Sustainable energy supply and consumption by 2050 and outlook towards the end of the century: Possible scientific breakthroughs

Lennart Bengtsson, Elisabeth Rachlew, Friedrich Wagner

INTRODUCTION

A project launched by the European Academies’ Science Advisory Council (EASAC) in 2013 identified possible areas of scientific breakthroughs in energy supply and consumption with a long-term perspective up to and beyond 2050.

The project facilitated interactions and information sharing among scientists in Europe and worldwide through electronic communications and two dedicated workshops. A steering committee with eighteen scientists from eleven countries was appointed by the EASAC participating academies (Box 1). The first workshop concentrated on nuclear energy and explored its possible future scientific and technological developments, while the second workshop addressed renewable energies, energy systems and storage (Table 1). The papers presented in this Special Issue were written by experts who participated in the project and benefitted from the opportunities for international information sharing and discussion.

The main sources of energy supply addressed during the project were carbon-based fossil fuels, solar photovoltaics, biofuels and nuclear. Whilst energy efficiency was an essential issue throughout the discussions and special consideration was given to the energy efficiency of engines and appliances, particular attention was given to the future of electricity grids, electricity storage and fuel cells. Lastly, concerning energy consumption, there was an important focus on energy for transport.

One important conclusion from this project is that the energy issue should not be split up into independent contributions: electricity, heat, mechanical work, etc. The transformation to a largely CO₂-free energy supply requires that the chemical energy forms are replaced predominantly by electricity. Even more than in the past, an energy policy and development strategy requires keeping in mind the total picture—energy generation, energy transportation and energy usage and each area calls for increased research. Even if a timespan for this transition of more than thirty years does seem long, we nevertheless have to conclude that fossil energy will still be in the energy mix for a long time globally. Therefore, we have to accept the unavoidable need to develop carbon capture and storage techniques, even if Europe could escape to employ this technology. MacElroy (2016) points out clearly the present situation and what research is needed for the future for closing the carbon cycle. Furthermore, the technological development in nuclear energy could alleviate the question of long-term storage of high level nuclear waste. Nuclear fusion research has the chance within the next decade to demonstrate the feasibility of this concept and to demonstrate that a fusion reactor could be an option in the long-term energy mix which is highlighted in the article by Horvath and Rachlew (2016).

Wind and solar power have shown a remarkable growth in many countries inside and outside Europe. In countries like Germany, the added installed power level matches peak demand. The efficiency of the solar cells has reached levels where solar cell panels could give considerable contributions to the energy mix in most European countries. Still, new materials might emerge with even better photovoltaic properties. Several basic science research areas within the fields of solar and biofuels are highlighted. The article by Inganäs and Sundström (2016) highlights the
possible development for photovoltaics to enter in a large scale with more efficient, resilient and economic solar panels and takes a look into the research development of the materials needed. The scene of the many functionalities of biofuels is painted by Aro (2016) in her article, which highlights where worldwide research is flourishing.

The introduction of intermittent electricity sources into the production requires more planning and changes to the distribution net which is modelled and discussed in the paper by Kuhn et al. (2016). In many countries most of the fossil contributions come from the transport sector which would need a transformation to electric vehicles and/or a combination with fuel cells. Both these issues are discussed in the articles by Furfari (2016) and by Niakolas et al. (2016).

Some basic science and major technology research areas have not been included, such as development of chemical and electrical storage systems, and development of new materials (for nuclear reactors, for batteries, for solar panels, for cables), in order to focus this issue more towards the generation of the energy needed for the future.

In summary, the seven papers included give an overview of fields in energy research which could promise essential progress in low-carbon energy supply and use.

