Options for a new energy scenario

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Artifical nuclear fusion: researchers at the Max Planck Institute for Plasma Physics in Garching work on the production of clean and safe energy at the ASDEX Upgrade device. © MPI for Plasma Physics

Even if the finite nature of the resource stocks is not the only factor that influences oil prices, speculation also plays a role in this process: peak oil, that is the point in time when oil production cannot be increased despite maximum efforts, will be reached in the near to medium-term future – indeed, some analysts believe that it has already been reached. This development is further exacerbated by the increasing energy hunger of the emerging states, particularly in Asia, with their large populations. Moreover, the energy problem is irrevocably linked with that of global warming. All of the available data point to the fact that anthropogenic emissions of carbon dioxide, a large proportion of which are generated by the combustion of fossil fuels, contribute considerably to climate change.

It is thus a matter of extreme urgency that the future course be set for our energy system in a way that enables us to meet these challenges effectively. Unfortunately, global and national energy systems are very sluggish, and changes to supply or consumption structures require considerable periods of time to implement. The coal-fired power plants built now will still be in operation in 2050. The effects also only make themselves felt in the long-term: our planet reacts slowly to changes in the composition of the atmosphere - which means it will take decades or even centuries for the success of our energy system's reorientation to become evident.

What role can research play in the reorientation of our energy system, in particular basic research, which is typical of the work carried out by the Max Planck Society? It is helpful here to take a look at the structure of standard conventional 'energy research' and to compare it with the typical Max Planck structures. The energy sector is characterised by a strongly system-oriented approach. The development of individual components of a new energy system alone is not sufficient to bring about fundamental change to the overall system. This is illustrated by the following example: if hydrogen is to be used as a future fuel, storage materials for hydrogen, as are being developed at the Max Planck Institut für Kohlenforschung, are also urgently required.

Such storage materials are only useful, however, if vehicles with fuel cell drive systems are used that are compatible with the conditions under which the hydrogen storage works. In addition, sustainable processes for efficient hydrogen production must be available, and distribution infrastructure systems must be developed that can supply the hydrogen in the pressure range required for the storage material. Finally, it must also be possible to produce the storage material cost-effectively and in large volumes. Similar considerations also apply to many other energy technologies and their individual components. Moreover, the research on energy technologies – at least the technologies that are likely to be used in the relatively near future – is strongly influenced by the engineering sciences.

These characteristics are not easy to reconcile with the typical Max Planck research an approach which generally involves research projects that have a long-term horizon, are strongly rooted in basic research and are carried out by individual scientists. Moreover, the Max Planck Society's activities are mainly focused in the natural sciences, humanities and social sciences. Only one of the Max Planck institutes, the Max Planck Institute for Dynamics of Complex Technical Systems, has a predominantly engineering-based profile.

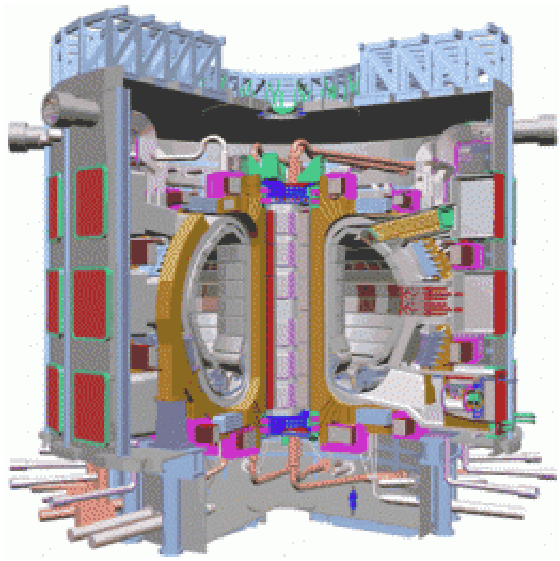
Nonetheless – or, perhaps, precisely because of this – the Max Planck Society also plays a key role in energy research, particularly in relation to very long-term questions of fundamental significance and approaches that lie outside of the 'mainstream' of application-oriented research, because their exploitation lies too far ahead in the future or their prospects of success are assessed as being too low. In view of the complexity of the task that faces us in developing energy systems, this role of the Max Planck Society will become more clearly defined in the future, as the pressure on the dwindling energy sources will increase; as a result, the fundamental results of the research carried out by the Max Planck Society and other institutions committed to basic research will be increasingly incorporated into technological development. A few examples of the ways in which typical Max Planck research is helping to shape our future energy supply are presented below.

