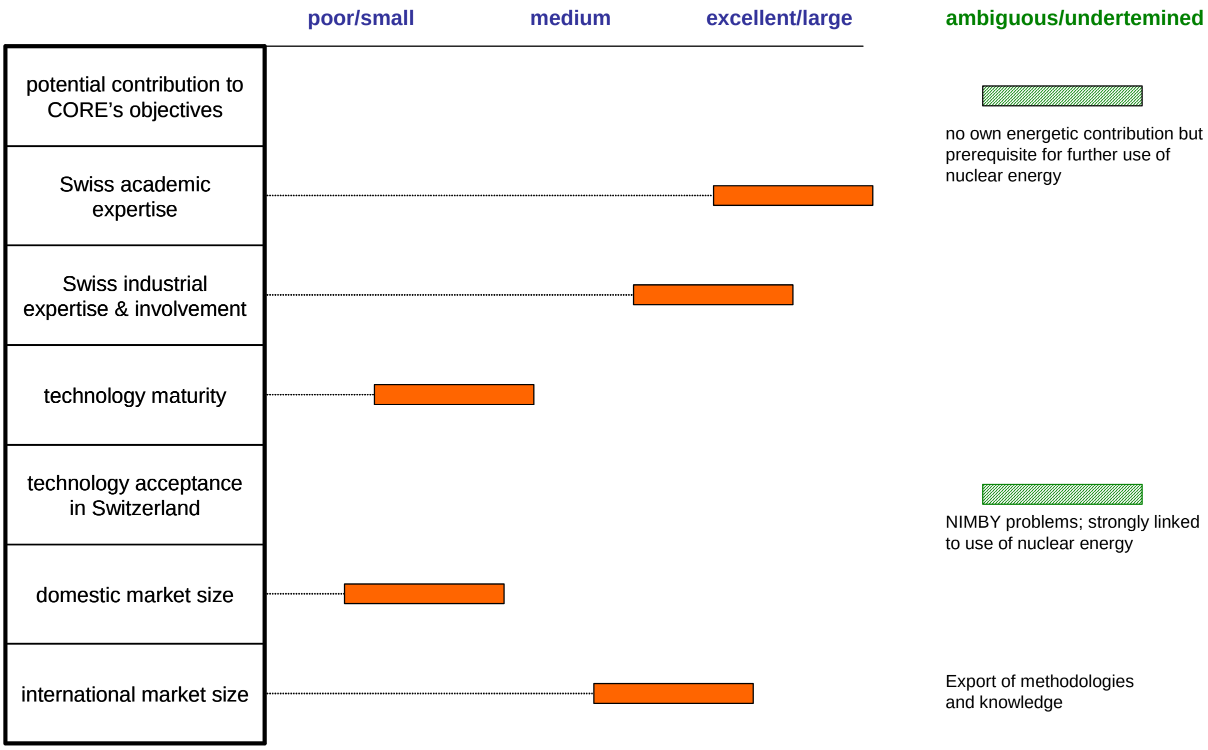


Nuclear waste disposal technologies: Fact Sheet (1)

• Nuclear waste disposal technologies are required irrespective of future use of nuclear energy

• High academic expertise in Switzerland on disposal technologies

• Significant expertise in social and political science of decision making processes for disposal locations



Nuclear waste disposal technologies: Fact Sheet (2)

2005	2010 2020 2030 2040	2050
status		**prospects**

2005 – status

- Worldwide no long-term nuclear waste repository in operation
- Nuclear waste generates major "NIMBY" problems

2010 – 2040

Possible path
- positive evaluation of one or more generation IV concepts
- development of acceptable nuclear waste disposal strategies
- settlement of nuclear waste disposal dispute
- choice of pilot plant concept
- proof of concept in pilot plant

2050 – prospects

- significant contribution to the settlement of electricity demand (~25%)
- contribution to transport energy demand by production of hydrogen (i.e. ~12%)
- possible production of high-temperature heat for industrial processes

