Blue Sky Research for Energy Technology

Workshop Summary Report

14–15 June 2017

IEA Experts' Group on R&D Priority Setting and Evaluation
Birmingham, United Kingdom

International Energy Agency

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its mandate is two-fold: to promote energy security among its member countries through collective response to physical disruptions in oil supply and to advise member countries on sound energy policy. The IEA carries out a comprehensive programme of energy cooperation among 28 advanced economies,[1] each of which is obliged to hold oil stocks equivalent to 90 days of its net imports.

The Agency aims to:

- Secure member countries' access to reliable and ample supplies of all forms of energy—in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context, particularly in terms of reducing greenhouse gas emissions that contribute to climate change mitigation.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
- Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organizations, and other stakeholders.

IEA Experts' Group on R&D Priority Setting and Evaluation Research (EGRD)

Research, development and deployment of innovative technologies are crucial to meeting future energy challenges. The capacity of countries to apply sound tools in developing effective national research and development (R&D) strategies and programmes is becoming increasingly important. The EGRD was established by the IEA Committee on Energy Research and Technology (CERT) to promote development and refinement of analytical approaches to energy technology analysis, R&D priority setting, and assessment of benefits from R&D activities.

Senior industry, science and policy experts engaged in national and international R&D efforts collaborate on topical issues through international workshops, information exchange, networking, and outreach. Nineteen countries and the European Commission participate in the current programme of work. The results and recommendations provide a global perspective on national R&D efforts that aim to support the CERT and feed into analysis of the IEA Secretariat. For further information, see http://www.iea.org/aboutus/standinggroupsandcommittees/cert/egrd. For information specific to this workshop, including agenda, scope, and presentations, see https://www.iea.org/workshops/blue-sky-research-for-energy-technology-2017.html.

This document reflects key points that emerged from the discussions held at the June 2017 EGRD workshop. The views expressed in this report do not represent those of the IEA or IEA policy, nor do they represent consensus among the discussants.

[1] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Republic of Korea, Luxembourg, Netherlands, New Zealand, Mexico, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States; the European Commission also participates in the work of the IEA.

The Workshop on Blue Sky Research for Energy Technology

The *Blue Sky Research for Energy Technology* workshop was held on 14-15 June 2017, at the University of Birmingham, hosted by the Birmingham Energy Institute, and was organized under the auspices of the EGRD. This topic fulfils the three-year mandate (2017–2019) of the EGRD.

This summary report provides an executive summary, the meeting rationale, and summaries of the experts' presentations and discussions.

In addition to the EGRD national experts, input was provided by senior scientists in the fields of technology, social sciences and modelling and program managers from industry and the IEA.

We would like to thank Robert Marlay and Alexander McLean of the Department of Energy (United States) for presenting an excellent first draft with the help of Namrata Patodia Rastogi et all. of Energetics Incorporated (United States). We also would like to thank Carrie Pottinger (IEA) for scoping this workshop and providing additional IEA knowledge.

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Executive Summary

Innovation continues to be the most important driver of economic growth for developed economies, and creating novel energy technologies is essential for solving the world's most pressing environmental problems and enabling clean growth. Basic scientific research is a fundamental component of technological innovation, giving rise to the discoveries that drive targeted research and development (R&D). Projects that have the capacity to solve distant, large-scale problems by first asking questions about the fundamental nature of the world can be called blue sky research. Such efforts are often conducted not so much with an eye toward specific practical applications, but rather with a broad awareness of the potential nascent and perhaps as-yet-unknown utility for future innovations. These types of projects often depend on public funding, since the scientific discoveries they drive generate large societal benefits that can be difficult to capture.

The Innovation Landscape

Innovation is critical to address the growing challenges presented by energy systems across the globe. In developed countries, legacy energy systems must adapt, evolve and decarbonize to meet the international goal of limiting global warming below 2°C. Energy systems are also rapidly becoming integral to the economies of developing countries, and new technologies are necessary for sustainable development that facilitates increasing electrification and industrialization without growing emissions. Recent technology developments have shown great promise, often with larger impacts than anticipated. Reduced costs of efficient lighting, wind and solar generation and lithium batteries have reduced energy demand, reduced generation emissions, and facilitated a transition away from petroleum fuels, respectively.

However, more innovation and greater investment are necessary to meet the coming challenges. To prioritize investments, governments need to be aware of the innovation landscape and the role that relationships among government agencies, private firms, and academic and research institutions play in the innovation process. To further innovation, policymakers must consider the funding landscape, the people and researchers that contribute to breakthroughs, the means and mechanisms of knowledge flow, and how innovation relates to the wider energy sector.

Despite the critical role blue sky research plays in the innovation process, calculating and expressing the value of such efforts is a persistent challenge. On a project level, it is difficult, even impossible, to demonstrate the future value of unanticipated and unplanned innovation. Furthermore, securing private funding for blue sky research is uncommon, because the benefits of fundamental scientific discoveries—while large for society—can be difficult for private companies to capture.

Therefore, funding for energy-based blue sky research is limited, and efforts are needed to incentivize greater public and private investment in blue sky research goals. Global spending on clean-energy-related research, development, and demonstration (RD&D) (in energy efficiency, renewables, nuclear, and carbon capture and sequestration [CCS]) have stabilized at a global total of $26 billion annually. Various efforts are underway to address this funding gap. For example, through

Mission Innovation [2] 22 countries and the European Union aim to double clean energy R&D investment over five years. In the private sector, the 30 members of the Breakthrough Energy Coalition[3]have committed to invest USD1 billion, as well as work to direct promising research efforts. More efforts such as these are needed to incentivize greater public and private investment to drive energy innovation.

Blue Sky Research and Innovation

Innovation is often non-linear, despite some models framing innovation as a linear process. The default conceptual model of innovation imagines a straight line from basic scientific research through application of discoveries to targeted R&D that results in a novel technology. In this model, there is tension between the 'technology push' of technologies trying to convince the market of their utility and the 'market pull' of needs-driven innovation. However, new technologies or improvements to existing technologies can be invented or discovered at any point throughout the process, whether intentionally or serendipitously. Likewise, applied R&D can often open new questions appropriate for basic scientific inquiry, such as the fundamental nature of materials or physical interactions.

The timing, value, and content of blue sky research can never be accurately and completely expressed and evaluated until after the fact, and patience is often required. Supportive institutional policies that accommodate funding a particular research competence, rather than a creating a specific product or solving a particular problem are needed. Blue sky research often delivers results that are useful, but not necessarily in the way that was initially expected. Policymakers and industry must have the flexibility for unintended but beneficial results to fully capture the benefits of blue sky research.

Knowledge sharing is an essential aspect of transforming research findings into breakthrough innovations. Identifying critical stakeholders for a research project and incorporating their input at the planning stage enables maximum utilization of the innovation. Outputs of blue sky research should be communicated such that those with the competency to utilize them can benefit from their findings.

Innovation for Energy

A large number of critical energy technologies are ripe for innovation and can benefit from near-term improvements in economics, performance, efficiency, and sustainability of energy technologies, as well as transformational discoveries that could lead to replacements for current technologies in the long term. While near-term innovations are largely the result of targeted R&D to address specific challenges, blue sky research plays an important role in creating or enabling the long-term innovations that could replace or disrupt today's cutting-edge energy technologies.

[2] Mission Innovation, launched following negotiations of the 2015 Paris Agreement, aims to dramatically accelerate global clean energy innovation. Participating countries have committed to seek to double their governments' clean energy research and development (R&D) investments over five years, while encouraging greater levels of private sector investment in transformative clean energy technologies.

[3] The Breakthrough Energy Coalition (BEC) is a partnership of 30 multinational enterprises which have committed to broadening investment in new energy technologies by investing their own capital. BEC works with over 20 governments which have committed to significantly increase public investments in the basic research that leads to breakthrough innovations.

Near-term innovations are necessary to bring the performance and cost of some clean-energy-enabling technologies in line with competing legacy technologies. These performance and cost improvements require innovations to enable existing technologies such as comprehensive industrial energy efficiency, battery electric vehicles and drop-in biofuels for transportation, and wide-scale deployment of renewable generation technologies. Associated research subjects include industrial control systems, integration, and systems planning; battery chemistry; novel catalysts, catalyst support structures, and designs; and pyrolysis technologies for biofuels.

Over the long run, blue sky research is needed to solve fundamental scientific problems that will enable future generations of clean energy technology. Examples of long-term technologies include next-generation solar cells including high-efficiency multi-junction cells and low-cost thin-film cells; net-negative carbon generation technologies that remove carbon dioxide from the atmosphere; and nuclear fusion reactors that can generate power without harmful emissions or toxic waste.

Process, Policy, and Programs for Innovation

The non-linearity of innovation in practice highlights the fundamental problem of policymakers, academic research directors, or private managers in planning, evaluating, and funding blue sky research. Because blue sky research does not always anticipate the practical end uses that result from investments, it can be difficult to justify the expense. Compared with targeted R&D focused on an incremental technological improvement, blue sky research presents greater uncertainty and, therefore, greater risk. Designing programs that enable innovation can present challenges associated with cost, uncertainty, knowledge management, and communicating stakeholder value. Maintaining awareness of the need for these types of research, as well as the need for clear processes to evaluate, disseminate, and incentivize these types of research is a challenge for researchers, institutions, industries, and policymakers. The following lessons can be drawn from the experiences of successful past research programs, such as those coordinated by the IEA, as well as national and international efforts. Effective collaboration is important, both within governments and among governments, businesses, and research institutions.

Recommendations

- As the societal benefits of blue sky research are indirect, they can be non-obvious and difficult to convey. Policymakers often lack understanding of its value to society and the importance of public sector funding. Therefore researchers and their institutions could make greater efforts to consistently communicate the benefits of blue sky research to policymakers and emphasize the importance of public resources and continued support. Developing processes and methodologies to document and measure the value that blue sky research affords to society can help build the case for such research and boost additional public and private sector funding.
- The timing, value, content, and outputs of blue sky research may be uncertain. Unfortunately supporters generally fund a particular research competence rather than a specific result. Up addition, outputs from blue sky research are often useful, but not necessarily in the way that was initially expected. Therefore to fully capture the benefits of blue sky research policymakers and industry actors need to have the flexibility to make use of unintended but beneficial research outputs. With increased flexibility, promising discoveries will not be abandoned in favor of short-term achievements that meet predetermined research goals.

- Public–private research collaborations are invaluable for blue sky research and innovation. Public private partnership can help in de-risking blue sky research for private enterprise. However, a clear understanding of the ownership and benefits is vital to avoiding. A research pathway that may benefit a particular industry. Policies that support such collaborations, as well as regulatory policies that incentivize private sector investment in innovation to reduce risk are needed.
- Inspired creativity does not occur in isolation. Highly interactive organizations - that foster cross-fertilization of ideas, are challenge-driven, and encourage cross-sector partnerships - demonstrate greater innovation. Therefore research institution programs could encourage both individual and collaborative endeavors.
- The ideal enabling environment for blue sky research comprises a simple management structure without funding concerns or the pressure to publish. Research institutions undertaking blue sky research could incentivize risks. For example, projects and grants could be designed with selection criteria and evaluation processes that incentivize innovative approaches. Currently researchers are pressured to publish to demonstrate added value for the investment. And most often researchers are rewarded for positive results yet knowledge attained through 'failures' is equally valuable.
- Collaborations among governments should be explored, both to share the burden of expensive cutting-edge research facilities and to foster knowledge exchange. Partnerships among entities that share world-class laboratory facilities not only provide cost efficiencies but also allow for cross-fertilization of ideas, a key element of innovation.

Background

Global energy markets today are dynamic and undergoing a process of transformation. Advanced technologies, many of which arise from investments in research, create new options for energy systems. Innovations can improve productivity, reduce costs, and enable solutions to pressing problems that had previously been thought to be out of reach. Witness the deep reductions in the cost of technologies, such as light-emitting diode (LED) lighting, lithium-ion batteries, wind and solar power; new materials with revolutionary properties that open vast new horizons for innovation; integrated design, equipment, communications, and controls that dramatically improve energy efficiency in buildings and transport; and new technology for modernizing the transmission, distribution, and storage of electric power. The coming decade represents an important period in the development of an even smarter energy system.

The capacity to innovate is fast becoming the most important determinant of economic growth in the 21st century global economy.[4] It is also central to bringing practical solutions to vexing challenges in energy and environment. But if innovation is the engine of productive change, what drives innovation?

Innovation is a shared consequence of inspired creativity, leadership and investment in research by both the public and private sectors. Many of the most innovative technologies shaping global energy markets today can trace their origins to public investments in 'blue sky research', that is in basic sciences, novel approaches, risky exploratory research, and early-stage technology development. While publicly supported blue sky research may be a wellspring of new knowledge and discovery, the private sector has, and must continue to, identify, evaluate, and carry forward the best ideas to commercialisation. A robust innovation ecosystem depends on both, but it is fed and nourished by public investments in blue sky research.

Government Models

Many governments around the world have recognized this need for innovation in the energy sector and have set up various schemes to fund and support innovation – from research and development to demonstration and pilot project to market launch support and market integration of new technologies.

However, many of these programmes, especially when industry is involved, focus on rather late stages of development and higher Technology Readiness Levels (TRLs), aiming at improvements of existing technologies, which have already been successfully validated in the lab, and preparation of innovative products for future markets by increasing reliability and reducing production costs.

Besides these innovation funding schemes with clear and well defined goals, governments around the world run programmes in basic research, or blue sky research. Blue sky research (BSR) is basic science research where practical applications may be envisioned but are not immediately apparent.

In the long run many topics, which once were investigated in the context of basic research, turn out to be useful for the development of new innovative products. However, it is often difficult to foresee the possible impact of individual lines of research for later applications. Policy makers face the challenge of understanding possible impacts at an early stage and engaging industry, both for investment in basic research topics and to help guide this basic research to the creation of new innovative products.

[4] U.S. National Research Council, 'Rising to the Challenge', www.nap.edu/catalog/13386/rising-to-the-challenge-us-innovation-policy-for-the-global.

In addition, governments are exploring ways to stimulate radical innovation: radical or abrupt changes that challenge and transform larger social, economic, environmental and/or governance systems. These disruptions may be lead to positive change, as with a new clean technology, or negative change, such as a significant socio-economic adjustment. As radical innovation is primarily a business model challenge rather than a technology challenge, the role of industry and the private sector are paramount.

For governments there is also the challenge of how to stimulate organisations that can arbitrate between the innovation assets of the public and private sectors; acting to translate basic research into a form where it can create value for society. How can these intermediaries assist in the process of stimulating, informing and creating value from blue sky research?

In this workshop, the EGRD examined ways to stimulate blue sky research within the energy sector in the broadest sense of the word. Different methods were presented and discussed. The goal was to find examples of practical results borne out of blue sky research, determine how lessons from these examples could be applied to stimulate the pace of innovation in the energy sector, and advise policy makers as to how to engage at critical points in the process.

Scope

The goal of this workshop was to learn from examples of how the transition from BSR to application has been successfully undertaken in other sectors for example, space research, medicine or solid state physics in the context of microelectronics, and to identify from current basic research selected areas or ideas that might potentially have a huge impact on the energy sector. This should inform an understanding of how different governments engage in, fund, and structure their investments in energy-related basic science programmes.

The EGRD workshop focused on blue sky research and its possible contributions to the developing energy system in various countries. With input from speakers representing public authorities, research institutes and the private sector, the participants discussed the rising demand for innovation, specific technologies, various models for applying public funds, target-oriented R&D programmes and reasonable incentives to harvest the lessons and results of blue sky science for the development of the energy system of the future.

Target Audience

In addition to EGRD members and national experts, input was sought from research, development and demonstration (RD&D) decision-makers, strategic planners, and programme managers from industry, academia, think tanks, national laboratories, and government. Participation in EGRD workshops is by invitation only.

Outcomes

The workshop resulted in a summary report that identifies challenges concerning basic research and best practice examples in various countries and technology sectors. This workshop report identifies priorities and gaps in current programmes for RD&D planners, and makes recommendations. The workshop summary and presentations have been made available on the workshop web page.

Questions that were discussed at the workshop:

- What are the drivers for government basic science programmes: science, society or both?
- What are the linkages between basic research, applied science and disruptive innovation?

- How can such lessons be applied to guide or improve future public investments in energy-related basic science research?
- What are the means for transitioning BSR outcomes to innovative energy-related products?
- Which current topics in basic science could potentially have a big impact on the energy sector?
- What are the most effective framework conditions for stimulating BSR schemes?
- At what point is industry involved in basic science programmes or their outcomes?
- What are the processes that lead to a disruptive innovation? What are the effects on socioeconomic issues (economy, lifestyles)? Are they seen as being positive or negative?
- What lessons can be drawn from the history of blue sky research and various government innovation models, in terms of best practices and disruptive, but productive innovation?
- Can disruptive innovations for the energy sector be anticipated? If so, how could these horizon scanning efforts be integrated into programme planning?

Session Summaries

Session 1. Introduction

Chair: Gavin Harper, University of Birmingham, United Kingdom

1.1 Overview

In today's constantly evolving global economy, the ability to innovate is increasingly becoming a critical determining factor for a competitive economy. Innovation, defined as the implementation of a new or significantly improved product, process, marketing, or organizational method, is a result of a clear focus on a specific research topic, which may be cross-cutting, by an entity. Genuine innovation is a result of strong leadership, inspired creativity, single-minded focus, and considerable investment by multiple actors from both the public and private sectors. Several types of innovation exist—game-changing, breakthrough, and disruptive—each having a different level of impact on the market or society.

As innovation can be complicated, having a better understanding of the process greatly improves the chances of positive outcomes. Tracing the origins of the most innovative technologies helps provide this understanding and pinpoint what might be needed to accelerate blue sky research. For example, the advent of lithium-ion batteries, a technology that has become extremely prevalent in our daily lives, traces its origins to blue sky research conducted in the early 1900s. The evolution of the technology highlights that scientific progress, along with advancements in the manufacturing processes, help in bringing technology to market.

Economics is a critical determinant in whether an innovation reaches the market. A clear vision from the government and adequate policy support that is reflected in integrated policy frameworks help accelerate the process of innovation. Understanding the stage of technological development, and crafting policies accordingly, maximizes benefits and minimizes risks. Partnerships and collaborations bringing together academia, government, and the private sector provide a cross-cutting perspective and stimulate out-of-the-box thinking. Undertaking a whole-systems approach and horizon scanning can identify potential new innovations and foster commercialisation of technologies.

1.2 Welcome

Martin Freer, University of Birmingham, United Kingdom

- Link to presentation slides: https://www.iea.org/media/workshops/2017/egrdjunebluesky/0.BEIJune14.pdf

The West Midlands region in the United Kingdom (UK), the birthplace of the Industrial Revolution, is aspiring to be a critical part of the revolution that changes the way energy is delivered and consumed by developing various partnerships and institutes across the region. Energy Capital is a bold new initiative to establish the West Midlands as the global capital for energy systems innovation and market development, associated with its energy, waste, and transport infrastructure. The initiative's ambition is to establish itself as a global leader in the $2.7 trillion market in energy technologies. The initiative will focus on smart and distributed energy solutions that support the connected smart cities of the future. Energy Capital is a regional initiative, designed to transform the midlands through co-ordination and organisation and by creating a series of Energy Innovation Zones where technologies can be deployed at scale. The initiative proposed engagement with local regulators to receive dispensation to regulate the Energy Innovation Zones to help encourage innovation to flourish and business model experimentation to occur. A working example of an Energy Innovation Zone is an area located close to the University at Tyseley Energy Park, where generated waste (about 50,000 tonnes of waste per year) goes into an incinerator that feeds the power into the grid. Another example is a wood gasification power station, which takes waste wood and feeds the power into the grid, and a local manufacturer. The initiative is planning to use the electricity for electrolytic production of hydrogen.

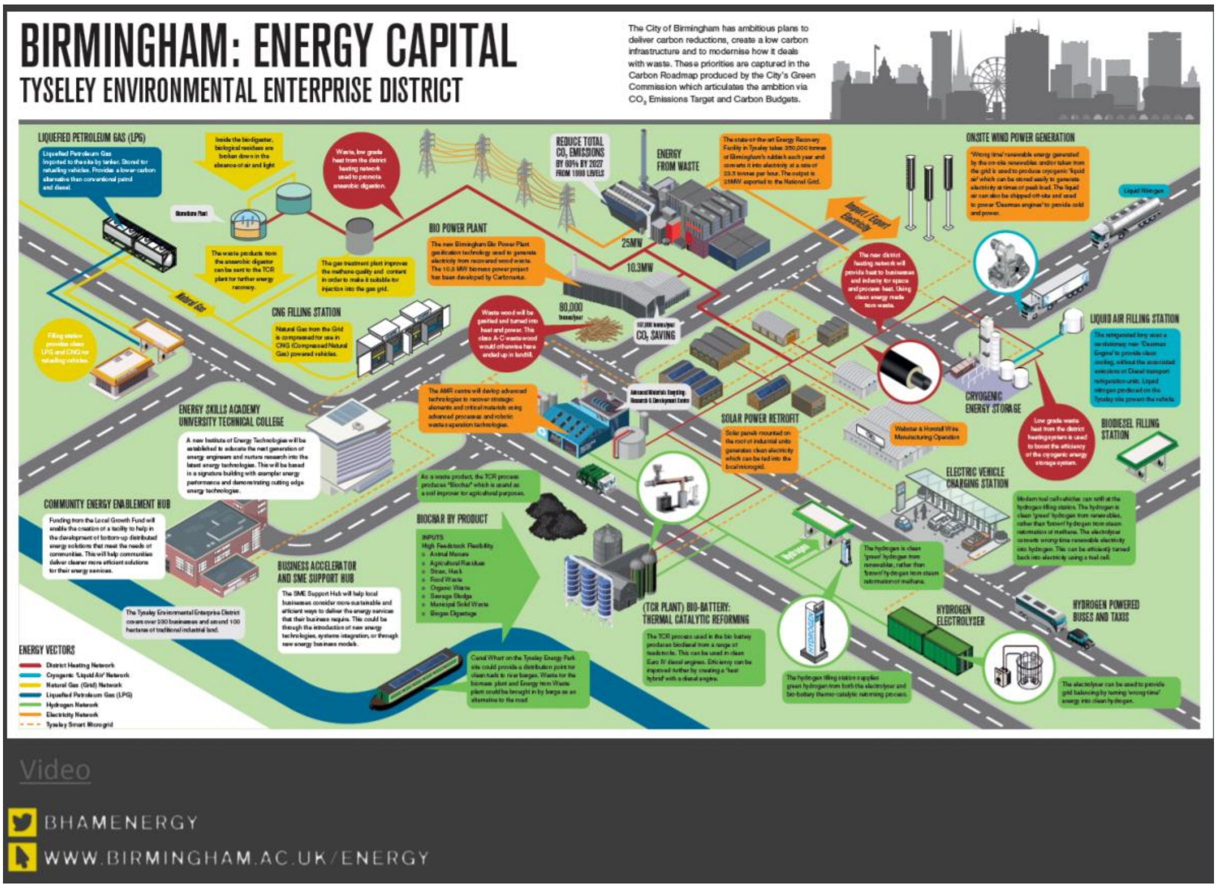
There are ambitious plans for a novel and innovative industrial ecology which brings together both proven energy technologies that are close to market, but also new innovations which require basic research to enable their scale up and deployment.

The University of Birmingham's Energy Institute has a wide energy portfolio ranging from topics such as energy storage to energy law. Academics at the Institute are exploring energy technologies, economically sound solutions with a focus on business models, and energy policy issues. The Institute attracts over 140 academics from four colleges with an external funding award of £75 million.

The Birmingham Energy Institute is a part of the Energy Research Accelerator, a multimillion pound research hub that will build on the expertise of six leading midlands universities. This includes the Universities of Aston, Birmingham, Leicester, Loughborough, Nottingham, and Warwick and the British Geological Survey. A government-funded activity, the Accelerator has received funding of £180m: £60m from the government and around £120 million from industry partners. The research hub is expected to give the UK a competitive advantage in energy research and development (R&D). There are three research streams envisioned: thermal energy technologies, both hot and cold; geological energy systems; battery technologies; and the integration of those technologies into energy systems. The consortium essentially supports fundamental research within the universities, aligning academics across the consortium of institutions; and deploying solutions at scale, for demonstration and validation. An important focus is to manufacture technology at large scale; as a result, the University of Birmingham is investing about £10 million and working with small and medium enterprises (SMEs), small businesses, and others.

