EurEnDel

Technology and Social Visions for Europe's Energy Future

- A Europe-wide Delphi Study

Contract ENG1-CT2002-00676

Summary Report

November 2004

This document contains a summary of the main results of the EurEnDel project. It includes the findings of the European Energy Delphi survey and the resulting recommendations for R&D policy.

For a complete picture of the EurEnDel project the reader is referred to the EurEnDel final report and other EurEnDel working papers which are available from the project website: www.eurendel.net.

We would like to thank all participants of the EurEnDel Delphi survey for their contributions which were vital for the project's success.

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EurEnDel is a European Union research project
funded under the 5th RTD Framework Programme

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1 Introduction

EurEnDel is the first Europe-wide Delphi study on future developments in the energy sector. The ultimate objective of the project was to provide advice on energy R&D priorities, based on sound expert knowledge. With a time horizon of 2030, this expert survey not only provides a useful perspective on long-term developments of energy technologies, but also evaluates these technologies against different sets of social values or “visions”.

More than 3,400 energy experts from 48 countries were originally invited to participate in this two-round, web-based Delphi exercise. The response rate of about 20%, obtained in the first round, ensures that the results represent a broad European perspective on the challenges that Europe’s energy system will be facing over the next two and a half decades. The following pages document the expert opinions emerging from the survey, including insight from the more than 1,600 written comments sent by the participants.

In the survey and in the analysis of the results equal emphasis was placed on the technology-push perspective “What *will* the future be like?” and the normative social-pull perspective “What *should* the future be like?”. In this respect, considerable attention was given to the different responses received from technology experts, generalists and decision makers.

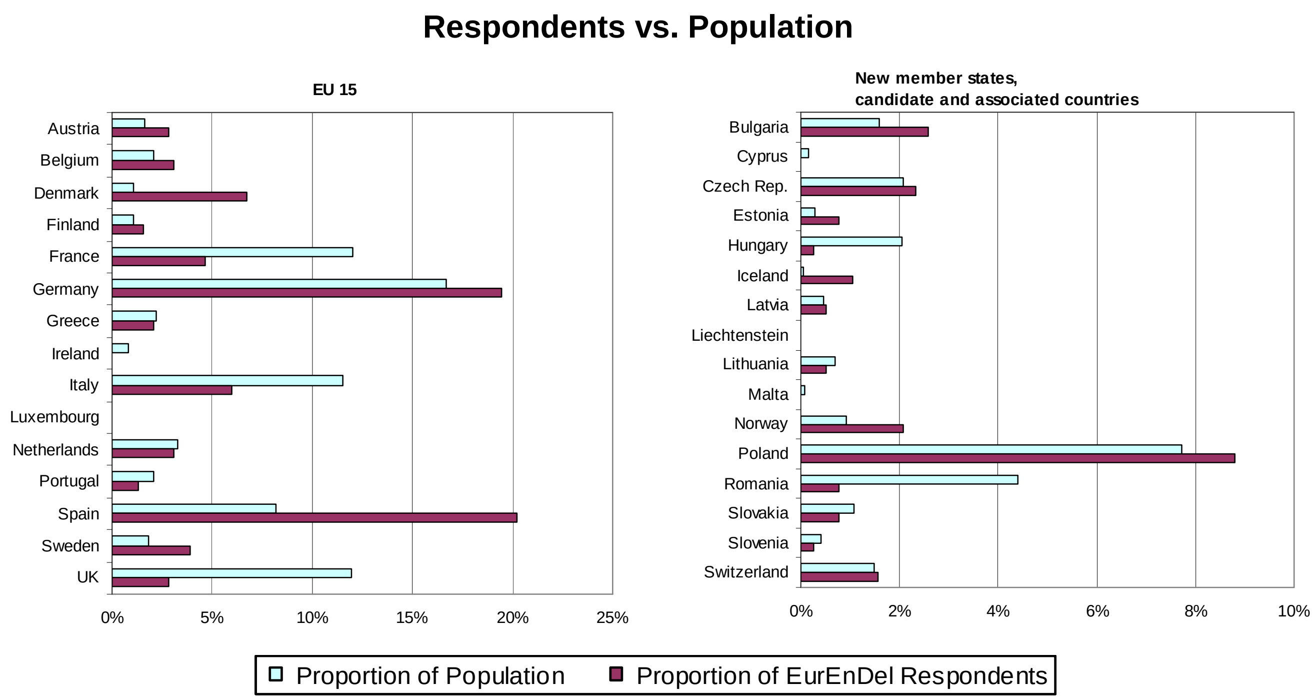
The results of the Delphi were interpreted on the background of three qualitative scenarios of Europe’s energy futures up to the year 2030. In a world of uncertainties, EurEnDel recognized the impracticality of referring to a single energy scenario. For this reason it adapted the classical Delphi approach, employing a variety of foresight approaches both in the design phase and in the later analysis of the results.

A full description of the methodologies applied, a detailed account of all research phases, additional background information and related material, which cannot be presented in this brief summary, are available on the project homepage: www.eurendel.net.

2 Expert Selection and Design of the Questionnaire

2.1 Expert Selection

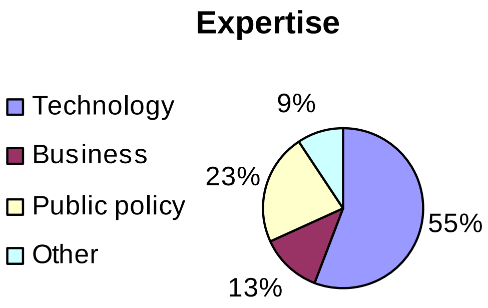
The survey participants were selected by the EurEnDel partners in cooperation with regional and national energy authorities, drawing upon existing expert databases and calling on authors of energy publications as well as speakers at energy congresses. Nomination of experts through the project website was also possible, but used to a minor extent. Special attention was paid to gathering a sample of experts with a high degree of diversity regarding expertise, institutional background and geographical origin.



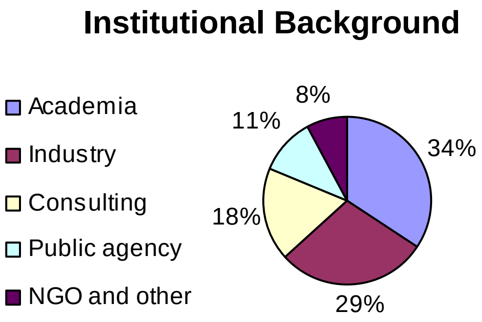
Graph 1: Share of respondents to the second Delphi round in comparison to the size of their country of origin. 100% refers to all countries listed.

Respondents to the survey came from 48 countries with 94% of the experts residing in Europe. The distribution of EurEnDel experts among European countries generally reflects the population of the countries quite closely (see Graph 1). The influence of the experts' geographic origin on the overall results are discussed in section 3.3 with special focus on the three countries with highest participation rates (Germany, Spain and Poland).

The respondents represent an even mix of technological and non-technological expertise (business or public policy related – see Graph 2). Likewise, the respondents show a reasonable distribution in terms of institutional background, with roughly one third of the participants came from academic research (34%) and from industry (29%) as shown in Graph 3.



Graph 2: Respondents by Expertise (2nd Delphi round)



Graph 3: Respondents by Institutional Background (2nd Delphi round)