Objectives

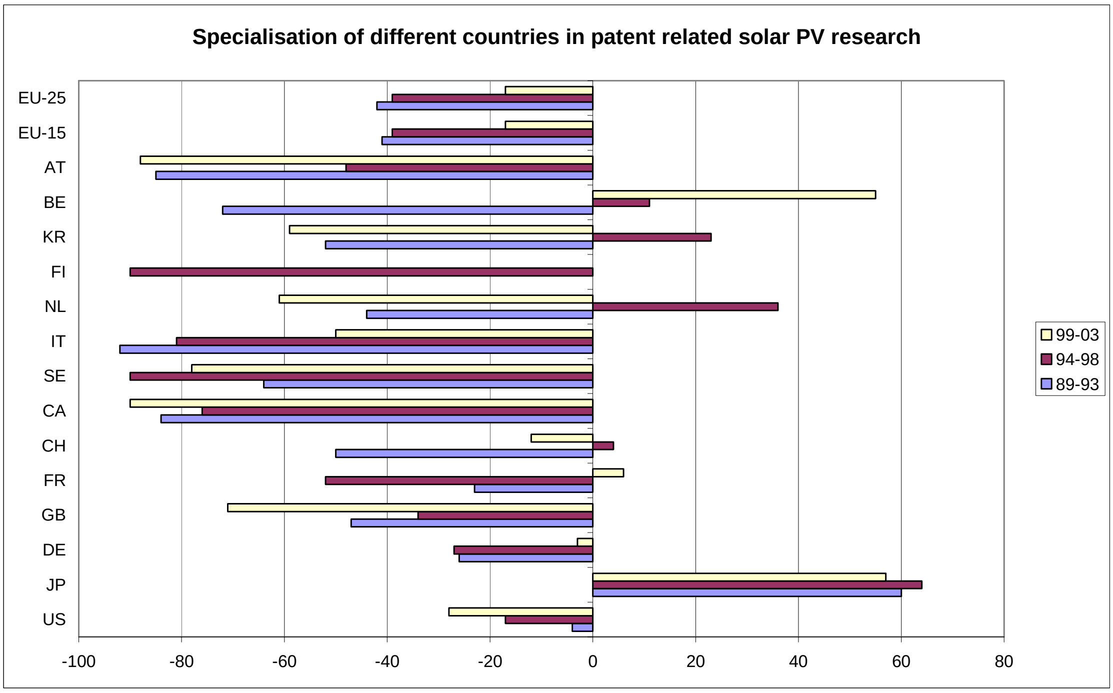
- Achieve longtime repository stability
- Understanding of repository behaviour and comparability of reposiories
- Generate and preserve long-term administrative, public and scientific knowledge about repository locations and threats

Research topics

Repository construction technology	Low disturbance construction, effective backfilling and sealing
Development of repository performance assessment criteria and methodologies	Site characterization methods
Testing methods and testing of long term behaviour of repository systems	Behaviour of barriers (natural and engineered), examination of barrier behaviour and radionuclide migration
Waste packaging technologies and quality assessment	Understanding radioactive behaviour of packages, methodologies for achieving defined actinide contents and chemical composition
Very long-term information strategies for repositories	Safeguarding knowledge despite of political, social and cultural changes
Management strategies for waste and spent fuel	