The University recently signed an agreement with Fraunhofer UMSICHT to conduct fundamental R&D, demonstration and validation, and manufacturing and productionization of technologies. The International Thermal Energy Manufacturing Accelerator (ITEMA) initiative is developing thermos-catalytic reformation technology that takes a range of organic feedstocks and produces liquid fuels, hydrogen and syngas, with biochar as a by-product.

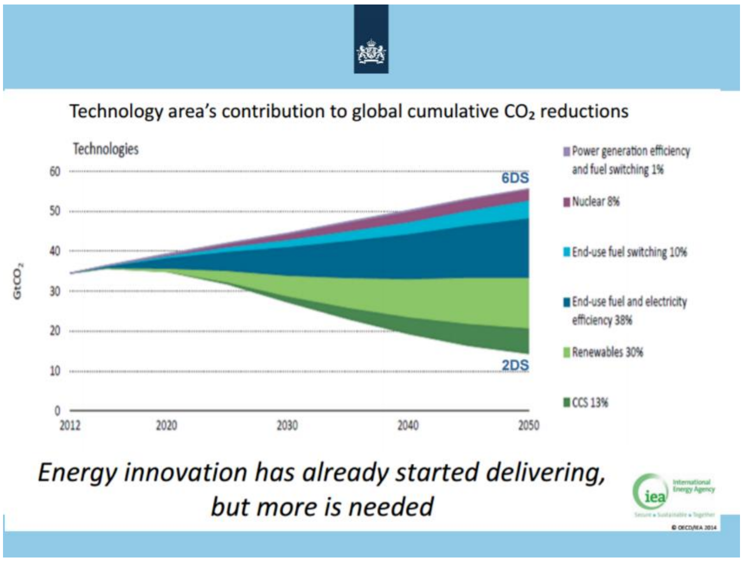
The University of Birmingham is a founding member of the Manufacturing Technology Centre, an independent research and technology organisation that aims to bridge the 'the valley of death'. As its name suggests, it focuses on the manufacturing space, and the University is developing state-of-the-art intelligent manufacturing that includes Industry 4.0 standards, virtual factories, and 'Factory in a Box', which is a small, packaged solution.



1.3 Introduction

Rob Kool, EGRD Chair, RVO.nl, Netherlands

- Link to presentation slides: https://www.iea.org/media/workshops/2017/egrdjunebluesky/0.1IntroEGRDKoolj uni17.pdf



The International Energy Agency's (IEA's) Experts' Group on R&D Priority Setting (EGRD) is part of the IEA Energy Technology Network. The Committee on Energy Research and Technology (CERT) comprises senior experts from IEA member governments and considers effective energy technology and policies to improve energy security, encourage environmental protection, and maintain economic growth. EGRD is established by CERT to examine cross-cutting issues relevant to energy technology research through expert workshops and discussions. EGRD focuses its programme of work on analytical approaches to energy technologies, policies, and R&D. Its recommendations contribute to supporting the methodology of priority-setting and evaluation, discussing IEA work with practitioners, assisting in creating collaborative opportunities between the IEA and practitioners, and exploring topic areas in a cross-cutting manner that helps identify solutions faster and determine blind spots. Each workshop generates a comprehensive report; previous examples include the IEA EGRD reports on Smart Grids, Climate Preparedness, and Transportation and Mobility.

Global energy markets today are dynamic and undergoing a transformation. Advanced technologies are needed to create new options for energy systems. To meet the Paris goal of limiting global warming to well below 2°C, innovative technologies need to be developed, and progress needs to be demonstrated. Technological and/or policy interventions in the recent past have had considerable impact: dominant products have been replaced, and market acceptance has been better than expected. For example, the world is witnessing deep reductions in the cost of technologies, such as LED lighting, lithium-ion (Li-ion) batteries, and wind and solar power. New materials with revolutionary properties that open vast new horizons for innovation are being developed that contribute to economic growth as well as greening of the environment.

Combined with the fast growing possibilities of ICT and smart grids, the options for a rational use of energy are growing by the day.

The capacity to innovate is fast becoming the most important determinant of economic growth in the 21st century global economy. Innovations tend not to be a product of an individual but rather a shared consequence of inspired creativity, leadership, and investment in research by both the public and private sectors. Many of the most innovative technologies shaping global energy markets today can trace their origins to public investments in 'blue sky' research, which is the focus of this research workshop.

1.4 Blue Sky Research

Ryan Bayliss, Oxford University, United Kingdom Behalf of George Crabtree, Director of JCESR, ANL, USA

- Link to presentation slides: https://www.iea.org/media/workshops/2017/egrdjunebluesky/1.JCESR_Crabtree_STFC_53117.pdf

The Joint Center for Energy Storage Research (JCESR) is one of four major energy innovation hubs of the U.S. Department of Energy (DOE), with a budget of $125 million over five years. Started by the Obama administration, the initiative aims to advance promising areas of energy science and engineering from the earliest stages of research to the point of commercialisation. It has several partners, including ten universities, five national laboratories, and five private sector organisations.

Li-ion batteries have revolutionized the use of personal electronics and the way society interacts with people and information. However, personal electronics uses only 2% of energy in the United States, as compared to almost two-thirds of energy use in transportation and the electric grid. This presents a clear opportunity for energy storage solutions and the next generation of Li-ion batteries. Widespread deployment of solar and wind energy makes it imperative that the electric grid be resilient, reliable, and flexible. The grid market needs solutions that shift away from the operating paradigm of instantaneous generation driven by instantaneous demand. Diverse uses of storage in the grid sector may lead to the development of diverse batteries with a range of applications.

For electric vehicles, storage options are needed that will provide hundreds of miles of driving range, and rapid charging options. Reducing costs is critical. Driving down the costs from $80,000 to $20,000 will make the electric vehicle more affordable. Recycling of Li-ion batteries is crucial, and discontinuous improvements in cost and performance may be needed. While costs remain important, understanding the impact of an electric vehicle crash to ensure safety and increasing the battery life are important elements as well. Currently, General Motors Bolt and the Tesla 3 Model are in the price range of $35,000 for 200 miles. For example, Tesla Motors has been researching the stabilisation of batteries for a greater number of cycles, through putting chemicals in the electrolyte at the interface between the electrodes to extend the life. However, a transformation is needed in the transportation and electric grid sector: the next generation of energy storage solutions must deliver both higher performance and lower cost. Li-ion batteries, while competitive, are not necessarily transformative.

Exploring the development of Li-ion battery technology can offers insights into developing next-generation batteries to serve the technology needs related to electric vehicles and the electricity grid. A paper recently written by George Crabtree, Elizabeth Kocs, and Lynn Trahey found that from a basic science perspective, one can trace the discovery of Li-ion batteries back to 1926, when the intercalation of ions into graphite was discovered. A big breakthrough in this technology occurred in 1979 when John Goodenough invented many of the materials that are still found in batteries of today. In 1990, Sony released the first cell based on this technology, the Lithium Cobalt-A. Minor advancements have been made to the chemistry since then, but most of the gains have come from improving the manufacturing processes. In the past few years, about a ten-fold increase in energy density has been seen as the technology has witnessed a simultaneous cost reduction.

JCESR's remit is a highly ambitious project that recognizes this need and opportunity in the transportation and grid sector. The aim of the project 'Beyond Lithium-ion Batteries for Cars and the Grid' is to transform transportation and the electricity grid with low-cost, high-performance storage options. Its mission is to deliver electrical energy storage with five times the energy density and one-fifth the cost within five years.

JCESR is employing a unique cross-cutting approach that includes techno-economic modelling, an electrochemical discovery lab, an electrolyte genome, and a materials lab to achieve its goals. This approach has proved to be a game changer. JCESR is a single interactive organization with a razor-sharp focus on batteries beyond Li-ion. Researchers are using their expertise from multiple battery technologies such as redox flow, lithium-oxygen, lithium-sulphur (Li-S), and others to tackle each challenge.

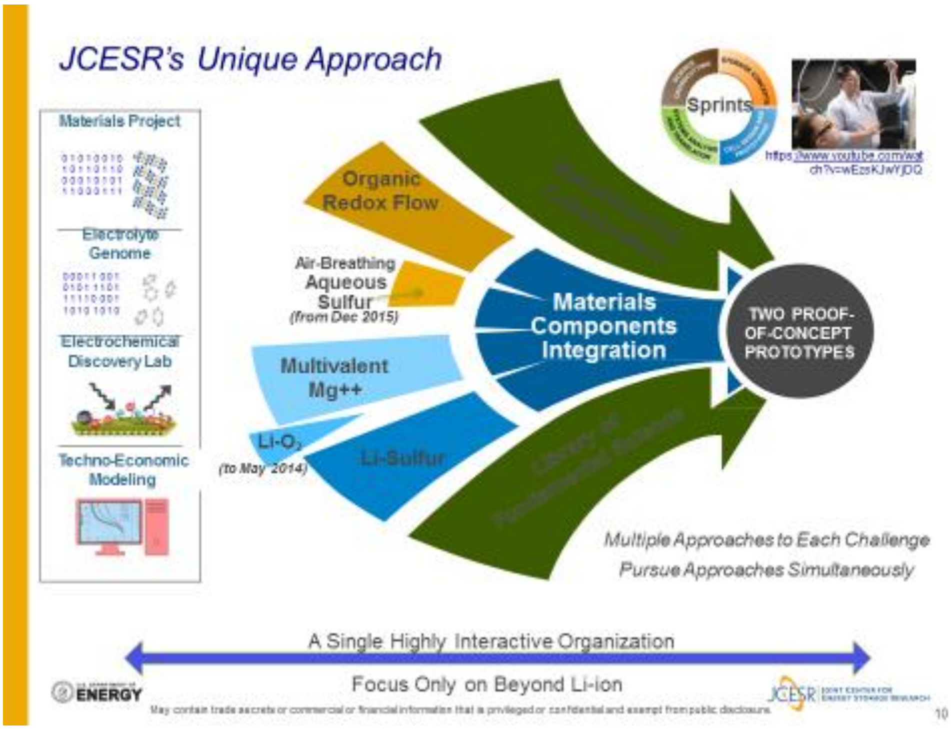


Figure 1. JCESR's unique approach that leads to the development of two proof-of-concept prototypes

This approach feeds into the creation of a library of the fundamental science of the materials and phenomenon of energy storage at atomic and molecular levels by JCESR. JCESR is creating two prototypes, one for transportation and one for the electricity grid, that when scaled up to manufacturing will have the potential to meet JCESR's transformative goals. Through its research, JCESR is creating a new paradigm for battery R&D that integrates discovery science, battery design, and research prototyping.

JCESR researchers are conducting techno-economic modelling in Li-S batteries and found that to reduce the weight of the electrolyte, 'sparingly solvating electrolyte' must be used. As a result, JCESR has established a target of below 1 millilitre/gram of sulphur for an electrolyte for Li-S batteries. JCESR is also investigating organic flow batteries for the grid. These would be scalable to any capacity, and power and energy could be separately controlled. Currently, Vanadium redox flow batteries exist, but they are expensive, with few design options. JCESR is developing materials for a non-aqueous redox flow battery with organics that would be inexpensive, recyclable, and environmentally benign, with a rich design space.

JCSER has spun out two companies, Blue Current and Sepion Technologies, that are looking at novel battery technologies. Both companies are a direct outcome of JCESR's work. Blue Current is researching a Li-S battery with a novel polymer–inorganic solid-state electrolyte developed in JCESR, while Sepion Technologies is researching microporous polymer membrane that blocks Li polysulphides and redox active organic oligomers. The aim is to market JCSER innovations, train the next generation of entrepreneurs, and build relationships. One of the key reasons for its success so far has been the structure and operation of JCESR. It is a highly interactive organization, with specific 'rules of engagement' laid down by the U.S. Department of Energy and supported by the National Science Foundation. The general foundational structure of this framework is challenge-driven, which gives researchers the freedom to interact, collaborate, and partner that enables genuine innovation.

The energy storage ecosystem encompasses new markets, economic and job growth, innovation and competitiveness, and manufacturing across several sectors: electric grid, transportation, personal artificial intelligence, and military.

1.5 Disruptive Innovation

Carrie Pottinger, International Energy Agency

- Link to presentation slides: https://www.iea.org/media/workshops/2017/egrdjunebluesky/2.DisruptiveinnovationPottinger.pdf

The IEA has 29 member countries in Asia Pacific, Europe, and North America, and the main premise of the IEA is the three E's of energy policy: energy security, environmental protection, and economic growth. The IEA was originally formed in 1974 as a response to the oil shock of 1973 as an emergency response for energy security. The IEA's mandate has been evolving and now includes strengthening capacity in global gas supply security, continuing to deepen work on electricity security in the context of the low-carbon transition, and broadening the oil security mandate to engage with more partner countries. The IEA has several signature products, the *World Energy Outlook* and the *World Energy Investment* being the most well-known, and conducts energy market analysis. Recently, the Agency added a fourth E to its energy policy: engagement, which is a central element of the IEA's work to tackle energy security and other global energy challenges.

To facilitate innovation within the IEA, the Agency established the committee on Energy Research and Technology (CERT) and the EGRD. The objectives of CERT Medium-Term Strategy for Energy R&D are to support research and innovation activities and to enhance and expand analysis to inform policy decisions, taking a whole-system perspective; to further strengthen the Energy Technology Network[5]; and to engage with partner countries, the private sector, and relevant international partnerships and organizations.

The most recent *Energy Technology Perspectives* highlighted that energy innovation has already started delivering, but that more efforts are needed. Some energy technologies are on track to deliver but that more support is needed for all stages of energy technology R&D. The *Tracking Clean Energy Progress* report, which assesses collective progress towards long-term goals, underlines that where policies have provided clear signals on the value of the technology, innovations have improved technologies such as solar photovoltaics (PV), onshore wind, energy storage, and electric vehicles. Recent progress in some clean energy areas is promising, but many technologies still need a strong push to achieve their full potential, such as more efficient coal-fired power, carbon capture and storage (CCS), biofuels for transport, and building envelopes.

Energy RD&D spending should reflect the importance of energy technology in meeting climate objectives, yet energy R&D investment represents only 4% of total R&D investments. Most of which are provided by governments. To address this funding gap, Mission Innovation, a global initiative of 22 countries and the European Union, was launched in 2015 during the Paris climate negotiations. Mission Innovation members have committed to doubling their clean energy R&D investment over five years. This initiative will provide the much-needed boost to R&D spending in the energy sector. The Breakthrough Energy Coalition, a private sector initiative launched at the same time as Mission Innovation, is a partnership of 30 private entities from 20 countries that are committed to helping

[5] There are some 6,000 experts in the IEA's Energy Technology Network which is comprised of the CERT, four Working Parties, the EGRD and 38 Technology Collaboration Programmes, or TCPs.

accelerate the cycle of innovation through investment (USD1 billion), partnership, and thought leadership.

Governments play a critical role in supporting technologies and influencing the marketplace for technologies.

Figure 2 groups energy technologies by those that need greater R&D support, such as nuclear and CCS; those needing increased market demand, such as EVs; and those already competing in the commercial sphere, such as LEDs.

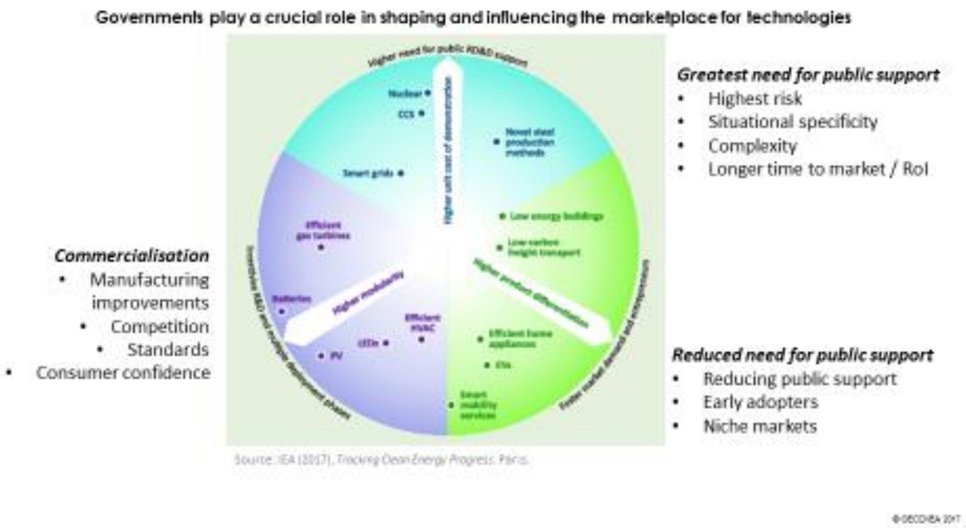


Figure 2. Technology characteristics influence relative needs for public innovation support

Understanding RD&D investment patterns and targeted efforts by stakeholders results in accelerated deployment and innovation, and international collaboration can boost these efforts. The IEA's TCPs are time-proven, flexible mechanisms for encouraging innovation. They are created or discontinued in response to energy policy challenges. Currently there are 38 TCPs supporting discrete topics such as energy efficiency, fossil fuels, fusion power, renewable energy, and hydrogen. TCPs are focused on increasing the understanding of the socio-economic aspects of technologies, reducing greenhouse gas emissions, advancing science and technology, contributing to benchmarks and international standards, facilitating deployment, and improving efficiency.

The IEA has been analysing energy R&D and innovation for many years. The Agency has found that, while unpredictable, the outcomes from innovation can still be supported and nurtured to create conditions maximising benefits and minimising adverse risks. The right policy support depends on the maturity of the technology and the rate and degree of market uptake.

From proof of concept to commercialisation, there are a range of different technologies, some with a longer gestation period, while others come to market more rapidly. Understanding these aspects of a technology and implementing policies accordingly will support technology innovation and maximize societal benefits. For example, the global electric vehicle car stock grew significantly from several thousand in 2010 to 2 million in 2016, yet in 2017 sales dropped 30%. Maintaining the momentum requires continued policy support.

As the energy sector innovates slowly, both incremental R&D and disruptive innovations will be needed to decarbonise the global energy system in the near-term. Government support across all phases of R&D can facilitate this process.

Innovation is defined as the implementation of a new or significantly improved product, process, marketing technique, or organizational method, and can be the result of R&D within one area or cross-fertilisation across R&D areas. Innovation tends to be a non-linear, iterative process in which progress or problems at each stage may feed into previous phases, resulting in further developments. Thus innovation is a departure from linear, incremental R&D. Several types of innovation exist.

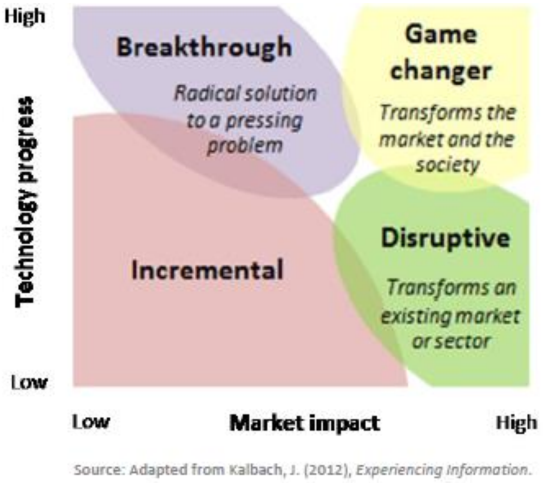


Figure 3. Types of innovation

Game-changers transform the market and the society (e.g. automobiles, the internet); breakthrough innovations provide radical solutions to a pressing problem (e.g. steam for power generation); and disruptive innovation transforms an entire market or a sector (e.g. digital photography, solar PV or onshore wind).

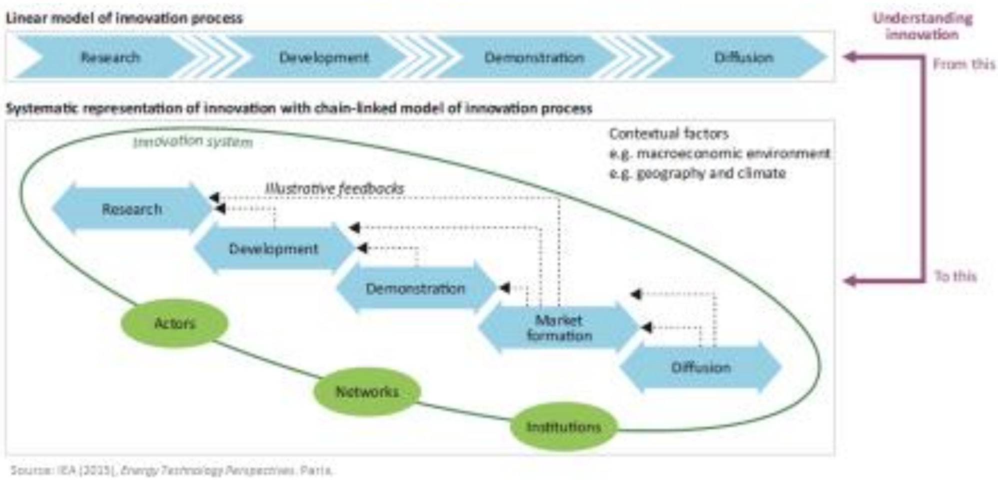
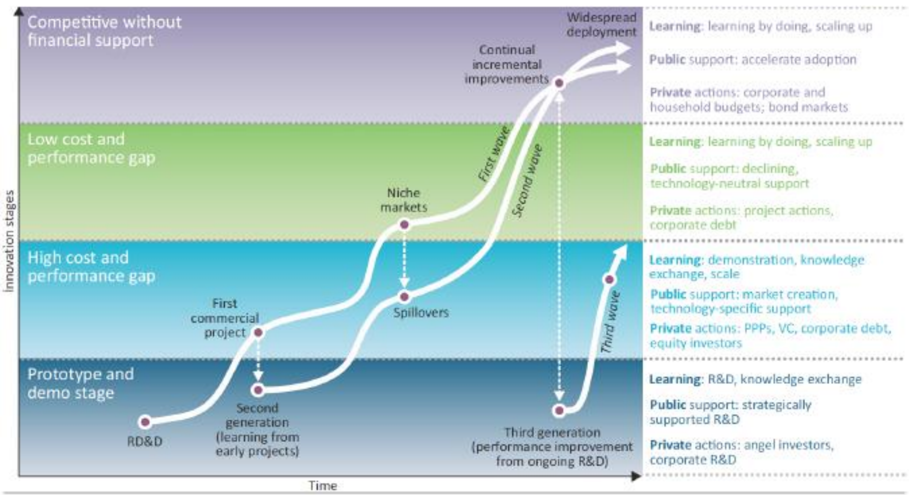


Figure 4. The non-linear nature of innovation

Innovation is (

Figure) an iterative process with links to the successes, setbacks, or failures of linear R&D. A complex process with many actors, innovation can be aided through the integration of technology policies and market measures, and a clear vision from government. As an example of the non-linearity of innovation, solar PV has been informed by different technological breakthroughs that have boosted the development of this technology, and highlights the non-linear nature of innovation. Similarly, publicly funded research for a range of different sectors led to development of the iPod and, following further public research in various sectors, to the iPad.



Source: IEA (2017), *Tracking Clean Energy Progress*. Paris.

Figure 5. An example of the non-linearity of innovation: solar PV

Innovation may be facilitated through new approaches or process. For example, “Innovate or Die” was an innovation challenge aimed at developing a pedal-powered machine with environmental benefits. The winning team designed a pedal-powered concept vehicle that transports, filters, and stores water for the developing world, which could improve the safety, sanitation and education of women and girls. Other challenges include the Google “Little Box” Challenge, the EU “Energy Transitions” and the global “In the Ring” challenge.

