Energy related Delphi statements in comparison –
Expert responses from earlier foresight surveys
sorted by relevant problem fields

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About this document
This document represents part of the results of the literature review carried out within the EurEnDel project. It was used as one input to develop the questionnaire of the European Energy Delphi – EurEnDel.

To us the roadmap charts of future energy innovations became a good tool for our daily work. We hope that the information compiled in this document may be helpful for your work also.

The EurEnDel team

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Overall Energy Demand

Energy efficiency in buildings
- Retrofitting of housing stock - passive solar (-15 - 20% of heat demand)
- Energy management techniques in home
- No cooling demand due to intelligent windows and facade systems (vs air-conditioning) widely employed

Residential heating and cooling
- Widespread low energy houses (-50%)
- 30% improved cooling
- Combined heating and cooling

Appliances and energy saving technologies - residential sector and industry
- Widespread saving technologies
- Self-controlling lighting
- 50% efficiency gain in household appliances
- 30% reduction of demand for industrial processes

Overall energy demand
- Overall energy efficiency + 50%
- 60% share of global energy consumption in developing countries. Overall increase 100 - 200 %
- Penetration rates:
  - Heat pump water heater: 8% to 21
  - Dedicated CFL Lighting Fixtures: 7% to 15%
  - Horizontal Axis Clothes Washer: 91% to 98%

+ 57% worldwide
+ 35% Europe, but - 66% per capita?
Transport and Mobility

Infrastructure development

- Redesign and integration of transport and energy systems
- New propulsion systems and fuel processing
- Large diffusion of in-vehicle traffic information systems
- Intelligent systems on highways
- Maglev trains
- Hypersonic planes
- Light-weight materials in aircraft and trains

Advanced technologies

- From hybrid vehicles to electric cars
- 20% alternative fuels
- Transition to hydrogen fuel, including aircraft

Overall efficiency

- 20 - 30% efficiency gains in vehicles
- Decoupling from economic growth – 2 l car
- Transport still a problem in the US

Freight transport

- 30% efficiency gains in freight transport
- New logistics and combined transport

Passenger transport

- Substitution of 10 – 50% of private car use by public transport
- New mass transport systems in metropolitan areas

EurEnDel – European Energy Delphi
Expert responses from earlier Delphi surveys sorted by relevant problem fields
slide no. 2
Grid Development

**Cost**
- Cost reduction of 50% in district heating
- Underground cables cost competitive

**Efficiency**
- Superconducting Technologies
- High Efficiency Transformers
- CHP and use of process heat
- Doubling share of electricity generation by CHP
- Ever smaller CHP units, 0.001 MW/unit

**Application**
- Advanced two-way metering
- Digitally controlled T&D grid
- AC electronic components (FACTS)
- FACTS measuring+on-line analysis
- Hybrid energy systems in off-grid areas
- DC in power T&D
- On-line systems to detect leakages in pipelines
- Use of trench-less pipelaying tech.
- Alternative to LNG or pipelines for utilising natural gas from remote locations

**General Outlook**
- Distributed generating plants (<100 Mwe) in UK and effectively used for back-up
- International network for Intermittent grid electricity and H2 from RES

2003 2010 2020 2030
Renewables’ Fate: Overall Contribution

**Renewables Europe**
- "100% renewable " communities established
- Increased use - 2010: 12% of consumption

**Renewables worldwide**
- Operating RE systems in developing countries - RE provide 10% of consumption
- Significant impact
- RE provide 33% of world energy
- RE provide 50% of world energy

**Competitiveness**
- RES mature and fully competitive
- Cost reduction:
  - Biomass and wastes: 10-15%
  - Wind onshore: 15-25%
  - Wind off shore: 20-30%
  - Solar PV: 30-50%
  - Solar thermal power: 30% or more
  - Geothermal: 10%
  - Hydro: 10%

**Contribution to electricity production**
- > 10% w/o large hydro
- CHP 75-100% in Denmark
Renewables’ Fate: Wind & Wave

2003 2010 2020 2030

Onshore Wind

- 1-5 MW turbines, commercial competitiveness; 15% cost reduction; investment below 1000€/kW
- Capital costs for wind power drop to $611/kW
- 50% cost reduction per kWh

Offshore Wind

- 5,000 MW offshore installed in Europe

Wind general

- 10 MW turbines
- Planning tools and participation models- 40,000 - 60,000 MW
- 150,000 MW installed in Europe; 10% of electricity from wind

Wave, Sea and Tidal

- Wave (near shore) commercially available
- Wave energy (offshore point absorption) and tidal current turbines commercially available
- Large-scale commercial take-up of marine technology
- Ocean ‘farming’ for food and energy widespread
- 1 TWh/yr from wave energy
- 200 MW installed capacity of point absorber wave energy systems
- Wave power plants are in practical use
- Temperature differences of the sea are used for power production

10 MW turbines
Planning tools and participation models- 40,000 - 60,000 MW
150,000 MW installed in Europe; 10% of electricity from wind
Large-scale commercial take-up of marine technology
Ocean ‘farming’ for food and energy widespread
1 TWh/yr from wave energy
200 MW installed capacity of point absorber wave energy systems
Wave power plants are in practical use
Temperature differences of the sea are used for power production

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Expert responses from earlier Delphi surveys sorted by relevant problem fields slide no. 5
Renewables’ Fate: Solar Thermal

Solar-thermal power plants - electricity production

- Cost-efficient hybrid plants
- ST plants with air- or salt cooling commercially available
- Cost-efficient concentration systems
- 1 GW installed in Europe
- 7 GW installed in Europe
- Solar thermal plant electricity generation: 0-2 EJ
- Competitive with fossil engines in the South

Solar-thermal appliances for heat and hot water, process heat

- Widespread use in buildings with centralized heating and hot water
- Competitive solar process heat in industry
- 30% of warm water supply in moderate climates
Renewables’ Fate: Photovoltaics

**Costs**
- < 3 euro / W
- Competitive with conventional systems in residences
- 75% cost reductions

**Efficiency**
- Efficiency increase 20 - >25%
- 3rd generation > 85% efficiency
- Conversion efficiency 50%
- Ultraefficient systems
- Conversion efficiency 85%

**Applications**
- Technology commonly used in rural electrification
- Integration in buildings
- Space generation systems

**General Outlook**
- 18 GW/yr worldwide shipment of photovoltaics (total market of 27 billion US$)
- PV central for changing energy picture
- Key industry for 21st century

EurEnDel – European Energy Delphi
Expert responses from earlier Delphi surveys sorted by relevant problem fields slide no. 7
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<tr>
<th>Biomass</th>
<th>2003</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturing of technology</td>
<td></td>
<td>25 - 30% of EU primary energy demand</td>
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| Biogas | | | | |
|--------| | | | |
| Widespread use of biogas from garbage dumps | | | | Bio plant electricity generation: 1-12 EJ

| Biofuels | | | | |
|---------| | | | |
| Ethanol price competitive in Europe | | | Mass market |

| Waste | | | | |
|-------| | | | |
| Extension of waste gasification and co-firing for heat and electricity production | | | Biotechnologies for methane production from waste |

| Crop production | | | | |
|-----------------| | | | |
| 10% of energy sources - Germany | | | 250-750 Mt/year of energy crops in EU |
Carrier Fuels and Storage Technologies

Batteries
- Advanced batteries
- Lead-acid
- Nickel/lithium
- Lithium-polymer
- Polymer batteries with energy density of 400Wh/kg

Fuel Cells (FC)
- SOFC delivered from industry
- SOFC + SPFC/PEMFC
- Commercial development in industry
- FC in the residential sector
- Widespread used for CHP applications in industrial, commercial + residential use

Hydrogen (H2)
- H2 production from fossil fuels
- H2 production from non-fossil fuels
- H2 production from RES
- H2 transport + storage technologies
- H2 turbines + use in gas turbines
- H2 routinely used in energy systems
- Use of H2 gas turbines
- H2 distribution network

Other storage Technologies
- Conventional flywheel + advanced cable / insulation materials
- Flywheel with superconductors
- Long term storage tech.
- Advanced gas storage systems
- High temp. supercond.
- Large solar/low temp. heat (Aquifers)
- Supra conductors (1Mio kWh)

H2 production from fossil fuels
H2 production from non-fossil fuels
H2 production from RES
H2 transport + storage technologies
H2 turbines + use in gas turbines
H2 routinely used in energy systems
Use of H2 gas turbines
H2 distribution network