Appendix 2

Cross-country comparison of specialisation in energy technology related research


Specialisation of different countries in patent related solar PV research
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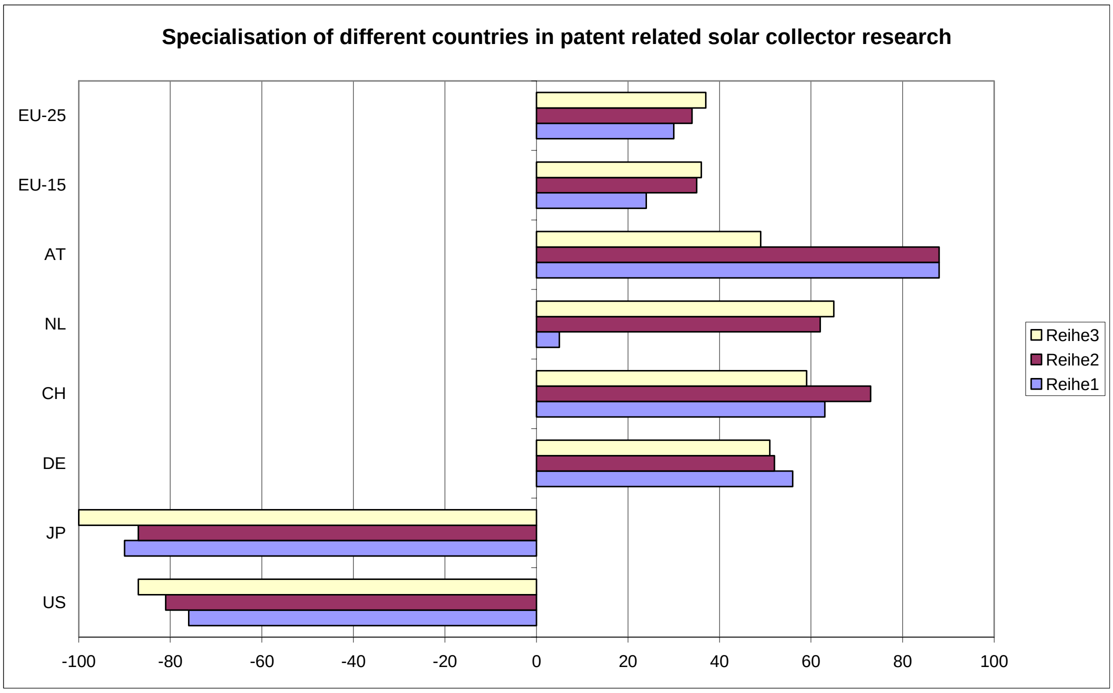