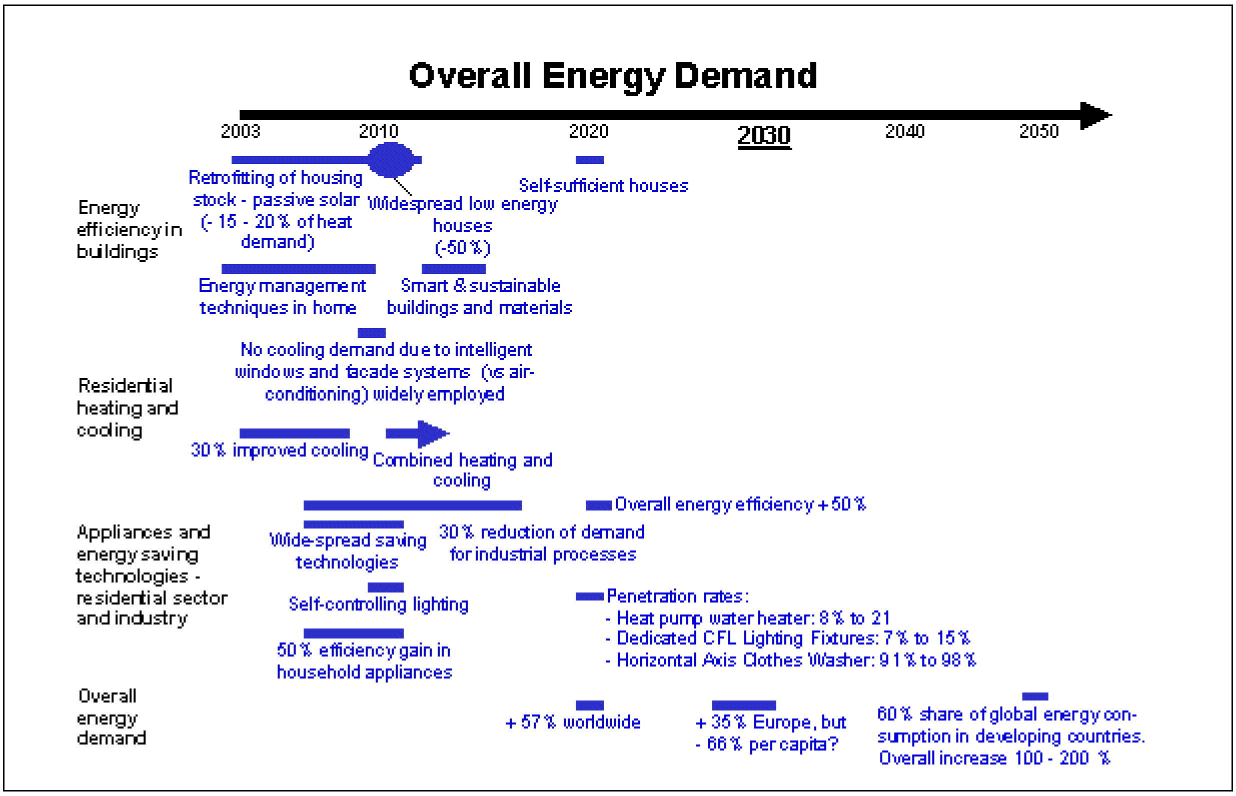
2.2 Choice of Time Horizon

The year 2030 was chosen as time horizon for the Delphi exercise, because this is a reasonable time frame for emerging technologies to enter the market and for R&D efforts to support the innovation process. By 2030 major transformations in Europe's energy system will most probably have occurred: a large share of today's power plants will need to be replaced, making room for new technology options. Furthermore, it seems likely that conventional oil production will have peaked by then [Illum 2004], rendering major changes in Europe's energy supply inevitable.

2.3 Questionnaire Design

EurEnDel aimed to address energy perspectives in the broadest possible way. At the same time, it realised the complexity of the evolving energy system and the need to reduce it to manageable size within the bounds of the project. Its primary concern in the design of the Delphi questionnaire was to find a suitable trade-off between covering all major energy related issues at the same time as exploring technologies in appropriate depth. The approach chosen was to identify one or two key statements reflecting the degree of success of the major energy technologies over the coming decades.

The design process was launched with a cross-impact analysis aimed at isolating the main drivers of Europe's future energy system. A total of 42 drivers were considered relating to both demand and supply options, but also to political and social trends, which are most likely to influence the future structure of the energy system. Those drivers which have an important impact and at the same time are under the control of European decision makers were selected for further investigation in the Delphi questionnaire. The technologies were chosen on the basis of "technology roadmaps" (see Graph 4), derived from an earlier set of 17 national Delphi and foresight exercises (see references).



Graph 4: *"Technology Roadmap" on overall energy demand. Corresponding roadmaps where developed from an analysis of 17 national Delphi surveys for each field covered in the EurEnDel Delphi survey.*

The Delphi questionnaire consisted of two parts:

Part 1 – The explorative perspective

Part 1 represented the technology push perspective: the survey participants were asked to assess 19 "classical" Delphi statements of energy technologies regarding their probable Time of Occurrence, their Impact and the Actions Needed to promote an early occurrence of each statement. In addition the respondents were asked to indicate their level of knowledge in each technology field, which allowed identifying specific experts groups for the different technology fields and compare their opinions to those of the "energy community" as a whole, represented by all respondents who were to some extent familiar with the subject. Survey results from the first part of the questionnaire are summarized in chapter 3.1.

Part 2 – The normative perspective

Part 2 covered the social pull perspective: Three normative visions were presented and the participants were asked to assess the importance of energy technology innovations and energy sources for each of these visions. Each vision represented a different set of values, which were assumed to be highly relevant for Europe's society in 2030. A short description of the visions and the related survey results are given in chapter 3.2.

3 Main Survey Results

The Delphi results and the experts' comments indicate that there is **no business-as-usual case** for the European energy system, when looking at a longer-term horizon (2030). Major structural changes are already taking place and are likely to intensify in the coming decades. The large majority of the respondents are nevertheless optimistic about the potential for technological progress in the field of energy.

A comparison of the EurEnDel Delphi results with two energy scenarios, which were developed from quantitative models[1], indicates that the EurEnDel participants anticipate more rapid development of substitute technologies and higher market shares, particularly those based on renewable energy resources. These expectations logically extend to changes in related systems, such as advanced storage and distributed energy technologies. However, recent research [Laitner 2004] suggests that economic models tend to underestimate the potential of emerging technologies. Furthermore, the scenario assumptions behind these reference studies (which are very careful business as usual assumptions) are unlikely to correspond to the framework conditions underlying the EurEnDel experts' anticipations.

In fact, the EurEnDel Delphi results on expected time frames should be more correctly be interpreted as identifying achievable future developments, given the right framework conditions and incentives.

3.1 19 Technology Trends

The 19 technology statements highlighted important developments in energy demand and supply, focussing on emerging technologies most relevant for formulating R&D recommendations. The selection does not imply that excluded technologies are not significant for future energy systems. To pick one example: large offshore wind parks were not included in the first part of the questionnaire on technology statements, because they were expected to be commercially competitive long before 2030. The opinions expressed in the social visions part clearly confirmed the important role of wind energy in the coming decades.

3.1.1 Time of Occurrence

The technology statements involved varying degrees of accuracy ranging from specific penetration rates, such as 25% market share, to less precise indications distinguishing between **Practical Use** (the first practical use of an innovative product or service) and **Widespread Use** (the product or service is in common use).

Graph 5 presents the anticipated Time of Occurrence as assessed by the participants in the second round of the Delphi survey, who considered themselves to be either experts, knowledgeable or at least familiar with the topic[2]. As indicated by the mean value of the returns, most of the technologies addressed in the survey were expected

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[1] These were "European Energy and Transport - Trends to 2030" published by the European Commission, DG TREN [Mantzos et al. 2003] and the "With Climate Policies" (WCLP) scenario which is used as one of the baseline scenarios in the EU-wide CAFE (Clean Air For Europe) process managed by the European Commission, DG Environment. [Zeka-Paschou 2003].

[2] The graph excludes the statement on natural gas infrastructure development due to defective formulation which made the interpretation of the corresponding results problematical. Responses on natural gas development from the second part of the questionnaire could nevertheless be retained.

to experience major advances in the medium-long term (2020 – 2030). The right hand side of Graph 5 reports the share of respondents who found the corresponding statement unlikely ever to occur.