Disruptive innovation transforms an existing market or sector as the innovative technology may introduce simplicity, convenience, accessibility, and affordability where complication and high cost are the status quo. This is usually a niche market that may initially appear unattractive, inconsequential or too radical to industry incumbents. As a result, disruptive innovation requires an innovative business model that targets non-consumers (new customers who previously did not buy the products or services) or low-end consumers (the least profitable customers).

A disruptive innovation may have positive or negative results. For example, innovations leading to life improvements, new markets, or advances in scientific understanding tend to be positive, yet they may also result in destabilizing socio-economic adjustments such as creating winners and losers, or increasing the gaps between haves and have-nots.

The IEA is undertaking important research in the field of digitalisation. Digitalisation and energy storage are expected to be the next game-changers for the energy sector. Digitalisation sits at the intersection of investment in the energy sector to digitalise processes and systems, and investment by digital companies related to energy use. This includes for example the digital readiness of the energy sector, trends and outlooks for electricity demand through digitalisation, and assessing the impact of digitalisation on energy end-use (industry, transport, and buildings).

The IEA further supports blue sky research as a co-operative forum for academia, government, and industry to brainstorm ideas, improve understanding of researchers’ needs, and define pathways going forward to further advance the research of a particular technology.

In summary, the IEA is committed to facilitating and supporting innovation. For innovation to deliver, policies must consider the full technology cycle and leverage international collaboration. An integrated systems approach must be implemented now to accelerate progress. Each country needs to define its own transition path and scale up RD&D support accordingly. Horizon scanning can assist governments with identifying possible disruptive innovations and prioritising the relevant R&D investments and policy instruments.

Session 2: From Blue Sky Research to New Emerging Technologies – and Beyond

Chair: Birte Holst Jørgensen, Denmark Technical University, Denmark

2.1 Overview

The session took its departure in Pasteur's quadrant, more specifically the Bohr part of it combining a high degree of the quest for fundamental understanding and low degree of consideration of use (session 4, on the contrary focused at the Pasteur part of it with a high degree of the quest for fundamental understanding AND consideration of use). However, it was also acknowledged that the energy (and climate) challenge requested urgency in providing open-ended solutions within a foreseeable future. As the British economist Keynes once stated. in the long run. we are all dead!

Blue sky research is often characterized as a necessary precursor to applied research. However, fundamental scientific research and applied research often go hand-in-hand. Both types of research are necessary to develop generational improvements in technology. Researchers, institutions, industries, and government policymakers should maintain an awareness of the need for both types of research, as well as the need for clear processes to evaluate, disseminate, and incentivize these types of research.

Information sharing is an essential component of transforming blue sky research into breakthrough innovations. The Energy Technologies Institute (ETI) provides a practical example of the planning and foresight that goes into its comprehensive low carbon and energy technology programme. ETI factors knowledge sharing into all its projects, identifying and down-selecting relevant stakeholders at each step and designing project outputs to be useful for partners. Similar examples arise from the evaluation of cybersecurity risks in the rail sector, which generate insights into processes that are more broadly applicable to industry at large.

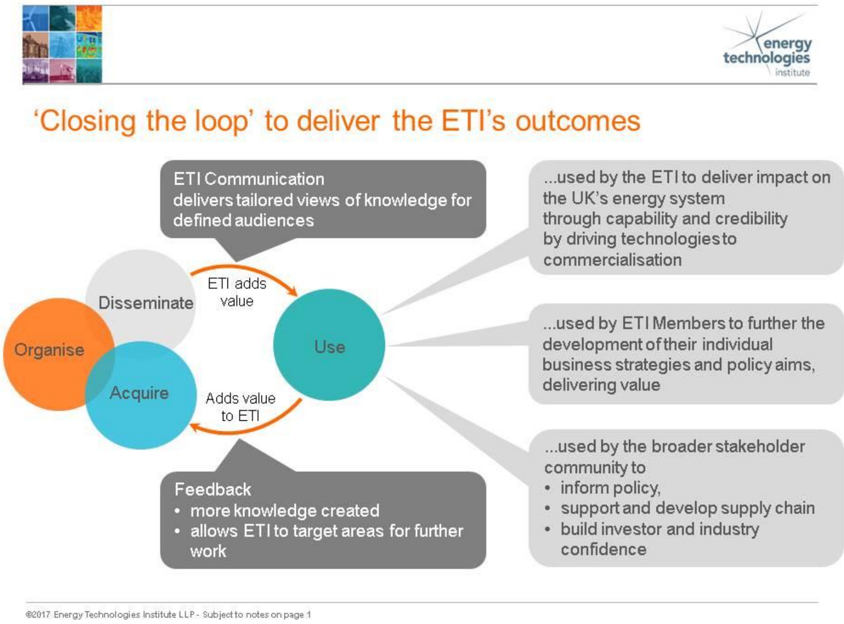
Battery chemistry research is an example of how applied research can occur alongside fundamental research into the physics of materials. Improved batteries are crucial to the development of emerging clean energy technologies in both transportation and grid-scale energy storage. The physics of lithium and other transition-metal batteries offers a wide range of pathways for future battery chemistry research, and efforts to make incremental improvements for current technologies may open pathways for new and unexpected battery chemistries such as anion redox chemistry.

2.2 Sustainability in Turbulent Times

Mike Colechin, Energy Technologies Institute

- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/3.170614SustainabilityinTurbulentTimestoIEAExpertsGroup.pdf

The Energy Technologies Institute (ETI) is a public–private partnership between global energy and engineering companies and the UK Government, established in 2007. ETI acts as a conduit between academia, industry, and government to accelerate the development of low-carbon technologies. The organization's goals include the development of affordable, secure, and sustainable technologies to help the UK address its long-term emissions reduction targets and deliver near-term benefits. To achieve these goals, ETI makes targeted investments in a portfolio of technology programmes across heat, power, transport, and the infrastructure that links them.



In 2007, the financial crash caused ETI's members to become more risk-averse and shift their strategies away from large-scale investments in low-carbon energy and towards their core competencies. This subsequently affected the research priorities and approaches of ETI, and ever since, ETI has been focused on ways to maximize the value of its products for its members and other stakeholders. Initially, ETI was focused on developing large-scale demonstrations of energy technologies, but over time, it has transitioned to creating value by producing knowledge products and innovation.

Knowledge delivers value for both ETI and its partners. ETI's approach allows project managers to design project activities in such a way that a pre-determined group of stakeholders can access the knowledge created by the project. For example, ETI and its oil and gas members were initially focused on carbon dioxide (CO_2) storage in the UK. Researchers from the UK Storage and Appraisal Project (UKSAP) identified potential CO_2 storage sites, including suitable large saline aquifers. The consortium also evaluated the cost and potential capacity volume of these storage sites. Important to this task was determining how to organize the acquired data into a database that could be widely disseminated in a way that created value for stakeholders. By working with Crown Estates to ensure the knowledge is widely available, the UKSAP supports its members' strategy and policy development, strengthens ETI's CCS capabilities, and generates confidence in a wider group of stakeholders, allowing them to progress to the next step.

Recognizing that engineers, scientists, and technologists may focus primarily on the lowest-cost option, ETI additionally evaluated the techno-economic dimensions of CO_2 storage (social, political, etc.), as these are also important factors for decision makers in determining which technologies to deploy.

Identification and consideration of stakeholder needs is a crucial concern. The process by which knowledge is acquired, organized, and disseminated will affect how the information is used by stakeholders, so it must be tailored to meet their needs. ETI has a large number of stakeholders, so identifying and prioritizing stakeholders is an important challenge, as a project that engages too many stakeholders may frustrate efforts to generate meaningful impact. ETI's outputs are used by several actors: ETI itself uses the knowledge it generates to deliver impact on the UK's energy system by driving technologies to commercialisation; ETI members utilize ETI's outputs to further the development of their individual business strategies and policy aims; and the broader stakeholder community benefits from ETI's knowledge base by using it to inform policy, support and develop supply chains, and build investor and industry confidence.

In the UK, the demographic context underlying the future of the energy system is growth in population, vehicle ownership, and housing. By 2050, the population is expected to grow from 65 million to 77–79 million, the number of vehicles from 24 to 35–43 million, and housing from 24 to 38 million. Historically, these trends have not grown in a linear fashion; however, predictions for future energy consumption patterns anticipate the need to meet targets that reduce emissions by 80% by 2050.

The UK energy system is a unique and complex set of interlinked assets and infrastructure that is facing a number of challenges. As several power plants in the UK come close to the end of their lifespans or need significant upgrades, the country is in a unique position to consider other, cleaner options for energy. The UK has several options to choose from: it has significant potential in wind and marine energy, offshore CO_2 storage, and biomass. While the country has reasonable public support for all low-carbon options, its old and low-efficiency housing stock can be a significant challenge. Progress to date has occurred largely as the electricity sector begins to decarbonize itself and in improving the fuel efficiency of vehicles. Remaining challenges include investing in solutions to achieve the UK's energy and emissions targets while ensuring that energy is reliable and affordable.

ETI's modelling of energy system costs estimates that by 2050, the total UK energy system costs could be as much as £300 billion/year, compared to current costs of approximately £120 billion/year (Figure 3). A large percentage of government spending goes towards energy: the National Health Service spends approximately £100 billion/year, and the Ministry of Defence spends around £40 billion/year on energy.

ETI estimates that an optimal technology investment path to meeting its emissions reduction targets could cost less than 1% of GDP. For the period 2010–2050, ETI estimates that with the optimal engineering solution, the total aggregate cost of low-carbon infrastructure would be around £200 billion by 2050; with practical measures, the total cost of this route would be around £300 billion (Figure 4).

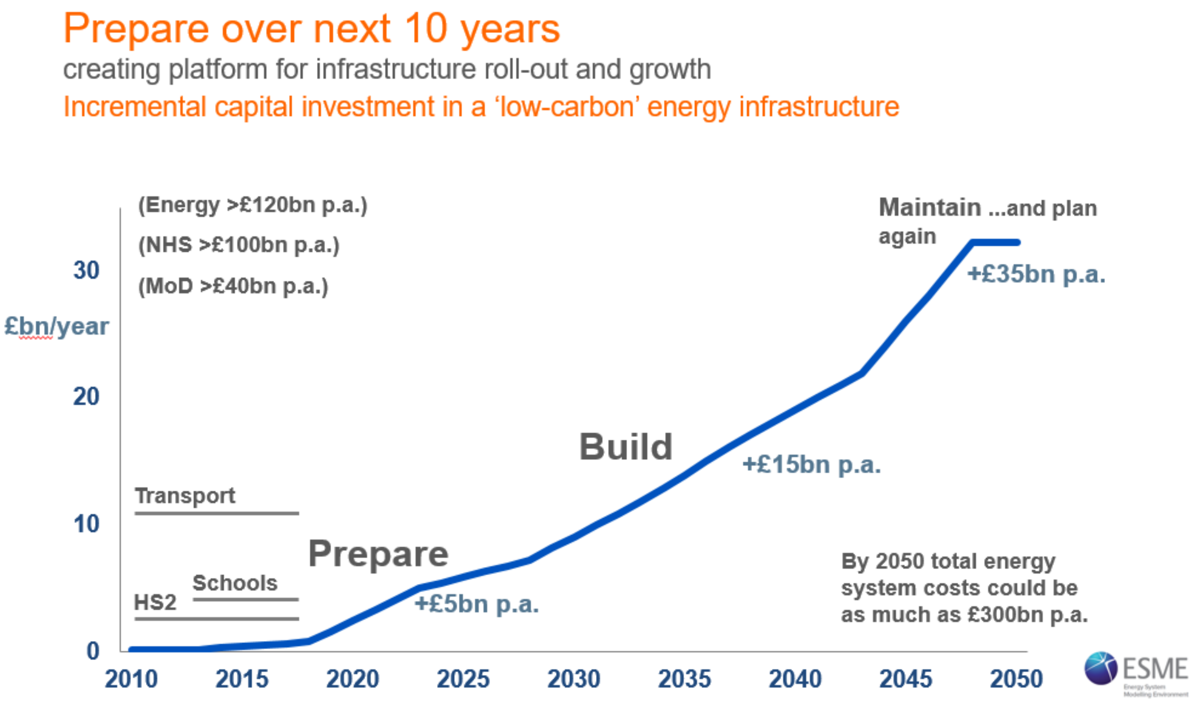


Figure 3. Incremental cost of building low-carbon energy infrastructure in the UK

The estimated cost relies on assumptions about the availability of specific energy technologies, especially CCS and bioenergy. If these technologies are not available, the cost of an energy system capable of meeting emissions reduction targets could potentially double (Figure 4). Other uncertainties remain. If building efficiency gains are uncaptured or nuclear power technologies are not brought online in a timely manner, these circumstances can also affect the costs of meeting emissions targets.

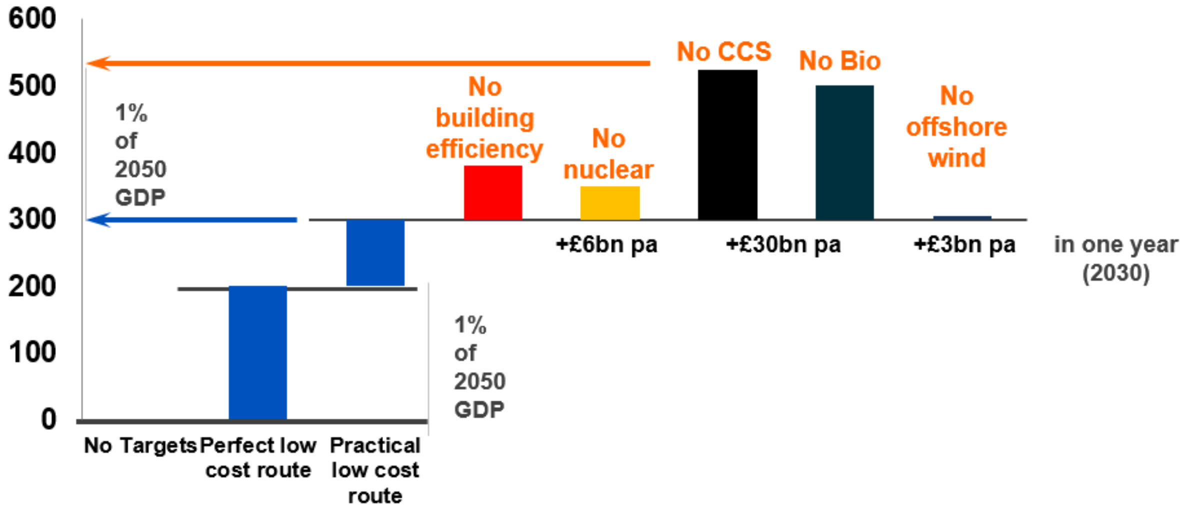


Figure 4. Additional aggregate cost of meeting 80% emissions reduction targets in the UK energy system; additional cost of delivering -80% greenhouse gas energy system (£ bn NPV 2010–2050)

The UK can implement an affordable (~1% of GDP) 35-year transition to a low-carbon energy system by developing, commercialising, and integrating known—but currently underdeveloped—solutions. A key technology that can help in shifting to a low-carbon pathway is building heating and energy efficiency technologies. Building heating is extremely inefficient in the UK, and reducing building emissions can be more cost-effective than making deep cuts in other sectors. Large opportunities exist to deploy advanced integrated home energy monitoring systems, develop cost-effective home energy retrofitting solutions, invest in district heating networks, and expand the use of heat pumps (including air-source and ground-source).

Another key opportunity for an affordable energy transition is the development of energy storage technologies. The intermittent nature of many renewable energy sources puts increasing pressure on network operators to balance supply and demand. Distribution-scale energy storage technologies can give network operators flexibility to balance the grid; however, new approaches to energy storage are still needed. Distribution-scale storage needs to be large-capacity, high-efficiency, and rapid response—but also cost-effective. ETI has supported the development of pumped heat electricity storage technology, which converts electrical energy to heat, stored in low-cost gravel storage vessels with an achievable round-trip efficiency of approximately 75%. There are also significant opportunities for distributed residential energy storage. For example ETI's study of consumer behavior in terms of charging electric cars at home indicates that smart systems for demand-side management can be key in reducing system costs and allow for viable aggregator business models.

2.3 Battery Technology and Basic Science

Peter Slater, University of Birmingham, United Kingdom

- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/4.Prof.PeterSlater.pdf

Efficient, grid-scale electrical energy storage is vital for society to effectively utilise renewable generation technologies. Blue sky research into battery technologies can pave the way for greater penetration of renewables and electric vehicles. Many promising research pathways in the field of metal ion batteries—pathways that can ultimately benefit energy storage solutions—are currently being explored by the University of Birmingham Solid State Chemistry Unit.

Materials, chemistries, and configurations for battery technologies are areas that demonstrate significant potential opportunity for both fundamental blue sky research and targeted R&D to bring known technologies to market readiness. Typically, the best batteries for portable or transport applications are lightweight and small. Li-ion and sodium ion batteries are preferred primarily for these qualities. In applications in which weight and size are less important, other battery technologies may be considered.

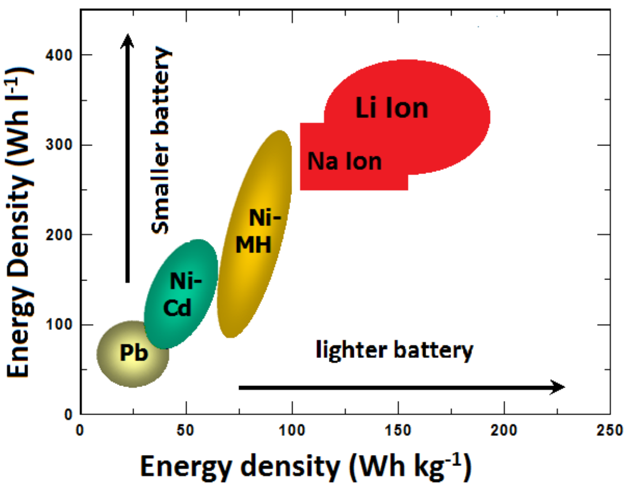
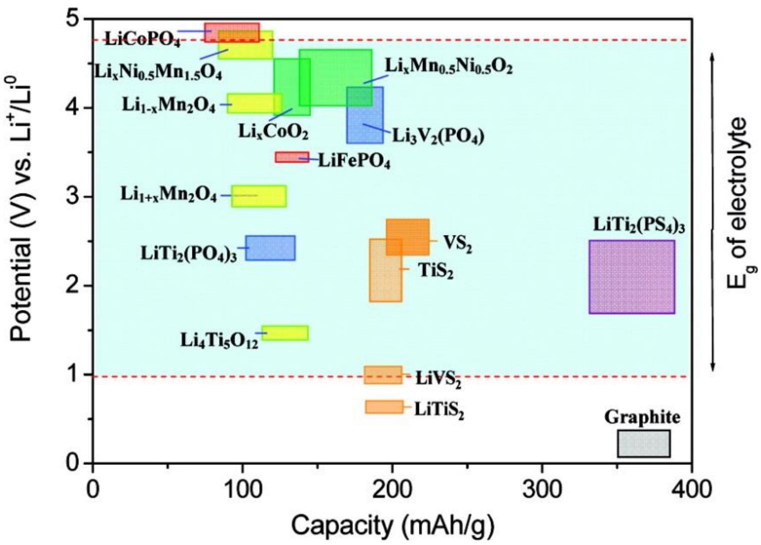


Figure 5. Battery technologies with respect to energy density

Lithium batteries work by shuttling ions from one side of the cell to the other. The design goals should be to ease the process of shuttling lithium back and forth, so as to increase the charge and discharge rates. Additionally, the battery should have high energy storage capacity, have low weight and volume, and be cost-effective. Finally, an issue of increasing importance is material safety: the battery should be stable, and the components should have reduced environmental impacts.

One fundamental factor driving battery research is the relationship between the two electrodes and the electrolyte. The electrodes must be stable in conjunction with the electrolyte. , from a review article by Goodenough and Kim, shows the potential difference and capacity of various battery chemistries; the larger the separation, the higher the voltage of the battery. Higher voltages are preferred; however, the electrolyte must remain stable at the same time. Graphite, which is one of the most commonly used electrolytes, forms a solid electrolyte interphase (SEI) layer (or passivation layer) that helps to stabilise the system.

For lithium-based batteries, layered lithium transition metal oxide materials are typically used. The goal of the battery is to easily remove the lithium-ions from the layers and then easily put them back. The first commercial battery cathode was cobalt-based $LiCoO_2$. Even though this material (or a variant containing other transition metals, e.g., $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$: NMC) is still widely used, it continues to have high costs, toxicity issues, and low capacity.



Iron-based cathode materials could potentially lead to lower-cost raw materials and improved safety when the battery is rapidly and repeatedly discharged and recharged. Potential iron-based formulations include $LiFePO_4$, Li_2FeSiO_4, and $LiFeSO_4F$. However, these benefits come at a price: iron-based cathodes require a higher manufacturing cost and have poor electrical conduction.

Figure 6. Anode and cathode potentials need to be within the stability window of the electrolyte (left axis). Source: John B. Goodenough and Youngsik Kim, 'Challenges for Rechargeable Li Batteries', *Chem. Mater.* 2010, 22, pp. 587–603

Graphite is the most commonly used anode; however, more research is needed to understand the SEI layer. Additionally, future research may consider materials that can accommodate a much higher amount of lithium.

Electrolytes in lithium batteries are typically Li salts in a non-aqueous solvent. Stability is a key issue with these electrolytes, as flammability and instability (especially towards higher-voltage cathode materials) is an increasingly concerning risk.

Capacity is determined by the amount of lithium that can be reversibly intercalated and deintercalated (i.e., inserted and deinserted into the cathode layer) and by the weight of the material. In $LiCoO_2$, the maximum achievable removal of lithium ions per $LiCoO_2$ unit is 1.0, but in practice, it is limited to approximately 0.5 for safety and stability purposes.

In order to increase battery capacity, either the amount of lithium that can be intercalated/deintercalated must be increased, or the material weight must be decreased. For battery materials research, only the first row of the transition metals is being considered (i.e., titanium, vanadium, chromium, manganese, iron, cobalt, and nickel) because of the weight consideration (subsequent rows add too much weight). Thus many of the opportunities for both applied and blue sky research in lithium battery materials are based on increasing the amount of lithium that can be reversibly intercalated.

Increasing the amount of lithium that can be reversibly intercalated requires increasing the change in oxidation state elsewhere. This strategy is the subject of a great deal of ongoing research, including anion redox chemistry studies. In a conventional $LiCoO_2$ battery, cobalt 3+ is oxidized to cobalt 4+. However, with anion redox, batteries can be made with manganese 4+. In this case, rather than changing the manganese oxidation state, anion redox batteries rely on changing the oxidation state of the oxygen. Anion redox chemistry presents challenges in that the resultant oxygen 1- is very reactive and can damage the electrolyte.

Following anion redox chemistry, one of the potential next steps is lithium-oxygen batteries (often misleadingly called Li-air batteries). In a lithium-oxygen battery, the transition metal is removed completely. In the battery chemistry, lithium becomes lithium peroxide in situ, and so while charging or discharging, oxygen is being added or removed. This chemistry results in a very high potential capacity. However, there are challenges with the presence of water, CO_2, and nitrogen in air, so these must be removed. An electron conducting matrix is also required, and there are safety concerns if lithium metal is used, along with issues with the stability of the electrolyte because the formation of peroxide oxidizes many commonly used electrolytes. Additionally, the battery needs to be connected and open to an oxygen tank to allow oxygen to move in and out of the battery.