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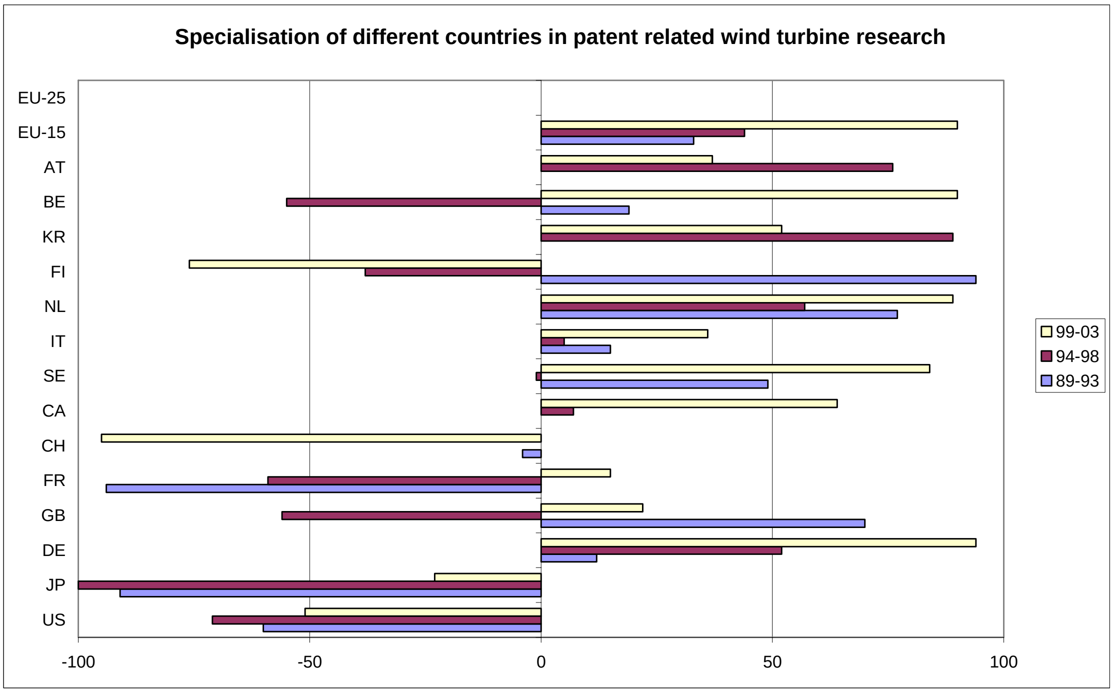
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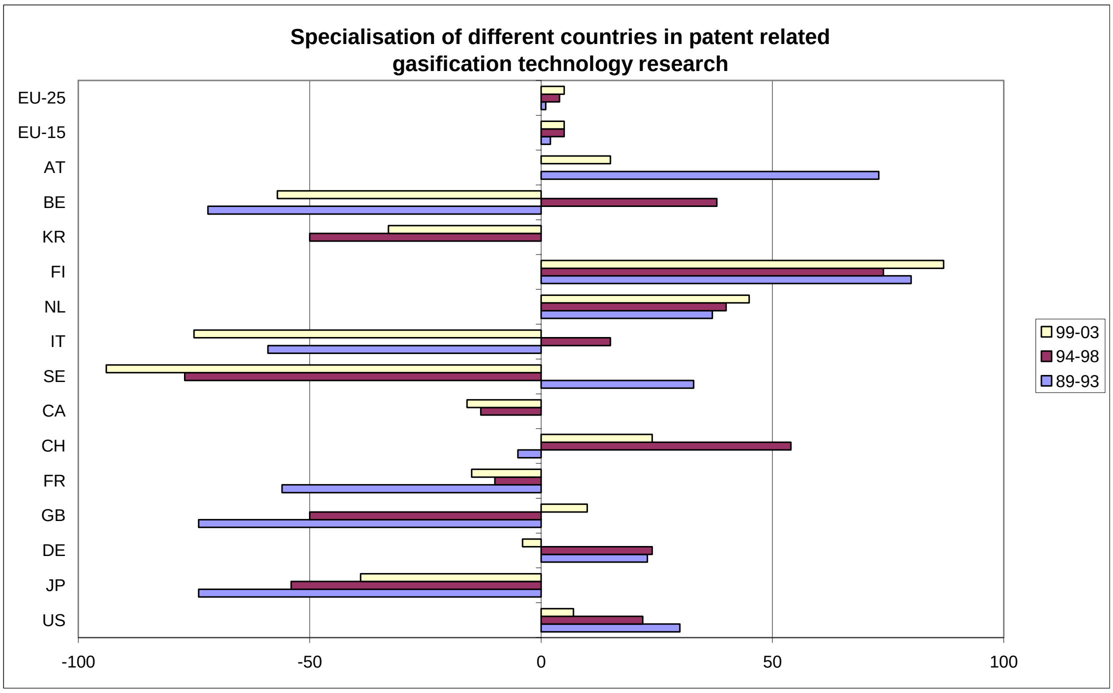
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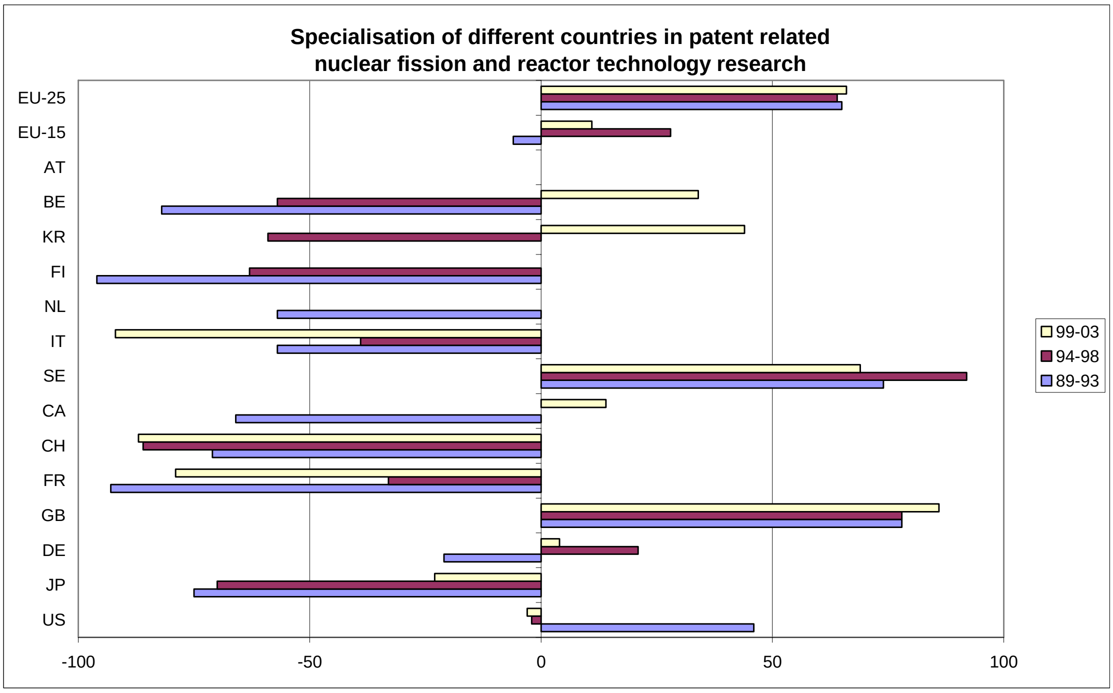