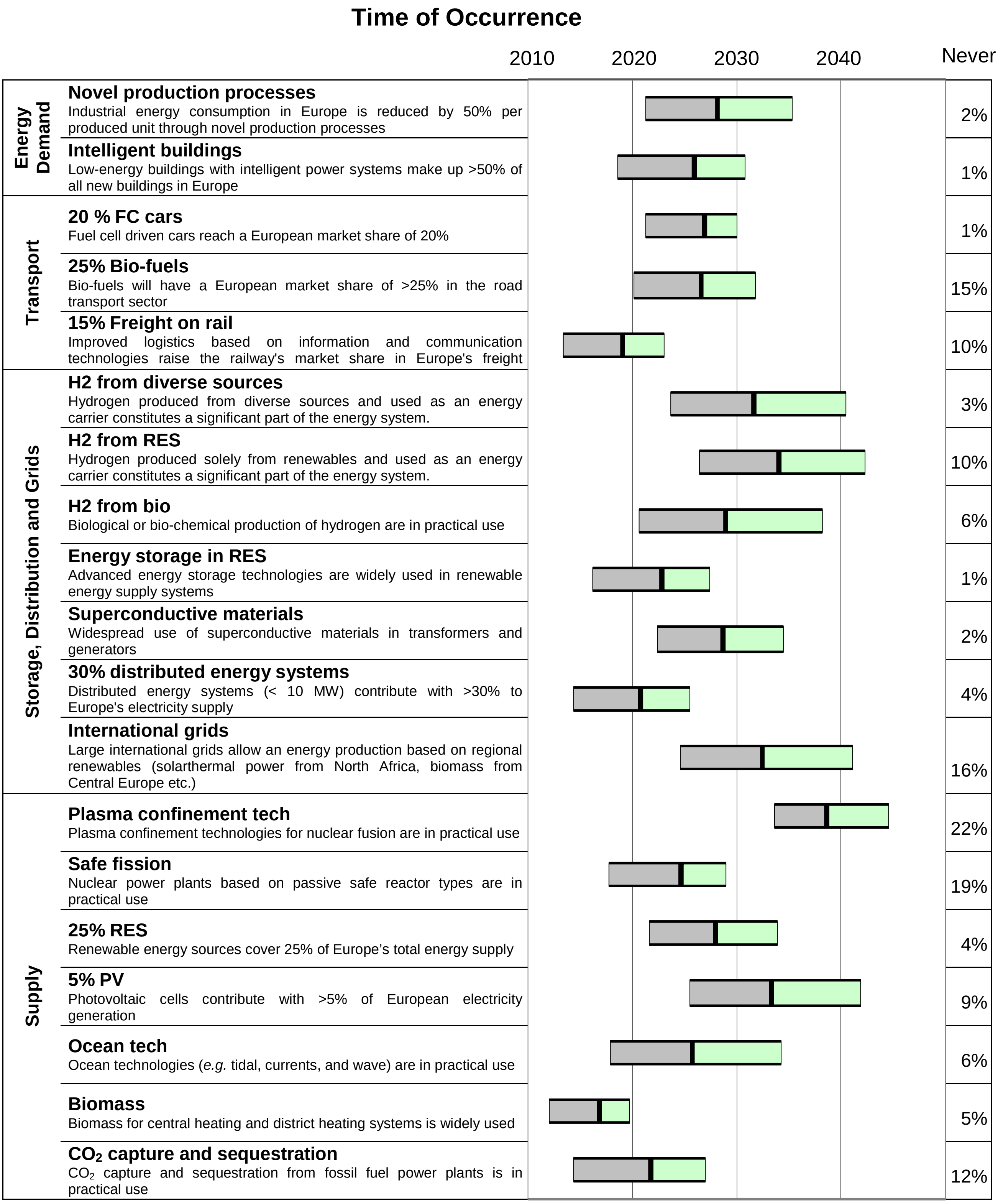
The statistical spread of answers became smaller from the first to the second round, as intended with the Delphi method. However, for many statements the difference between the lower and upper quartiles still surpasses 10 years. It was interesting to observe that between the 1st and the 2nd round the majority of the statements experienced a slight shift towards a later Time of Occurrence. Also, some critical issues, such as safe fission, were highlighted by pronounced “double peaks” (“early occurrence” or “never”). Regarding answering patterns by level of knowledge, it is noteworthy that respondents declaring themselves experts in a specific field of technology anticipated technology developments within their field of expertise to occur earlier than anticipated by the overall group of respondents. This phenomenon of “professional optimism” has been frequently observed and discussed in research (Häder and Häder 2000).

The **degree of consensus on the Time of Occurrence** differs strongly from statement to statement.

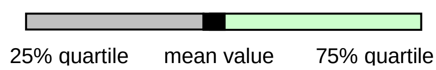
- The statements with **highest degree of agreement** among the respondents are “Biomass for central heating and district heating systems is widely used”, with 61% of the respondents expecting a time of occurrence between 2011 and 2020, and the statement on fuel cell driven cars predicting a 20% market share between 2021 and 2030 (57% of respondents).
- **Least consensus** is found in statements on the practical use of ocean technologies (*e.g.* tidal, currents, and wave), in statements referring to hydrogen production, and in the statements “Large international grids allow energy production based on regional renewables” and ” Nuclear power plants based on passive safe reactor types are in practical use”. In these fields the uncertainty of the expert’s predictions is highest.

Important findings by technology field:

- **Energy Demand**
  On both statements on energy demand there is a great consensus by the survey participants. Doubling the energy efficiency in industrial production is considered to be likely before 2030 by 65% of the respondents. An even higher percentage, 75% of the respondents anticipate 50% of all new buildings in Europe to be low energy buildings before 2030. Only a marginal share (1 to 2%) consider these developments to be totally unlikely.
- **Transport**
  A 20% market share of fuel cell driven cars is expected by the respondents in the late 2020s. Note that this is well before hydrogen is expected to play a significant role in Europe’s energy system.
  On the issue of a 25% share of biofuels for transportation the expert’s opinions are divided: The majority expects this to happen before 2030. However quite a large share (15%) of respondents consider 25% a too larger number. Comments indicate that the major restraining factor was the limited overall potential for biomass production



Graph 5: *Mean value of Time of Occurrence of technology statements in the second Delphi round. Left hand side of the bar indicates 25% quartile and right hand side 75% quartile.*



- **Storage, Distribution and Grids**
  There is a large consensus that the trend towards a more decentralised electricty supply prevails. A 30% share of decentralised generation is expected by 2020. In contrast there is quite a controversy when and if at all large international grids allow for an energy transportation of regionally produced renewable energy. 16% of the experts do not believe that *e.g.* solar-thermal power from North-Africa or Biomass from Central Europe will be used beyond for regional supply.
  Energy storage is considered to be in widespread use by the early 2020s to support renewable energy systems. Hydrogen, as one storage option is considered to constitute a significant part only after 2030.

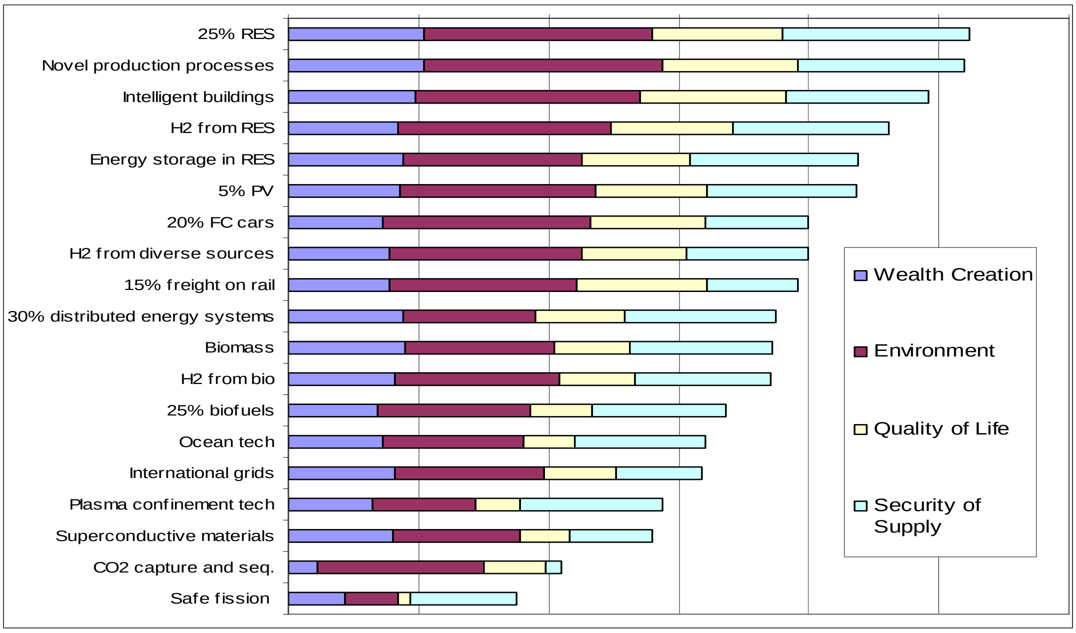
- **Energy Supply**
  The respondents are quite split concerning the future of nuclear energy. Both statements, on fusion and on fission, received the highest “never” shares. Those experts who consider these technologies to come anticipate to passive safe reactor types around 2025. Fusion is considered a very long-term option. Plasma confinement technologies, a prerequisite for fusion reactors, are not considered to be in practical use before 2040. The perception of the respondents revealed certain country specific differences on this issue, which are further analysed section 3.3.
  As for renewable energy sources there is little doubt that a 25% share of Europe’s total energy supply is possible. 66% of the respondents consider it likely that this share is reached before 2030. A high contribution of photovoltaic to this share is a truly long-term goal. The majority of respondents consider a 5% contribution of PV to Europe’s electricity supply realistic only after 2030.