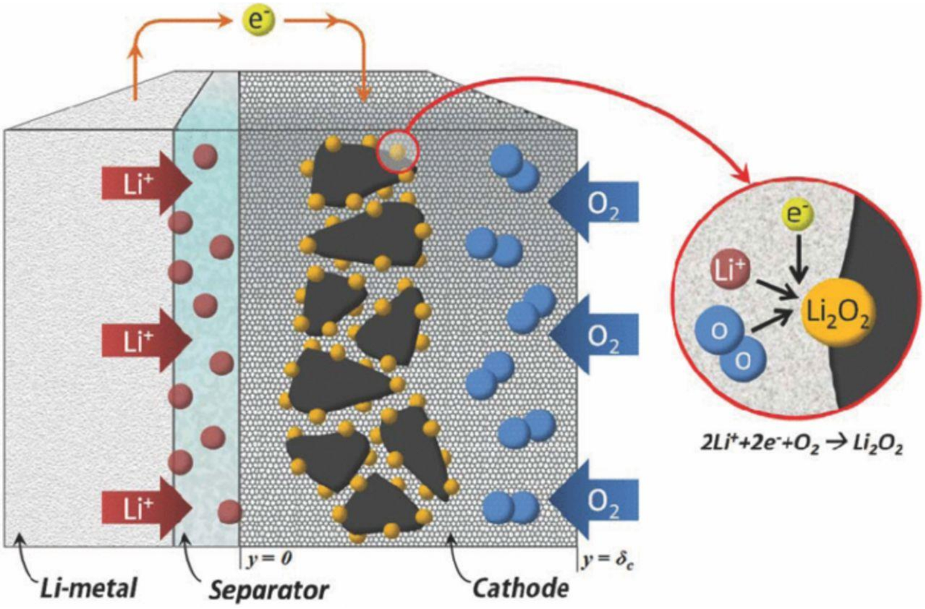


Figure 7. Lithium-oxygen battery schematic. Source: Yun Wang and Sung Chan Cho, 'Analysis of Air Cathode Performance for Lithium-Air Batteries', ***J. Electrochem. Soc.*** **2013, 160, pp. A1847–A1855.**

Lithium-sulphur batteries are another potential anion redox battery technology. While oxygen is a gas, sulphur is a solid, so the battery overcomes issues related to having an open oxygen tank. One current challenge with the technology is the solubility of LiS_x in common battery liquid electrolyte systems.

A future target technology is the use of solid-state electrolytes. Current technologies using liquid electrolytes have problems with safety and flammability. Some cathode/anode combinations are capable of producing voltages higher than 5V but cannot be used with existing liquid electrolytes. New electrolytes could include polymer or solid-state systems, producing all-solid-state batteries. These batteries could yield significant improvements in safety, as these electrolytes could be non-flammable materials. Solid-state cells could also potentially be smaller and introduce new possibilities with simplified, bipolar cells (cells in which the cathode and anode of adjacent cells share the same current collector). Additionally, solid-state batteries have lower leakage currents than liquid electrolyte batteries, indicating greater potential applications in energy-harvesting devices.

Key requirements for a solid-state electrolyte material include high lithium ion conductivity, low electric conductivity, and chemical stability under operation, low costs, and safe materials. Solid-state cells face challenges with the retention of electrode–electrolyte interface during charge and discharge cycles. Volume changes during charging and discharging can cause interface failures from which it is potentially difficult to recover.

One potential solid-state electrolyte is garnet. Stoichiometric garnet structures do not function well as lithium ion conductors but, through doping, the ionic conducting properties can be improved. Additionally, because garnet structures can also exchange lithium ions with hydrogen ions while maintaining high conductivity, these structures may also have fuel cell applications.

Future target technologies for anodes are another area of research. Graphite is a good anode material but is limited in the amount of lithium that can be incorporated in its structure. Alternative anode materials such as silicon or tin have much higher capacity for lithium uptake but have problems with large volume changes upon lithium uptake.

For grid-scale stationary power storage applications, current Li-ion batteries are too expensive. Sodium ion batteries are attractive because of the high availability and low cost of sodium. Even though sodium ion battery technologies are heavier, they are a good choice for stationary applications, as these do not need to be as weight-sensitive as portable/mobile applications. Sodium analogues of Li-ion batteries may work, but one of the main issues with sodium ion batteries is that sodium will not reliably intercalate into graphite, so it cannot be used as an anode. Current research is focused on new types of anodes for sodium batteries. Sodium-based batteries are also very moisture-sensitive, owing to the use of sodium metal. This could present challenges in terms of cost and manufacturing. Finally, sodium batteries have slower cycling rates than Li-ion batteries. Potassium ion batteries have also attracted some interest for stationary storage.

Magnesium ion batteries are another technology that has attracted some interest. Because there are two electrons per magnesium ion, magnesium batteries could potentially double the capacity of comparable lithium batteries. However, in practice, it is more difficult for a 2+ ion to move than a 1+, which means the battery chemistry suffers significantly lower ion conductivity. Also, finding suitable insertion electrode materials is a challenge.

Finally, battery recycling is a critical challenge that faces all battery technologies. Recycling Li-ion batteries is expensive. Current-technology petroleum vehicles have a target of ~95% recyclability. In order for battery electric vehicles to meet this target, a strategy for recycling batteries is necessary. Potential solutions include reusing automobile batteries in stationary and less demanding applications and designing batteries to better enable disassembly and recycling.

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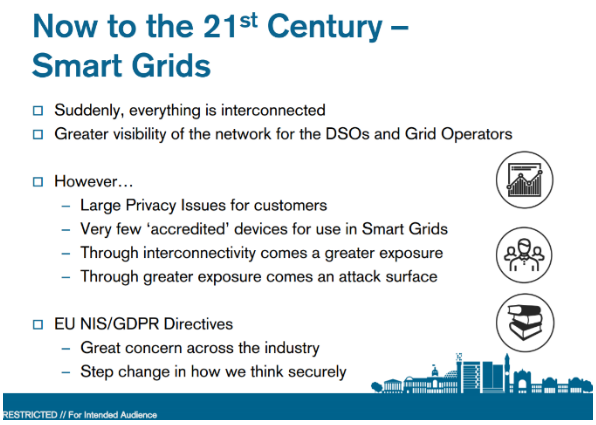
2.4 Threats to Industrial Control Systems: Lessons Learned from Rail

Richard Thomas, University of Birmingham, United Kingdom

- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/5.RichardThomas.pdf

Even though cybersecurity threats pose an increasing risk to industrial control systems, such as those in rail networks, consideration of cybersecurity frequently remains as an afterthought for system owners and operators. Recent initiatives in the UK, US, and EU governments are starting to address cybersecurity by considering how to protect critical national infrastructures. Part of this effort is the Research Institute in Trustworthy Industrial Control Systems (RITICS), coordinated by the Institute of Security Science and Technology at the Imperial College London. EU efforts to address cybersecurity threats to critical infrastructure are also a part of the Horizon 2020 programme, the EU's framework programme for research and innovation.



At the University of Birmingham, the active RITICS project is called SCEPTICS[6]. SCEPTICS focuses on lessons learned from rail control systems and how these might inform the research needed to protect the energy sector. In computer science terminology, modern industrial control systems (ICSs) consist of human–machine interfaces, programmable logic controllers (PLCs), sensors, and actuators such as motors. Security for these systems depends on the CIA Triad (Confidentiality, Integrity, and Availability). With critical infrastructure, integrity and availability are typically highly emphasized, while confidentiality is typically a lower priority.

Siemens SIMATIC Step 7 (S7) PLCs are one example of logic controllers used in ICSs. As an example, they consider one potential attack that could take place, but could affect products from any vendor. It is important to note that not all PLCs are vulnerable and it depends on the deployment to ascertain whether they could be vulnerable.

Cyberattacks can be carried out by an unauthorized person walking into an environment and connecting to an ICS to reprogram an S7. For example, the PLC can be reprogrammed to make equipment run out of the safe range of operation, risking damage, causing fail-safe systems to be engaged.

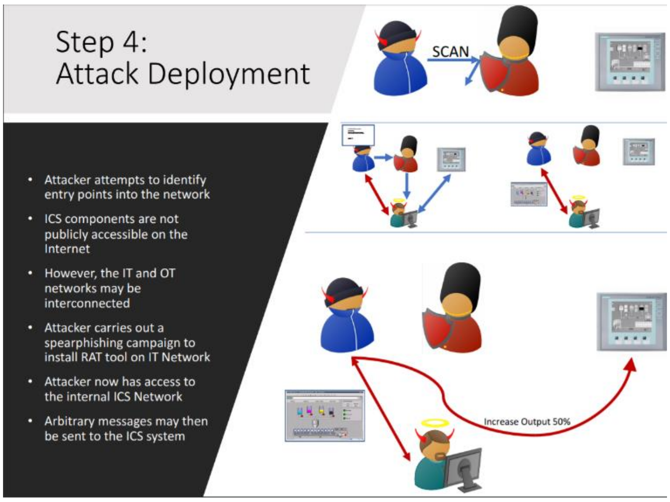
Sometimes critical infrastructure ICSs need to be connected to the Internet so that systems can be monitored remotely. For example, in the North Sea, it is important to be able to monitor the output of remote oil rigs. Another unique challenge is that many systems use legacy equipment in the same system as modern equipment. Significant research effort has been focused on evaluating these types of vulnerabilities, but more research is needed about potential novel attacks on these systems and how such attacks may impact wider ICS networks.

[6] Systematic Evaluation Process for Threats to Industrial Control Systems

There are three key components of the power grid addressed by the SCEPTICS project: generation systems, transmission systems, and distribution systems. From an architectural point of view, the system is straightforward, with a mix of manual and automatic controls that the three systems use under regular operating conditions. Many of the ICS networks for these systems are isolated, with dedicated and safe communications links between systems. These systems are also monitored by government agencies. In the UK, the Government Communications Headquarters monitors traffic on these systems.

Upgrading grid technology, such as by deploying smart meters, may also introduce new threats. These technologies bring many benefits to both consumers and system operators but also require greater interconnectedness. Unfortunately, there are few certified, secure smart grid devices available in the marketplace, and the large amounts of data that these devices generate have the potential to create security risks. For example, if no energy is being used in a residential space, a potential attacker with access to this data would be aware that a person is not at home, enabling criminal activity.

One example of cybersecurity in practice comes from the Smart Grid Protection Against Cyber Attacks (SPARKS) project, funded under the EU Seventh Framework Programme for Research and Technological Development (FP7, the EU-wide research program for 2007–2013). This example shows what a conventional attack might look like. The attacker's first step is to scout the target site and identify the types of equipment connected and in use. As an initial cybersecurity measure, a firewall will help to keep people out of the site.



Another route an attacker might take is to find a target individual in the office and send an email to the staffer with a phony link to update software. Under the Networking and Information Security (NIS) Directive, systems should be kept up to date in order to remain secure, so the targeted individual may think he or she should download the latest update. However, in this scenario, the attacker has also put in a remote access Trojan (RAT) tool, which gives the attacker control of the entire system, including the keyboard, mouse, and desktop display. Once the system is compromised, the attacker has complete access to the system. For example, attackers could make amendments to the ladder logic on the PLC or siphon off data from the plant.

The SCEPTICS project focused on rail control systems, and one of the lessons learned from this project is that the European Rail Traffic Management System uses a dated, potentially vulnerable communications standard. Trains authenticate to a signalling centre and use message authentication codes. These codes use a custom-built encryption algorithm that was broken in 2017, where the communications layer itself may have its encryption broken in as little as 9 seconds. Over the course of three to four years, it would be possible for an aspiring attacker to collect enough information to capture data from train communications. Since the control system consists of a mixture of legacy and modern equipment, it remains vulnerable to cyberattacks.

A key output of the SCEPTICS project was the development of a methodology that an engineer can apply to identify critical systems and exposure to security hazards and risk analysis. When this tool is used to evaluate the system architecture for a train control system, it lays out the complex interrelationships between controllers and evaluates the exposure of different components of the system. The rail system requires all users to use the same standardized equipment specifications, which facilitates risk evaluation. However, in the power sector, the grid may have subtle differences in the implementation of the specifications that could have large effects that need to be taken into account. The Institute of Electrical and Electronics Engineers (IEEE) standard for power systems lays out the method for determining the exposure of systems to potential attacks. This means it is important to consider how accurate the modelled architecture is when evaluating exposure to attacks.

Industry stakeholders can take actions to minimize their exposure and to address cybersecurity threats. One important step is to introduce a secure supply chain. A secure supply chain is one that ensures that all suppliers and service providers have robust vetting and security procedures for both staff and equipment. It is important that every point in the purchase of a piece of equipment or software has been proven to be secure by default.

Another important step is to conduct an audit of all the devices in a network. Everything in use should have a purpose, with extraneous or obsolete equipment removed from service. Intrusion detection systems are not a panacea, as they have to be trained with data from the network before they can be effective. If the attacker is already accessing the network, the intrusion detection system will not recognize that activity as a threat. Another recommendation that applies to the rail sector is to establish a regular review of specifications and standards to ensure currency.

For NIS compliance, understanding the architecture of a system is critical in order to anticipate which weak points a potential attacker might probe. Previously, most approaches to cybersecurity have been based on anticipating potential attacks. However, the blue sky approach presents a simple and novel alternative. Using a simple Visio/SysML model, it is possible to look at how best to defend a system. This approach is new, and system managers have not been able to use this approach before to estimate the risks around cybersecurity. This new, novel methodology takes into consideration the whole system and assists in securing these 'systems of systems'.

Website: https://ritics.org/wp-content/uploads/sites/16/2017/10/Ritics_Brochure_web.pdf

Further information (including papers): http://www.cs.bham.ac.uk/~rjt195/publications

Session 3. Converging and Enabling Technologies for Energy

Chair: Herbert Greisberger, eNu, Austria

3.1 Overview

Blue sky research is essential to create disruptive innovation that can make generational leaps in the energy sector. When innovations discovered in blue sky research are applied to industrial settings and future energy paradigms, technologies can progress rapidly, leapfrogging incremental improvements, and creating new frontiers for R&D. Blue sky research can lay the foundations for fundamental innovations and bring about significant increases in energy efficiency through implementation in industrial processes. Fundamental improvements in the conversion, reforming, and upgrading of biofuels and generational transitions in manufacturing energy efficiency are - among many others - technologies that have the potential to achieve large-scale reductions in energy-related emissions and environmental impacts.

Fundamental to the nature of blue sky research is the non-linearity of research goals: discoveries and advancements can improve a wide variety of industrial processes. Catalysis holds promise to improve the cost and efficiency of many such processes, including upgrading heavy oils (such as tar sands), deoxygenation of pyrolysis oils (important for biofuels), and pre-combustion carbon capture technologies. Novel structures for supporting catalysts and catalytic materials show promise for many applications relevant to energy technologies. Likewise, the Thermo-Catalytic Reforming (TCR©) process is designed to convert waste biomass into liquid, gas, and solid fuels, but it has wider applicability to the creation of agricultural products and to critical materials recovery. TCR also presents an opportunity to overcome many of the challenges associated with traditional biofuels by switching to alternative and waste biomass feedstocks.

Energy efficiency is typically considered an incremental process, but improvements in industrial settings can also be achieved through comprehensive reconfiguration of the industrial process around energy planning, recycling, and controls. The ETA Factory is a testbed that holds promise for revolutionary improvements in building energy efficiency through recycling energy and integrating process controls in a model factory. Although applied to a single process, the method for developing drastic reductions in energy consumption is applicable to any industrial process.

The presentations show the potential of transferring (often unintended) results from blue sky research to industrial processes in terms of energy efficiency and environmental improvements.

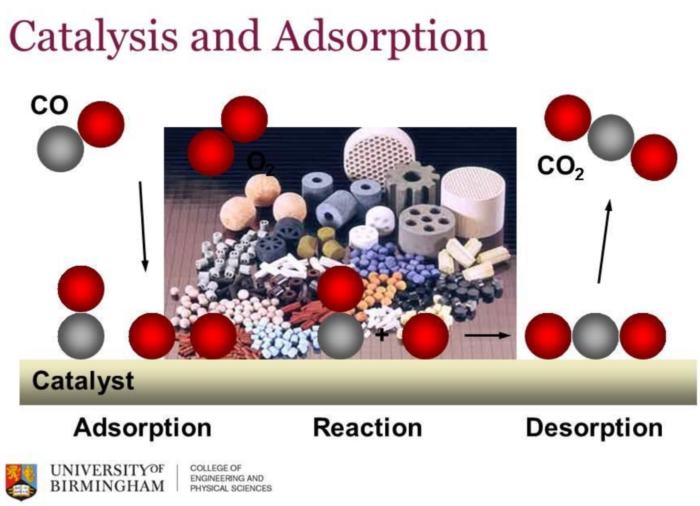
3.2 Reducing Critical Materials through Chemical Analysis

Joe Wood, Birmingham Centre for Strategic Elements and Critical Materials, United Kingdom

- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/6.JoeWood.pdf

The University of Birmingham's School of Chemical Engineering hosts research on the applications of catalysis for recovering critical materials, improving the efficiency of heavy oil extraction, and other areas of both applied and blue sky research. The research group's current projects include work with the University of Nottingham on the upgrading of fossil fuels and research on the recovery of heavy oils from tar sands with the Natural Environment Research Council Center for Doctoral Training at Heriot Watt University. The group is also initiating research into plastics and renewable fuels, including using catalysis to upgrade pyrolysis oils.

The research group's primary focus is on the use of heterogeneous catalysts: a porous support material impregnated with some metal nanoparticles that serve as the catalyst (See figure below)). One example is a catalyst composed of cobalt-molybdenum particles supported on an alumina structure. Renewable catalyst supports are also an area of interest for reducing the amount of material going to landfills. The group has worked with a wide range of porous catalyst supports onto which metals can be deposited**.**

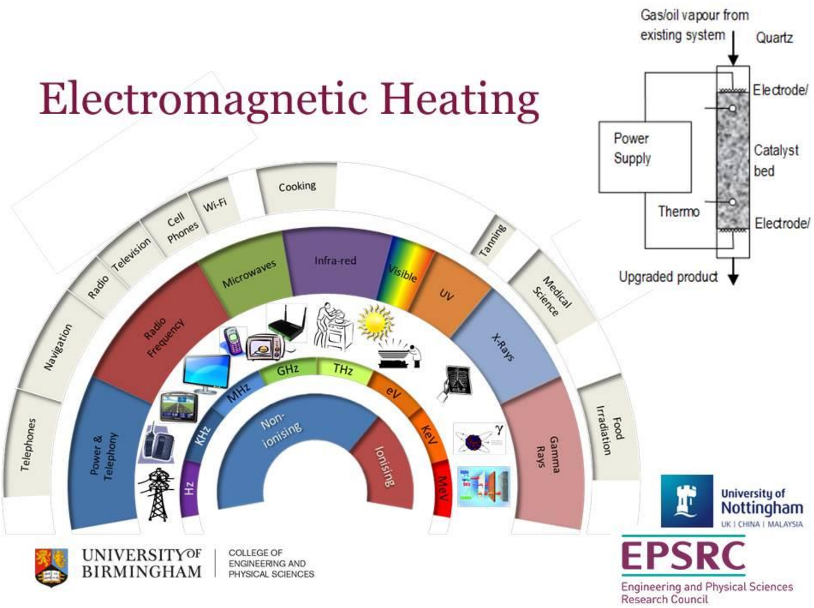


The typical heterogeneous catalytic process relies on adsorption of a substance onto the very high surface area of the support structure, bringing the substance into contact with the catalysis site. The catalyst allows a reaction to occur at a lower energy, thereby speeding the reaction chemistry. The products can then be desorbed off the catalyst. One of the major elements of catalysis research is understanding how substances will attach to the catalyst and how they will desorb to produce the useful product. The kinetics occurring at the catalyst particle can be complex. There can several different kinds of transport resistance at the point of catalysis, including resistance caused by the adsorbed substance undergoing a phase change. A large part of reaction engineering is trying to design a way to bring the components into intimate contact. In terms of chemical engineering problems, the focus is typically on large-scale products, so small efficiencies are important improvements.

The variety of reactor designs throughout history is large, from stirred-tank reactors from 150 years ago to modern efficient reactor designs. The research group has evaluated a range of alternative types of reactors, including the trickle bed reactor, which is suitable for high-volume applications including those in the oil industry, and more specialised reactors such as the monolith design, which is similar to those used in automobile catalytic converters.

One driver behind research into catalysts is the need to identify new types of catalysts that may be more abundant or might be less vulnerable to supply disruption. The Birmingham Centre for Strategic Elements and Critical Materials was recently established to address some of the problems associated with reliably procuring critical materials, especially those that may be difficult to extract (platinum group and rare earth metals) or that are located in parts of the world where political problems may affect the reliability of supply chains.

With the development of new types of electric vehicles, demand for the materials used in batteries, fuel cells, and motors is expected to increase. Similarly, the growing deployment of renewable electricity generation technologies such as solar and wind power will increase the demand for very large batteries that can store energy for use on the power grid. (See figure below) All these new energy technologies will require materials that are challenging to procure, such as lithium and rare earth elements, among others. Platinum group metals are especially critical, so research efforts on replacing these metals with less-critical resources or on recycling these metals, are especially pressing.



A unique research effort at The Birmingham Centre for Strategic Elements & Critical Materials led by Professor Macaskie studies biological methods to recycle strategic elements and critical materials. For example, one potential source of critical catalytic materials is urban road dust. When cars accelerate, very small amounts of the metals in the vehicle's catalytic converter come off and can accumulate in the form of road dust. Another potential alternative source of waste metals is scrap electronics. The research work is exploring uses of bacteria that can then be subjected to a metal-containing solution under hydrogen so that the bacteria can then absorb metals into their outer layers. Eventually, the cells are washed, dried, and killed in acetone, leaving the catalyst deposited on a carbon substrate. The residue is then dried and ground to produce a black powder that can be reused. This mechanism has the advantage that it can be used in a range of different applications.

The use of catalysis to generate polymers from renewable materials is another promising blue sky goal of catalyst research. Plastic cups are made of polyethylene that could be recycled by melting and physical recycling. However, it is desirable to make new polymers based on renewable materials. For example, polylactic acid is a polymer made from renewable material. It is possible to generate homogenous catalysts, which can disassemble the polymer into its basic building blocks.

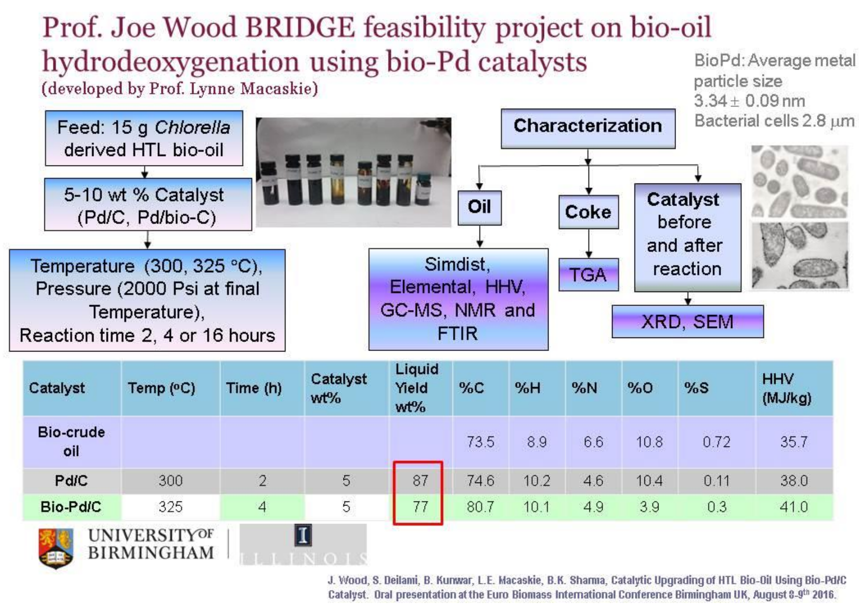
Subsequently, the compounds useful for a renewable polymer could be separated from the rest of the reaction mixture using specialized membranes. This would improve the efficiency of the reaction.

Since the 2010s, the production of heavy oils has been increasing, while production of light oils from the Middle East has declined. The extraction of these oils in Canada can be quite environmentally damaging. Catalysis has promising applications for the upgrading of heavy oils.

In situ catalysis of heavy oils during toe-to-heel air injection (THAI) can improve the efficiency of the process and reduce downstream energy spent on upgrading. THAI involves drilling a horizontal well, which is used to produce the oil, as well as an injection well that is used to heat the oil well or to inject air once a combustion front has been started. The combustion front burns around 15% of the oil in the well, but it heats the oil and water in the sands. As the oil flows, thermal cracking reactions can take place. If a catalyst is packed into the well before the combustion front begins, the heated oil can flow over this catalyst, increasing the thermal efficiency of the process.