Thermo chemical process for H2 derivation
Converting CO2 into methanol using H2
Use of metal hydrids and nanotubes

H2 transport + storage technologies
Flywheel with superconductors
Long term storage tech.
Advanced gas storage systems

H2 transport + storage technologies
Flywheel with superconductors
Long term storage tech.
Advanced gas storage systems

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Expert responses from earlier Delphi surveys sorted by relevant problem fields
Hydrocarbon Bottleneck (part I)

Raw materials

- Oil will remain the basic raw material
- Coal will be a competitive raw material during first half of the century
- Projected imported dependence of EU and EU-30: 54% and 42%
- Projected imported dependence of EU and EU-30: 62% and 51%
- Projected imported dependence of EU and EU-30: 71% and 60%

Techniques generated by 3D seismic surveys to analyse and interpret (full wave)
Remote sensing
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Techniques generated by 3D seismic surveys to analyse and interpret (full wave)
Remote sensing

Exploration & Production

- Consumption of biologically degradable fuels will increase
- Natural Gas grows from 23% to 28% of global primary energy consumption
- Proportion of economically recoverable oil by 50%
- Oil shale and tar sands
- Proportion of economically recoverable oil by 50%
- Oil shale and tar sands
- Proportion of economically recoverable oil by 50%
- Oil shale and tar sands

- Reduction in costs of oil/gas drilling by 50%
- Recovery and utilisation of coal-bed methane
- Exploitation of oil/gas in deep water and severe environments
- Exploitation of oil/gas in deep water and severe environments
- Exploitation of oil/gas in deep water and severe environments

- Unconventional natural gas covers >25% of the world gas demand
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2003 2010 2020 2030
Hydrocarbon Bottleneck (part II)

Conversion Technologies

- Supercritical coal-fired power plant
- Fluidised bed combustion
- Carbon dioxide fixation technology
- Direct coal liquidation and turbine
- Efficient gas turbine combined cycle (75%)
- High efficiency combined cycle
- Oil residue & coal gasification
- Improvements in gas turbines and coal & waste incineration
- Retrofitting of power plants
- Direct conversion of methane to heavier hydrocarbons
- Integrated FC / combined cycle plants on market (70%)
- Widespread use of gasified coal
- Coal hydration is economically feasible
- In-site gasification in coal mines
- 10% improvement in efficiency of gas turbines
- US moves away from fossil fuels
- Continuing privatisation and liberalization of the gas market
- Energy supply still relies on fossil fuels
- Extension of domestic utilisation of natural gas

General Outlook

- Extension of domestic utilisation of natural gas
- US moves away from fossil fuels
- Energy supply still relies on fossil fuels

Energy supply still relies on fossil fuels
Continuing privatisation and liberalization of the gas market
Extension of domestic utilisation of natural gas
**EurEnDel – European Energy Delphi**

**Expert responses from earlier Delphi surveys sorted by relevant problem fields**

### Nuclear

#### Advanced reactors
- Small, modular reactors
- Fusion: from demonstration to commercial use
  - Third generation reactors
  - LWR competitive with fossil fuels
  - Fast Breeders

#### Treatment of nuclear waste
- Deep underground storage
- Safe storage technologies (separation, encapsulation, glass ceramics)
- Reuse

- Growth of market for decommissioning

#### Risk of accident and long-term perspectives
- Extension of useful life
- Nuclear widely accepted

- Risk of large-scale contamination

**2003 2010 2020 2030 2040 2050**

- **2030**
  - Fission accounts for 50 % of electricity generation 3 - 18 EJ
List of Delphi statements

Sorted after problem fields

*X refers to the reference list

1. Future energy demand – increase vs. efficiency gains

1. World energy consumption is expected to increase 57% *10
   2020
2. World energy consumption is expected to increase 100-200% *10
   2050
3. Energy consumption per capita in ‘advanced nations’ falls to 66% of 1990 level (normative assumption) *1
   2025
4. Energy consumption per capita in the rest of the world will be 160% of 1990 level *1
   2025
5. Global primary energy use, high growth scenario: 1040-1495 EJ *11
   2050
6. Global primary energy use, sustainability scenario: 601 EJ *11
   2050
7. 60% share of global energy consumption in developing countries (35% in 1990) *12
   2050
8. 35% increase in energy demand in Europe *12
   2030
9. 2% decrease in total energy consumption in Denmark *12
   2012
10. 57% growth of energy use. Fossil fuel share will be 90%. Demand of developing countries will exceed that of the
    OECD countries (IEA) *5
    2020
11. Dramatically reduced extraction of virgin materials (mining, logging etc.) gives significant energy savings *1
    2025
12. Many new techniques that substitute energy-intensive processes in heavy industry (for example membrane
    technologies instead of thermal separation processes, microwave and impulse drying) will be applied, so that energy
    demand for industrial processes will be reduced by one third. *9
    2017
13. Insulation, LTS deployment schemes *14
    2000-2
14. Energy saving technologies of high economic value and strategic importance to the Netherlands *15
    2005-10
15. Reductions of several dozen percent in energy use in high energy-consuming industries *15
    2005-10
16. R&D for energy saving technologies increasingly important *15
    2000-10
17. Public research for energy saving technologies increasingly important *15
    2000-10
18. Reduced energy consumption in the areas *15:
    Redesign of industrial processes
    New catalysis methods
    Process integration for re-use of heat
    Process control and sensors for energy efficient control
    Alternative separation processes
    Biotechnological processes
    Materials technology
    Dematerialization
19. Energy savings will be achieved by using energy efficient heating systems and electrical devices, and by improving
    the thermal integrity of buildings. Energy saving potential offered by new technologies in refrigeration, illumination and
    in entertainment in the residential and service sector only constitute 1% of Finland’s total electricity consumption (p.
    158). *5
20. Cleaner and more efficient energy technologies *1
    <2025
21. Energy-efficient and cost-efficient remanufacturing and re-use of materials *1
22. New production techniques which reduce industrial demand by one third *6
    2006-10
23. Efficient lighting and cooling system in the commercial and residential sector *6
    2006-10
24. Energy efficient household appliances (50% demand reduction) *6
    2006-10
25. Energy efficiency improves by 50% through innovations in transportation, industrial processing, environmental control
    etc. *8
    2021
26. Stand-by loses can be avoided in most appliances due to cheap control systems. *9
    2008
27. Lamps with an efficiency of 75% exist. *9
    2017
28. Household appliances have 50% of today’s energy demand *9
    2014
29. Widespread purchasing of domestic appliances (refrigerators, washing machines, hi-fi, cooking etc.) which are 50% more energy efficient than today’s best*16 <2007 (or never)

30. Widespread application of switched reluctance motors (providing variable speed and high efficiency electric drives) in domestic and industrial markets *16 <2010

31. High efficiency condensing boilers become the preferred choice for domestic and industrial installations in the UK *16 <2005

32. Aerogels for insulation *1 2025

33. A new technique for producing raw iron (optimized ovens, direct reduction or reduction through melting) is developed for which only 70% of the current primary energy demand is required *9 2019

34. Non-electrolytic reduction techniques for the production of aluminum metals are in use *9 2018

35. In Industry, new technologies that could have the largest impact include *13: >2010
   - black liquor gasification (paper)
   - impulse drying (paper)
   - smelt reduction (steel)
   - membranes (chemicals, food)
   - heat pumps (chemicals, food)
   - inert anodes (aluminum)
   - new grinding technologies (non-metallic minerals, mining)
   - process control and equipment (all sectors)
   - high efficiency and high temperature CHP including gas turbines and fuel cells

36. Widespread use of energy recovery from combined HVAC (and DHW) systems which reduce energy demand by 30% *16 <2010

37. Contracting services reduce the energy demand in households and industry by 20% *9 2009

1a. Future energy demand – increase vs efficiency gains: Energy efficiency in buildings

38. Building without energy loss based on isolation, optimization of energy consumption, in appliances, no-energy required ventilation and renewables *4

39. Widespread low energy houses (half of today’s consumption) *9 2013

40. Energy efficient buildings (50% demand reduction) 2006-10

41. Wide spread self-sufficient houses due to energy efficiency and longterm energy storage *9 2020

42. Low energy passive heating and/or cooling techniques adopted in a majority of new buildings and major refurbishments of existing buildings *16 <2010