3.1.2 Impact Assessment

The respondents were asked to rate the anticipated impact of the statements in the areas of Wealth Creation, Environment, Quality of Life and Security of Supply. An index based calculation of the impacts, allowed comparison between the technology statements (see Graph 6). Major findings were:

- A share of **25% renewables** for Europe's total energy supply was considered to be overall the most beneficial in the four areas considered. In addition to the positive ecological impact, the respondents highlighted the strong contribution to security of supply.
- Following closely were the two statements on **efficient use of energy** – the statement on novel production processes and the statement on low-energy buildings.
- The two statements on **nuclear energy** (safe passive reactors and plasma confinement technologies for nuclear fusion) received low overall ratings. The greatest positive contribution of these technologies was seen in the area of security of supply. But even in this field, these statements had only average impact, the crucial factor being the lack of public acceptance of nuclear fission.
- **CO_2 capture and sequestration** in fossil fuel plants was assessed to be beneficial only for environmental reasons, but generally obtained very low ratings.
- The statements on **fuel cells and hydrogen** were generally perceived as providing only medium benefits. However, hydrogen production from renewable sources was judged to have more positive impacts than hydrogen produced from diverse sources.

Impact Ratings of Delphi Statements



Graph 6: Average ratings of Delphi statements for the four areas of impact. The statements are ranked in descending order of total impact obtained as the sum over all four impact ratings.

Most technology statements scored higher on environment and on security of supply rather than on wealth creation and quality of life. This may reflect the high costs respondents associate with the energy transition process but also the clearer understanding of environmental impacts and the concern for security of supply, while wealth creation and quality of life are more relative criteria and not so directly linked to energy development.

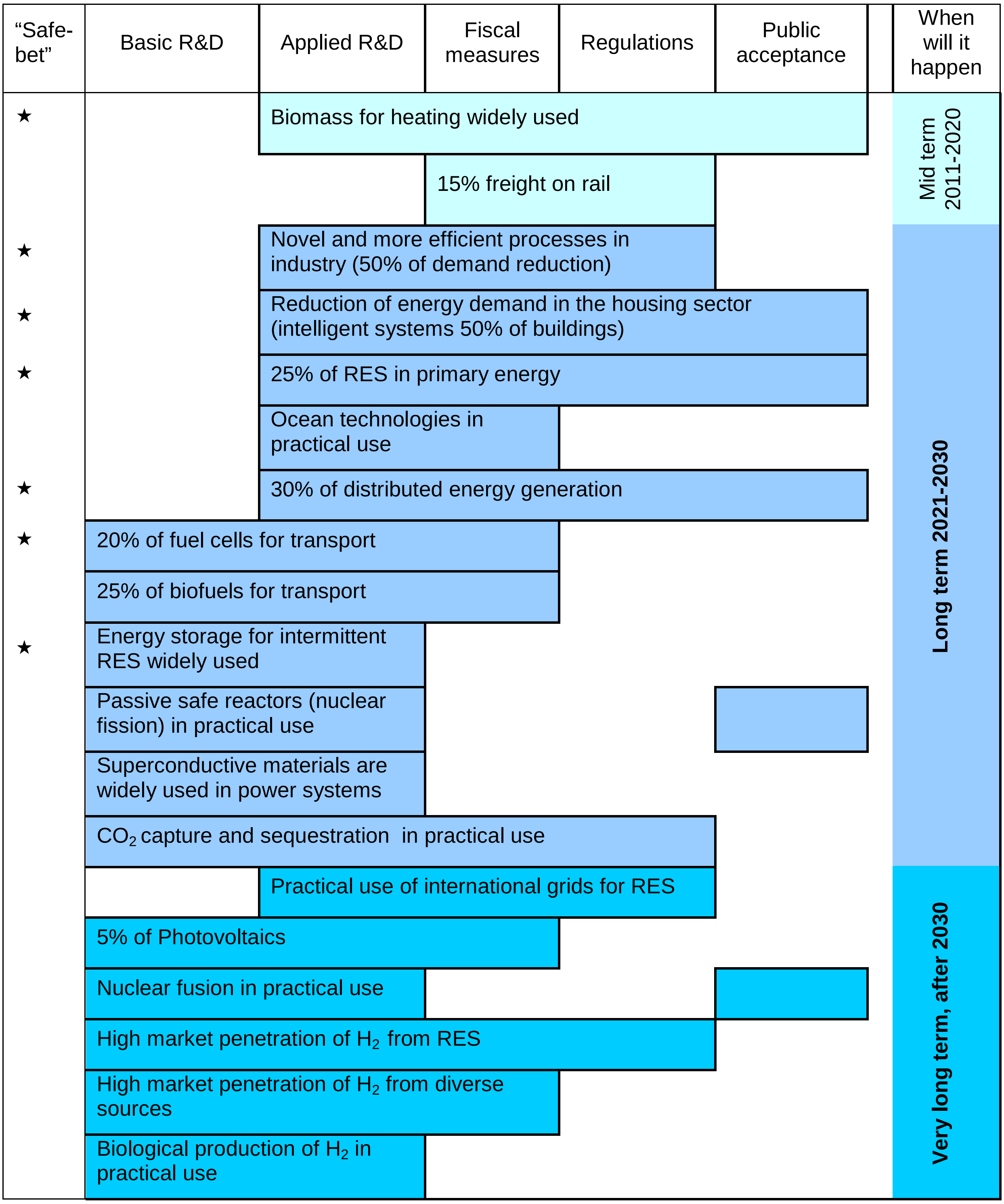
These findings were further stressed in a subsequent analysis based on the **“closeness of occurrence”**, calculated from the “time of occurrence” by assigning declining “likelihood” weights as the perceived period of occurrence recedes into the future (from 1 in the immediate future to 0 when the statement is never expected to occur). This index allows exploring the line of thought that the sooner technologies become available the more beneficial they are in economic terms. The analysis, which also examined divergences between experts in specific technologies and the general energy community, showed that:

- Evaluations based on “closeness of occurrence” did not change the ranking of two statements related to the efficient use of energy, “**novel production processes**” and **“intelligent buildings”,** which retained the highest preferences.
- Consideration of the “closeness of occurrence” improved the performance of two technology statements: the widespread use of **biomass** for heating purposes and **energy storage systems** for renewable energy sources.
- The ranking of a number of statements worsened because their feasibility seemed unlikely on a short time horizon: a market share of 25% in the transport sector for **biofuels**, the use of plasma confinement technology for **nuclear fusion**, the role of international grids for the promotion of renewable energy sources, **hydrogen production** from renewable or diverse sources, and also a 5% contribution of **PV cells** to electricity production in Europe.
- The ranking of **safe passive reactors** worsened not because of the remote time of occurrence, but because the benefits expected by the Energy Community in terms of social impacts were far lower than those anticipated by the specialized experts, revealing problems of social acceptance. The experts on nuclear fission highlighted the high contribution of this technology towards security of supply, whereas respondents as a whole considered this contribution only of intermediate importance in comparison to the other technologies.

3.1.3 Supportive Actions

Part 1 of the questionnaire also asked the respondents to assess which actions were necessary to promote an earlier occurrence of the Delphi statements. The results of this assessment were an important contribution in the formulation of policy recommendations to the European Commission.

An overview of the results is presented in Graph 7, displaying the kind of actions that were considered most important to enhance higher market penetration rates for the respective technologies.



Graph 7: Summary of actions considered most important for faster developments in the respective fields.

Graph 7 also draws attention to those technologies which may be considered as a "safe-bet", in the sense that all of the analyses carried out within the project resulted in their priority ranking. They are perceived as important for their beneficial impacts (EurEnDel technology perspectives) and their contributions to meet social demands (EurEnDel normative visions). Moreover, they have a high degree of robustness under different framework conditions (EurEnDel scenario exercise; see chapter 4) within the analysed time horizon of 30 years.

3.2 Three Societal Visions

In the second part of the questionnaire, three societal visions were outlined and the respondents asked to assess the importance of energy technologies and sources on the background of the set of values identified in each of the visions. The visions correspond to some extend to the three cornerstones of sustainable development:

1) The vision of **Individual Choice** placed emphasis on individual needs, liberalised markets and consumer sovereignty in the choice of products and services.
2) The vision of **Ecological Balance** valued protection of the ecosystem, ecological awareness and sustainable production and consumption.
3) The main features of the vision of **Social Equity** were a reduction of income disparities and of social exclusion, accompanied by community balance and cohesion at the European level, while allowing for regional solutions.