An example of an in situ catalyst is a perforated well liner, which consists of a cobalt-molybdenum-impregnated alumina support (See Bridge figure). One of the key challenges of the catalyst being located underground is that if there is a malfunction, then it can be very difficult to reactivate the catalyst. The research group has developed a test rig that allows the evaluation of different types of catalysts and different reaction conditions. THAI oil is run through the rig, and if in situ catalysis can upgrade it to a specific gravity of 22.3, the oil could be pumped along a pipeline to refineries.

One of the challenges with this approach is that the catalyst will be degraded by deposits of carbon filling the pipe. Researchers are working towards finding solutions to either reactivate the catalyst in situ or prolonging the life of the catalyst. One method is to convey nanoparticles into the rock structure. Simulations have been carried out using Lattice Boltzmann techniques to examine the penetration of catalysts into the well. Another approach uses bacteria as a catalyst support. The bacteria are preferable to conventional catalyst supports**.** Finally, some catalysts begin to fail at a certain level. One approach is to use microwaves to inductively heat the catalysts from antennae or coils in the well. This technique could achieve a desired temperature in the catalyst bed (Fig 2).



Catalyst	Temp (°C)	Time (h)	Catalyst wt%	Liquid Yield wt%	%C	%H	%N	%O	%S	HHV (MJ/kg)
Bio-crude oil					73.5	8.9	6.6	10.8	0.72	35.7
Pd/C	300	2	5	87	74.6	10.2	4.6	10.4	0.11	38.0
Bio-Pd/C	325	4	5	77	80.7	10.1	4.9	3.9	0.3	41.0

There are several other areas of catalysis-related research from which researchers could benefit. Fraunhofer UMSICHT researchers using TCR could potentially benefit from integration of advanced catalysts into the TCR process. The bio-oils produced from the TCR process result in products that must be deoxygenated before they can be used as drop-in replacements for conventional fuels. Catalysis could potentially be a solution to this problem. Additionally, the currently low price of oil implies that the TCR process could be useful for other products from a bio-refinery, for example, bio-pharmaceuticals.

Scientists from the University of Illinois at Urbana–Champaign are evaluating the potential to upgrade bio-oil products produced by their research process. For example, bio-palladium performs at a level similar to the traditional types of industrial palladium on carbon (Fig 3). This indicates a potential future route to making renewable transport fuels through the use of recycled catalysts.

Carbon capture is another potential area of research. In collaboration with the University of Nottingham, researchers evaluated step-change adsorbents for the adsorption of CO_2. The University of Nottingham researchers have significant experience with activated carbons. Additionally, research at the University of Liverpool has focused on applicable microporous materials such as amine-modified hydrotalcites. These are layered structures on which amine groups can be attached in order to make them more basic and attractive to CO_2. Some of the formulations captured up to 3 mml of CO_2 and so were attractive as absorbents.

Pre-combustion carbon capture technology, in which fuel is separated into CO_2 and hydrogen before combustion is completed, is one potential use of novel catalysis technology. At the University of Birmingham, research is being conducted on a small fixed-bed reactor to evaluate the performance of carbon when a slug of CO_2 is introduced into the catalyst particles to see how they react to remove the CO_2.

The Rural Hybrid Energy System is another project that takes waste biomass and converts it into cleaner fuels in a rural setting. Current investigations include anaerobic digesters powering landfill gas engines and stoves using gas from hydrolysis. These fuel production methods use a core shell catalyst.

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3.3 Foresight Applied to Energy

Miloud Ouadi, Fraunhofer UMSICHT, Germany

- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/7.ArturMajewskiFraunhofertosynfuel.pdf

Fraunhofer UMSICHT Institute branch Sulzbach-Rosenberg (SuRo) focuses on the conversion of biomass into biofuels and other products and on intermediate pyrolysis technologies. The pyrolysis technologies have gone through three generations, and researchers at the Institute focus specifically on the TCR process. Miloud Ouadi presented the results of her work and of Artur Majewski
The first step in developing the TCR process was the Haloclean project, which was built in 2006-9 in Karlsruhe, Germany. The project successfully converted biological wastes into bio-oil, but the quality was poor. In 2008, the pyroreformer was built at Aston University in Birmingham, UK. The pyroreformer was a robust device that could produce fuels for the facility's combined heat and power system, but it produced oil products that were too acidic for wider use. Finally, the TCR plant was constructed at University of Birmingham (30 kg/h) and Fraunhofer UMSICHT, which converts residue biomass into bio-oil. The next step is to develop a larger device that is capable of processing 300 kg of biomass per hour and that can use sewage sludge as a feedstock (under construction – Rotherham Harbour 2020).

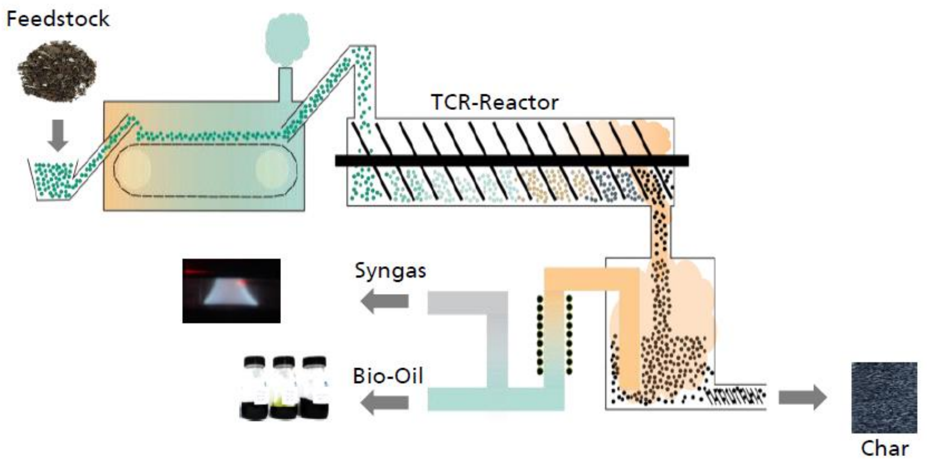

Figure 8. TCR process overview

Compared with other bio-oil production processes, the value of TCR is that it uses feedstocks such as biomass residues and waste biomass that do not compete with food or woody biomass and, as a result, do not create pressures on food markets or create deforestation incentives.

The products of TCR include bio-oil, syngas, and bio-char. The bio-oil can be refined into transportation fuels, including fuels for automobiles. Bio-oil produced with TCR is low-viscosity and of sufficient quality that it is miscible with common fuels; the process is relatively easy and produces no tars. The bio-fuel product has a high calorific value of approximately 37 megajoules/kg. TCR using sewage sludge produces a naphtha product whose boiling point and other properties are sufficiently similar to gasoline that the two are easy to blend.

The remaining products of the TCR process are bio-char and syngas. Bio-char can be used as a solid fuel, with high calorific value, low hydrogen and oxygen content. Ash content depends on the feedstock. For example, char obtained from sewage sludge feedstocks have a final carbon content of approximately 20% and an ash content of approximately 76%.
The TCR char consist of highly porous carbon with Ca/Al that can function as an active catalyst for gasification of carbon, CO_2 capture and bio-oil upgrading (sustainable replacement to dolomites). Bio-char also has applications in other industries, such as agriculture, as the product can serve as a soil stabilizer and phosphate-potassium fertiliser. Additional potential applications need further examination.
The syngas produced by TCR is an engine-ready gas composed of hydrogen, carbon monoxide and carbon dioxide, methane, and a small number of longer-chain hydrocarbons. The composition of the syngas varies with the feedstock source, with sewage sludge and paper sludge yielding the highest ratios of hydrogen. The product is both tar- and dust-free, with a high hydrogen content, and free of aromatic compounds. As a result, after an efficient cleaning process, it can run directly in syngas motors.

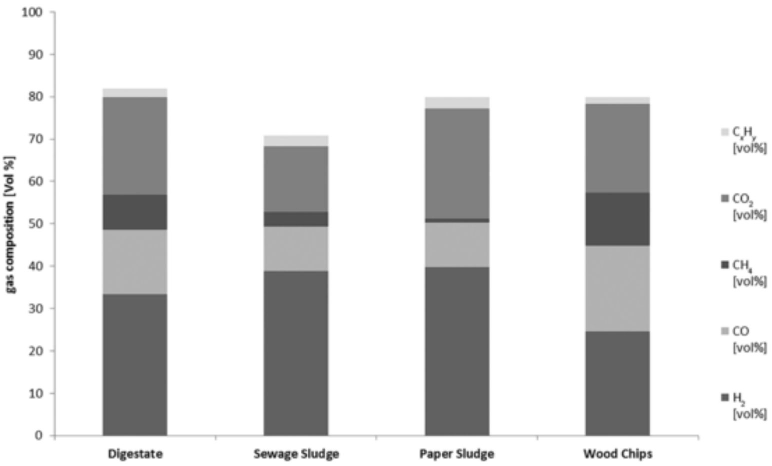

Figure 9. TCR syngas composition, based on different feedstocks

The TCR process has been tested with not only sewage sludge but a variety of other feedstocks including paper sludge, wood chips, olive pomace, straw, and digestate from animal manure and from energy crops. SuRo recently collaborated with Harper Adams University in Newport, UK, to test the use of waste seaweed as a feedstock. When mussels are harvested, seaweed is collected as a by-product. Seaweed grows along the submerged ropes, and during the collection process, large amounts get tangled in the ropes. The team at Harper Adams University have developed a silage process that converts the seaweed to a preserved pelletized form. When the converted seaweed is used as a feedstock in the TCR process, the oil and syngas quality is comparable to the products using other feedstocks. Currently, this feedstock is used only in a feasibility study, but its use can be expanded upon in the future, considering the availability of seaweed. Treatment with anaerobic digestion has also been attempted with similar results.

One of the potential fields for further study of the TCR process is in exploring alternative uses for bio-char products. One potential use is as a cheap source of activated carbon, as the char has a useful pore size distribution. If TCR proves to be a cost-effective source of activated carbon, one potential direction of future research is to explore ways of optimizing the process to get different grades of activated carbon. Activated carbon applications could include using it as a soil additive in planting.

Because of the porous structure, bio-char is excellent at retaining water. Currently, SuRo is experimenting with an in-house planting test using bio-char, and larger-scale tests may be promising.

Another potential application is as a replacement for barbeque charcoal. Using beer brewers' residuals (spent grains) as a feedstock in the TCR process produces a high-quality char, which can then be pressed into briquettes that burn slowly and for a long time. Yet another potential use is as a form of residential insulation. Although this potential use is very speculative, the structure and stability of the char could provide adequate insulation.

A variety of proposed blue sky research efforts are centred on the TCR process. For example, one concept is the use of hydrodeoxygenation (HDO) to treat the bio-oil products of TCR. Processing the bio-oil through HDO could theoretically remove the aromatic compounds and nitrogen, resulting in an oil that meets the standards of diesel and would therefore not require any blending. The HDO process is already at a higher technology readiness level (TRL). The demonstration project of the scale-up integrated TCR-HDO process is under construction at Rotterdam Harbour.

The current state-of-the-art production process of biofuels requires multiple stages of purification. Processing sewage sludge by standard pyrolysis requires the use of catalysts for reforming of tarry materials from syngas, and one of the problems with catalysts is that they coke and require regeneration, which increases the energy inputs to the process. A similar problem faces the bio-oil (from biomass pyrolysis) upgrading process. The alternative TCR process by integration of a hydrothermal process reduces the need for catalysts such as precious metals. Researchers are exploring the potential to simplify the process by using TCR, as it could break down biomass, which contains high amounts of DMF components. This research has the potential to have wider impacts, spinning off into a range of other projects from higher- to lower-TRL projects.

Sourcing precious metals for catalysts is another research topic. Because sources for precious metals are limited, efforts are underway to recycle precious metals from various waste streams such as textiles and waste electronics and electrical equipment. Currently, only a small number of metals are recycled, but in the future, rare earth metal recycling will be more important. Recycling of other waste streams such as scrap tyres and carbon fibre are further subjects that could be studied for development of future devices.

Currently, research is focused on the use of sewage sludge as a TCR feedstock with biofuels as the primary output. A project funded by the Engineering and Physical Sciences Research Council (EPSRC) is examining the production of dimethylfuran (DMF), a high-energy-density biofuel from biomass. Another project under the Horizon 2020 programme received about €14.5 million in funding and is a higher-TRL project.

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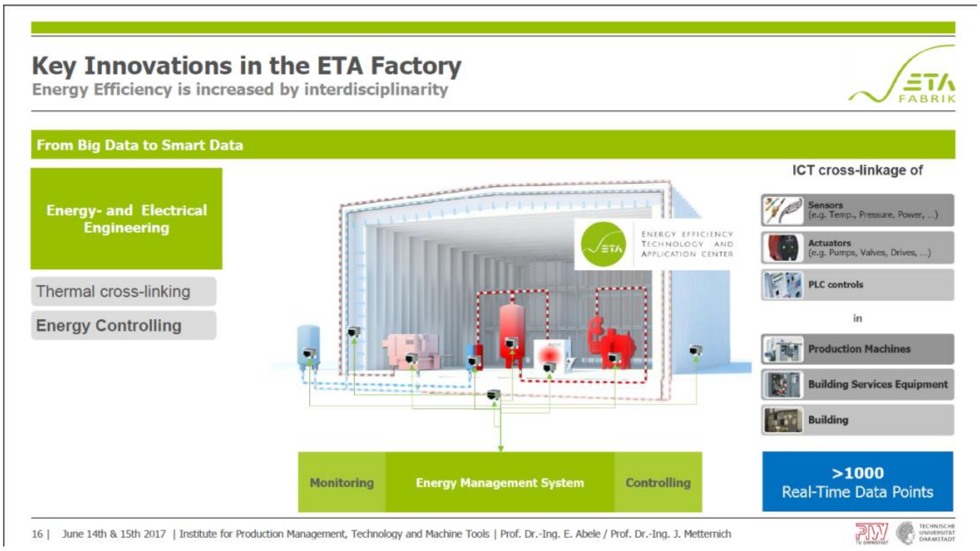
3.4 Welcome to the ETA Factory

Ann-Christin Frensch, Institute of Production Management, Technology and Machine Tools (Head of Institute: Prof. Dr.-Ing. Eberhard Abele), Technische Universität Darmstadt, Germany

- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/9.WelcometotheETAFactory.pdf

The ETA Factory is a research facility located at TU Darmstadt, known for its Faculty of Mechanical and Process Engineering. The Institute of Production Management, Technology and Machine Tools is the faculty's largest institute, with over 100 employees and 6 research groups focusing on the topics production technology and production organization. The Sustainable Production group is an interdisciplinary team that allows research in fields such as energy efficiency, production and resource efficiency, as well as energy flexibility in production.

A major project of the Sustainable Production group is the ETA-Project. The ETA Factory project has its roots in a previous research effort called MAXIEM. The MAXIEM researchers discovered that a large amount (26%) of the operating cost of a machine tool is electricity consumption. To reduce costs, the researchers optimised the machine for energy efficiency and reduced electricity consumption by 52%. The majority of innovations paid for themselves within two years.

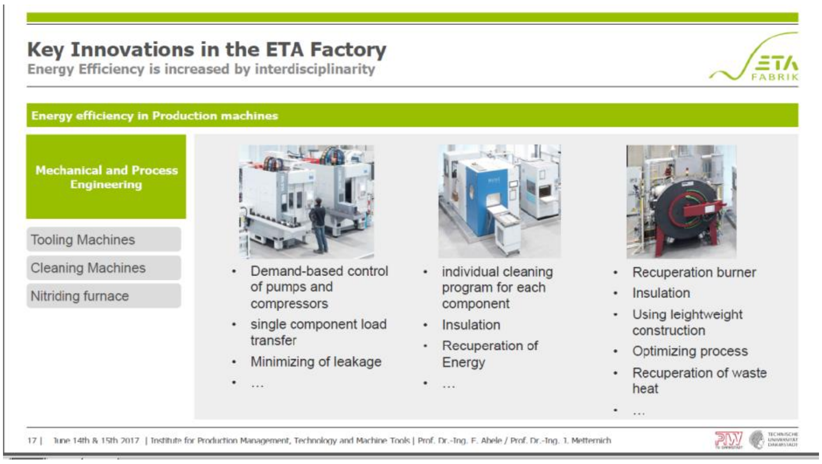


Drawing from this result, the ETA Factory was established as an effort to address energy efficiency in a production process in a comprehensive way, optimizing the factory's subsystems holistically instead of in isolation. The project was supported by the Germany's Federal Ministry for Economic Affairs and includes 36 partners from research and industry, and took an aggregate time of 911 research months to complete.

If subsystems within the production process are optimized for energy efficiency individually and in isolation, the resulting total efficiency gains are less than in a holistically optimized system. For example, if the energy consumption of the building can be reduced by 25%, the process chain consumption by 20%, and the energy consumption of the machines by 30%, the overall savings in the factory will be around 30%. In contrast, the ETA Factory can achieve reductions in energy consumption of up to 40% by optimizing all subsystems as a whole, taking advantage of synergies in system controls and energy recovery.

The ETA Factory is an innovative building that hosts a real, functional production chain that manufactures control discs for a hydraulic pump – a real part from the industry. The factory was built with the goal of replicating an existing partner's production chain and improving energy performance by 40%. The factory shows a number of processes, including lathing, drilling, cleaning, heat treating, and grinding.

The interdisciplinary team takes advantage of civil engineering, energy and electrical engineering, and mechanical and process engineering insights to reduce energy consumption. Building improvements include a modular structure that allows expansion when needed, the use of an innovative micro-reinforced concrete with high heat conduction, and embedded capillary tube mats throughout the walls that can be used to heat or cool the building and to dissipate the waste heat.



Innovative energy and electrical controls allow waste energy from one process to be reused in another process. For example, the machine tool uses electricity to drive motors, the cleaning machine uses electric heating, and separately, the building uses energy for space heating. In the interlinked factory, the waste heat from one process can be used with a heat pump and thermal storage to provide the heat for another part of the process. This is called thermal cross-linking. In the ETA Factory the heat produced by the machine tool is used for heating the bath of the cleaning machine and can also be used for heating the building. Through the use of a sorption chiller, waste heat can also be used for cooling.

While delivering higher energy savings, the thermally cross-linked factory is three times more complicated to control, as operation of one process affects all others. It requires many more sensors for monitoring and controlling the entire system. For this case, the ETA Factory uses an energy management system that collects over 1000 individual data points in real time.

Mechanical and Process Engineering also plays an important role in reducing energy consumption and allowing interlinkage of processes. In the machine tools, demand-based control of pumps and compressors allows single component load transfer and minimizes leaks. The cleaning machines feature additional insulation for each heat conducting component, have optimised cleaning programs, and allow recuperation of heating energy. In the highly insulated nitriding furnace, a recuperation burner also reduces energy use and allows the reuse of waste heat.

Without the energy efficiency innovations and thermal cross-linking, more than 20% of the machine tool's energy consumption is used for cooling, while 16% of the cleaning machine's energy consumption is used to electrically heat the cleaning bath. With thermal cross-linking, the tooling machine is cooled by the sorption chiller, which is powered by waste heat from the other processes.

To have a bigger and wider impact on the energy sector, the innovations and learnings of the ETA Factory are being shared primarily through workshops for skilled workers from industry. Additionally, the ETA Factory runs a teaching facility for university students and has had approximately 1000 visitors from other universities, industries, and policymakers in 2016.

Future research at the ETA will continue to focus on energy efficiency, broadening its scope to transferring ETA outcomes to industry. Another new field of study will be energy flexibility: designing factories and machines that can make use of multiple different energy sources. Flexible machines could react to changes in energy prices and switch sources to utilize the most economic energy options.

Websites:

- www.ptw.tu-darmstadt.de
- www.eta-fabrik.de

Session 4. Use-Inspired Basic Research and Innovative Processes

Chair: Alexander McLean, U.S. Department of Energy, United States of America

4.1 Overview

This session had five presentations outside the usual energy research. The overarching question of the session was what can be learned from basic research (BR) in other sector.
As such the presenters touched on the following questions of the rational.

- What are the linkages between basic research, applied science and disruptive innovation?
- How can such lessons be applied to guide or improve future public investments in energy-related basic science research?
- What are the means for transitioning Blue Sky Research (BSR) outcomes to innovative energy-related products?
- What are the most effective framework conditions for stimulating BSR schemes?
- At what point is industry involved in basic science programmes or their outcomes?
- What are the processes that lead to a disruptive innovation? What are the effects on socioeconomic issues (economy, lifestyles)? Are they seen as being positive or negative?

In summary this let to the following observations:

Several successful examples of use-inspired basic research exist. A recent example is the unprecedented growth witnessed in solar PV that was not foreseen even a decade ago. Crystalline silicon solar cells dominate the solar market, with recent advancements being made in thin-film and multi-junction cell technologies. The recent rapid growth of solar technologies is due to economics; the technology has experienced a great reduction in costs. Progress is being demonstrated for the use of solar technologies in space. By making the thin films flexible, the Centre for Solar Energy Research (CSER) has developed an innovative solution for the use of thin-film technology in space applications. These unique films can be ‘rolled up’, and as a result, not only is the product lighter but costs are reduced owing to a more efficient manufacturing process.

The ground-breaking proof-of-concept International Thermonuclear Experimental Reactor (ITER) project currently being built in Southern France will help make nuclear fusion technologies a reality. A truly innovative project, ITER has a collaborative process that provides several lessons learned. LEDs are another technology that has had a transformative impact on the electricity sector. LEDs are substantially more efficient than previously used incandescent lamps, have a longer lifespan, and enable off-grid lighting options. All of these benefits have contributed to its market success.

Tracing the pathways that led to the success of many of these technologies provides insight into the components that lead to impactful and transformative innovations. A clear commitment and devotion from researchers is a key ingredient. Akasaki, who won the Nobel Prize for Physics for inventing the blue-emitting diode along with other colleagues, attributes his success to recognizing early on in his career that the field of blue-emitting diodes would be his ‘life’s work’. Another key factor is to provide an enabling environment for researchers that fosters creative thinking and allows for continued research in spite of failures. Another determinant of genuine innovation is a simple management structure that encourages the researcher to focus on the research as opposed to an environment that is wrought with funding pressures, pressures the researcher to publish, or forces the researcher to navigate a complicated management.

Governments, and the support they provide for R&D initiatives, can play a critical role in driving innovation. When designing R&D initiatives, governments should implement design such that the key criteria for selection reflect the goals of the project and foster innovation. Criteria used by Japan's National Energy and Environment Strategy for Technological Innovation (NESTI) clearly implements this strategy. NESTI's selection criteria include innovativeness, long-term investment, and competitiveness, all factors that contribute towards the ultimate market deployment of technologies. Providing a clear focus for an initiative, such as bridging the valley of death, can provide a much-needed boost to some technological innovations. Implementing policies and regulations that provide an enabling framework can jumpstart the innovation. For example, South Korea and the European Union have demonstrated clear commitments for nuclear fusion technologies by establishing targets within their policies.

As innovations become cost-effective, investors help in value creation and market deployment. Building partnerships that bring the best minds together provides a cross-cutting perspective and generates solutions that otherwise might not have been possible. Creating an environment of enablers, drawing on expertise from academia, governments, and the private sector, can help in identifying challenges for deployment of breakthrough innovations from a whole-system perspective.

4.2 The Promise of Fusion

Ian Chapman, Chief Executive Officer, United Kingdom Atomic Energy Authority, United Kingdom

- Link to presentation slides:

There are several benefits to nuclear fusion power: it is clean and safe, does not emit any carbon emissions, and can potentially provide limitless energy. It is possible to get an entire lifetime's worth of energy from one bathtub of water and two lithium laptop batteries using nuclear fusion—as compared to about 1600 wheelbarrows of dirty coal. However, fusion technologies are not a reality yet, primarily because the isotopes of hydrogen must be fused together to release the energy at extremely high temperatures, equivalent to about 150 million °C.