43. Practical use of improved air tightness, energy recovery and air movement equipment makes mechanical ventilation the most energy efficient and preferred option for all buildings types *16 <2010 (or never)

44. Sustainable building practices and norms *7 2015

45. Large-scale dissemination of energy saving techniques *7 2010

46. Integration of current understanding and techniques into mainstream building design results in new buildings routinely requiring 50% less energy than current designs *16 <2007

47. Development of an integrated approach to retrofitting existing buildings, using existing techniques and understanding, which improves the energy performance of refurbished buildings by 50%. *16 <2012 (or never)

48. Widespread incorporation of passive solar aspects into mainstream building design contributes 20% improvement in energy efficiency of new houses *16 <2010 (or never)

49. Passive solar gains contribute with >15% of total space heating demand in residential buildings in most European countries *7 2010

50. A heating and cooling system which employs a heat pump and uses solar energy is in practical use *9 2011

51. Energy management in newly built private homes is standard (employing a central computer, sensors, light-, heating-, cooling management *9 2010

52. Smart building materials self adapting to climatic conditions offer options for further energy demand reduction in housing *9 2013

53. No cooling demand due to intelligent windows and facade systems *9 2011

54. Widespread use of ‘smart’ techniques (for services, controls, dynamic fabric characteristics, etc.) enables achievement of significantly improved energy performance of buildings in practice *16 <2010
55. Public and private buildings are equipped with decentralized data buses that take over the transfer of data to a functional unit, which in turn manages the complete energy demand of each building automatically, integrating all consumers. *9 2014

56. Widespread use of efficient self-controlling lighting systems in newly build houses *9 2010

57. Air conditioning widely employed *7 2010

58. 30% improvement in system efficiency of building cooling systems compared with today's best practice *16 <2008

59. Widespread use of combined heating/cooling systems in new housing in UK *16 ? (or never)

60. Widespread use in commercial buildings of dehumidification systems that do not use refrigeration technology *16 <2012

61. Widespread use of storage of low-grade heat and/or 'coolth' in new buildings to exploit off-peak power *16 <2012 (or never)

62. Low-energy windows have >90% market share in Europe *7 2010

63. Superwindows provide energy efficiency and automated building management *15

64. Sorption-chilling pumps (fuelled with natural gas, oil and biogas) are widely used *9 2013

65. In newly built housing areas (in moderate climates) local heat systems are the predominant concepts *9 2017

66. Penetration Rates for Selected Technologies in the Building Sector (% of equipment stock) *13: 2020

Residential:
Heat pump water heater: 8% to 21%
Dedicated CFL Lighting Fixtures: 7% to 15%
Horizontal Axis Clothes Washer: 91% to 98%
In commercial buildings:
Electronic Ballasts: 100%

67. Low-energy lighting becomes the preferred choice for domestic, commercial and industrial applications *16 <2008 (or never)

68. Electricity demand doubled *7 2020

69. Wallboards and floors that change their crystalline structure for heat storage *2

70. Multifunctional facades and surfaces *7 2010

71. Building simulation tools widely employed *7 2010

72. Angle selective coatings, thermotropic/-chromic coating and glazing forms employed *7 2010

73. Widespread use of adsorption cooling employing solar or district heat *9 2012

2. Transport and mobility

2.a. Overall energy efficiency in transport and infrastructure development

74. Transport patterns will be redesigned in cities and urban areas e.g. to improve energy efficiency *1 2025

75. Ensuring increased transport safety *3

76. Change in mode of transport can contribute to greater energy efficiency (public transport, rail and remote working) (p. 189) *5 trend 2010

77. Thanks to the „dematerialisation“ of transport flows (for example by rationalising and combining the movement of goods, telecommunication services for classical household consumption goods) overall economic growth and transport growth can be decoupled. *9 2015

78. Transport and automobiles continue to be an energy problem in the US *1 2025

79. Development of the transport infrastructure in the context of the European infrastructure *3 2010

80. Integrated transport and energy systems: *4 2030

81. Infrastructure will be financed less by taxes and more by user fees and via capital markets (road tools etc.) *17

82. Smooth transfers and payment systems will make it easier to utilize the most convenient and optimal transport means. Travel centers will play a key role and serve as a node in intermodal transportation system (emission-free rental cars for everyday travel) *17 2020

83. 30% efficiency gain in the specific energy consumption of motorized vehicles *6 2006-10

84. Motor vehicle with fuel efficiencies 30% greater than today *14 2006-8

85. Widespread use of highly efficient low emission engines for transport (>20% improvements) *16 <2010
86. Practical use of diesel engines with commercially available fuel which meet current EU regulations for emissions from gasoline engines fitted with catalysts *16 <2010 (or never)
87. Elimination of particulate emissions from exhausts of 50% of all diesel engines on the road *16 <2010 (or never)
88. Cost competitive zero emission vehicles capture 10% of UK road vehicle market *16 ? (or never)
89. Large diffusion of in-vehicle traffic information systems *14 2007-9
90. 120 mile-per-gallon cars in widespread use *1 2025
91. 2 liter car in serial production *9 2014
92. Ceramic combustion engines allow 2 liter car with low emissions without catalytic converter *9 2014

2.b. Advanced transport technologies
93. Intelligent transportation systems are commonly (30%) used to reduce highway congestion *8 2016
94. Automated highways *8 2021
95. Transportation means driven by electrical, chemical or thermal energy interchange
96. High speed trains (Rail or Maglev) are available between most major cities in developed countries *8 2017
97. Maglev trains are mature 2032
98. 50% of the EU plane traffic is substituted by high speed trains (goods and people) *9 2018
99. Intelligent transport systems with information and control capabilities to a.o.t. increase (? improve?) fuel consumption *15
100. Hypersonic planes traveling at more than five times the speed of sound are used for the majority of transoceanic flights *8 2030
101. Hypersonic air carriers common *1 2025
102. Widespread use of extremely energy efficient Turboprop air planes with speeds comparable to Jets *9 2018
103. The emerging technologies that offer the potential to reduce significantly the energy use and GHG emissions include *13:
   - Cellulosic Ethanol
   - Hybrid Electric Drivetrains
   - Lower Weight Structural Materials
   - Direct Injection Gasoline and Diesel Engines
   - Fuel Cells
   - Aircraft Technology
104. Lightweight composites in aircrafts and rail vehicles in ‘world 2’ countries *1 2025
105. Alternative engine designs for greater efficiency and reduced weight *15
106. Most ICE (Internal combustion engine) cars are hybrids (IC-HEV) *5 2010
107. Market share of > 5% for electric or hybrid vehicles *6 2006-10
108. Hybrid vehicles that combine electric and internal combustion engines are commercially available *8 2013
109. Battery powered electric cars are commonly (30%) available *8 2006
110. Widespread use of electric engines in cars (similar costs and output compared to today’s combustion engine) *9 2019
111. Hybrid electric vehicles reach mass market *14 2002-3
112. Hybrid electric vehicles compete with conventional vehicles *14 2010
113. Market share of > 2% for biofuels *6 2006-10
114. Gas, ethanol, and methanol cover 20% of the fuel consumption in transportation (app. 80% oil) *11 2020
115. 10% of energy consumed by road transport come from fuel generated by renewable resources *16 ?
116. Oil is still the primary fuel for transportation *11 2005
117. 20% of fossil fuels in transport sector replaced with alternative fuels (EU goal) *12 2020
118. Widespread use in the UK of alternative fuels for vehicles, e.g. methanol for cars or natural gas for light commercial vehicles *16 ? (or never)
119. Hydrogen replaces hydrocarbon in internal combustion engines *6 >2010
120. Hydrogen replaces fossil fuels in the transport sector *14 2011-14
121. Metal hydrogen storage systems allow for 10% of hydrogen fuelled cars *9 2019
122. Widespread use of gasoline engines fuelled with hydrogen *9 2023
123. First use of Hydrogen fuelled airplanes. Some airport have hydrogen infrastructure *9 2022
124. Widespread use of PEM fuel cell driven cars *4 2010
125. Fuel cell vehicles enter niche markets *14 2001-2
126. FC vehicle enters mass market *14 2011
127. Fuel cells reach significant market share *14 >2020
128. Auxiliary power units based on SOFC fuel cells in freight transportation and lorries *4
129. FC-Evs start dominate in new car sales (fuel cell – electric vehicle) *5 >2020
130. Direct hydrogen-fuelled FCV enters the market *5 2006
131. Fuel cell use and distribution system *6 2006-10
132. Fuel cells powered electric cars are commonly (30%) available *8 2012
133. Widespread use of fuel cell cars fuelled with methanol *9 2021
134. The cost of a hydrogen fuel cell system is reduced to $1,540 more than a comparable gasoline vehicle *13 2020
135. Cars powered by hydrogen fuel exceed 10% of total automobile production *14 2011-20
136. High energy capacitors for clean vehicles *15
137. Development of cost-effective refinery processes that meet future requirements for clean transportation *16 <2010
138. Non-IC propulsion systems e.g. in electric cars *15
139. For many applications in CHP and transportation diesel engines are fuelled with vegetable oil *9 2011
140. First commercial use of cost-effective fuel cells for electric vehicles using alcohol or hydrocarbon fuels *16? (or never)
141. In the production of fuels alcohol from algaes reach 10% of the worldwide production *9 2020