None of the three visions should be interpreted as a forecast of a likely future, nor should they be confused with the EurEnDel scenario exercise (see chapter 4). Rather, they represent the extreme situations that would materialise if the values upon which they are based became predominant and if Europe's energy system were shaped according to those values alone. It seems more likely that European values in 2030 will reflect a combination of the visions. Nonetheless, the exercise undertaken in the second part of the questionnaire is valuable because it allows an assessment of technologies and energy sources, not just with respect to their technical and market potential, but also in relation to different social contexts.

The most significant conclusions emerging from the survey responses were:

- **Energy conservation technologies** and demand-side management techniques are considered to be of highest importance **and reached the highest ranking** in each of the three visions.
- In the vision of **Individual Choice**, fuel cells were given very high importance, presumably as an option to develop individually tailored energy solutions.
- In the vision of **Ecological Balance**, Wind and Biomass were rated second, seemingly reflecting their perceived limited impact on environment.
- In the vision of **Social Equity**, biomass was rated highly probably because of its high labour intensity and potential for regional wealth creation.
- The role of **hydrogen** was considered to be rather independent of social values and achieved intermediate ratings in all three visions.
- **CO_2 sequestration** received a low rating, except for the vision of Environmental Balance, in which it was assigned intermediate importance.
- **Nuclear fission** was rated lowest in importance in all three visions.

3.3 Country Specific Analysis

The objective of the EurEnDel Delphi was to investigate energy futures on a *European* scale. The technology statements and visions were European in scope and in principle the nationality of the respondents should not significantly influence the nature of the responses. Although the distribution of respondents over Europe was quite fair (see Graph 1), a country specific analysis was performed in order to investigate a possible national “bias” on the overall results of the survey. Germany, Poland and Spain were the countries with the highest absolute number of responses, and were thus chosen for a statistical analysis exploring national peculiarities in the expert responses.

From the country specific analysis it can be concluded that:

- The assessment of the **Time of Occurrence** of the technology statements was hardly influenced by the national origin of the respondents; compared to the overall statistical spread of the responses, the deviations due to nationality were minimal for most technologies. In this sense, the Eurendel respondents were sharing a common European perspective.
- For the Delphi statements concerning nuclear technology, especially nuclear fusion, the respondents assessed the **Likelihood of Occurrence** very differently, depending on their national origin. In particular, there was a large share of “never” answers among the German respondents in the nuclear fusion statement, while there was little doubt about the feasibility of the technology among the Spanish and Polish respondents.
In fact, the reply patterns of the respondents were quite in line with the policy priorities and/or the social and political setting in the respective countries. Since the technology statements did not address only the perception of technical feasibility but also the likelihood of practical use, political and social perspectives are inextricably involved. In seems that on such politically controversial issues, as nuclear energy, the respondents have tended to side more with a national than a European perspective.
- The survey responses seem to reveal a greater degree of national divergence for the **assessment of impacts** of the technologies in the different guiding societal visions than for the assessment of the Time and Likelihood of Occurrence. In some cases, such as nuclear power, this can be largely explained by the fact that the assessment of impacts is more a socio-economic than a technical issue, reflecting the political setting and the ongoing energy debate in the various countries. In other cases, the different assessment seems to be more related to geographic and resource diversities. *E.g.* slightly higher impact ratings on the biomass statement by Polish respondents relates to the large biomass resource potential in this country.

Summarising, in terms of time horizons for technology development, the EurEnDel Delphi exercise is largely representative for the current judgments of the *European* energy community, comprising the EU33 countries.

4 Europe's Energy Future in 2030 – Three Scenarios

Three qualitative scenarios were derived from the Delphi results to put the seemingly unrelated data on different technologies into a coherent context. They illustrate the findings of the Delphi and serve as a tool to check the robustness of technological choices under different framework conditions. The transformation of the European energy system as well as the pace of this process, are largely dependent upon political will, but also upon external framework conditions, which cannot be completely controlled by the main political actors, *i.e.* the European Commission and the countries and regions, which form part of the European Union. Decisive factors, which may act as motors or restraints, are related to the accessibility of fossil fuels, the mainstreaming of ecological values throughout the European society and its institutions, and also the level of risk perception in society. The frameworks of the scenarios are based on different trends in these three fields.

The scenarios itself are presented in the long version of the EurEnDel final report, which is available on the project website. In this report only short summaries are presented to give a short overview of the contents of the scenarios.

Scenario 1: Change of Paradigm

The first scenario combines hypotheses, which are closely related to a strong policy shift towards sustainable development in the years up to 2030: it is due to a combination of political will, technological progress, structural changes in the economy and urgent environmental pressures that Europe 25 is on the way of achieving great progress in energy efficiency. These combined features trigger an aggressive and self-learning move towards much lower levels of energy intensity across all processes and countries. It is mostly a universal attitude, which seeps across all layers of societies and spheres of activity, summing up efforts by many and in many places.

Scenario 2: Fossil Fuel Wars

Fossil Fuel Wars stands for a crisis scenario, in which climate change concerns play a minor role when defining priorities for energy policies. Conflicts between the different interest groups prevail on European, as well as on national levels. Economic, social and environmental policy goals are difficult to integrate and there is a general lack of willingness among companies and citizens to bear the increasing costs of environmental protection.

Scenario 3 : Muddling Through Across the Gas Bridge

In the third scenario there is also a major drive towards sustainability, but it is assumed that long-term climate change impacts cannot be avoided. In 2030, Europe is still caught in the middle of a slow transition process towards a more sustainable energy system. Natural gas plays a key role as intermediary solution, not only in power generation, but also in transport.

5 In-depth Analysis of Results and Recommendations

This chapter summarises the findings of the EurEnDel project with reference to four major fields of energy R&D:

- Energy Demand
- Transport
- Grids and networks
- Energy supply

The body of this chapter is based on the results of the Delphi survey, outlined in Chapter 3. These are supported by facts, figures and ideas submitted by the respondents in the course of the survey in the form of more than 1,600 comments to the technology statements and accompanying enquiries. Further contributions to the analysis have been provided by parallel research undertaken within the scope of the project. This included an analysis of energy R&D expenditures and priorities in the European Union and its Member States, the US and Japan.

Major considerations and recommendations for R&D policy are highlighted in the boxes.

5.1 Energy Demand

Industry and housing

Concerning energy savings in the housing sector, many experts point out, that the technology is already available. Thus a share of 50% low-energy houses of all new build houses in Europe could be reached before 2030. However, the experts consider the higher costs of investment in new technology as the greatest problem for energy efficient buildings. Furthermore efforts should not be limited to new buildings only but should increasingly address existing buildings in order to reduce the overall energy consumption. A separate issue concerns the strong increase in air-conditioning and in other energy intensive appliances which contribute to offsetting the rate of overall energy efficiency improvements in buildings despite gains in the efficiency of individual technologies. In a similar manner, diffusion of residential CHP/fuel cells may contribute to increasing energy efficiency of buildings but reduce funding available for energy efficient technologies in appliances and space heating applications.

For an increase of energy efficiency in industrial production the experts point out that many large-scale production processes are already optimised, so that further improvements must rely on energy-efficient innovations, such as electrochemical substitutes for chemical reactions, heat integration in production processes, etc. The Delphi respondents state that in the time range considered a goal of a 50% decrease in energy consumption per unit of industrial production is facilitated after enlargement to EU25 (and beyond), because of the much greater energy saving potential of the new member states compared to the EU15.

In both fields the technological maturity of energy saving technologies is relatively high, so that support mechanisms should concentrate on fiscal measures, such as the internalisation of external costs of conventional energy production, as well as on energy R&D in industrial process technologies.

There is a very clear consensus among participants in the Delphi survey that technologies reducing energy demand have the most beneficial impacts and must be favoured independently of the pursued social values. Energy efficiency was rated most important no matter which aspect of sustainability was to be emphasised. Both in industry and the residential sector, energy efficient technologies are certain to become the most decisive element of Europe's energy future. However, high levels of energy efficiency in these sectors can only be achieved in a longer term perspective, after 2020.

Demand-side oriented technologies have historically suffered from under-investment and may not be receiving appropriate support. Improving energy efficiency in housing and industry needs to be strongly backed by applied research. However, due to the long life expectancy of buildings (80 -100 years), drastic improvements in energy efficiency in the short and medium term are difficult to achieve, while energy savings in existing buildings require fiscal incentives, regulation and public sector support even more than applied R&D. Given the high priority of energy demand reduction and considering the strong research engagements of the USA and Japan in energy efficiency research, it is recommended that applied research efforts in related technologies and systems are intensified.