Joint European Torus (JET), one of the world's largest nuclear fusion devices, set the world record for fusion power by generating 16 MW of energy in 1997. However, to generate that amount of energy, about 25 MW needed to be used. Operationally, this is a complex project. JET is the only project currently in operation in which deuterium can be fused with tritium to produce a neutron, which releases energy. Researchers are grappling with several challenges. These atoms have a very high flux and high fluency as they collide with the wall, changing the property of the material used to construct them, posing issues. Another challenge is releasing the incredible amounts of heat in the centres of these reactors. The system is designed such that the heat hits one surface of the vessel wall, and this undergoes extreme heat fluxes. Hydrogen for these purposes is 'bred' from lithium by surrounding the reactor in a blanket of molten lithium. Neutrons then pass through this molten lithium and convert it into tritium.

The next generation of fusion power is being studied at the International Thermonuclear Experimental Reactor (ITER), the world's largest experiment in fusion technologies. ITER is currently being built in southern France. The aim is to generate more energy from the fusion process than it takes to initiate it, something that has not been achieved as yet. One of the primary challenges that have to be overcome before this technology can become a reality is that the fuel must be made 10 times hotter than the inside of the sun.

The ITER has several members—China, the European Union, India, Japan, Korea, Russia, and the United States—who are collaborating closely to build and operate the ITER and bring fusion technologies to a point at which a demonstration fusion reactor can be designed. The ITER is unique, as countries are placing their best minds and technologies in a multilateral setting towards the achievement of one goal.

The ITER device is being designed to trap plasma in a huge magnetic ring and cause the hydrogen isotopes to fuse together to release energy. A toroidal donut-shaped magnetic cage called a tokamak is used to trap the plasma. This is a tried and tested method that has been used since the 1960s.

The ITER device uses 18 magnets, and the superconducting strands are produced in a collaborative manner in which six different partners in different locations and companies provide different manufacturing services. A company in Florida manufactures the cable-in-conduit superconductor and conducts the testing to create a jacketing bench and maintain alignment. Other countries contribute by manufacturing the remaining superconductor and providing treatment facilities.

There are three drivers that determine the economics of a future fusion power station: the cost, power output, and availability factor (percent of time that the reactor is available to produce power). It has been observed in the UK that the private sector has had to undertake enormous amounts of risk for nuclear projects, for example, the Hinkley Point C nuclear power plant. One third of the cost of the ITER reactor is in the magnets. As the scale of the plant increases, the capital cost decreases dramatically. ITER costs have been unpredictably high, an order of a magnitude more than the scale predicted. One reason is the regulatory changes for earthquake resistance that were implemented in the wake of Fukushima. Economics is the main driver that brings technologies to market, and the cost of a technology hints at the areas where one should innovate. In the case of nuclear fusion, innovation in magnets that drives down the cost will have a much bigger impact than any other component of the reactor. The availability factor of the plant is a critical driver of the cost of the electricity, and while electricity generated from nuclear fusion is still decades away, it is important to consider this factor.

JET is paving the way for the ambitious goals of ITER, and many of the experimental results and design studies performed by JET are consolidated to a large extent into the ITER design. JET has an extremely high temperature core, and it is essential to be able to dissipate the heat, as the heat being generated is almost equivalent to a space shuttle re-entering earth. The surface must be designed to ablate and exhaust the heat. Currently, this is being resolved by placing coils at the bottom of the fusion reactor to change the path of the extremely hot particles. By doing this, scientists believe that it could reduce the heat flux by a factor of 10 and, as a result, to temperatures that are experienced in an everyday car engine. Additionally, incredibly precise sub-millimetre engineering is required to ensure that all the coils and the vessels are aligned correctly. The heat flux surfaces created for the dissipation of heat is built from graphite, and the centre coil is compact, a different structure from the ITER. This method needs to be tested, and if it is successful, theoretically one could consider building fusion reactors smaller than the ITER. The structure of the coils, if successful operationally, could reduce costs by two to three times.

Several policies have been implemented that are supporting the development of nuclear fusion technologies and ITER in particular. The European Union has committed to a roadmap in which nuclear fusion is a reality by 2050. South Korea has an R&D target on nuclear fusion mentioned in the Constitution and a strong commitment to achieve nuclear fusion by 2037.

By retracing the innovation pathway that is leading to the advancements of nuclear fusion, one can learn several things about blue sky research. Half a century ago, countries worked on nuclear fusion technologies in isolation and secrecy. International collaboration has significantly improved the funding situation for blue sky research for nuclear fusion. The prohibitive capital costs, need for significant amounts of advanced hardware, and need to get the best minds to conduct the research have driven the international community to develop a collaborative project to ensure that the science of fusion technologies advances. By driving down costs and attempting a truly innovative project, ITER is breaking ground and showcasing the importance of collaborations and partnerships.

- Website: https://www.gov.uk/government/organisations/uk-atomic-energy-authority

4.3 Spin-Offs from Space

Stuart Irvine, Centre for Solar Energy Research, Swansea University, United Kingdom

- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/10.StuartIrvineSpinoffsfromSpaceEGRD.pdf

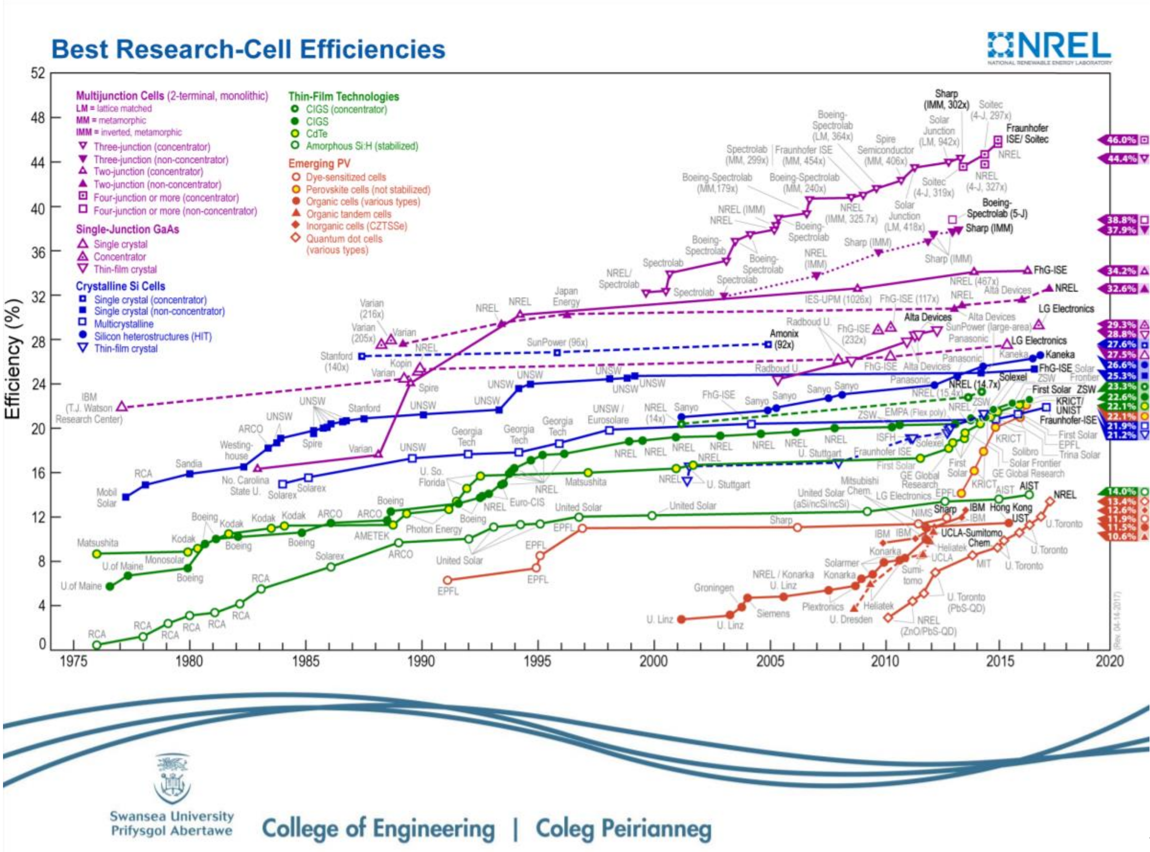
The Centre for Solar Energy Research (CSER) at Swansea University is exploring the potential of solar energy and solar energy materials.

IEA projections for renewable energy, specifically solar energy, from a decade ago never predicted its unprecedented growth seen in the last few years. In 2015, renewables accounted for more than half of new additions to power capacity and overtook coal in terms of world cumulative installed capacity. In 2016, another record was broken when solar PV annual additions surpassed those of wind and experience growth almost 50% higher than in 2015. China saw accelerated growth with annual grid-connected solar PV capacity in China more than doubled in 2016 versus 2015, with 34.5 GW becoming operational. This phenomenal uptake of solar technologies is driven primarily by economics.

The IEA 'two degrees scenario' projects that a significant amount of energy is expected to come from renewables if the global goal of limiting global temperature rise to 2°C by 2100 is to be met. The scenario anticipates approximately 3000 TWh of electricity generated from solar and over 6000 TWh from wind by 2040. Together, these would amount to about 37% of global energy. Japan and Germany are also leaders in solar PV technologies. The United Kingdom is ranked within the top ten leaders of solar energy in the world. This can be attributed partly to the introduction of a generous feed-in tariff by the Labour government that incentivized these technologies.

While the ultimate goal of using clean technologies such as solar PV to generate energy is to reduce carbon emissions, it is the economics of the technology that will ultimately determine its success in the market and the rate of deployment. In recent years, the prices of solar PV systems have continued to fall dramatically, with *PV Magazine* reporting that the total installed costs of utility-scale PV systems have fallen to only about $1/watt.

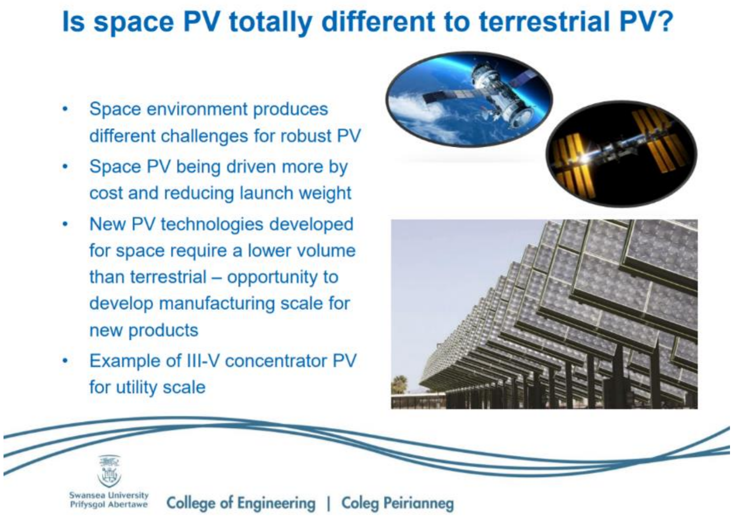
Several different types of solar cells are currently being developed, with varying levels of efficiency and cost, which determine solar's applications in the industry. Currently, crystalline silicon solar cell technologies comprise 90% of the market, and their annual output continues to grow at a rapid pace. These are primarily manufactured in China or by Chinese companies, and these have witnessed a general downward trend in costs. Thin-film technologies have been improving over the years, and since they are flexible and can be coated onto thin sheets of stainless steel, they are more adaptable and considered more attractive for many applications such as building integrated PV (BIPV). Multi-junction III-V technologies have been developed for space applications and have the highest efficiency. However, multi-junction cells also tend to be the most expensive. Other solar cells such as organic and dye-sensitised solar cells are also being manufactured for niche purposes and at small scales. Along with driving down costs, market uptake is also determined by improving efficiency. Thin-film solar cells made of copper indium gallium selenide (CIGS) and cadmium telluride (CdTe) have seen significant improvements in recent years and are starting to approach the efficiencies of silicon.



The efficiency of crystalline silicon laboratory cells has remained unchanged for a long time, but the manufacturing technology has improved. Multi-junction cells can break the Shockley–Quiesser limit, and as a result, these are more efficient. The most efficient multi-junction cell has been designed by Fraunhofer, using a concentrated light source. Solar cells used in space have lower efficiencies, as a higher proportion of infra-red light is also present; thus multi-junction technologies are attractive for these applications with capture further into the infrared. Dye-sensitised solar cells do not have the efficiency and durability that other solar cells offer. Crystalline silicon cells are durable: a PV module made from these cells has a lifespan of about 40 years and is typically sold with a guarantee of 25 years. On the other hand, dye-sensitised cells last for only about 10 years. However, there are some niche applications for which dye-sensitised cells are used. R&D teams from Heliatek, a German solar manufacturing company, recently achieved record conversion efficiency for an organic PV multi-junction cell, and they are in the process of scaling up its manufacturing. These cells are a plastic sheet roll, which can be laminated with building materials. Perovskite solar cells are being manufactured in the laboratory with greater efficiencies than before. However, their stability still remains uncertain; if this is resolved, then they can be manufactured at larger scales.

By studying how solar PV came into fruition, one can gather insight into the innovation process. The birth of solar dates to 1839, when French physicist Alexander Becquerel discovered the PV effect. In 1954, Bell Laboratories manufactured the first practical silicon solar cells. One of the first practical applications was the cells' use in space. Vanguard 1, the fourth artificial satellite orbiting Earth, was powered by a 1 W silicon PV array of 9600 cells. Only in the 1980s did terrestrial applications of solar power become more concrete.

For solar panels used for commercial building applications, the main design parameter is specific power: cells must have a high power-to-weight ratio. High specific power is important when one is trying to access roof spaces that are not designed to support a lot of weight, for example, retail park roofs that are designed to support wind and rain loads but not more than that.



Solar cells that are used in space face particular challenges. The harsh environment leads to several materials challenges. The cells are exposed to high-intensity ultraviolet, proton, and neutron radiation. Scientists are still unsure of the total dose of radiation these cells are exposed to when they go on space missions, as this occurs not in a steady state but in bursts. Additionally, the cells experience tremendous swings in temperature. To test these cells and ensure that they can withstand such a harsh environment, the cells are heated and then immersed in liquid nitrogen to thermally cycle them.

CSER is currently exploring ultra-thin glass technologies, which can be less than 200 microns thick, combined with thin-film solar panels. Ultra-thin glass is used on the screens of smart phones and other digital devices. For CSER's new solar cell technology to be used in space, CSER partnered with Qioptiq Space Technology, a company in North Wales that produces the ultra-thin glass for protecting solar cells in space. The Qioptiq glass is cerium-doped , which allows it to withstand the intense radiation environment, as ordinary glass darkens under radiation exposure. This is the standard protective cover on solar panels for satellites. CSER has developed a process whereby thin film solar cells are deposited onto this cover glass using the metal–organic chemical vapour deposition process. By depositing the thin films for the solar cell directly onto the cover glass, CSER has developed an innovative thin film that reduces the weight and the cost of these cells. These thin films are unique, as the cover glass can be 'rolled up' before and after the solar cell is applied to it, and this flexibility allows for cost reductions due to a roll-to-roll manufacturing process. This flexible solar cell technology for space opens up potentially new pathways for stowage and subsequent deployment.

CSER has acquired a payload on a nanosatellite, the AltSat Nano, which is being flight-tested. The power for this satellite is being produced through multi-junction III-V solar cells, with the experimental thin film cells mounted on an adjacent face of the satellite. AltSat Nano was launched from Southern India and is orbiting the earth on a low Earth orbit every 90 minutes. The four cells are functioning in space and achieving about 16% to 17% efficiency. This performance is better than the terrestrial tests. The voltage appears to be much higher than what has been measured on earth, and scientists are trying to get a better understanding of this phenomenon.

Based on the UK's Department of Energy and Climate Change (now closed) 2014 strategy document, the potential of this technology was significant, as it could be used on up to 250,000 hectares of south-facing commercial roofs in the UK. Several new solutions are needed that can integrate PV with building materials. The use of PV in space and its use on earth face different challenges, but the primary driver is to reduce costs for both applications. The opportunity is to convince an investor to scale up the production of a new high-risk technology. However, if cells for a niche application can be produced, then small-scale manufacturing is justified.

The innovation that led to reduced costs and the ability of these technologies to be used for terrestrial application can be attributed to the high efficiency that these technologies were able to deliver and thus penetrate the markets. For example, when laminating PV onto steel roofing sheets, the cost of the PV can be higher, as the cost of the building material is displaced. The UK solar strategy document provided incentives for building integrated PV that enabled researchers to test new and cutting-edge technologies. An opportunity exists for similar incentives to be implemented Europe-wide. Another challenge that can hinder the innovation process is that the qualification process for PV modules can be burdensome and requires several tests. Viewing PV integrated with its building, rather than as a separate element, will help in making this process less burdensome.

- Website: http://cser.org.uk/

4.4 Innovations in Japan and Negative CO_2 Emission Technology

Atsushi Kurosawa, Institute of Applied Energy, Japan

- Link to presentation slides: https://www.iea.org/media/workshops/2017/egrdjunebluesky/14.Kurosawafinaldistributionrev2.pdf

Several innovation research initiatives exist in Japan. Drawing on the Low Carbon Technology Plan in 2008 and New Low Carbon Technology Plan in 2013, Japan announced the National Energy and Environment Strategy for Technological Innovation towards 2050, called NESTI 2050, in 2016..

There are four criteria with defined target technologies within NESTI 2050. The criteria are innovativeness, significant greenhouse gas reduction, long-term investment, and competitiveness. There are nine technology research areas, two of which are system technologies and seven of which are elemental technologies. These include energy storage, energy saving, carbon capture utilization and storage, new renewable energies and others with energy road mapping. The R&D initiative encourages coordination among government ministries, stimulates private industry investment, and promotes international coordination and joint R&D.

Impulsing Paradigm Change through Disruptive Technologies Program (or ImPACT) is led by Japan's Council for Science, Technology and Innovation and promotes high-risk and high-impact research. The initiative was announced in Japan's fifth Science and Technology Basic Plan, which outlines initiatives aimed at achieving disruptive innovation. The initial ImPACT funding amounts to 55 billion Japanese yen (JPY). The initiative's research focus areas include materials, biology, information and communications technology (ICT), and other innovative research areas. The ImPACT initiative has designed a Green Information Technology Devices programme with the aim of using information technology devices for long periods of time without charging. This can be accomplished by using non-volatile memory and spintronics logic integrated circuits. ImPACT is also designing an ultra-big data platform for reducing social risk, a combination of ultra-big data that will be capable of ultra-high-speed analysis and ultra-wide-area data collection that exceeds today's data processing abilities.

In the Paris Agreement, countries agreed to limit global warming to 2°C by the end of this century and pursue efforts to limit the temperature increase even further to 1.5°C. To achieve this, negative carbon emissions technology will be needed in the long term. Negative emissions technologies remove CO_2 from the air indirectly (through biomass or ocean sequestration) or directly. However, costs and resource limits are uncertain in most options. Advances in CO_2 removal can potentially help achieve this.

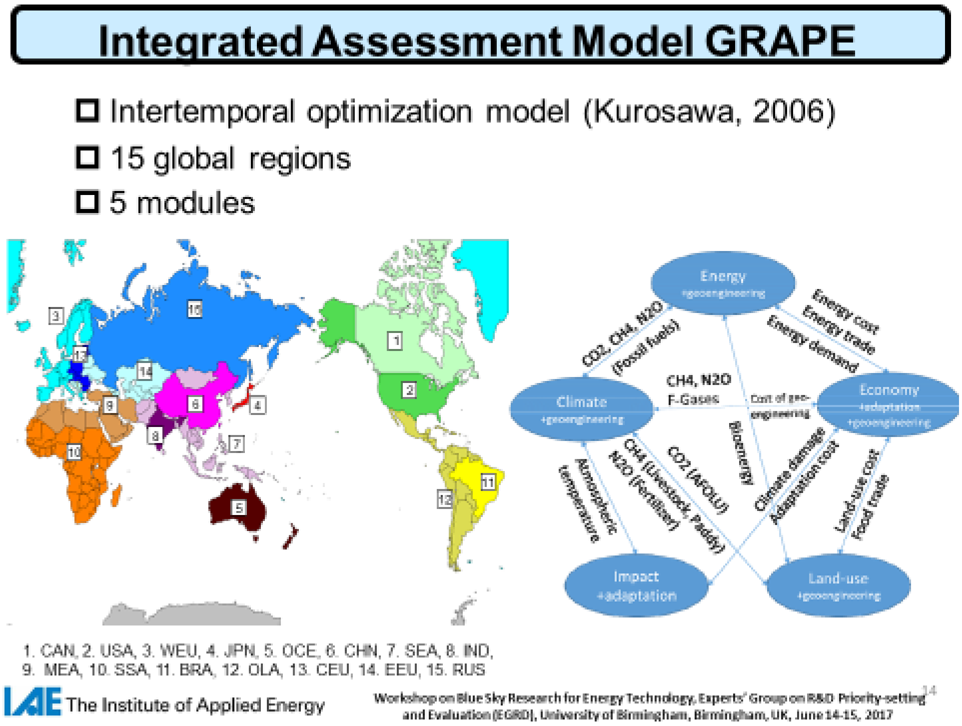


Figure 10. The GRAPE model used to analyze negative carbon emissions technology

To analyse the opportunity presented by negative carbon emission technologies, Institute of Applied Energy developed an intertemporal optimization global model, GRAPE, with 15 global regions. The model runs up to the 2100 time horizon. Currently, biomass energy and its role in long-term carbon scenarios are being evaluated, and initial results will be made public in 2018.

A bioethanol production facility with CCS is located in Decatur, Illinois, USA, and its CO_2 source is dehydrated wet CO_2 from an ethanol fermentation process. The captured CO_2 is stored in the Mount Simon Sandstone formation with scale of 1 Mt per year, and the project has cleared the U.S. Environmental Protection Agency's Underground Injection Control Class VI regulations.

The 'Biomass Industry City Saga' project in Japan includes a CO_2 capture utilization facility. The 10 tCO_2/day capture facility was launched in August 2016. The CO_2 source is a municipal solid waste power plant. CO_2 is transported through a 200-metre pipeline to a 2-hectare algae cultivation area for fertilization to produce cosmetics and supplements.

A biomass power generation plant with CO_2 capture located in Mikawa, Fukuoka, Japan, is a demonstration project of sustainable CCS technology. Originally a coal-fired plant, it has been retrofitted for biomass fuel. The facility is expected to have a capacity of more than 500 tCO_2/day and is scheduled to start operations by 2020. Direct air capture (DAC), another negative CO_2 emissions technology, is already being used in closed-space applications such as submarines and spaceships. However, as the ambient CO_2 concentration is very low, large amounts of energy are needed for CO_2 separation. Typical separation technologies are liquid sorbents and solid adsorbents. Analysis of the cost of DAC reveals that there is a broad range of estimates with a three order-of-magnitude difference. A DAC plant with CO_2 filtering became operational in 2017 in Switzerland. The plant is sponsored by the Swiss Federal Office of Energy. It is expected that the plant will have a capacity of 2,460 kg CO_2 capture per day.

Negative emissions technologies can potentially play a crucial role in limiting global temperatures, but these are not silver bullet solutions. Negative emissions technologies at scale could offset carbon feedstock use emissions in materials production. However, concerns about the feasibility of the technology exist, and these were evaluated by a paper written by Smith et al. Smith and his colleagues found that while the potential to remove CO_2 emissions is high, and land requirements are low, the use of water and energy is high, and costs can be high, making the potential of this technology limited.

Innovative research programmes play an important role as technology enablers. Systems integration using a combination of 'enablers' helps to create an environment that fosters new value creation and technology demonstration at scale. Public initiatives are imperative to stimulate private R&D. When this EGRD workshop took place, Japan was preparing to host an annual innovative competition, Innovative Cool Earth Forum, in Tokyo in October 2017. The forum will encourage participation from top researchers, business executives, and policymakers to address climate change issues, and a 'Top 10 innovation' event is being held that focuses on R&D opportunities.