2.b. Passenger transport

142. In passenger transport, the expected mobility of labour force, the necessity of further preference of public transport at the expense of individual transport and the increase of demands on business and recreation trips will be of substantial importance *3
143. Increase in free time due to increased productivity and the ageing of the population can lead to growth in leisure trips, mostly undertaken with passenger car (p. 189) *5 2010
144. Private mobility demand reduces to 50% because public mobility services are comfortable and cheap *9 2020
145. Teleworking and videoconferences substitute a considerable part of traffic related to business. *9 2008
146. Public transport substitutes 10% of private car use *6 2011-15
147. Long-distance travel will increasingly rely on environmentally friendly transport means thank to improved logistics for ticket sales (air / train), the use of combined tickets for public transport and / or rented cars, including advanced information management for switching transport modes (for example indicating the station and the time of departure for subways), for further travel to the final destination.*9 2013
148. Car-like capsules on guide rails or other personal rapid transit systems are installed in most metropolitan areas *8 2024

2.c. Freight transport

149. Increasing use of business-to-customer e-commerce could lead to an explosive increase in door-to-door deliveries with undue effect on transport movements and emissions, unless common carrier companies and network-based wireless data systems can be used to greatly enhance the efficiency of such parcel transport. (p. 189) *5 trend
150. Gain in transport capacity of railways due to new transport logistic (telematic guidance) *9 2010
151. Combined transport using „intelligent containers“ substitutes a large part of long-distance road transport *9 2015
152. 30% efficiency gain in freight transport 2006-10

3. Spatial movements

153. Clustered, self-contained communities in urban areas reduce the need for local transportation *8 2023
154. Diversity will characterize regions and cities. Major efforts to ensure that cities can attract events, conferences and tourists *17

4. Grid development

155. Intermittent grid service in third world countries *1 2025
156. A digitally controlled transmission and distribution grid in operation to move high-quality power precisely and reliably to where it is needed *5 2030
157. The combining of FACTS (flexible alternate current transmission system) wide-area measuring system and on-line analysis on a European level *5 2030
158. Use of direct current (DC) in power transmission and distribution will increase. DC can supply digital devices on the customer’s site directly and can connect DC systems (fuel cells) without converters. *5 2030
159. Decentralization of the electricity grid (distributed systems) *6
160. Advanced two-way metering systems (for supplies to and from the grid) *6 2006
161. Improved grid performance due to technologies based on AC electronic components (FACTS) *6 2006-10
162. Development of superconducting transmission cables for long distance transfer of low-cost power *5
163. Practical use of supra conducting cables in electricity grid *9 2021
164. Supra conductive current limiter allow for low short circuit currents *9 2013
165. Superconductors in power transmission, energy storage etc. *15
166. First commercial application of high temperature superconductors for power applications *16 2005-2015
167. Long distance DC power transmission (1000kV) *9 2010
168. Cost reduction of 50% in district heating due to new laying techniques and insulation *9 2012
169. Fast and decentralized power producers are effectively used for back-up power, *9 2009
170. Hybrid Energy systems (sun/wind/diesel) are the most important generators in off-grid areas. *9 2009
171. An extensive data exchange system between electricity producers and consumers is use for efficient demand side management *9 2008
172. International distribution network for electricity and hydrogen produced from renewables – to be distributed into regions according to demand *9 2024
173. By use of an east west electricity grid peak loads in accordance with sunshine can be met – rise in use of renewables *9 2020
174. Wireless transmission in Earth’s Energy future: electricity would be converted to microwaves, beamed over long distances by satellite, and then converted back to electricity without damaging the environment *10
175. T&D Technology Development *13: >2020
  - High voltage direct current transmission
  - High temperature superconducting (HTS) cables and transformers
  - More efficient line transformers
  - Real-time control using automated controls
176. High-power solid state switches *15
177. Improved power electronics e.g. for integration of renewables in the system *15
178. Widespread use of remote condition monitoring and control of distribution grids *16 <2005
179. Underground power cables cost-competitive with overhead transmission *16 <2015 or never
180. Widespread use of high efficiency transformers (for grid application), with at least 25% reduction in losses *16 <2010
181. Construction of small (<100MWe), distributed generating plant provides the majority of additions to non-nuclear power station capacity in UK *16 <2010 (or never)
182. Cogeneration and use of process heat *6 2006-10
183. Cogeneration of heat and electricity in residential buildings *6 2005
184. Installed capacity of co-generation in UK industrial and commercial premises reaches 5 GW *16 <2010
185. Doubling of the share of world-wide electricity generation produced by co-generation/combined heat-and-power *16 <2017
186. Widespread use of domestic (circa 2kWe) combined heat and power package *16 ? (or never)
187. Highly integrated multi-supply systems which use various materials and energy input and combine various technologies to produce different combinations of products: power, heat & cool, desalinated or otherwise purified water, and chemical products such as bio-oils and gases *5
188. Superconductors central for the changing energy picture *1 2025
189. Superconductive coils for powerstorage into use *1 2005-7
190. Penetration Rates for Selected Technologies in the Building Sector (% of equipment stock) *13: 2020

In commercial buildings: High Efficiency Transformers: 41% to 74%
191. First commercial use of alternative to LNG or pipelines for utilising natural gas from remote locations *16 <2015
192. Widespread use of low-cost materials for hydro-carbon pipelines and equipment that do not require replacement as a result of corrosion through a 30 year operational life *16 <2010
193. Practical use of intelligent, on-line inspection systems to detect all leakages and failure-producing defects in pipelines *16 <2007
194. Practical use of trench-less pipelaying technology which enables hundreds of metres of flexible pipe up to 600mm diameter to be laid from the launch point *16 <2009
195. Development of improved technology for liquefaction of natural gas reduces cost of liquefaction by 25% *16 <2009
196. Bifurcated trend in power production: 1) bigger and efficient plants 2) smaller, simplified plants for distributed generation *5
197. Electricity is generated in ever smaller CHP units, 0.001 MW/power/unit *5 2030

5a. Renewables’ fate, in general

198. The share of energy produced from renewable sources in the CR, particularly biomass, small water power stations, geothermal and sun energy, will increase *3 2010
199. 305 TWh/yr total electricity by RE technologies (1990: 191 TWh/yr) *7 2010
200. 12% contribution from renewables to EU gross, inland consumption (EU target) *7 2010
201. RE technologies fully economically competitive *7 2015
202. Renewables play a significant role in the energy systems *7 2020-30
203. Applied schemes for RE systems integration into existing electric power supply in Europe *7 2010
204. 100% RE systems communities/regions established *7 2010
205. Operating RE systems in developing countries *7 2010
206. RE provides >50% of world energy (shell scenarios) *7 2050
207. RE provides 33% of world energy *7 2030
208. Decrease in world energy consumption from fossil fuels and nuclear sources *7 2050
209. A significant portion (10%) of energy usage is derived from alternative energy sources, such as geothermal, hydro-electric, solar/photovoltaic *8 2010
210. Renewable energy will mature *8 2017
211. Share of power produced from renewables (without hydro) exceeds 10% *9 2020
212. Significant impact of renewables on the global energy mix, especially driven by environmental concerns *12 >2020
213. Effective power and heat supply systems in Denmark in which 75-100% of the electricity is based on RE resources *12 2030
214. Practical use of systems with combined solar/fossil power generation (>100MW) in areas with sufficient solar intensity *9 2016
215. 1200 GWh/yr surplus electricity production in Denmark (due to a.o. RE and CHP systems) *12 2020
216. 280 GWh/yr surplus electricity production in Denmark (due to a.o. RE and CHP systems) *12 2010
217. Cost reductions for energy technologies (p. 100) *5:

Biomass and wastes: 10-15%
Wind onshore: 15-25%
Wind off shore: 20-30%
Solar PV: 30-50%
Solar thermal power: 30% or more
Geothermal: 10%
Hydro: 10%

5b. Renewables’ fate: Biomass, biogas and waste

218. Genetically engineered biomass that produces more ethanol *2
220. Wide-spread use of biogas from garbage dumps *6 2009-13
221. 135 Mtoe/year biomass in EU (three-times increase) *7 2010
222. 225 Mtoe/year biomass in EU corresponding to 25-30% of current primary energy *7 2015
223. 75 Mtoe/year bioheat in EU (doubling) *7 2010
224. 250-750 Mt/year of energy crops in EU *7 2015
225. 75-150 Mt/year of short rotation forestry in EU *7 2015
226. 30% increase in biomass energy resources from wood wastes and municipal solid wastes in EU *7 2015
227. Co-combustion with other materials with >30% of the caloric value from biomaterials *7 2010
228. >30% improvement in combustion efficiency *7 2015
229. Biomass gasification widely employed in power plants *7 2015
230. Pyrolysis oil as transportation fuel *7 2020
231. Biodiesel (esterification) employed widely at mass markets *7 2015
232. Competitive bioethanol prices in Europe *7 2010
233. Biological materials, such as crops, trees, and other forms of organic matter, are used as significant (10%) energy sources *8 2011
234. 10% of Germany’s energy demand is met by biomass *9 2012
235. High efficient energy conversion from biomass (eg, gasification) are widely used. *9 2013
238. Commercial contribution from bioethanol *12 2004
239. Biomass cofiring: Use can be increased relatively easily to 2-4% of coal generation *13 <2020
240. Biomass used as common technology *14 2004-9
241. Organic energy sources (biomass) exploited through economical technologies *15
242. First practical use of commercially competitive energy crops for electricity generation *16 <2006
243. Treatment and reuse of wastes to obtain energy such as methane at low cost using biotechnology *14 >2014
244. Widespread recovery of energy from waste materials in UK *16 <2006
245. Waste plant electricity generation: 0-2 EJ/yr *11 2020 and 2050
246. The planning of new industrial parks comprises the use of waste heat for other processes *9 2012
247. Utilization of low grade industrial waste heat becomes normal commercial practice in UK *16 ? or never
248. Combination of biomass and waste gasifiers with gas in gas-fired combined cycle power plants *5 <2012

5c. Renewables’ fate: Photovoltaics

249. Photovoltaics central for the changing energy picture *1 2025
250. Photovoltaics panels increasingly used in rural areas of ‘world 2’ and third world *1 2025
251. Solar cells provide 4% of US power *1 2025
252. Multi-junction photovoltaic cells that use a very wide range of the electromagnetic spectrum. This will result in higher conversion efficiencies *2 2020-30
253. Polymeric based solar cells as opposed to solid-state semiconductors. Will improve conversion efficiencies to electricity by over 50%. *2 2020-30
254. Optical films that concentrate solar energy *2
255. Space based power can be beamed via microwaves to receiver parts on earth where microwaves could be converted back into electricity. *2 2030-50
256. Low cost and highly efficient photovoltaics with long life time. One million 4kW systems on rooftops equal to one 4GW nuclear plant *2
257. Highly efficient thin film photovoltaic modules > 15% *6 >2014
258. Ultraefficient photovoltaic systems *6 >2014
259. Integration of photovoltaic panels in buildings *6 <2003
260. Solar cell industry becomes the key industry of the 21st century *7 2025
261. System cost <3.0 Euro per installed W *7 2010
262. ‘Third generation’ photovoltaics cells with efficiency ideally up to 85% *7 2020
263. Efficiency of c-silicon and thin film cells higher than 20% respectively 15% *7 2010
264. Efficiency of advanced cells (tandem, concentration, GaAs stacks) > 25% *7 2005
265. New artificially constructed materials for high-efficiency thin-film cells *7 2020
266. Multilayer solar cells reach an efficiency of 50% (widespread use) *9 2020
267. Practical use of large a-Si solar cells with > 20% efficiency *9 2013
269. Large thinfilm solar cells with +20% efficiency are in practical use *9 2013
270. Solar cell plant electricity generation: 0-14 EJ *11 2020
271. Solar cell plant electricity generation: 0-60 EJ *11 2050
272. 18 GW/yr worldwide shipment of photovoltaics (total market of 27 billion US$) *12 2020
273. Commercial contribution from polymer photovoltaics cells *12 2012
274. Outphasing of crystalline silicon photovoltaics cells *12 2025-35
275. Outphasing of thinfilm and photoelectro-chemical cells *12 2050
276. Photovoltaics: 75% cost reductions possible in long term *13 <2020
277. Photovoltaic technology commonly used in rural electrification *14 2008-15
278. Solar cells for power supply for residences competitive with conventional systems *14 2008-10
279. Large amorphous silicon solar cells with a conversion efficiency of more than 20% *14 2012-15
280. Space photovoltaic power generation systems *14 >2020
281. Mass production of high performance solar cells and solar thermal power technologies *15 2005-10
282. Ex-works costs of photovoltaic modules are reduced below $2 per peak Watt *16 <2010

5d. Renewables’ fate: Small hydro
283. Small hydroelectric plants *6 2004-8
284. 185 TWh/yr hydro output in the current 12 EU countries (compared to 165 TWh/yr in 1990) *7 2010
285. Extra 4000 MW SHP installed in EU *7 2010
286. World capacity of SHP 55.000 MW (37.000 in 2000) *7 2010
287. Accelerated development scenario for SHP: 21.700 MW in Western Europe and 4.200 in Eastern Europe & CIS *7 2020
288. Hydro plant electricity generation: 10-16 EJ *11 2020
289. Hydro plant electricity generation: 15-35 EJ *11 2050
290. Hydropower: Increased efficiency and enhanced environmental performance with advanced technology *13 <2020

5e. Renewables’ fate: Solar thermal power plants
291. Cost advances for hybrid solar-thermal plants (combined solar + fossil fuels) *6 2006-10
292. Significant contribution to efficient, economical and clean energy supply by solar thermal concentration systems *7 2010
293. 1 GW of STPP installed in Europe *7 2010
294. 7 GW of STPP installed in Europe *7 2015
295. STPP cost competitive with fossil fuels plants *7 2010
296. Direct steam generation trough technology *7 2020
297. Integrated solar/fossil power plants *7 2010
298. In southern countries solar thermal stirling engines are widely used *9 2015
299. Solar tower plants with air-cooling or salt-cooling are commercially available. *9 2018
300. Solar thermal: Limited cost-reduction potential *13 <2020
301. Mass production of high performance solar cells and solar thermal power technologies *15 2005-10
302. Solar thermal plant electricity generation: 0-2 EJ *11 2020
303. Solar thermal plant electricity generation: 5-12 EJ *11 2050

5f. Renewables’ fate: Solar thermal appliances
304. Wide-spread use of solar appliances for hot water in buildings with centralized heating and hot water facilities *62004-8
305. Solar combi systems (hot water and heating) widely employed *7 2010
306. Competitive solar process heat systems *7 2015
307. In countries with a high insolation, process heat for industrial and commercial use is often produced using thermo-solar installations. *9 2015
308. Widespread use of cheap and large solar/low temperature heat (eg. Aquifers) *9 2020
309. 30% of the warmwater supply is produced with solar energy (in moderate climate areas) *9 2021