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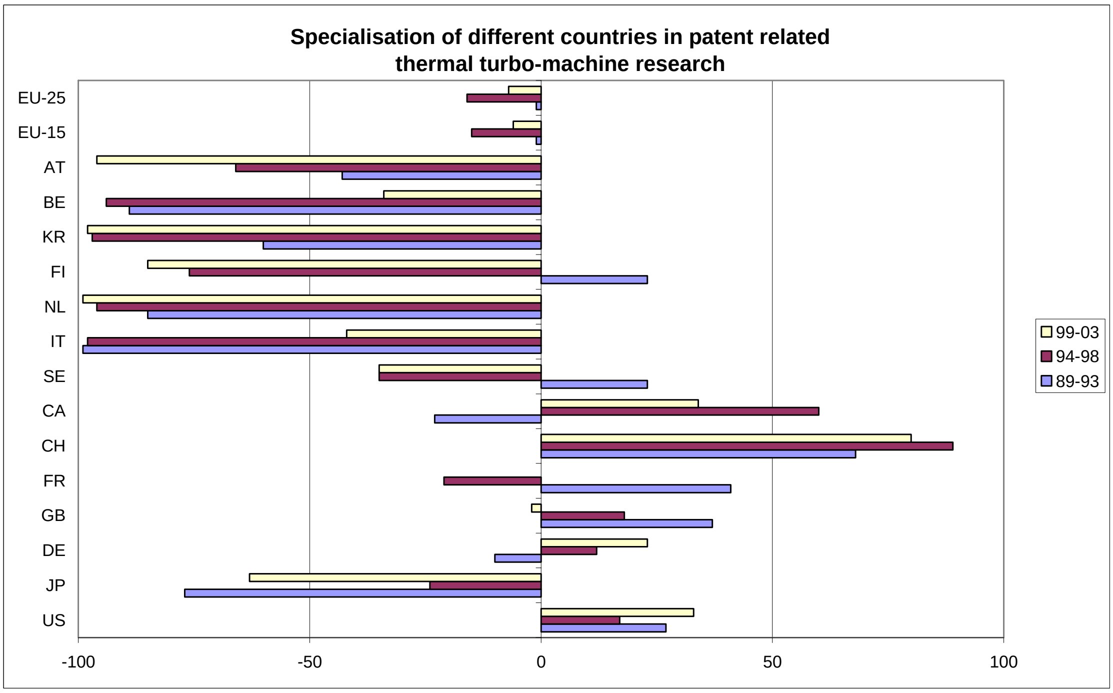
Specialisation of different countries in patent related
thermal turbo-machine research
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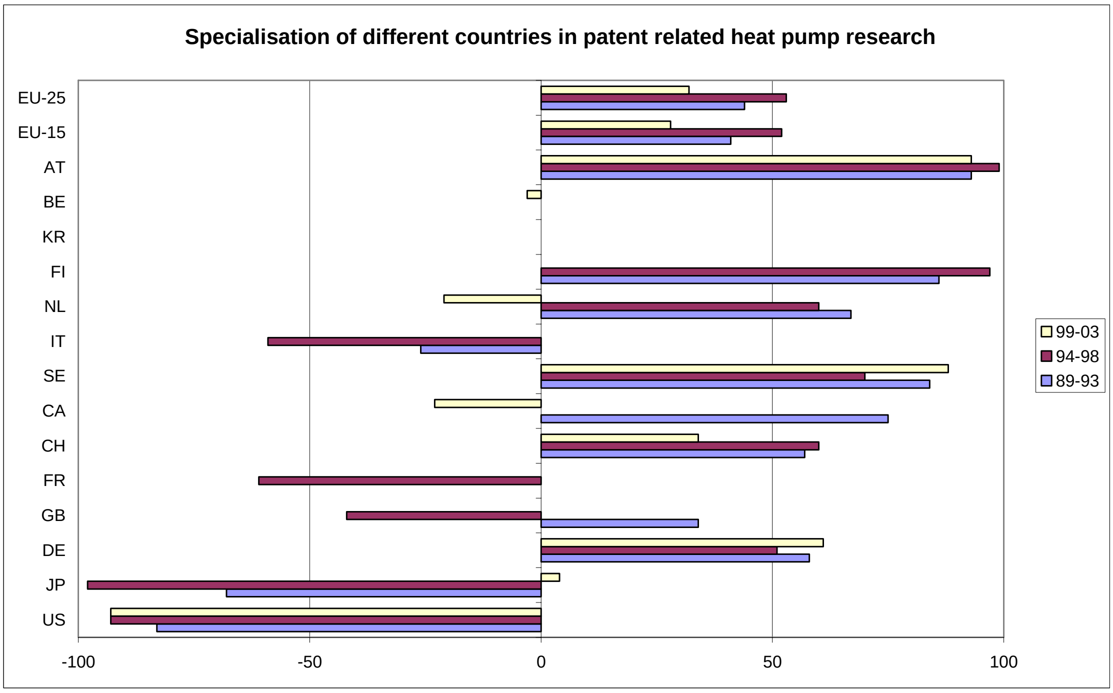
