Future Priorities for Energy Research in Europe

This position paper complements the overarching Helmholtz FP10 position from 02/2024.

Introduction

The most important challenges of our time are inextricably linked to the energy system. Climate change is one of the major challenges that our society faces. The climate crisis is not only causing environmental disasters associated to rising sea levels and record temperatures, but it is also adversely affecting peace and stability around the globe. In the last century, human activities have been the main driver of climate change, primarily due to the greenhouse gases generated when burning fossil fuels. A drastic reduction of the energy sector emissions is essential to limiting global temperature increase, as the energy system is responsible for more than 75% of the EU's greenhouse gas emissions today.

The transformation towards a climate-neutral energy system must be economically viable, environmentally sound and socially acceptable and will require a fundamental transformation of all economic sectors. This transformation must also ensure a diversification of energy sources and independent access to critical raw materials. The current geopolitical disruptions have proven that they are essential to ensuring resilience and security of the future energy system. Research and innovation are critical for delivering the required solutions and system transformations. They are key to accelerate the deployment of renewable energy sources, increasing energy efficiency and establishing a circular energy value chain in Europe.

Future Directions

The most important overarching challenges are:

- Establish a sustainable and resilient energy system: This comprises supply, distribution, and usage to address reliability, resilience, justice, and material circularity embedded in and accepted by society.
- Adapt the energy transition to societal demands.
- New sustainable technologies must be developed and deployed: This comprises safe, reliable, affordable, resilient energy production, storage, use, and distribution. It is a must to close carbon and materials cycles. Key technologies still need to be developed to market maturity in due time, requiring rapid scientific and technological innovation.
- Talent management and lifelong learning: The energy transition can only succeed if enough experts in the energy sector are able to fulfil the tasks.

More concrete, thematic challenges are:

Resilient Electricity Supply: Boosting the electricity supply from renewable energies by reducing levelized cost of electricity, ensuring reliable and flexible power generation and using Energy Systems Engineering to develop models and algorithms for the simulation, optimization and control of energy systems.
Integrated solutions and smart grids: Developing integrated solutions and smart grids that balance energy efficiency, resource availability, sustainability, and technological advancement.
Heating and cooling: Meeting the climate-neutral energy demand for heating and cooling in buildings, industrial processes and in the transport sector.

Energy efficiency: Fostering energy efficiency on the demand side (industry, SME, buildings, households etc.) demonstrating clear economical and societal benefits.
Electrochemical energy storage: Advancing electrochemical energy storage for stationary storage technologies and solutions for electrification in the transport sector.
Thermal Energy Storage and Supply: Technology development for renewable heat production and storage for buildings and industry, cross-sectoral integration of electricity and heat generation including geothermal energy.
Hydrogen economy: Advanced sustainable technologies for economic mass production of green hydrogen and derivatives, efficient storage and transport of hydrogen, advancing hydrogen-based energy conversion both for balancing variable energy sources and for energy supply where electrification is unfavourable.
Synthetic fuels and green chemicals: Transforming the global fuel ecosystem for the cross-sectoral sustainable use of chemical energy carriers to meet the technical, economic, social and environmental demands of the urgent defossilization of our power, transport, and heat systems and developing economic processes to synthesize sustainable base chemicals.
Carbon management to close the carbon cycle: To achieve "net-negative emissions", technologies must be developed that can be integrated into a system of CO_2 utilization and CO_2 storage which efficiently remove CO_2 from inevitable process emissions and the atmosphere.
Circular Economy, materials efficiency and Raw Materials Supply Resilience: The creation of a sustainable circular economy is a prerequisite for climate-neutral industrial production without using fossil raw materials and for the recycling of scarce materials.
Materials Breakthroughs: The design of materials and components for new technologies that significantly improve the sustainability and resilience of the value chain must be considered. The accelerated, autonomous discovery of materials and development of components will help to achieve such breakthroughs.
Fusion technologies: Advancing the physics and technology basis for the design of magnetic confinement fusion power plants for their application in the energy system.
Nuclear waste: The safe management of nuclear wastes and ultimately their deep geological disposal still includes significant scientific-technical and political-societal challenges, because different regions in the European Union need specific tailor-made solutions.
Safe operation of nuclear power in Europe: Throughout all member states, actions should cover maintaining and further developing knowledge and expertise for the safety assessment of existing nuclear power plants and innovative reactor concepts.
Photovoltaics: Photovoltaic technologies for the multi-TWp era - materials, cell architectures and production strategies beyond single junction silicon and for European value chains.

These challenges for energy research towards a climate-neutral energy system are taken from our Helmholtz Energy Transition Roadmap and are well aligned with national (e.g. BMWK 8th Energy Research Program, BMBF and BMU strategies) and international (e.g. IEA, EU) research strategies. They can only be tackled by extensive research and development activities embedded in a systemic perspective covering technical, ecological, social, as well as economic aspects.

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