5g. Renewables’ fate: Wind energy
310. Low RPM generators to eliminate gearbox assemblies in turbines *2
311. Large wind turbines 1-3 MW *6 2004-9
312. Cost reduction for wind turbines from 300 euros / m² a 200 euros / m² *6 2004-9
313. Commercial competitiveness of wind parks *6 2004-9
314. New generation of wind turbines with reduced maintenance costs *6 2004-9
315. 10% of world electricity from wind energy *7 2020
316. 50% reduction of costs per kWh *7 2020
317. 15% reduction of costs per kWh *7 2005
318. 150,000 MW installed in Europe *7 2020
319. 5,000 MW offshore installed in Europe *7 2020
320. 5MW turbines on the market *7 2005
321. Decentralized, small units for grid connection or stand-alone operation widely employed *7 2015
322. Prediction and planning tools for wind energy and systems *7 2010
323. Public participation models and practices for the development, land use etc. established *7 2010
324. Windpower systems with several MW peak and investment costs below 1000€/kW are on the market *9 2005
325. Offshore windparks >100MW are being built *9 2011
326. Wind mill electricity generation: 2-5 EJ *11 2020
327. Wind mill electricity generation: 10-20 EJ *11 2050
328. 40 GW windpower in Europe (EU goal) *12 2010
329. 60 GW installed in Europe (EWAE proposal) *12 2010
330. 150 GW installed in Europe (EWAE proposal) *12 2020
331. 10% of world electricity from wind power (Wind Force 10 report) *12 2020
332. >10% of EU electricity from wind power (Wind Force 10 report) *12 <2020
333. 50% electricity produced by wind turbines *12 2030
334. Wind electricity fully economically competitive with new conventional power technologies *12 2007-10
335. Offshore wind energy covers 6-8% of world wind power market *12 2005
336. Fast growing world market for small wind turbines: 100MW installed *12 2005
337. Large (10-20MW) wind turbines *12
338. Capital costs for wind power drop to $611/kW *13 2016
339. Wind Power Fixed O&M costs decline from $25.9/kW-yr throughout the period down to $16.4/kW-yr *13 2020
340. Wind Energy: Costs competitive on kWh basis in near future in some markets *13 <2020
341. 10 MW class wind power generation systems *14 2002-8
342. Widespread use of commercially competitive wind turbines for grid-connected application *16 <2008 or never

5h. Renewables’ fate: Sea, tidal and wave energy
343. Ocean ‘farming’ for food and energy will be widespread *1 2025
344. Wave energy (near shore) commercially available *7 2003
345. Wave energy (offshore point absorption) commercially available *7 2005
346. Tidal current turbines commercially available *7 2005
347. Ocean thermal energy conversion demonstration projects *7 2005
348. Large-scale commercial take-up of marine technology *7 2015
349. 1 TWh/yr from wave energy *7 2010
350. 200 MW installed capacity of point absorber wave energy systems *7 2010
351. Demonstration of third-generation offshore devices *7 2010
352. Wave power plants are in practical use *9 2019
353. Temperature differences of the sea are used for power production *9 2026
354. Tidal and wave energy are a commonly used technology *14 >2014

5i. Renewables’ fate: Geothermal energy
355. In areas with good geothermal conditions low temperature supply with or without heat pumps are widely used *9 2015
356. Geothermal energy is exploited by the hot dry rock method *9 2015
357. Geotherm plant electricity generation: 0 EJ *11 2020 and 2050
358. Geothermal Hydrothermal: Resource identification *13 <2020
359. Hot dry rock power generation technology *14 >2020

5k. Renewables’ fate: Solar chemistry
360. Solar fuels that can replace oil and natural gas products *7 2030
361. Substitution of artificial light in photochemical and photocatalytical processes with solar light *7 2010-30
362. Solar detoxification and sterilization of water *7 2020
363. Solar high temperature processes applied in recycling of metals and for vitrification of filter dusts *7 2020

6. Carrier fuels and storage technologies
6.a. Batteries
364. Advanced batteries *15 2005-10
365. Batteries double the current specific energy (?)*14 2004-6
366. Lead-acid batteries, nickel-cadmium/lithium batteries, lithium-polymer batteries that are light and have long life time and low cost are available *2 2010
367. Battery use of electricity storage *6 2006-10
368. Batteries with a high energy density (> 200 Wh/kg) are widely used *9 2012
369. Rechargeable Polymerbatteries with an energy density of 400Wh/l are in practical use *9 2015
370. High density (200 Wh/kg) secondary batteries *14 2008-11
371. Rechargeable polymer batteries with a volume-specific capacity of double current ones *14 2012-20
372. Rechargeable polymer batteries 400 W h/litre *14 2010-12
373. Widespread use of high density (4 times that of lead-acid) battery competitive with lead-acid technology *16 <2014

6.b. Fuel Cells
374. Micro distributed power systems in a distributed generation systems (based on SOFC and PEM fuel cells) *42015-20
375. Use of fuel cells for heat and electricity production in industry *6 2006-10
376. Use of fuel cells for heat and electricity production in the residential sector *6 2015
377. Fuel cells a predominant form of electrochemical energy generation *1 2025
378. Reversible fuel cells to create the fuel cell fuel with electrical input *2 2010-20
379. Fuels cells converting fuels to electricity are commonly used (30%) *8 2019
380. Fuel cells (solid electrolytic) >10 MW are used in regional CHP and power generation plants *9 2017-20
381. Power plants on the basis of coal-gas fuelled high temperature fuel cells (200 – 300 MW) are in use *9 2023
382. PEM fuel cells are widely used for CHP applications in houses *9 2020
383. Widespread use of decentral high temperature fuel cells for CHP applications in industrial and commercial use *9 2019
384. Fuel cell electricity generation (coal, gas): None *11 2020
385. Fuel cell electricity generation (coal, gas): 0-90 EJ/yr *11 2050
386. Hydrogen fuel cell electricity generation: 0-10 EJ/yr *11 2020
387. Hydrogen fuel cell electricity generation: 0-75 EJ/yr *11 2050
388. SOFC (Solid Oxide) delivered from industry *12 2005
389. Commercial contribution from SOFC (ceramic) and SPFC/PEMFC (polymer) fuel cells *12 2010
390. Outphasing of alkaline, phosphoric acid, and molten carbonate fuel cells *12 2010-18
391. Fuel cells an integrated part of the hydrogen energy system *12 2010
392. Fuel cells as highly efficient environmentally safe and portable power sources *14 2012-20
393. Commercial development of fuel cells *15 2005-10

6.c. Hydrogen
394. An extensive distribution network to supply decentralized customers with hydrogen is established *9 2027
395. Hydrogen transport and storage technologies *6 2006-10
396. Hydrogen production from renewables *6 2011-15
397. 10% H2 produced from renewables *14 >2020
398. The biological production of hydrogen by use of solar energy and biological organisms (or parts) works on industrial scale. *9 2023
399. Hydrogen use in gas turbines *6 2010-15
400. Hydrogen turbines *6 2010-15
401. Hydrogen becomes routinely used in energy systems *8 2020
402. Hydrogen (gained by electrolysis in solar or wind parks) is used as energy storage and fuel for electricity production *9 2022
403. Practical use of a thermochemical process for hydrogen derivation *9 2020
404. Use of metal hybrids to increase energy density of hydrogen storage *5 long term
405. Carbon nanotubes to draw hydrogen into the storage, increasing the filling efficiency *5 long term
406. Practical use of hydrogen fuelled gas turbines for public power generation *9 2023
407. Commercial contribution from hydrogen carrier technology *12 2017
408. Significant improvement in H2 technology, main production from fossil fuels *14 2003-5
409. H2 production from non-fossil fuels *14 2008-9
410. Thermochemical decomposition processes for hydrogen production *14 2006-10
411. Practical use of methane and methanol derived from coal and biomass by use of hydrogen gain by electrolysis (non fossil) *9 2020

6.d. Other storage technologies
412. Conventional flywheel energy storage *6 2006-10
413. Flywheel energy storage combined with superconductors *6 2011-15
414. First practical use of other large-scale energy storage (e.g. flywheels, compressed air) competitive with pumped storage technology *16 ? (or never)
415. Superconducting storage devices *6 2011-15
416. Superconducting, magnetic energy storage with high efficiency, high capacity energy storage systems to compensate for large daily swings in power requirement and to stabilize transmission systems against disturbances *2 2026
417. Practical use of energy storage systems employing superconductors with a capacity similar to pumped storage hydro plants (1Mio kWh) *9 >2015
418. High temperature superconductors *6 2006-10
419. Advanced cable and insulation materials *6 2006-10
420. Improved natural gas storages *15 <2011
421. First practical use of advanced gas storage systems able to hold 4 times as much as current systems *16 <2011
422. Integrated transport and energy systems: *4 2030
423. Electricity surplus to be produce hydrogen or charge batteries
424. Gradual development towards this integration, highly dependent on both policy push for environmental regulation as well as on technology push for improvements in fuel cells, storage etc.
425. Hydrogen economy: the ideal production technology would be electrolysis of water, but its costs are 3-4 times higher than the current steam reforming.
426. Storage in inorganic crystal structures such as carbon nano-tubes (long run) *5
427. Long term storage technologies employed *7 2010