The Max Planck Society makes a significant contribution to research studies which investigate the effects of our energy systems on the global climate. The WDC Research Cluster "Earth System Research", to which the Max Planck groups working in this field belong, is a global leader in climate modelling, and the roots of its expertise extend far back into the past. Paul Crutzen, for example, from the Max Planck Institute for

Chemistry studied the effect of trace gases in the atmosphere on the depletion of the ozone layer back in the 1970s and was awarded the Nobel Prize for Chemistry in 1995 for this work. This and other basic research findings have been incorporated into the development of the global climate models used today. The climate models produced by the Max Planck institutes constitute an important basis for the reports of the IPCC (Intergovernmental Panel on Climate Change). Global models for the development of the world's climate are calculated on the basis of different scenarios using the supercomputer at the German Climate Computing Center (DRKZ). Enormous computing capacity is required to carry out these model calculations. For example, approximately 5,000 years were simulated in real time for the last IPPC report - an operation that required a total of 400,000 CPU hours. Even more important than the pure computing time, however, are the experience and expertise in the development of the actual models that have been gained over many years and are contributed by the Max Planck scientists. Many of the primary data used in the climate models are collected by the Max Planck institutes involved in the WDC Research Cluster "Earth System Research".

According to all of the models, anthropogenic (manmade) carbon dioxide emissions represent a crucial factor that will have a significant influence on the global climate in the decades and centuries to come. Most of these anthropogenic emissions originate from energy generation processes based on the burning of fossil fuels, for example coal and oil in power plants for electricity production, and the combustion of petrol or diesel in engines. While energy-saving measures currently offer the greatest potential in terms of reducing CO2 emissions, work needs to be done on the fundamental transformation of our energy systems over the long term. This requires comprehensive application-oriented development projects; however, knowledge-oriented research that is not tied to a particular application and as is typical of the work carried out by the Max Planck Society is of similarly crucial importance for the development of a future energy system on a temporal scale of decades.

The most obvious example of this kind of research can be found at the Max Planck Institute for Plasma Physics (IPP) in Greifswald. The main focus of the research carried out at this institute of the Max Planck Society is on nuclear fusion. This approach is based on the vision of enabling the energy-generating processes that take place in the sun, that is the fusion of light atomic nuclei, for example deuterium and tritium, to heavier nuclei such as helium, to take place under terrestrial conditions and thereby operate power plants using the energy released by this process. Although the associated reactor systems are already under construction, at present, numerous fundamental problems remain to be resolved. In a fusion experiment, extremely hot plasma must be confined, and a magnetic field is the only possible means of achieving this. The magnetic field can be designed on the basis of two different principles. The main approach that has been adopted up to now is the so-called tokamak principle, in which the plasma current flows in toroidal paths in a magnetic field and is confined in this way. The stellarator is an interesting alternative to the tokamak, in which a very complex magnet field ensures that the plasma is confined without a current being driven through the plasma itself.



Model of the ITER fusion machine © MPI for Plasma Physics

The considerable advantage of the stellarator principle is that it enables continuous operation whereas, without additional effort and expense, a tokamak can only be operated in pulse mode. The currently most technologically advanced nuclear fusion system, the planned international ITER project, involves the construction of a tokamak, as this would appear to be easiest to complete. The IPP is one of the central research institutes involved in the construction of the ITER reactor. However, work is also being carried out by the Max Planck Society in Greifswald on the Wendelstein 7XExperiment, which is by far the world's most ambitious stellarator experiment. Before such reactors are ready for use, answers must be found to fundamental questions regarding the optimal way of confining plasma in such magnetic fields. Thanks to the extensive freedom and scope they allow researchers in their work, the Max Planck Society's structure enables approaches to be developed in parallel to the mainstream that could result in the establishment of even better solutions in the distant future.

Along with the construction of such reactors and the implementation of the associated experiments, numerous extremely complex basic issues must be resolved to ensure that we will really be able to rely on nuclear fusion as one of our main energy sources in the future. These include, for example, the development of suitable material to line the wall of fusion reactors, as the plasma contact in such a reactor is one of the heaviest uses that any material can be subject to under terrestrial conditions.