5.2 Transport

Containing rising energy demand in the transportation sector has been identified as a crucial challenge for Europe's future energy system. The EurEnDel analysis confirms that purely technological solutions are not capable of achieving this end and that efforts must be intensified on various levels, employing all available means. Demand side technology options included in the Delphi were fuel cells and freight transport by rail.

Fuel cells for transport

It seems certain that fuel cells will play a major role in the future, contributing to improve energy efficiency in transportation and reducing local emissions. Fuel cell driven cars are predicted to have a major market share significantly before a hydrogen economy is established. Thus flexibility of design with the option to use natural gas as a transition fuel will be crucial in the development path of fuel cells for transportation.

A breakthrough in fuel cell development would be facilitated by high fuel prices and, in the longer term, shortages in crude oil supplies. While some participants in the Delphi link fuel cells directly to the need to build up a hydrogen economy, others argue that over the next 20 to 50 years fuel cells will be using predominantly natural gas. Many also point out that a central question in judging the technological and market impact is the origin of the hydrogen fuel: production from renewable energy sources, nuclear, or fossil. At the same time, it was underlined that an increasing market share of fuel cells would have a positive influence on the development of the hydrogen system.

Further strong support to research is necessary in order to achieve a technological breakthrough in fuel cells for transport. This must be undertaken bearing in mind that the choice of the fuel is decisive for maximizing environmental benefits of the option. At the same time, market instruments (mainly fiscal measures) are needed to ensure the timely extension of distribution infrastructures for the alternative fuels through the transition period.

Freight transport by rail

The share of freight transport by rail in the European Union has decreased steadily in the last 30 years, from 20% in the early 1970s to barely 8%. The European rail stakeholder (UIC, CER, UIPT, UNIFE) set the target for the share of "freight transport by railways" at 15% in 2020 [EC 2001]. The Delphi experts consider an increase in the railway share from the current 8% to 15% as realistic in the mid-term. However, a crucial element in achieving this objective is the price ratio between various transport options (rail, road and sea). Prices will be influenced by new investments needed to increase the capacity of transport systems and by policy instruments such as subsidies and taxes. Another important issue highlighted by the experts was the need to improve international connections between the EU countries and strengthening interoperability.

Increasing the share of "freight transport by railways" is perceived as desirable by most participants in the survey. However, basic or applied R&D in the field of logistics and inter-modal concepts is considered to have only minor importance in the effective promotion of this transportation mode. The success of inter-modal concepts and improved logistics in favour of rail transport is ultimately dependent on the structure and organisation of railway systems, the prevailing government policies, their management and governance. Though in the longer term innovations and technological improvements can positively influence the development of freight transport by rail, R&D efforts must be accompanied by infrastructure expansion, fiscal and regulatory support measures aiming at significant changes in the framework conditions.

5.3 Energy Storage and Grids

Energy storage technologies

Comments received from Delphi participants suggest that developments in energy storage may in time lead to a complete overhaul of the energy system. There is little doubt about the technical feasibility of electricity storage within the indicated time frame since technologies such as pumped storage have been in use over many decades and are frequently an essential part of existing power systems. Redox flow batteries, fly wheels, super capacitors, hydrogen storage and other systems are still too expensive to be in widespread use, but may become important in the medium term in specific applications. New fields of research contemplated for the longer term are based on organic and silicate chemistry and electrochemical storage. However, barring exceptional breakthroughs, these currently seem too expensive for use in renewable energy systems. The Delphi experts also differentiate between two areas of technology development: large seasonal storage and small short-term storage.

Besides the backup supply function, particularly in isolated systems, they stress the need for power quality as a further important driver for storage technologies.

One of the main issues regarding storage technologies is cost effectiveness and energy pricing, especially peak-time pricing. If prices are set right, storage systems may be expected to become a competitive element of power generation and distribution systems. Moreover, in the interests of security of supply, the Delphi experts discourage the extensive diffusion of storage technologies which are not yet fully developed and tested.

The consensus among most Delphi participants is that energy storage technologies will become increasingly important after 2020. They indicate a strong need for both basic and applied research, while there have been signs of under-investment in R&D other than in relation to the hydrogen system.

Innovations in storage technology are particularly crucial for the development of renewable energy systems, where storage is the key to integrating power generation from intermittent sources. A long-term research commitment in this sector with dedicated promotion by public authorities seems essential to support an increasing share of renewables in Europe's energy system.

Distributed energy systems

The results emerging from the Delphi survey indicate that the production of power, heat and biogas in distributed energy systems (DES) can play a key role in Europe's energy system, particularly in combination with the development of local renewable energy resources and storage technologies. In this regard, recent technological advances in small scale (<10 MW) combined heat and power production from biomass open up new opportunities in the development of DES.

Distributed generation technologies are in very different stages of development. A number of power generation systems available today in the 1.0 to 10 MW range can already be reliably embedded in existing distribution networks. However, prime movers in smaller sizes (10 to 500 kW) remain more difficult to control on the low voltage side of existing grids. Wind power and cogeneration plants as well as photovoltaic power systems are particularly well suited for integration in DES. Promotion of these technologies can have positive synergic effects also on the development of DES. However, instability problems need to be resolved in the case of wind, while the high cost of photovoltaic power make this solution prohibitive as a key element of DES at the present time.

The basic obstacle for the development of DES is the lower efficiency and higher cost of small scale generating plants compared to central station power generation. However, avoided investments in high voltage transmission lines, the potential savings in grid operation and management, due to a more balanced distribution of power nodes, and the benefits of greater security of supply can significantly reduce the costs of DES in the case of suitably meshed networks.

A steadily increasing share of distributed electricity generation is considered very likely under all framework conditions analysed in EurEnDel and highly beneficial for its contribution to increasing security of supply. Energy R&D needs to be directed specifically to the development of small scale technologies using local renewable energy resources and to attaining greater stability in low voltage distribution grids. Delphi respondents refer to environmental taxation, feed-in tariffs, and changes to the legal framework (for example, legislation on rented housing) as primary steps towards the promotion of distributed energy systems. Regulations and fiscal measures can also contribute to guaranteeing adequate grid development.

Super-conductive materials in the electricity sector

The relatively few comments received on super-conductive materials express serious doubts that significant savings would actually result from their widespread use. In addition, several respondents recall that extensive implementation of the technology depends on the development of **high temperature** systems. It was also pointed out that in the longer term the development of hydrogen as an energy carrier could reduce the importance of superconductivity in energy transport.

Overall, the Delphi respondents consider the development of super-conductive materials to support the strengthening of the European electric power system, through greater efficiency in energy transport and storage. Despite its currently low degree of maturity, 98% of the experts believe the technology to be a viable option in the longer term. EurEnDel participants recommend that the most effective way of promoting technological progress in this area is by intensifying basic and applied R&D also through projects undertaken jointly with other EU research areas (such as medical science) with interest in super-conductive materials.

Hydrogen carrier

In their comments, the Delphi experts recognise that hydrogen energy systems have been investigated for a long time without significant progress. Implementation of a viable fuel cycle before 2030 requires increasing research efforts on a European scale. Current efforts are unlikely to lead to a significant role for hydrogen as an energy carrier before 2050. Nevertheless, distinct time scales are expected for transport and stationary applications. There is a lack of consensus on the importance of hydrogen as a substitute for fossil fuels over the time horizon of the study, whether this could take place on a regional scale and, more specifically, whether Europe should strive towards a “hydrogen economy”. At one extreme is the point of view of respondents who consider that it will be inevitable some time before 2030 in the wake of increasingly costly and depleting oil and gas resources; at the other, is the conviction that there are more efficient and less costly alternatives to bridge the possible gap between supply and demand.

The main problem associated with the use of hydrogen is the need to invest in extensive, new infrastructure for production, transport and storage as well as the safety considerations. Technical difficulties related to the handling of this fuel may be solved by European standardisation. But hydrogen is likely to be perceived as potentially dangerous and one major accident could jeopardize advances in research. Moreover, serious doubts exist concerning the overall efficiency of the fuel cycle.

A key issue regards the long-term impact of the hydrogen fuel cycle on the environment. Production from fossil fuels and as a by product from nuclear fission are explicitly rejected by many experts as a long term solution, although production from fossil fuels may be important in the transition period. There are strong recommendations to strive for the production of hydrogen from renewable energy sources, avoiding CO_2 emissions. But the potential of renewable sources in the EU may be too limited for large-scale production.