7. Hydrocarbon bottleneck
7.a. Raw materials
428. Crude oil will remain the basic petrochemical raw material. *3 2010
429. Consumption of biologically degradable fuels will increase *3 2010
430. Coal will be an important competitive power and non-power-producing source in the CR during the whole first half of the 21st century *3 2010
431. Europe will become more dependent on gas imports from Russia, NIC, North Africa and Near East *5
432. Unconventional natural gas (hydrates, gas from coal mines) cover >25% of the worlds natural gas demand *9 2025
433. Reserves-to-production ration, high growth scenario: 37-330 years *11 2100
434. Reserves-to-production ration, middle scenario: 28-55 years *11 2100
435. Reserves-to-production ration, sustainability scenario: 10 years *11 2100
439. Today natural gas accounts for 23% of global primary energy consumption. It is expected to raise from current 2.4Tm3/a to 4.5 Tm3/a or 28% of primary energy mix (IEA reference scenario) *5 2020

7.b. Exploration & Production
440. Remote sensing of hydrocarbons becomes a standard commercial technique in exploration *16 <2006
441. Development of advanced techniques to analyse and interpret (full wave) generated by 3D seismic surveys *16<2004
442. Reduction in costs of oil/gas drilling by 50% *16 <2006
443. Widespread exploitation of high pressure, high temperature oil/gas reservoirs *16 <2006
444. Widespread exploitation of oil/gas reservoirs in deep water and severe environments *16 <2009
445. Increase the proportion of economically recoverable oil by 50% in existing reservoirs by appropriate modelling and physical/chemical treatment *16 <2010
446. Commercial use of microbial-enhanced recovery techniques to improve the yield from oil reservoirs *16 <2014
447. Commercial use of multiphase well-stream transport over distances in excess of 200km and in water depth up to 3,000 m. *16 <2010
448. Reduction in capital costs of offshore platforms by 50% compared with best practice today *16 <2010
449. Widespread exploitation of oil shale and tar sands *16 >2015
450. Advanced automation and robotics become a standard part of long-wall coal mining equipment *16 <2005
451. Reduction of 25% in the cost of removal of sulphur from run-of-mine coal *16 <2010
452. Widespread commercial recovery and utilisation of coal-bed methane *16 <2008
453. Environmentally benign recovery of petroleum resources and deep sea oil & gas production technologies *15

7.c. Conversion technologies
454. Appropriate methods of exploitation of coal methane and development of new technologies of its use (fuel cells, cogeneration, fuel of motor vehicles, chemical use) will be developed *3 2010
455. New generation of CFB (circulating fluidised bed boiler) plants with supercritical steam cycle combines high fuel flexibility and high efficiency *5
456. Higher power-to-heat ratio is expected by integrating a high temperature fuel cell with an IGCC plant (Integrated gasification combined cycle) – for wood gasification about 60% and for natural gas-fired fuel cell boosted plants about 70% *5 2030
457. Pressurized coal combustion technology *6 >2015
458. Liquefied coal technology *6 >2015
459. IGCC (coal gasification) *6 >2015
460. Fluidized bed combustion *6 2005-9
461. Combined Cycle (gas) *6 <2005
462. In-site gasification of coal mines *9 2022
463. Widespread use of power plants using gasified coal *9 2014
464. coal hydration is economical feasable *9 2017
465. High efficient combined cycle power plant (entry temperature >1500°C) are widely used *9 2009
466. Integrated high temperature fuel cells / combined cycle power plants with efficiencies of 70% are on the market *9 2015
467. Supercritical coal-fired power plant developments *14 2000-5
468. Efficient gas turbine combined cycle (75%) *14 2003-6
469. Direct coal liquidation *14 2005-9
470. Large-scale combined cycle power generation using high-efficient gas turbines (>1500°C) *14 2007-10
471. Direct coal-fired turbine (advanced thermodynamic cycle) *14 2008-11
472. Carbon dioxide fixation technology *14 >2013
473. 50% of orders for new coal generating plant in OECD require gasification or other clean coal technology *16 <2009
474. First practical use of gasification of oil refinery residue for power generation which is cost-competitive with upgrading residue to liquid products. *16 <2008
475. Development of direct (non-syngas) conversion of methane to heavier hydrocarbons *16 <2013
476. First commercial use of large, efficient gas-fired combined cycle power generator *16 <2005
477. Improved gas turbines – high-temperature bearing materials, combustor design *15 2005-10
478. Development of improved open-cycle gas turbines providing 10% improvement in efficiency *16 <2005
479. First commercial use of large, efficient gas-fired combined cycle power generator *16 <2005
480. Retrofitting of power plants (prolonging their useful life) *6 2005-9
481. Improvements in treatment of coal and waste incineration *15 2005-10

7.d. General Outlook
482. US moves away from fossil fuels *1 <2025
483. A number of changes may be expected in the utilization of natural gas, both institutional (continuing privatisation and liberalisation of the market) and factual, particularly the extension of domestic resources *3 2010
484. Die Frage, ob abitogenes (sich im Erdinnern selbst bildendes) Erdgas gewonnen werden kann, ist weitgehend geklärt. *9 2021
485. Energy supply still rely on fossil fuels *11

8. Nuclear Power
8.a. Advanced reactors
486. Advanced light-water reactor incorporating new passive safety systems *5
487. High-temperature gas-cooled reactors (HTRs or HTGRs) promise competitive unit size of 100-300 MW as well as high efficiency. HTR can be used to produce high-quality steam or hydrogen for the process and chemical industries. *5
488. Fusion nuclear power is used commercially for electricity production *8 2046
489. Small and medium sized nuclear power plants are used to supply heat and power to cities *9 2020
490. A fast breeder reactor is in practical use *9 2026
491. A fusion reactor is developed. Waste problems are solved *9 2028
492. Fusion (with magnetic plasma) is used for power (and hydrogen) generation *9 2028
493. Generation IV reactors (commercial contribution) *12 2030
494. Generation III+ reactors (improved gen. III) (commercial contribution) *12 2010
495. Demonstration of fusion energy technology *12 2020
496. Commercial contribution from fusion energy technology *12 2050
497. Fast breeder reactor *14 >2015
498. Next generation nuclear reactors – light water, inherently stable types *15
499. Light-water nuclear reactors produce electricity at costs competitive with other base-load generation *16>2015 or never
500. First commercial use of Fast Reactor *16 >2015 or never
501. First commercial use of small (<300MWe) modular nuclear reactor incorporating passive safety design *16 2005-20

8.b. Treatment of nuclear waste

502. Nuclear waste a principal risk issue *1 <2025
503. Glass ceramics preferred medium for storing of radioactive wastes *1 2025
504. A highly developed technique for the reuse of nuclear waste, which also permits the separation of highly contaminated waste by groups according to decontamination periods, is possible *9 2022
505. The safe and secure encapsulation of Plutonium 239 is operational worldwide. *9 2019
506. Practical application of treatment procedures (for example transmutation) for highly contaminated, solid nuclear waste. *9 2020
507. Nuclear waste can safely and permanently be stored due to special insulation techniques and video or satellite-based control systems *9 2016
508. Closed nuclear plants can be safely and economically decommissioned *9 2011
509. Reuse of nuclear waste *14 2009-13
510. Deep underground repositories become the universal method of disposal of all intermediate and high level nuclear wastes *16 2005-15
511. Commercial use of nuclear fuel reprocessing which is cost-competitive with direct disposal of spent fuel and its associated waste and meets all applicable safety requirements *16 ?
512. Ten-fold increase in that fraction of the world market for nuclear decommissioning services in which UK companies can compete *16 <2010

8.c. Risk of nuclear accident and long-term perspectives

513. Widespread contamination (worse than Chernobyl) by a nuclear device will occur *1 <2025
514. Synergy of coal and nuclear defines the long-term development trajectory of Czech power engineering. *3 2010
515. Fission nuclear power is used for 50% of electricity generation *8 2046
516. Due to climate concerns and improve security nuclear power is widely accepted in Europe *9 2015
517. Nuclear electricity generation: 10-35 EJ/yr *11 2020
518. Nuclear electricity generation: 3-180 EJ/yr *11 2050
519. Improved efficiency and life extension of current plants possible at low cost. New small plants may better meet market needs *13 <2020
520. Widespread use of improved techniques for remote condition monitoring, inspection, maintenance and repair significantly extent the operating life of nuclear generating plant and associated fuel cycle facilities *16 <2004