Websites:

- IAE: http://www.iae.or.jp
- JFS: https://www.japanfs.org/en/news/archives/news_id035624.html
- Nesti 2050 summary: http://www8.cao.go.jp/cstp/nesti/gaiyo_e.pdf
- ImPact Programme: http://www.jst.go.jp/impact/en/index.html
- DAC technology: https://ssrn.com/abstract=2982422
- DAC Plant in operation: http://www.climeworks.com/
- ICEF: http://www.icef-forum.org/

4.5 The Quantum Technologies Hub

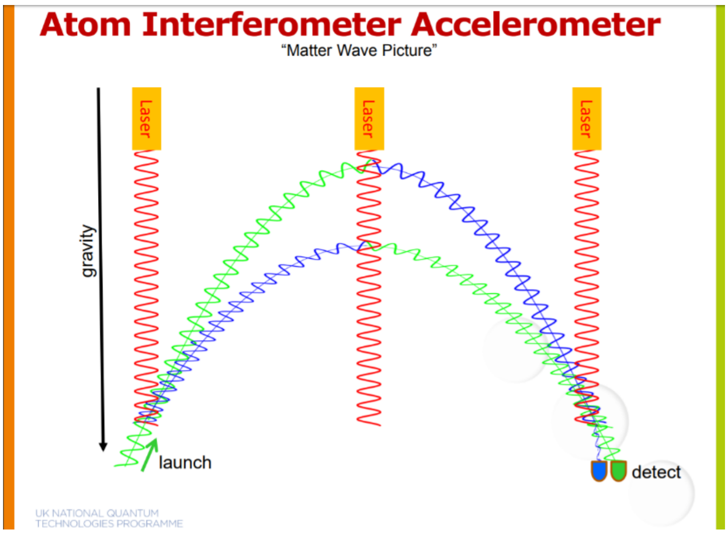
Kai Bongs, United Kingdom National Quantum Technology Hub in Sensors and Metrology, United Kingdom

- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/12.KaiBongs.pdf

The UK National Quantum Technologies Programme is a five-year, £270 million programme, announced by the UK government in 2013. The Programme supports investment, research, and skill development in quantum technologies to accelerate its commercialisation into the marketplace. The programme is currently at a critical juncture at which it can enable the translation of its innovation into market deployment and cross the well-known innovator's 'valley of death'.

The programme is enabling innovators to bridge this valley of death. The programme includes the Quantum Technology Hubs, a £120 million investment in four hubs that aims to explore the properties of quantum mechanics and how they can be harnessed for use in technology. The four hubs are Quantum Enhanced Imaging, Sensors and Metrology, Quantum Communications Technologies, and Networked Quantum Information Technologies.

Max Planck, the German physicist who discovered energy quanta, questioned how heat is transformed into light in an incandescent bulb. The spectrum of light could not be explained by the theories existent at that time, and he was unable to explain the existence of light in the infra-red or ultraviolet ranges. This series of questions led Planck finally to ascertain that light is not a continuous wave; instead, it occurs in quanta.



This discovery has become the bedrock of modern technology that is reliant on the understanding of quanta. Quantum theory was also able to explain how atoms are able to emit only certain frequencies of light. When a light wave strikes an atom, the wave represents the probability of finding the electron and the ability of the atom to move between different states. There are several devices—laser systems, conductors, etc.—that are fundamentally reliant on the effects of quantum mechanics. These are considered part of Quantum 1.0.

Researchers from the programme are now exploring Quantum 2.0. This subject includes studying devices that create, manipulate, recombine, etc. states of matter using the quantum effects of superposition and entanglement. The Sensors and Metrology hub is dedicated to improving the accuracy of measuring time, frequency, rotation, magnetic fields, and gravity. This includes devices such as clocks, gravity sensors, magnetic sensors, and others. Quantum theory enables the development of gravity sensors and other compact instruments that are resistant to noise, drift, and constant calibration. These instruments also provide superior signal detection sensitivity.

In 1997, Steven Chu, C. Cohen-Tannoudji, and William Phillips were awarded the Nobel Prize in Physics for the development of methods to cool and trap atoms with laser light. To bring the atoms close to rest and make them nearly stand still, a laser is used. The primary principle is that the photons have momentum that can be transferred to the atom. For a typical CD laser, one can get a velocity change of about 6 mm/second imparted to a Rb atom. If an atom is bombarded at the rate of ten million photons a second, one can get it to accelerate quite rapidly, 10.000 times faster than a Formula One car.

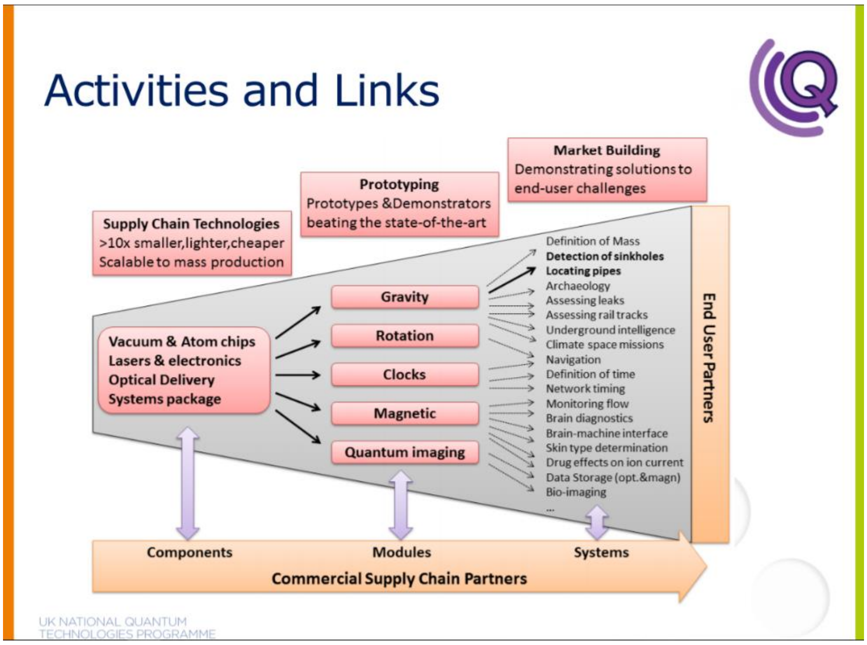
Advanced quantum sensors can take advantage of the behaviour of light at the atomic and subatomic levels. The Doppler Effect causes a velocity dependence and causes changes in frequency or wavelength of a wave as it moves towards or away from the observer. When it moves towards the observer it is at a higher frequency, but when it switches direction and goes away from the observer, it is at a lower frequency. If a laser with a frequency below the atomic resonance frequency is fired from both directions at an atom, a phenomenon called ‘optical molasses’ is witnessed, which is a friction force in a light field. This slows the atoms down, which is equivalent to cooling them. No cryogenics is involved in this process. The thus prepared atoms can act as precise probe particles. For this again a laser is used, this time interacting resonantly with the atom in short pulses, which can be tailored to put the atom into a superposition of different momentum states, let these separate, bring them back together and mix them to create an interference pattern, which is ultra-sensitive to the difference between the two paths the atom has taken simultaneously in this process. It the paths differ in their height, the interference pattern will e.g. be sensitive to gravity. It is possible to build incredibly complicated quantum sensors that work better than classical devices with components that are on the market. However, the principle challenge is in scaling down the technology.

A gravity imager currently being developed by the hub can potentially look underground or through walls by detecting changes in gravity. Such a device has potential applications for the military, the nuclear industry, archaeologists, and others. These sensors could result in new ways of navigating, ultimately replacing global positioning system (GPS) satellites that are vulnerable to enemies, and also be immune to jamming. Gravity imaging sensors available currently experience a delay in the amount of time taken to image, which is about 10 minutes per spot site, and the newer imagers are trying to resolve that issue, aiming at measurement times of seconds per point. The main focus of the Hub is to build partnerships with the private sector so that these technologies can be built and commercialized. Increasingly, an ecosystem of industrial partners is emerging in which the companies building the lasers work in tandem with the companies that are using the systems.

Studying quantum technology in energy and, as a result, gravity may prove useful in monitoring geophysical changes. This can be used to understand geophysical landscape changes and can be especially valuable for the CCS industry, as this knowledge may provide insight into whether these changes could lead to eventual release of CO_2. The quantum gravity sensor provides an absolute gravity measurement, so one can compare readings over years and monitor sequestration at various sites over a long period of time. In the longer term, the technology could potentially be used by the oil and gas industry for exploration purposes; a device could fit inside a borehole and make detections in a faster and cheaper manner than the systems used currently.

A quantum clock, a type of atomic clock, provides very precise timing. These clocks provide three additional orders of magnitude of precision up to the point where they are limited since they become sensitive to the earth's gravity potential.

For the synchronisation of energy networks, one might want to consider local clocks to be independent of GPS to ensure the whole network stays in sync. Resilience of GPS systems is getting a lot of traction in the UK, as they can be vulnerable to attacks and as energy networks should not be dependent on these systems.



For the programme and its associated hubs, these cutting-edge technologies are catching the eye of investors and the private sector, which are seeing value in the various applications for these inventions. The programme works closely with its business partners and is now in consultation with companies on areas that help bring these technologies to market, such as IP rights, exclusivity remits for certain applications, partnerships with other relevant companies, legal contracts, and others.

- Website: EPSRC: http://uknqt.epsrc.ac.uk/

4.6 Bringing Nanotechnology into LEDs

Jaime Gomez Rivas, Eindhoven University of Technology, and Dutch Institute for Fundamental Energy Research, the Netherlands

- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/13.Jaime_Gomez_Rivas.pdf

Electricity for lighting accounts for approximately 15% of global power consumption. The world has recently undergone a solid-state lighting revolution (use of LEDs, organic LEDs, and polymer LEDs for illumination purposes) in which LEDs are highly prevalent and used for multiple purposes, including automotive and building applications. LEDs have several benefits that have led to their success. LEDs are about 20 times more efficient than incandescent lamps, they enable electrical artificial lighting off the grid, and they have an average life 100 times longer than that of incandescent lights and 10 times longer than fluorescent lamps.

Recognizing the transformative potential that LEDs have, the Nobel Prize in Physics (2014) was awarded to Akasaki, Nakamura, and Amano for 'the invention of blue light-emitting diodes, which has enabled bright and energy-saving white light sources'. These LEDs use phosphor in order to convert the blue light into white light. The phosphor re-emits the light in different colours as well as transmitting some blue light, which results in the generation of white light. Two conditions need to be met for this to occur: the use of a semiconductor with the right energy band gap and an efficient radiative combination using a junction to produce the right wave length.

Investigating how the Nobel Prize winners discovered the blue light-emission diodes provides an insight into the factors that drive innovation. A clear commitment and dedication towards researching and developing blue light-emitting diodes can be traced as far back as 1973, when Akasaki declared that 'the realisation of blue light-emitting devices by Ga-N p-n junctions' would be his 'life's work'. Two major challenges existed: the quality of the material and p-doping.

Gallium phosphide (Ga-P) was traditionally being used to make LEDs, along with the use of dopants (impurities). These LEDs gave out green and red light. Gallium nitride (Ga-N) was needed to manufacture the LEDs that would give out blue light; however, growing Ga-N crystals in a laboratory environment proved to be extremely difficult. Akasaki and Amano, and Nakamura separately, were first successful in growing appropriate Ga-N crystals for the first time in the early 1990s. Nakamura specifically clarified the annealing process (hydrogen passivation of acceptors) that allowed for the production of LEDs. The efforts of the three researchers, separately but concurrently, led to the invention of the blue light-emitting diodes, and from the mid-1990s onward, these LEDs were being developed with increasing sophistication for various applications.

The University of Eindhoven is currently researching the use of nanotechnology in LEDs and how nano-antennas can generate light more efficiently. The research is focused on improving efficiency, reducing material, and increasing functionality (e.g., beaming) of the LEDs. Specifically, researchers are exploring how to better use resonant structures, which are a highly localised and thus highly non-directional sources of electromagnetic radiation.

In 1959, in a speech to the American Physical Society, Feynman said to imagine an array of coils and condensers over a large area with little antennas sticking out at the other end and suggested that light could be emitted in the same way as radio waves are broadcast. This is the principle upon which the University's research is based.

Researchers are developing the concept to use nanoparticles, acting like antennas, in the proximity of the luminescent material. An antenna is a device that converts the energy of free propagating radiation to localised energy and vice versa. Traditional antennas are designed to be radiant at radio frequencies; however, small nanoplasmonic antennas are designed to be resonant at optical frequencies. Researchers are aiming to develop an array of antennas to produce a higher-intensity and beamed emission from the same source of blue light. Nanoparticles excite localised resonances as a function of their geometry. In a periodic array, diffraction in the plane of the array gives rise to an enhanced radiative coupling of localised resonances. This enhanced coupling leads to the so-called surface lattice resonances, which create high local light fields that are weakly confined. The antennas provide an enhancement of 70 times in certain directions and for certain wavelengths as a result of surface lattice resonances. Researchers are focusing on better understanding three elements: quantum efficiency, directivity, and absorption. These antennas can be used as receivers as well as emitters.

To provide an enabling environment that fosters innovation, several factors are critical. Chief among them is the pure dedication and commitment of the researcher(s), combined with the ability to continue research in spite of failures. Akasaki and Nakamura have examined the qualities and circumstances that led to their success and attribute it to a work environment that was conducive to primarily conducting research (as opposed to being distracted by complications due to a top-down management structure with advisory committees and so forth). In today's typical research institution, researchers are under pressure to publish, get promotions, obtain funding, and deal with other concerns unrelated to pure research. These pressures may limit the researchers' ability to fully dedicate themselves to the research they do. Researchers are increasingly being expected to provide quick results that have short-term impact, which is contrary to what is needed for basic research.

- Website TU Eindhoven: https://www.tue.nl/en/

Session 5. Policy and Regulatory Frameworks

Chair: Rob Kool, EGRD Chair, RVO.nl, Netherlands

5.1 Overview

The session reviewed best practice in establishing BSR programmes, including calls for tender, organisation, management, reporting and evaluation.
There were four presentations in this session:

- Integrating disruptive innovation into energy foresight by Jonathan Radcliffe, University of Birmingham,
- Mission Innovation Materials Challenge by Nelson Mojarro Gonzalez, Energy Sustainability Fund for Europe, Mexico
- New concepts in energy research, a pilot call for innovative projects by Tone Ibenholt, Research Council of Norway and
- Energy research under future and emerging technologies by John Magan, Directorate General CONNECT, European Commission.

The presentations gave input to the questions in the rationale of the meeting, more specific to the following questions:

- *At what point is industry involved in basic science programs or their outcomes?*
- *What are the processes that lead to a disruptive innovation? What are the effects on socioeconomic issues (economy, lifestyles)? Are they seen as being positive or negative?*
- *What lessons can be drawn from the history of blue sky research and various government innovation models, in terms of best practices and disruptive, but productive innovation?*
- *Can disruptive innovations for the energy sector be anticipated? If so, how could these horizon scanning efforts be integrated into program planning?*

Radcliff showed there is a serious uptake in decarbonisation of the energy system of the UK the last couple of years. In 2020 35% decarbonized production is a realistic projection.
Challenges will become more acute in the UK in pathways to 2050 and will emerge at different times:

- Large proportion of intermittent generation by early 2020s
- Increase in demand for electricity for heating and transport in late 2020s

Many scenarios which have guided policy not able to treat power system balancing effectively, nor the dynamic evolution of technology deployment. This needs a clear policy, in which storage plays an important role.
This policy is formulated by the National Infrastructure Commission. Their central finding is that smart power – principally built around three innovations, interconnection, storage, and demand flexibility – could save consumers up to £8 billion a year by 2030, help the UK meet its 2050 carbon targets, and secure the UK's energy supply for generations."
"Crucially, storage technology will not need subsidies to be attractive to investors – businesses are already queuing up to invest. Regulation, on the other hand, does require attention. When electricity markets were designed these technologies did not exist."
So there is a need for (basic) research, but updating regulation, social acceptance and market development are key to reach the goals. One of the problems in the market development is the scattered landscape in which options that are not the cheapest yet, but have a high potential might not develop in a non-subsidized market. Funding storage projects has peaked in the UK in 2012, now only the *Engineering and Physical Sciences Research Council* (*EPSRC*) is a substantial funder.

Using evidence to inform decisions is a central tenet of the policy making process in the UK. But, in practice, many other factors shape the outcomes, f.e.

- political expediency;
- restricted time frames and budgets;
- perceptions, ideas and competency of the actors involved…

Contributing to the questions on the role of governments: Studies showed: evidence can reduce uncertainty in some aspects of the policy problem, but also create space for uncertainty in other aspects;
Decision-making takes place in networks (a set of public or private sector actors involved in the policy-making process) of actors due to fragmentation.
Still there are gaps in our understanding of that need more research:

- the actors from different sectors (public, private, research) involved in energy policy making operating at each scale;
- the ways in which they interact with each other;
- the nature and quality of such interactions;
- their impact on outcomes in relation to energy policies and strategies.

Of particular interest are the role, identity and resources of organisations which (can) act as intermediaries within the networks of energy policy making.
In the presentation these statements are supported by examples of storage technology.

Nelson Mojarro showed the political support of the development of clean energy technology in a couple of slides, referring to the Paris Agreement, Mission Innovation and the Clean Energy Ministerial.
He put the emphasis not on blue sky research, but more on the acceleration of innovations. In his slides, about financing, there is a huge gap between the pilot faze and successful market entry. This commercialization is the valley of death in his model. The mentioned Mission Innovation and CEM should bridge this gap, but they are too slow.
Ongoing activities to bridge this gap are:

- Information Sharing: Baseline and Annual Updates on Investments
- Innovation Analysis and Road-Mapping: Build and Improve Technology Innovation Roadmaps and Other Tools For Optimizing and Leveraging Investments
- Joint Research and Capacity Building: Public-Private and Country-to-Country Collaboration
- Private Sector Engagement: Collaborate on Data, Analysis, and Technology Expertise, Engagement of Business and Investors

On the moment IEA's Fatih Birol claimed on June 8th that there is 27$ Billion total Investment on clean energy R&D, where 80% is public sector.
In the slides you can find detailed information on mission innovation. A very small part of the work aims at Blue Sky Technology; implementation is the most important goal. Still there is some BST: The Clean Energy Materials Innovation Challenge aims to accelerate by 10x the innovation process for new, high-performance, low-cost clean energy materials.
As MI is a policy instrument, there actions are one answer to the question what governments and the private sector can do:

- Build an improved, shared understanding of the state of technologies for the automation of materials discovery, as well as identify the knowledge gaps, opportunities and the recommendations from the leading scientists around the world;
- Promote collaboration opportunities to researchers, innovators, and potential investors;

- Develop new collaboration projects between key partners (government-to-government, researcher-to-researcher, public-private, etc.) in order to integrating and automating the components of materials discovery; and
- Inspire the decision makers and leaders around the world and showcase the possibilities and benefits that can be generated from bringing together the top minds in science and industry and from working together on finding solutions to the biggest global materials challenges.

Tone Ibenholt emphasized that tackling challenges in the energy sector and the climate policy will require ground-breaking innovations. In Norway it is recognized that most research and development activities lead to continual, incremental improvement. There is a need for novel approaches and radically innovative technologies that may result in major leaps in improvement in energy efficiency, use and costs. Ibenholt talked about the experiences from a pilot call carried out by the Research Council of Norway (RCN), aiming at stimulating to more disruptive thinking in the research community. Compared to other calls, there were made changes in evaluation criteria and assessment procedure, together with a closer follow-up of the projects that were funded. The most important learning from the pilot call, however, was that by encouraging researchers to think outside the box, the RCN was able to stimulate more disruptive thinking in the research community and acceptance for more risk-taking.
John Magan presented the Energy research under Future and Emerging Technologies (FET) in Horizon 2020. This program provides insight in the questions in two ways. The first one is that FET has a broad scope, as such it offers insight in the possibilities to stimulate BSR based on policy programs. Secondly, as it is open to all applications, including energy related topics, it proves what kind of goals can be set by a governmental body like the EU.
This is shown by a number of examples, two of them are mentioned here: the LirichFCC explores a new class of material for electrochemical energy storage characterized by a very high concentration of lithium atoms organized in a cubic dense structure. There are clear policy goals:

- Technology: Revolutionary storage materials with energy densities of 7500 Wh/L
- Environment: Push forward existing technologies that rely on compact electric energy storage (electric vehicles).
- Economy: Development of new storage concept: disruptive effect on the battery market in Europe.

A-Leaf aims to create an artificial photosynthesis device that uses sunlight to convert water and carbon dioxide into fuels and other chemicals, mimicking the action of plant leaves. This project has impact on:

- Science – photovoltaic materials and surface chemistry
- Technology – photo-electro catalytic devices for solar energy capture
- Society – potential for a carbon-neutral fuel cycle using conventional hydrocarbon fuels.

Overall FET has an ambitious expected impact:

- foundation and consolidation of a radically new future technology
- Potential for future returns in terms of societal or economic innovation or market creation.
- Spreading excellence and building leading innovation capacity across Europe.
- Build-up of a goal-oriented interdisciplinary community.
- Emergence of an innovation ecosystem around a future technology in the theme addressed from outreach to and partnership with high potential actors in research and innovation, and from wider stakeholder/public engagement.

If we consider other presentations as well, and especially those of Rivas, Colechin and Chapman, then we may conclude governments play a more important part in BST then industry, and they might even be the decisive factor to create the right environment for BST.

On top of the already mentioned challenges to stimulate BST (overall decreasing funding, linking industry to BST and, more specific for energy: outdated regulations), they mention both stimulating and inhibitory factors:

- Politicians tend to aim for short term solutions “and glossy papers”, BST can’t often deliver in the requested timeframe. The development of LED was presented as example.
- In kind collaboration between countries sometime makes impossible projects possible. However, these collaborations are not per se the best managed projects, cost might be higher than with cost shared projects. Iter was given as an example.
- If well-organized up front, public-privet collaboration does work, as was demonstrated by ETI.

So disruptive innovations in the energy sector might be anticipated, certainly on system level, but there is at least as much attention necessary for non-technology barriers as for BST options.

5.2 Integrating Disruptive Innovation into Energy Foresight

Jonathan Radcliffe, University of Birmingham, United Kingdom

- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/14.JonathanRadcliffe.pdf

Energy storage provides an interesting case study to better understand and gain insight into systems innovation. The UK government established a target of reducing greenhouse gas emissions by 80% from 1990 levels by 2050. Additionally, the European Union has set a target that mandates that 20% of final energy consumption must be from renewable energy sources, which for the UK translates to around 30% electricity. To meet these targets, a massive transition is needed to shift from a system with despatchable electricity to one with a lot of variability. This poses challenges, as policies are needed to incentivise massive growth and counter the massive variability that is anticipated.

In the UK, taking a whole-energy-system approach rather than picking a single technology is helpful when considering the deployment of sustainable technologies. An important element to consider when using this approach is increased flexibility in the UK energy system through the 2020s. As the UK moves towards decarbonisation, several challenges will become more acute in pathways to 2050 and emerge at different times. This includes a large proportion of intermittent generation by the early 2020s and an increase in demand for electricity for heating and transport in the late 2020s.

Some of the scenarios that have guided policymaking in the past have assumed that a transfer to renewables for this longer timescale can occur without taking into account the ability to balance a power system effectively and the dynamic evolution of technology development. It is critical that renewables generation, and its impact, is understood in the whole energy system at every timescale level. Near-term storage options are likely to be over a timescale of seconds or minutes. However, high penetration levels of inflexible generation will mean the need for larger storage of energy over hours to days. Challenges are unique for every timescale. For example, at every second, renewables generation introduces harmonics and affects power quality. At the minute timescale, renewables generation requires rapid ramping up to respond to changing supply from wind generation. At the hour timescale, daily peak for electricity is greater to meet demand for heat. In the hours-to-days timescale, variability of wind generation needs back-up supply or demand response. In the month timescale, increased use of electricity for heat leads to a strong seasonal demand profile.