Apart from geothermal power and tidal energy, the other major energy sources available to humanity in the long term are based either directly or indirectly on the sun's radiation. The sun radiates so much energy that, based on the efficiency of the photovoltaic cells currently available on the market, an area of around 800 x 800 km2 in the Sahara would be sufficient to supply the entire global population with the average amount of energy consumed by an average central European.

However, although silicon-based solar cells are very advanced technologically, the cost of generating energy using this technology is far too high. Photovoltaic systems based on organic semiconductors could provide an interesting alternative. These may prove more cost-effective in the future, as the raw material costs involved would be lower and they could be used relatively simply in different forms. There are numerous ways of producing such organic semiconductors at molecular level. Extended conjugated aromatic systems, which are being developed based on benzene and related molecules at the MPI for Polymer Research, are an interesting class of materials.

The associated research findings, which resulted primarily from basic research aimed at synthesising large molecules from simple basic molecules, have now reached a stage where they are of relevance to practical application. However, it is not yet possible to predict which class of substance will ultimately prove to be most promising and suitable for integration into polymer photovoltaic cells. The role of research in this field is to make the widest possible range of potential systems accessible and thereby lay a solid foundation for targeted technological development

Nature solved the problem of supplying energy through solar energy by means of the photosystem found in green plants. In this system, sunlight is converted into energy-rich compounds. Scientists from the Max Planck Society were the first to elucidate the structure of a light-driven enzyme system, which is that of the photosynthetic reaction centre in purple bacteria.

Hartmut Michel, Robert Huber and Johann Deisenhofer, the latter of whom worked at the Howard Hughes Medical Institute, were awarded the Nobel Prize for chemistry in 1988 for this work. Many aspects of the functioning of the photosystem of green plants are now also understood; a crucial breakthrough in the understanding of the central Mn4 cluster of photosystem II was recently achieved at the Max Planck Institute for Bioinorganic Chemistry. Although this research provides the blueprint for a system enabling the use of sunlight for the generation of energy, unfortunately we are still a long way from being able to copy this photosystem in the form of simple robust model systems, or from finding a different form of photocatalytic solar energy conversion. If we could succeed in converting solar energy into energy-rich molecules and storing it, we would make significant progress towards the resolution of our energy problems. The corresponding approaches are still far from ready for technological development and fundamental questions remain to be answered. These include the question as to how light-collecting molecules, so-called antenna systems, can be efficiently coupled to other molecules which mediate the transfer of electrons, and hence split water into its components hydrogen and oxygen.

The stability of such systems is also of fundamental importance. The plant photosystem is only intact for around 20 minutes on average when operational. After this, ingenious cellular repair systems must intervene to ensure that photosynthesis does not grind to a halt. Technology still largely lacks analogous autonomous repair mechanisms, the importance of which far exceeds energy generation. Irrespective of the way in which we will utilise solar energy in the long term without the detour via fossil energy sources – that is whether by direct imitation in the fusion process, the biological conversion of solar radiation, the photo-catalytic splitting of water or using photovoltaics – it will also be necessary to store and distribute energy differently than we do today. Hydrocarbons in the form of petrol, diesel, kerosene and heating oil are the main forms of energy storage and transportation currently used. Electrical energy must be generated at precisely the scale on which it is consumed; the storage of large volumes of electrical energy is not possible today.

Therefore, hydrogen is being widely discussed as a future energy source to replace hydrocarbons. However, there is no practically viable storage process for hydrogen the horizon, in particular for its use in vehicles powered by fuel cells in which the hydrogen must be stored in as small a volume and as low a weight as possible. A 700 bar pressure accumulator is currently the most highly developed hydrogen storage option. Liquid hydrogen storage systems have also been used in fuel cell vehicle prototypes. For various reasons, however, neither of these processes is truly satisfactory.

Interestingly, hydrogen can be packaged even more compactly in certain compounds from the metal hydride family than in liquid form. If hydrides can be found that absorb hydrogen in the required temperature range at high pressure and release it again at low pressure, this could provide a basis for the resolution of the storage problem. Research on this approach is currently being developed at the Max Planck Institut für Kohlenforschung - however, the starting point of this work was basic research carried out as far back as the 1970s.