The principal message that comes out of the Delphi survey is that the development of hydrogen production and storage requires greatly intensified basic and applied R&D. Even so, large-scale production of hydrogen as an energy carrier and as a substitute for secondary fuels will only occur in the very long term, after 2030. There was a fairly broad consensus among respondents on a long term strategy focussing on hydrogen production from renewable sources as opposed to fossil fuels and nuclear energy. In either case, it is necessary to address the issue of new transport and storage infrastructure early in time to avoid bottlenecks to future expansion. To this end an adaptable development path should be established identifying hydrogen's future role in the European energy system. Policies to promote the introduction and expansion of the hydrogen economy are premature, given the early stage of development of this fuel, but fiscal measures can contribute already in the transition stage while regulations may be postponed.

5.4 Energy Supply

Renewable energy technologies

In the 1997 White Paper "Energy for the Future" [EC 1997], the EU Commission identifies a 12% share of renewable energy sources (RES) in the primary energy balance as a strategic target for the EU – 15 by 2010. Most Delphi respondents indicate that it should be possible to achieve a 25% share in Europe as a whole shortly after 2020.

Reaching a 25% share of renewable energy sources is claimed to be realistic if appropriate political decisions are taken and total energy demand does not increase substantially. However, a significant number of respondents sees no chance of achieving a 25% target because of the limited technical potential in Europe, the slow penetration into entrenched fossil systems and the still considerable increase in energy demand. They also point to obstacles such as lack of political will, low public acceptance of local environmental impacts, continuing high costs and technological handicaps, such as intermittent production.

The nature of support measures required to accelerate the diffusion of RES vary widely among technologies. Relatively mature technologies, such as "biomass for heating", need less R&D but rely heavily on fiscal and regulatory policy for their growth. At the other extreme are immature technologies, such as ocean energy systems, for which market support is currently irrelevant. Technologies in intermediate stages of development, such as photovoltaic systems, require both intensive support in terms of both basic and applied R&D, but can also greatly benefit from promotional strategies aiming at enlarging their market capabilities.

Respondents broadly agreed that a strong increase in the use of renewable energy sources has important implications for the environment and for the long-term security of energy supplies. The development of RES also contributes to regional cohesion. However, intensified basic and applied research as well as specific and resolute support schemes promoting the diffusion of RES technologies are necessary to obtain a strong increase in their utilisation in the period to 2030. A strong synergic role in achieving a high share of RES in the primary energy balance can be played by efficiency improvements in the production, transport and utilisation of energy.

Biomass and biofuels

Biomass received very favourable ratings in the Delphi survey, not only because of its ecological attributes and its contribution to security of supply, but also for its role in wealth creation and regional cohesion, specifically the creation of jobs on a regional scale. The near term potential of this energy source and its expected positive impacts justify a stronger support than is currently the case. Many participants indicate that biomass is already widely used for heating in some Northern countries, but questions remain regarding resource availability, strong regional differences in potential, high production costs and logistic problems related to transport over long distances of low density fuels. The Delphi experts also point to potential environmental problems related to sustainability of biocrop monocultures and pollution from biomass use.

The key determinant in the penetration of biofuels into the transport market is the availability of suitable biomass sources. However, attaining a 25% share in this sector in the time scale considered depends ultimately on the growth in transport sector demand and many experts claim it will not be possible in the absence of strong measures to reduce this through energy efficiency improvements, shifts to public forms of transport and rationalisation of transport patterns. As in the case of biomass utilisation in other sectors, the main problem with strong biofuels development regards sustainability in relation to the strain on soil use and the environmental risk of monocultures. As a partial solution, some experts stress the use of crop waste rather than dedicated crops.

The majority of Delphi participants agree that biomass could be in widespread use already in the mid-term perspective, shortly beyond 2010. However, the resource potential can be a limiting factor over large areas of the European land mass, though this could be partly alleviated through the development of biomass delivery and trading schemes from regions with large potential.

Applied research in biomass utilisation and biofuel conversion technologies can significantly contribute to increasing the use of biomass resources in the short and medium term. In recent years there have been signs of under-investment in this field of energy R&D compared to most other renewable energy resources, though there is still much scope for technological progress both in relation to efficiency improvements and cost reduction. Because of uncertainties concerning the role of biomass and biofuels in Europe’s energy system, research is also needed to evaluate the potential of these resources under different development options, so that realistic implementation strategies can be planned.

Photovoltaics

The image of photovoltaics (PV) that emerges from the Delphi exercise is that of a highly valued and desirable technology. However, the experts comment on a number of significant obstacles limiting the role of this technology in Europe's energy system in the medium term. These are above all the relatively low potential of direct solar energy over most of the continent and the persisting high cost of electricity produced from existing and near term technologies, due to the low efficiency of conversion and high cost of materials. Moreover a number of experts felt that the development of other renewable energy sources could limit the rate of penetration of PV in Europe in the period considered. The general consensus is that R&D and activities in this field and in related areas such as energy storage should be strengthened also through international cooperation. Demand side measures to accelerate development in Europe include integration of PV devices in construction materials in combination with new building designs.

Achievement of a 5% share of PV in electricity production received an impact rating higher than any other renewable energy source analysed in the Delphi survey. PV does not classify as a “safe bet“ technology in the EurEnDel analysis, only because of uncertainties in the rate of technological progress. In fact, even a major breakthrough is not expected to significantly increase its role in Europe's energy supply before 2030. There is more scope for a substantial increase in the period beyond, depending on improvements and new discoveries. The qualification of PV as a viable long-term technology is justified by the promise of future technological advances. Most experts point to applied research as the key to progress and innovation in PV technology, although many indicate that basic research is still necessary.

Nuclear power (fission and fusion)

A number of Delphi comments point to the apparent contradiction between the high share of funding for nuclear energy research, especially fusion, and the meagre positive impacts anticipated over the next 35 years. Though fusion goes beyond the time scale of the EurEnDel study, there is great uncertainty on the potential of the technology, which is mirrored in the fact that almost a quarter of the respondents expect that fusion will never be in practical use. The technology is considered too expensive and there is as yet no clear evidence of a breakthrough, despite massive R&D investment over the years.

The crucial issue in the case of nuclear fission is public acceptance related to the safety aspect in all phases of the nuclear cycle. The respondents highlight as major obstacles the unsolved problem of waste management and the risks from political instability, terrorism and war. One of the few positive notes expressed in the comments in favour of nuclear technologies is that they are practically free of CO_2 emissions and thus are in a good position to fulfil the Kyoto targets.

The EurEnDel respondents are openly divided on nuclear technologies. They agree on the positive impact of nuclear power in reducing CO_2 emissions, but disagree on the perception of risk and safety as well as on the waste management problem. All are very much aware of the delicate issue of public acceptance. One group recommends improving public information on nuclear technology, while the other favours reorienting R&D resources from nuclear power to the alternative energy sources. Respondents qualifying themselves as experts in the field, perceive nuclear fission as important to enhance security of supply. However, this view is not shared by the energy community as a whole, which explains the low overall rating received in the impact assessment both for new fission reactors and fusion research. There is consensus on the need to improve public safety and waste treatment technologies, but overall the EurEnDel survey does not provide encouraging recommendations for long-term research.

CO_2 capture and sequestration

In their comments the Delphi respondents express a lack of belief in the technology as a long-term solution to greenhouse gas emissions, pointing to insurmountable technical obstacles. Although the technology is already in use in small-scale demonstration projects, the prevalent assessment is that the long-term prospects of CO_2 sequestration is in doubt. The key problem lies in the high costs of the infrastructure needed to sequestrate CO_2 in comparison to other emission reduction options (energy conservation, fuel switching, renewable energy development and reforestation). Essentially none of the respondents indicates sequestration as the preferred abatement option. Major uncertainties regard the long-term storage of CO_2 and public acceptance, given the unknown impact on the environment and considering the risks of leakage, industrial accidents and natural catastrophes such as earthquakes.

The Delphi respondents generally rated the anticipated impacts of CO_2 sequestration as rather low, largely in relation to the uncertainties connected with the technology. They indicated that research efforts should concentrate on minimising risks concerning public safety, also through the parallel development of monitoring and verification techniques.