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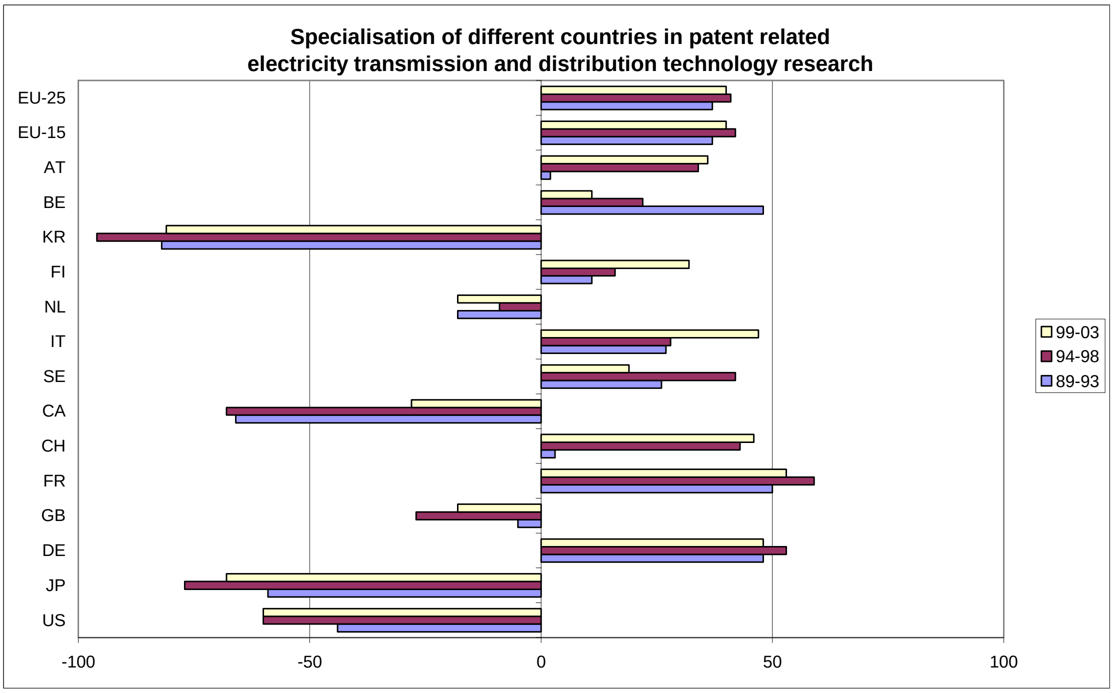
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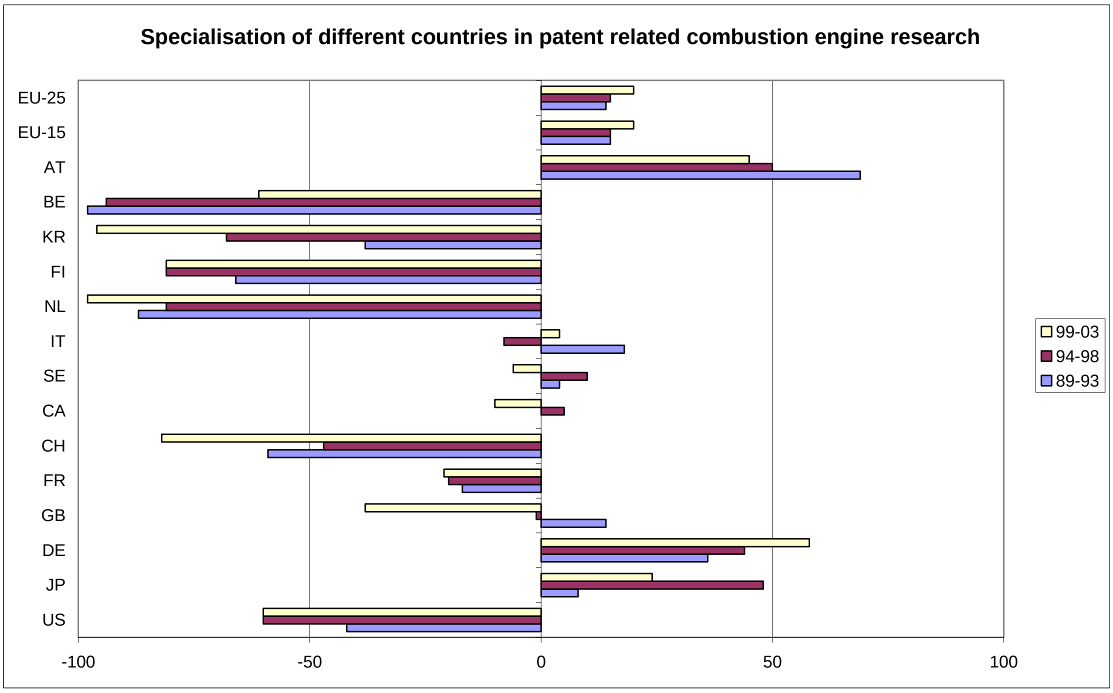
Specialisation of different countries in patent related combustion engine research