The particular focus of interest here was the homogenous catalytic production of metals. When extended to other hydrides and mixed systems, it was found that there is a huge increase in the hydration and dehydration rates of sodium aluminium when small volumes of other metals are added. Titanium was identified as the most effective element in these early studies. It is only by increasing the reaction rate through the use of such a catalyst that these systems could, in principle, be used in cars, as this would enable sufficiently rapid refuelling. Further research has allowed other catalysts to be, some of which display better characteristics than the titanium originally used. The way in which the catalysts work is now also understood in part. The sodium aluminium hydride system is currently among the best available hydrogen storage materials; however, the storage capacity it offers is still too low for use in cars. Therefore, based on these studies, other metal systems have been researched in cooperation with Opel/GM Fuel Cell Activities with a view to discovering other more efficient hydride systems. Although the long-term objective of this research is to develop hydrogen storage systems that are suitable for use in practice, it is characteristically very basic, as little work has been done up until now to investigate the material systems and some new synthesis pathways still need to be explored.

What conclusions can be drawn from all these considerations and examples? With the exception of the activities of the IPP, the purpose of which was the technical development of a fusion reactor from the outset, major developments from the Max Planck Society that are of relevance to new energy systems have emerged typically from the investigation of basic research questions. This is where the strength of the Max Planck Society lies: its task is to clarify the basic processes that play a role in energy transformation processes and to present new approaches that do not lie in the mainstream of technological development.

With its focus on individual researchers and their ideas, the Max Planck

Society is optimally positioned to fulfil this task. If this approach proves insufficient, however, the Max Planck Society has also developed tools with which interesting insights can be adopted and progressed beyond the level of basic research. One of these instruments is its inter-institutional research initiatives. The 'Enerchem' initiative, which researches carbon-based nanostructure systems as components of future energy systems, was established in the field of basic energy research. This initiative was created because top-level expertise for the resolution of individual issues in this field was available in a series of institutes and the bundling of this expertise enables more rapid progress to be made. Enerchem researches new electrode materials for high-performance batteries, for example; the expertise required here comes from the Max Planck Institute for Colloids and Interfaces, the Max Planck Institute for Polymer Research and the Max Planck Institute for Solid State Research. The suitability of ammonia for hydrogen storage is also being studied through cooperation between the Fritz Haber Institute of the Max Planck Society and the Max Planck Institute for Coal Research. The Max Planck Institute for Colloids and Interfaces and the Fritz Haber Institute are also working on the hydrothermal treatment of biomass for the generation of carbon, and are studying whether this could provide a feasible CO2 sink and thereby contribute to improving the carbon balance of the earth's atmosphere.

If the relevant expertise is not available within the Max Planck Society, research alliances can be formed with other research organisations. The Fraunhofer-Gesellschaft, with its application-oriented approach, is an ideal partner in this context. The joint ProBio project between the Max Planck Institute for Dynamics of Complex Technical Systems, the Fraunhofer Institute for Factory Operation and Automation and the Fraunhofer Institute for Ceramic Technologies and Systems aims to develop systems for the generation of hydrogen from biomass, which use a periodically operated metal oxide/metal system for hydrogen purification and storage. The metal oxide is converted into metal by a hot raw pyrolysis gas; when this process is completed, the metal can react with water and generate pure hydrogen, and the metal oxide is recovered. Several units of this kind operated in parallel could be used for the efficient production of hydrogen in such systems.

Thus far, the aspects of reorienting our energy systems that involve the humanities have been excluded from this presentation. Numerous basic issues that are typically researched by the Max Planck Society also arise in this context. Energy issues and climate change extend beyond national borders and affect goods that are not privately owned; such goods are the focus of interest of the Max Planck Institute for Research on Collective Goods. Basic research studies on the question as to how people make decisions, which have been carried out at the Max Planck Institute for Human Development, are also highly relevant to the energy debate. Consideration of the often highly emotional discussions surrounding our energy alternatives clearly shows that the decision-making processes which give rise to the preference for one technology option over another are an important research topic in themselves. All of the examples show that a wide variety of research is carried out by the Max Planck Society on problems of crucial significance to the development of future energy systems. Although energy research is strongly systematic in nature and needs to be carried out by large research alliances with strong engineering expertise working on a short to medium-term timescale, long-term basic research issues as explored in many institutes of the Max Planck Society must also be investigated to demonstrate new sustainable approaches for the transformation of our energy systems. This approach is hardly likely to yield short-term solutions - however, our society is reliant on the quest for more than short-term solutions. In order to provide a sustainable and viable basis for our energy systems, basic research must be carried out in parallel to the further development of already-known energy technologies.