6 Conclusions

The EurEnDel findings provide a twofold contribution to the analysis of Europe's energy policies:

- they corroborate the conflicting attitudes and paradigms prevalent among energy experts, with valuable new dimensions for the on going energy debate;
- they offer genuine new insight on energy issues, with added value for decision makers.

This final chapter summarises the most important results of the EurEnDel survey. The underlying objective of EurEnDel was the assessment of long-term trends and needs in the fields of energy technologies. Special attention is given to faithfully translating the trends and needs identified by the survey participants into recommendations for R&D and energy policies.

Highest Priority: Energy efficiency

- The foremost message from the EurEnDel exercise is that **energy efficiency** technologies are the decisive element in Europe's energy future. The EurEnDel participants are quite resolute in their appraisal that technologies to reduce energy demand have the **most beneficial** impacts and must be favoured independently of the societal vision pursued. No matter whether we strive for economic well-being and liberty of choice, ecological balance or social equity, demand-side options to reduce Europe's dependence on energy supplies are highest on the list of priorities.
- However, despite their high potential and societal needs, supportive actions to improve energy efficiency must be intensified combining research, fiscal incentives and initiatives to promote end-user acceptance in order to avoid the **high underinvestment risk**.
- In housing and industry, long-term strategies are vital since high rates of energy efficiency improvements in these sectors can be achieved only in long term perspective, beyond 2020. Efficiency improvements in housing and industry rely heavily on fiscal incentives and regulation. However, by analogy with the priority given to research in these fields in the USA and Japan, market measures **need strong backing from applied research** in energy efficiency technologies.
- Enhancing energy efficiency in housing and industry is facilitated in the enlarged Europe because of the greater energy saving potential in new member states. However urgent **action is necessary in all 25 member states**, to obtain the expected results.
- Containing the increase in **transport energy demand** was identified as one of the most difficult challenge for Europe's energy system. The EurEnDel analysis indicates that there is **no simple solution**, capable of meeting this challenge. Efforts need to be intensified on all levels and employ all available means. The EurEnDel survey focussed on fuel cells and freight transport by railways as two solutions that can play a significant role.
- **Fuel cells** meet all the criteria for classifying as **a safe-bet** technology. They are well placed to play a major role in future transport systems, contributing both to energy efficiency improvements and reduction of local emissions. Fuel cell driven

cars are expected to reach a significant market share well before the hydrogen economy is established. Thus flexibility of design using natural gas as a transition fuel will be crucial in the development of fuel cells for transportation.

- Though **fuel cells** for transport as well as **hydrogen production** still require substantial **research support**, many Eurendel respondents are of the opinion that the technology could already benefit from the **application of market measures** (essentially fiscal incentives), due to potentially strong cost reductions coming from economies of scale.
- As for other mature technologies, fiscal and regulatory measures are the most important means of supporting **freight transport by rail**, though research still has a significant role to play. However, the future role of railways in freight transport depends more than anything on political choice.

High Potential: Renewables

- The majority of the EurEnDel experts believe that **25% of Europe's total energy** demand can be **met by renewable energy sources before 2030**. However, this target is deemed to be realistic only if renewable energy technologies receive appropriate support and in combination with strong energy efficiency improvements.
- The survey respondents consider **a high share of renewable energy sources** as **highly beneficial** from a societal point of view. Renewable energy development rated second in priority after demand-side oriented solutions. Basic reasons behind the high overall ranking were its positive impact on the environment, its contribution to security of supply and its potential for regional development.
- **Biomass** has the greatest potential to play a significant role in Europe's energy future. Both biomass utilisation technologies **and biofuels** production need applied research to enhance their competitiveness over the short and medium term. However, biomass resources are limited and there will be a competition for the use of land for biomass production for different energy related purposes (electricity, heat, transportation).In this respect, considerable uncertainties exist concerning the role of biofuels in Europe's future energy system. Research directed at evaluating effective biomass potentials seems necessary to identify strategic long term options.
- **Photovoltaic** technology can play a significant role in Europe's energy future in the longer term. A 5% contribution to Europe's electricity supply is considered possible between 2030 and 2040. However, such a high share implies that PV is competitive with alternatives and is held to be realistic in this time frame only as a result of a major technical breakthrough. Attaining such an ambitious target requires both basic and applied research, but also market expansion through adequate economic incentives.
- Besides technical and economical hurdles a key factor hindering the development of some renewables (such as wind an biomass) is **public acceptance** in relation to land change issues, landscape pollution, reduced comfort and distrust towards unknown technologies. Lack of public acceptance and antagonism from some decision makers results in smaller demand for these technologies and can delay technological maturity.

Increasing Importance: Distributed Electricity Generation and Energy Storage

- **Energy storage** is not just one of many elements of existing energy systems, but a key component in the future generation of electricity from intermittent renewable energy sources. Achieving a high share of renewables in Europe's energy system is not possible without a long term commitment in this field. Yet the Delphi results clearly indicate the risk of under-investment in energy storage R&D under current support schemes. The participants in the survey underscore a strong need for both basic and applied research.
- Energy storage technologies are endorsed by the Delphi participants not only in relation to societal visions favouring renewable supply sources. **Energy storage** technologies will become increasingly important in the future also in relation to the development of distributed energy systems and are therefore a fundamental element of societal visions favouring individual choice.
- The hydrogen system has the potential to become a major storage option. However, due to the long time horizon for hydrogen to contribute significantly to Europe's energy system **other storage alternatives**, including batteries, flywheels and super-capacitators also have to be pursued.
- The assessment of the **hydrogen** economy provided by the EurEnDel respondents depends on the source of the hydrogen. A hydrogen economy for its own sake is difficult to justify from an economic and environmental standpoint and less beneficial. The prevalent position is that hydrogen production from renewable sources is to be preferred mainly for environmental reasons. However, other sources (natural gas, coal or nuclear energy) may be required as bridges in the transition to a hydrogen economy based on renewable energy sources. To this end it is deemed important to identify a suitable long term growth path establishing framework conditions for the large new infrastructure needs required in the expansion of the hydrogen economy.
- The development of **superconductive materials** was considered to support the fulfilment of major policy and technology goals such as strengthening of the European electricity transmission grid, reduction of transmission and distribution losses and more efficient energy storage. Although it is now in very immature stages of development, the vast majority of the EurEnDel participants consider it to be a **viable option** for the future energy system.

Controversial Issue: Nuclear Energy

- A large majority of the EurEnDel participants do not expect the introduction of passively safe reactor types in Europe before 2020. However, it seems a controversial issue considering that almost 20% of the respondents do not believe it will ever occur. Despite its importance for security of supply and CO_2 abatement, **nuclear fission** was given very low ratings in the impact assessments.
- Roughly three quarters of the experts believe that at some point in the future **nuclear fusion** will be in practical use. However, this was the most controversial issue covered in the EurEnDel survey. Due to the very long-term perspective for its technological maturity, fusion generally received very low impact ratings. Some experts even doubt whether high support levels for nuclear fusion should be continued at all as there have been no clear signs of a major breakthrough

and there are no chances for the commercialisation of this technology before 2030. In any event, the Delphi respondents generally agree that the perception of nuclear fusion in the public mind should be decoupled from that of nuclear fission.

- Both nuclear technologies elicit the **largest divergence** between participants **based on national origin**. While there seems to be a fairly high consensus between respondents from different countries on the technical feasibility and the anticipated time horizons, there are strong disagreements on the expected societal impacts and whether or not the technologies will be in practical use in Europe.

Intermediate Solution: Natural Gas

- Most of the Delphi participants agree that **natural gas** can play an important role towards a more sustainable energy supply future for Europe. However, they also stress the need to avoid excessive reliance on this energy source for security of supply reasons. Many emphasize the **transitional character** of this resource as a bridge to a more sustainable energy future not based on fossil fuels. Consequently growth strategies should ensure compatibility with truly sustainable long-term options. In any event in the period considered a strong increase in natural gas imports can be anticipated together with **high investments needed** to build up the necessary infrastructure (pipelines and liquefaction facilities). R&D efforts in this field can contribute to bringing down the costs of natural gas transportation and storage infrastructure.

Other issues

- Participants in the survey broadly agree that long term reliability and safety (both real and perceived by the public at large) are the **most crucial issues** for the development of **nuclear** power. To a lesser extend this also holds true for the **hydrogen** system (production, transport and storage) as well as **CO_2 sequestration and storage**.
- Another pervasive issue throughout the Delphi response is that, both in the case of demand and supply side technologies, the level of **energy prices** should reflect the external costs, in order to increase the economic competitiveness of emerging technologies.

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