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Box 1 EASAC steering committee for the Breakthrough study

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Table 1  The project has included the following meetings besides the four meetings of the steering committee: Workshop on the future of nuclear energy, Greifswald, April 8–9, 2013 (http://www.easac.eu/energy/wg-low-carbon-energy.html) and Workshop on renewables, storage and systems, KVA, Stockholm, September 20–21, 2013 (http://www.kva.se/en/Science-in-Society/Energy-Committee/Breakthroughs-in-Sustainable-Energy/)

| Researcher                | Institution                                      | Title of presentation                                                                 |
|---------------------------|--------------------------------------------------|----------------------------------------------------------------------------------------|
| **Workshop on the future of nuclear energy** |                                                 |                                                                                       |
| Hamid Ait Abderrahim      | MOL, Belgium                                      | Future Advanced Nuclear Systems And Role of MYRRHA                                     |
| Hardo Bruhns              | Düsseldorf, Germany                               | Framework aspects for the use of nuclear power in the longer-term future                |
| Ákos Horváth              | Budapest, Hungary                                 | New projects in Eastern Europe and the sustainability of nuclear energy                 |
| Boris Kuteev               | Moscow, Russia                                    | Possible outcome of fusion-fission power plant by 2050 and beyond                      |
| Alex C. Mueller           | CNRS, Paris, France                               | Pyroprocessing and fast reactors by 2050—reflections on pros and cons                  |
| Friedrich Wagner          | IPP, Greifswald, Germany                          | More effective energy distribution on a European scale                                  |
| Robert Wolf               | IPP, Greifswald, Germany                          | Fusion research and Wendelstein 7-X                                                   |
| Friedrich Wagner          | IPP, Greifswald, Germany                          | Options of nuclear fusion beyond 2050                                                 |
| **Workshop on renewables, storage and systems** |                                                 |                                                                                       |
| Paul Alivisatos           | Lawrence Berkeley National Laboratory, USA        | Nanoscience and the future of the Global Carbon Cycle                                  |
| Karl Leo                  | Technical University Dresden, Germany             | Recent progress in organic solar cells: From a lab curiosity to a serious photovoltaic technology |
| Markus Antonietti         | Max Planck Institute of Colloids and Interfaces, Germany | Lactic acid, ionic liquids and energy storage materials—Perspectives of Hydrothermal Biomass Upgrade |
| Eli Yablonovitch          | University of California Berkeley, USA           | Photovoltaics, high efficiency together with low cost                                  |
| René J. Janssen           | Technical University Eindhoven, The Netherlands    | Efficient polymer solar cells and first steps beyond that                              |
| Frank Dimroth             | Fraunhofer-Gesellschaft, Germany                  | Photovoltaic research for the support of European energy transition                    |
| Magnus Borgström          | Lund University, Sweden                           | Nanowires with promise for high efficiency photovoltaics                               |
| Anders Hagfeldt           | Uppsala University, Sweden                        | Hybrid inorganic–organic photovoltaics—HI-OPV                                         |
| Klaas Hellingwerf         | University of Amsterdam, The Netherlands          | Cyanobacteria as the ultimate photo-catalysts of the conversion of carbon dioxide into chemical commodities and liquid fuel, driven by either sunlight or electricity |
| Per Gardestrom            | Umeå Plant Science Center, Sweden                 | Energy and green chemicals from forest products                                       |
| Sascha Rexroth            | Ruhr University Bochum, Germany                   | Rational design of cyanobacteria for hydrogen production                              |
| Vincent Artero            | CEA, France                                       | Molecular science for artificial photosynthesis: from bio-inspired catalysts to nanomaterials |
| Erwin Reisner             | University of Cambridge, UK                       | Artificial photosynthesis with enzymes and synthetic catalysts integrated in nanostructured hybrid materials |
| Daniel Nocera             | Harvard University, USA                           | The artificial leaf (was hindered to participate)                                     |
| Styrbjörn Styring         | Uppsala University, Sweden                        | Artificial photosynthesis                                                             |
| Michel Armand             | The National Center for Scientific Research, France | Electrochemical energy storage, activity on all fronts                                  |
| Thomas Hamacher           | Technical University Munich, Germany              | Integration of renewable energies: competition between storage, the power grid and flexible demand |
| Hermann-Josef Wagner      | Ruhr University Bochum, Germany                   | Wind energy systems—present status and ecobalances                                    |
| Godfrey Boyle             | The Open University, UK                           | Renewables-intensive Energy Systems for the United Kingdom                             |
| Ujjval Vyas               | Alberti Group, USA                                | The importance of failure and the future of renewable energy                           |
| Sture Larsson             | Former Technical Director and deputy Director General at Svenska Kraftnät, the Swedish Power System Operator (TSO), Sweden | Requirements for system adaptations to intermittent energies                           |
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