9. Power play in the energy market (balance exterior)

521. 70% of EU energy imported *12 2030
522. Widespread use of technology which allows users to arbitrage automatically between fuels and suppliers based on pre-set preferences for fuel price, type, availability and emission characteristics *16 <2010 (or never)
523. Widespread use of network management systems, models and databases allowing dynamic electricity and gas system control in a de-regulated market *16 <2008
524. Use of local generators to supply electricity to 20% of villages in developing countries which are currently without electricity *16 <2010

10. Energy price and taxes

525. Rise in absolute costs of energy *1 2025
526. Powerpool with high price elasticity will push for advanced steering and regulation technology (intelligent consumption) that automatically regulates consumption (from washing machines, water heater etc) when prices are
low. Also the powerpool will push for development of storage technologies (hydrogen storage, batteries, phase change), in particular in distributed generation systems. Three preconditions are crucial for the implementation of powerpool:

527. Changed taxation and tariff system
528. Advanced ICT systems
529. Flexible consumption options offered by electricity producers *4

530. Green taxes
531. Prices for gas and electricity varying over time are standard *9
   Motor gasoline: +0,4% to +39,6%
   Other petroleum: +3,1% to +13,6%
   Natural Gas: -17,6% to -4,2%
   Coal: -27,3% to +73,4%
   Electricity: -23,4% to -11,5%

533. High price elasticity in prices to regulate this complex and highly distributed system

11. Future social relations
534. Supranational government will become effective (though not completely) with regard to environment and other issues *1
535. Structural shifts to information economy (major reason for reduced energy use in US) *1
536. Material changes lead to permanent energy savings in ‘world 1’ societies (US, EC, etc.) *1
537. Flexible and varied markets for housing and commercial space will take over from standardized and uniform ones *17
538. Energy and eco-balances are use by companies for product and engineering decisions *9

12. The future of work
539. Education of a workforce of 1.7 million in the wind energy area *7

13. Demographic trends

14. Technological progress
14a. Efficiency gains in power and heat production
540. Active coatings (eg. on buildings and cars) for power generation, heat storage and lighting *9
542. Efficiency gains in power plants due the new catalytic processes (low pressure, low temperature processes) *6 <2010-15
543. Practical use by electricity utilities of ultra-super-critical steam turbines *16
544. Wärmetransformatoren zur Anhebung des Temperatur niveaus in Abwärmeströmen werden in der Prozeßtechnik und der Fernwärmeversorgung in breitem Umfang eingesetzt. *9
545. Cheap oxygen separation allow for widespread application of burning processes with >800°C *9
546. Piezoelectric materials in wind and hydro power generation. Stands for 1.7% of US electricity
547. Piezoelectric materials in wind and hydro power generation. Stands for 12% of US electricity *1
548. Development of improved catalyst technology enables 30% of existing high temperature/high pressure chemical processes to be replaced by low temperature/pressure alternatives *16
549. Widespread achievement of at least 20% improvement in energy efficiency and reduction in emissions of industrial process plant through use of improved design methods (e.g. process integration, intensification *16
550. Widespread use of improvements in monitoring techniques (and appropriate refurbishment) extends the life of non-nuclear energy plant by 10 years *16
551. First practical use of Humid Air Turbine, or other advanced cycle, in large-scale operation *16
552. Power supply: high energy, low mass supplies and pulse supplies *15
14b. Information technology
553. Expert systems for power plant <2005

554. Information technology *17:
  Unlimited computer power and storage and transmission capacity
  Intelligent products
  Digital assistants

555. Optoelectronic switching prevailing in IT *1 2025
556. All-photonic switching prevailing in IT *1 2025

14c. Biotechnology
557. Biotechnology *17:
  Plant or microorganisms as a factory:
    Production of hydrogen
    Surface coating
    Biosensors

14d. Materials technology
558. Materials technology *17:
  Nanotechnology
  Artificial photosynthesis by means of advanced material sintesis
  Bioimplants made by semiconductor surfaces, custom-made at molecular level using micro-and nanotechnology
  Intelligent materials

559. Coating/structural materials for storage and transmission of hydrogen *1 2025
560. Superconducting films, wires etc. *1 2025
561. Superconductive materials in magnets in turbines and motors *1 2025
562. Superconducting materials are commonly used (>30%) for transmitting electricity in electronic devices, such as energy, medical and communications applications *8 2025
563. Commercial contribution from MgB2/metal superconductive technology *12 2005
564. Commercial contribution from coated conductor superconductive technology *12 2010
565. Out-phasing of BSCCO/Ag super-conductors *12 2015-28
566. Phase change materials that change state at 22C. *2

14e. Other applications and processes
567. Extensive monitoring, assessment, and analysis of resources and environment through sensor networks *1 2025
568. Practical use of a process with which water is dissociated through solar rays *9 2018-20
569. Widespread use of speed control in electric engines *9 2006
570. Advanced heat transfer fluids; non-corrosive, non-freezing, high heat capacity, low viscosity *2
571. Specific seismic sensors are developed for the detection and exploration of new, deep oil and gas fields, as well as other resources *9 2014
572. First practical use of ‘Intelligent’ meters incorporating 2-way communication and control of appliances to purchase electricity at times and rates chosen by the customer *16 <2005

15. Environmental restraints and objectives
573. ’Totally managed’ (though not fully understood) environment and resources *1 2025
574. Sustainability and environmentalism a basic value and organization concept of global society *1 2025
575. Energy is no longer among the primary environmental concerns due to significant improvements in energy matters *1 2025
576. Global warming and nuclear matters are among the top three environmental concerns *1 2025
577. Consumption of fuels and pressure on the state administration to improve conditions for air and water protection will increase *3
578. Electricity production with reduced NO\textsubscript{x} emissions *6 2005-9
579. 2/3 of the world’s CO\textsubscript{2} emissions from non-OECD countries *7 2050
580. Green manufacturing by most manufacturers *8 2016
581. Improvements in fossil fuel energy efficiency and greater use of alternative energy sources reduce greenhouse gas emissions by one-half from current volumes *8 2028
582. Industrial ecology is used by the majority of manufacturing facilities *8 2038
583. Ecosystem design *8 2039
584. Atmospheric CO\textsubscript{2} concentration, high growth scenario: 560-950 ppmv *11 2100
585. Atmospheric CO\textsubscript{2} concentration, sustainability scenario: 445 ppmv *11 2100
586. Greenhouse gas reduction of 8% in EU, relative to 1990 *12 2012
587. Greenhouse gas reduction of 21% in Denmark, relative to 1990 *12 2012
588. Comprehensive recycling systems (provide energy) *15
589. Elucidation of the relationship between man-made Carbon Dioxide and global warming to an accuracy of +/- 20% *16 ? (or never)
590. Widespread use of low NO\textsubscript{x} burners and combustion systems for all fuels *16 <2008

15a. CO\textsubscript{2} separation and sequestration
591. CO\textsubscript{2} capture and storage technologies in coal-fired plants *6 2010-15
592. CO\textsubscript{2} Emissions are reduced to one half by CO\textsubscript{2} immobilisation *9 2021
593. Fuel cells can be combined with other cycles. With carbon separation could achieve carbon and criteria air pollutant emissions near zero *13 <2020
594. CO\textsubscript{2} from fossil power plants will be stored in natural gas and oil fields (sequestration) enhancing at the same time the recovery of those fields *9 2015
595. Future strategies for carbon sequestration include injecting carbon dioxide into the earth or into the sea, separating the gases from the air and storing them by planting trees, and using chemistry to produce new products from these gases, such as methanol to fuel hybrid cars, and as an energy source for fuel cell cars *10
596. First commercial application of techniques for disposal/storage of CO\textsubscript{2} (other than by growing plants) *16>2010 or never
597. Practical use of a process which converts CO\textsubscript{2} emissions from big power plants into liquid fuel (methanol) by use of hydrogen *9 2024
598. Technologies for CO\textsubscript{2} fixation in power plants are in practical use *9 2021
599. Production of algae and other aquatic biomass is a potential concept for arid and sunny areas, where the growth of surface vegetation is limited due to precipitation. Algae systems might be connected to the sequestration of CO\textsubscript{2} from gases from a power plant. The long term goal could be algae that produces hydrogen for fuel cells *5 long term
EurEnDel – Energy related statements from previous Delphi surveys

References