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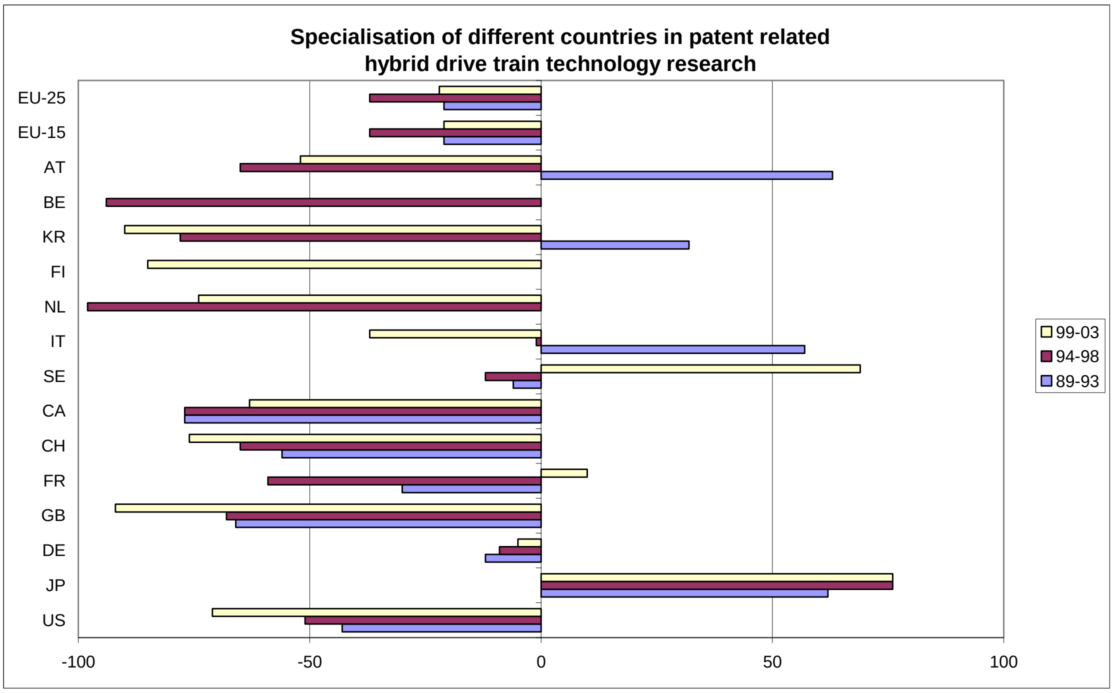
Specialisation of different countries in patent related hybrid drive train technology research
EU-25
EU-15
AT
BE
KR
FI
NL
IT
SE
CA
CH
FR
GB
DE
JP
US
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