To address flexibility concerns, several options exist. The most well-known is energy storage. However, in a whole energy system, other options exist, such as demand response, interconnection, and new capacity. For example, in the UK, when considering longer-term timescales, energy storage options exist in coal stockpiles and gas. In the shorter term, the UK has pumped hydropower, and at a local level, storage and flexibility options exist in homes in hot water cylinders, addressing the demand side of the equation. Several storage technologies exist or are being developed with a range of applications (Figure 11) that could address mankind's future needs.

Applications and technologies

Application description	*Scale of storage*	*Technology options (red indicates future potl)*
Domestic scale energy storage for domestic peak shaving	2-5 kW 4-10 kWh 2-8 hours	• Li-ion/lead-acid batteries • Thermal ES
District scale energy storage for peak shaving, deferring distribution n/w reinforcement	50-500 kW 200 kWh – 2 MWh 2 – 8 hour	• Li-ion/Pb-acid/NaS batteries, H2, flow batteries • TES with heat network • Cryogenic ES (CES), Superconducting Magnet ES (SMES)
District scale energy storage for balancing microgrids and renewables integration	200 kW – 1 MW 1-10 MWh 6 – 12 hours	• NaS/Pb-acid batteries, Hydrogen, flow batteries • TES with heat network • CES, SMES
District scale seasonal energy storage	200 kW – 1 MW 100's MWh months	• Thermal energy storage - underground hot water/rock storage • PCMs, hydrogen
Large scale storage for renewables integration	10 – 200 MW 100 MWh–2 GWh 12 – 48 hours	• PHS, CAES, Hydrogen, flow batteries • Pumped Thermal ES (PTES), CES, A-CAES
Energy storage for spinning reserve	5-500 MW 10 MWh – 1GWh 24 hours – weeks	• PHS, CAES, flow batteries • PTES, CES
Centralised large scale grid storage for wind integration	1-10 GW several GWh days - weeks	• PHS • PTES, CES, H2

Figure 11. Energy storage technologies for different applications that exist or have future potential

The UK's National Infrastructure Commission was asked to consider how the UK could better balance energy supply and demand, aiming towards an electricity market in which prices are reflective of costs to the overall system. In its 2016 report, the Commission recognized the importance of smart power—principally built around three innovations, interconnection, storage, and demand flexibility, and highlighted that smart power could save consumers up to £8 billion a year by 2030, help the UK meet its 2050 carbon targets, and secure the UK's energy supply for generations. The report makes practical recommendations towards the creation of a level playing field and a better managed network.

Learning from failures is an important aspect of the innovation process as well. In 2003, the development of a 100 MWh flow battery, Regenysys, was cancelled. In spite of there being a push from the government to develop large-scale energy technologies and substantial effort put into the blue sky research for this technology, the lack of a market pull or push mechanism led to its demise. Without a real business case for energy storage in the markets, the technology was unable to get to large-scale deployment.

Several barriers exist for the large-scale deployment of energy storage technologies. These technologies tend to be more expensive and have lower performance compared to others in the market. The future value of energy technologies is dependent on the energy system mix, and the true value of the energy is not reflected in the price. More fundamentally, the future long-term value of storage is not recognized in today's market. Other challenges are the inability to capture multiple revenue streams, an inadequate policy and regulatory framework, and the low societal acceptance of these technologies.

Previous literature suggests that several elements need to be taken into consideration when looking at the innovation framework. Firstly, the analysis of innovation needs to go beyond considering the technology itself. Innovation systems tend to take time to form, especially for radical disruptive technologies. Both the structure and function of innovation systems are important. Finally, barriers exist, most significant being path dependency and lock-in.

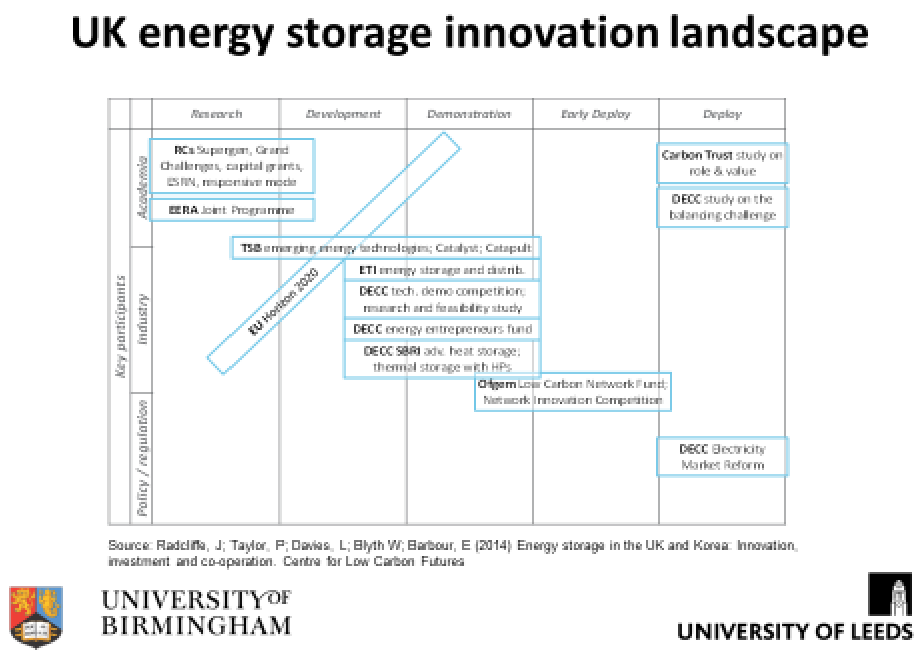


Figure 12. UK's Energy storage innovation landscape

The funding landscape for energy storage provides insight into the innovation framework (Figure 12). Funders range from research councils to government funding with many other players, leading to a fragmented landscape. For effective market deployment, the market should be ready such that the research and the resulting technological outcome are able to be commercialized effectively.

For wide-scale deployment of renewable technologies, energy storage is critical. However, the funding it receives does not match the importance of this technology. Thermal and large-scale energy storage receive a small percentage of the total funding for energy storage technologies, making the picture more complicated. The overall funding landscape, while increasing, remains low when compared to other technologies and does not necessarily line up in terms of importance and need for services. Adequate policy support is needed to provide the confidence for private sector engagement.

Evidence-based policymaking is a central tenet of the UK. However, in practice, several other factors come into play including political expediency, restricted timeframes and budgets, and others. Researchers are exploring the decision-making process in the energy policy framework in the UK. Previous studies found that evidence can reduce uncertainty in some aspects of the policy problem, but also create space for uncertainty in other aspects; and decision-making takes place in networks of actors because of fragmentation.

Researchers found that a small proportion of models are being used in the energy policy-making process, and 'usable' models need to be credible and legitimate sources of information, and they must hold political and scientific salience. Several gaps exist in our understanding of the actors from the public, private, and research sectors involved in energy policy-making operating at each scale;

the ways in which they interact and the quality and nature of these interactions; and their impact on outcomes in relation to energy policies and strategies. The role, identity, and resources of organisations that can act as intermediaries within the networks of energy policy-making is important to consider.

A better understanding of how energy policy-making could be supported can be achieved by identifying the relevant actor networks (structure, operation, and impact) with the aim of exploring how models can best support energy policy-making across scales and sectors, as well as improving the quality of evidence through models that better represent the energy system processes across scales in order to enhance their salience, credibility, and legitimacy.

Literature:

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- J Houghton, Royal Commission on Environmental Pollution (2000). *'22th Report Energy — The Changing Climate'*,
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- Radcliffe, J; Taylor, P; Davies, L; Blyth W; Barbour, E (2014) *Energy storage in the UK and Korea: Innovation, investment and co-operation.* Centre for Low Carbon Futures
- Winskel et al (2014) *"*Remaking the UK's energy technology innovation system: From the margins to the mainstream", Energy Policy

5.3 Mission Innovation Materials Challenge

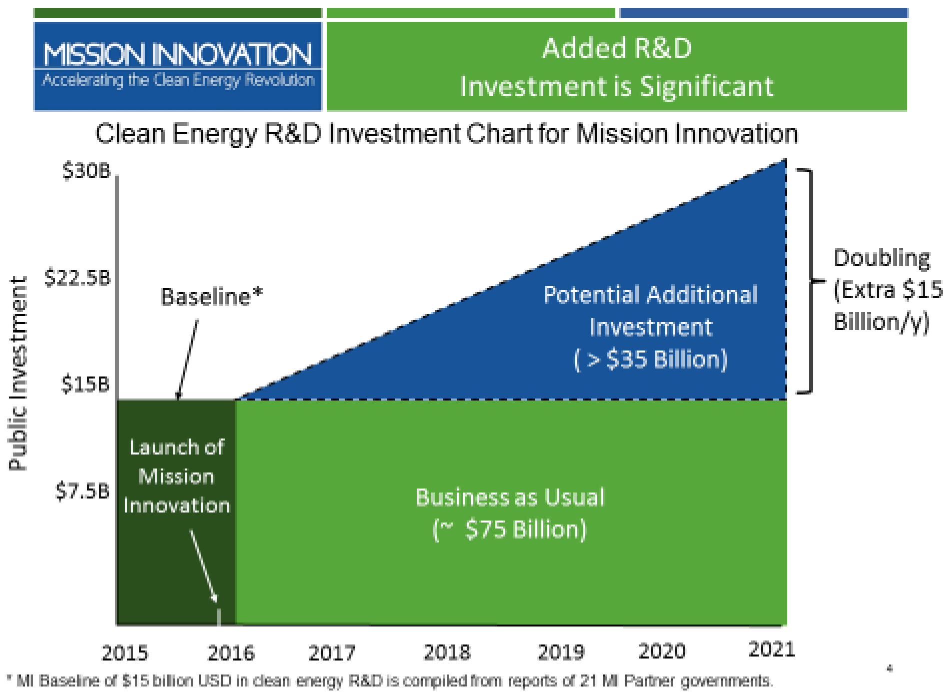
Nelson Mojarro Gonzalez, Energy Sustainability Fund for Europe, Mexico

- Link to presentation slides: https://www.iea.org/media/workshops/2017/egrdjunebluesky/17.NelsonGonzalez.pdf

In 2015, over 190 countries adopted the landmark Paris Agreement, the global climate deal that helps put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C. Alongside the negotiations at COP 21 that led to the Paris Agreement, leaders of 20 countries representing over 80% of global clean energy R&D investment signed a Joint Statement on innovation and launched Mission Innovation (MI). As part of this initiative, countries have committed to seek to double their governments' clean energy R&D investments over five years, while encouraging greater levels of private sector investment in transformative clean energy technologies. Since its launch in 2015, the Netherlands, Finland, and the European Union also joined the initiative. Alongside MI, a private sector initiative known as the Breakthrough Energy Coalition was launched, led by Bill Gates.

The goal of MI is to accelerate the pace of clean energy innovation to achieve performance breakthroughs and cost reductions to provide widely affordable and reliable clean energy solutions that will revolutionize energy systems throughout the world over the next two decades and beyond. There are several factors that led to the launch of MI. Most importantly, countries believed that time is running out to address climate change and the business-as-usual approach is not acceptable. Furthermore, the pace of technology innovation was determined to be too slow.

MI focuses on breakthrough R&D for the new technologies of tomorrow and complements the Clean Energy Ministerial, which focuses on scaling the deployment of technologies and solutions that are available today. Ongoing activities include information sharing, analysis and joint research, and business and investor engagement.



Current IEA estimates found that global investment in clean energy R&D amounts to about USD27 billion, an amount that has stagnated. About 80% of this funding is from the public sector. In 2016, MI members reported a baseline of USD15 billion per year in clean energy R&D investment. By

2020/21, MI members aim to double this investment to about USD30 billion per year (Figure).

MI is working together with private sector partners to drastically increase investment in early-stage R&D; attract private capital into a variety of potential solutions; and act quickly, given the long timeframes of energy transition. For example, MI has partnered with the Breakthrough Energy Coalition and World Economic Forum. The Breakthrough Energy Coalition comprises 27 investors and the University of California, with a collective net worth of over $300 billion. The Coalition is focused on creating an innovation pipeline to build and define mechanisms for co-ordination, building and expanding the coalition, making the case for early-stage investments by governments, defining mechanisms for coordination and information sharing with MI countries, and establishing a series of investment funds. MI's collaboration with the World Economic Forum will increase the initiative's collaboration with private sector partners.

Seven MI Innovation Challenges were launched at COP 22 in November 2016. These are global calls to action aimed at catalysing global research efforts in areas that could provide significant benefits in reducing greenhouse gas emissions, increasing energy security, and creating new opportunities for clean-energy-based economic growth. The Innovation Challenges cover the entire spectrum of RD&D; from early-stage research needs assessments to technology demonstration projects. Engagement in an Innovation Challenge is voluntary and is built around a coalition of interested MI members.

One of the Innovation Challenges, the Clean Energy Materials Innovation Challenge, is led by Mexico and co-led by the United States. Several other countries are participating: Canada, Denmark, the European Commission, France, Germany, India, the United Kingdom, and others.

The objective of this Challenge is to accelerate by 10 times the innovation process for new, high-performance, low-cost clean energy materials. The work conducted under this Challenge will be directed towards developing a fully integrated, end-to-end platform that will accelerate materials discovery. The focus is on R&D breakthrough technologies, with a long-term approach towards 2030 and beyond, that will lead to a single breakthrough as a platform. Using advanced theoretical and applied physical chemistry/materials science with next-generation computing, artificial intelligence (machine learning), and robotics tools, the expectation is that this Challenge will help create a comprehensive and fully integrated, end-to-end materials innovation platform. Experts and partners will work in a collaborative manner to automate and/or improve each step of the innovation chain of new materials, such as the discovery, synthesis, data and performance assessment, and process design and scale-up. Several benefits may be gained from this challenge. Specific application areas for new materials include, for example, advanced batteries, high-efficiency solar cells and fuel cells, low-energy semiconductors and solid-state lighting, thermal storage, coatings for various applications, and catalysts for the conversion and capture of CO_2. Many of the technologies for the implementation of this Innovation Challenge have been developed and are used in separate domains. Machine learning, for example, is heavily employed in the IT sector and has recently been applied to materials discovery, while advanced computational tools are common in the pharmaceutical industry and other sectors. The novelty and challenge of this initiative is the integration of the advances for separate parts of the materials innovation process into a single framework, or platform, to result in materials that can be successfully used in clean energy applications.

As of the EGRD workshop, the Challenge was preparing to host a four-day Energy Materials Innovation Expert Workshop in Mexico City on 11–14 September 2017, at which preeminent scientists and experts would identify critical R&D priorities and gaps in clean energy materials innovation processes and explore opportunities for deeper collaboration. A full report based on the findings of the workshop will be distributed to the 23 MI members and research institutions worldwide by the end of 2017. It will be used to inform policymakers and other stakeholders regarding research investments and for soliciting and supporting projects that take advantage of the R&D opportunities.

Literature:

- Report on COP-21, "Inside the Paris Climate Deal", *Science*, Warren Cornwall, Dec 2015: Vol. 350, Issue 6267, pp. 1451
- DOE (2015) "*Revolution…Now: The Future Arrives for Five Clean Energy Technologies* – Update"

Proposed websites:

- www.mission-innovation.ne
- www.breakthroughenergycoalition.com

5.4 New Concepts in Energy Research, A Pilot Call for Innovative Projects

Tone Ibenholt, Research Council of Norway, Norway

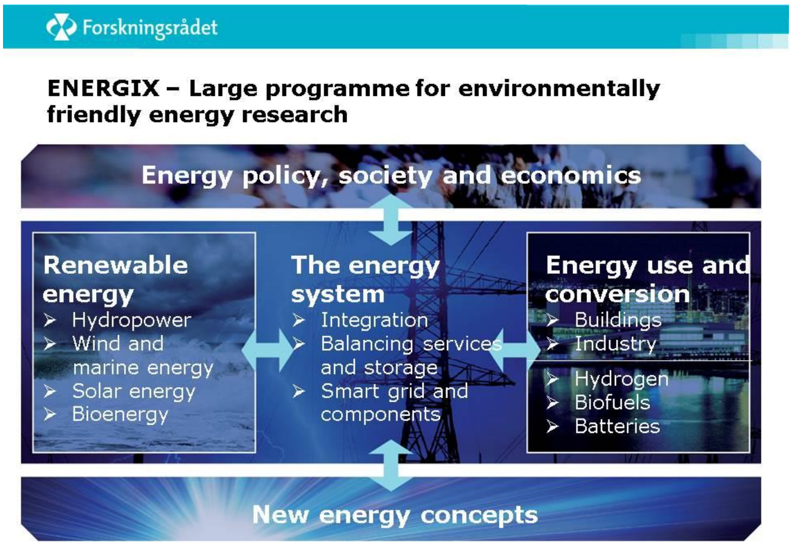
- Link to presentation slides: http://www.iea.org/media/workshops/2017/egrdjunebluesky/16.ToneIbenholt.pdf

The Research Council of Norway acts as an advisor to the Norwegian government. The Council aims to add value to the research system by facilitating research that actors in the system could not successfully achieve working on their own. The Council primarily funds basic research, implements national thematic priorities, and supports private R&D. Internationalisation is also an important element of the Council. It has four research divisions: Science, Energy, Resources and the Environment, Society and Health, and Innovation. Within the energy research programme, there are three targeted instruments: ENERGIX, CLIMIT, and the Centres for Environment-friendly Energy Research.

The ENERGIX programme is a broad programme covering a wide range of topics and one of the biggest programmes in the Research Council, with a budget of €45 million annually. CLIMIT is focused on CCS and has a budget of €11 million annually. The Centres for Environmental-friendly Energy Research have a budget of €20 million annually.

The Council determined that to understand what fosters radical innovation and disruptive thinking; the R&D instruments in funding agencies need to be examined to assess whether they are adequately targeted towards accelerating such innovation or whether changes are needed. An evaluation of the former energy programme in 2011 found that the programme was reasonably successful, but the programme was tending to 'reproduce itself' through funding incremental innovation. The Evaluation of the Research Council (2012) found that to promote disruptive change in basic research as well as in more applied areas, adequate mechanisms need to be established.

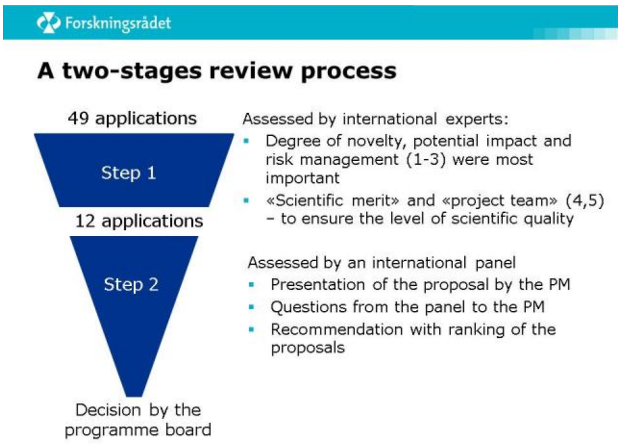
In response, 'stimulating new ideas and pathways of thinking' became a priority in the ENERGIX programme plan. The new programme does not look at specific energy research areas in isolation; instead, it undertakes a whole energy system perspective. New energy concepts were given a new boost in the programme plan. The new ENERGIX programme aimed to stimulate new ideas, concepts, innovations, and businesses by motivating researchers to be more creative in finding solutions and encouraging researchers to take more risk. The biggest challenge so far has been to change the behaviour of the research community and convince researchers that ENERGIX wanted them to change their usual ways of working and was encouraging creative thinking.



Changes were implemented across the entire programme area through a pilot call. New criteria were developed, and the previously existing standard criteria were used differently. Furthermore, a new template for project descriptions was developed, and a different two-stage selection process was established, with a finale for the best applications to be assessed by experts.

The new programme established seven new standard criteria for awarding funding: degree of novelty, potential impact, risk management, scientific merit, the project manager and the project group, socio-economic profitability and/or benefit to the environment, and relevance. The work plan of the projects must be divided into two phases with verifiable milestones in between.

The programme established a two-stage process for assessment of the applications. In the first stage, a review is conducted by international experts to ensure the quality of applications, including assessment against the following criteria: degree of novelty, potential impact, risk management, scientific merit, and the project manager and the project group. Following this, the applications are assessed by an international panel; the project manager makes a presentation and is interviewed by the panel. This process has been well received, and feedback received indicated the applicants believed that the new evaluation criteria should contribute to the goal of the announcement.



The aims of the first pilot call were to identify and fund a few creative research projects; attract good scientists from new research areas; stimulate new cooperation networks, nationally or internationally; allow higher-risk, higher-gain projects but with a close follow-up routine; and gain from this experience to learn from all of the levels. In the pilot call, four projects were funded, and these are in their final stages, with several noteworthy results. All the initial aims of the pilot call were filled, barring stimulating new cooperation networks. The projects funded were higher-risk and higher-gain than other projects in the ENERCIX-programme.

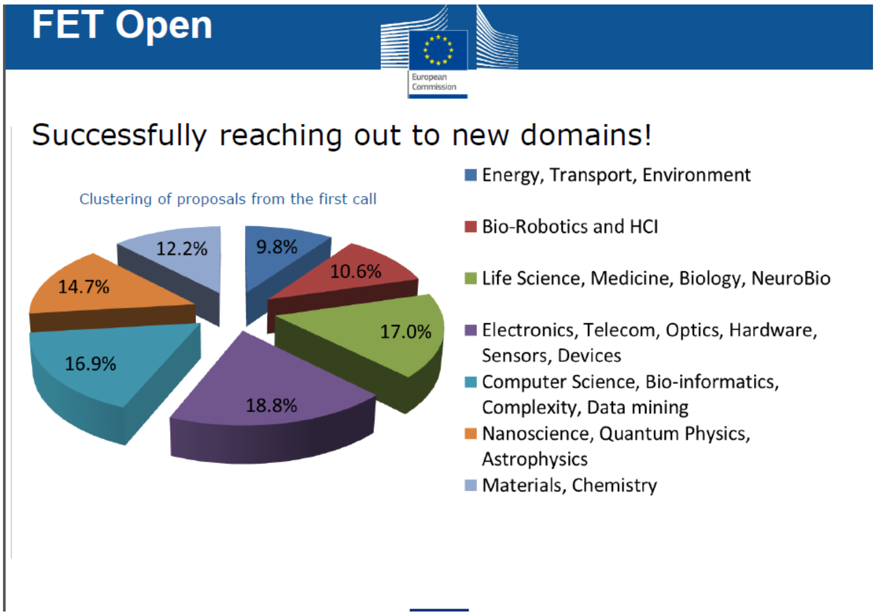
Through the development of this programme, several lessons have been learned. First, the criteria and the template for project descriptions were successful but can be further improved. Opportunities exist for cross-pollination of these ideas to other parts of the Research Council, not only for the energy programme areas. Most importantly, through this process, by encouraging and incentivizing researchers to think outside the box, the Council was able to stimulate more disruptive thinking and acceptance for more risk-taking.

5.5 Energy Research under Future and Emerging Technologies (FET)

John Magan, Directorate-General CONNECT, European Commission

- Link to presentation slides: https://www.iea.org/media/workshops/2017/egrdjunebluesky/20.EnergyresearchunderFutureandEmergingTechnologiesinH2020.pdf

Future and Emerging Technologies (FET) is built on the unique concept of bridging the gap between blue sky research and applications of innovative technologies. The FET mission is to turn Europe's excellent science base into a competitive advantage by uncovering radically new technological possibilities and to establish Europe as the best place for collaborative research and innovation in future and emerging technologies. This effort focuses on TRLs 1–3, similar to the European Research Council, with a view towards long-term industrial exploitation. FET is uniquely positioned within Horizon 2020, EU's framework programme on research and innovation, and complements what the European Research Council does. While the Council is more academic and single-researcher-focused, FET has a more collaborative approach, specifically with industry. The approach is visionary, aiming for scientific and technological breakthroughs, and research is interdisciplinary, with high-risk, high-gain outcomes. There is a broad research portfolio ranging from early-stage exploratory research, to thematic critical mass and community building, to addressing grand challenges.



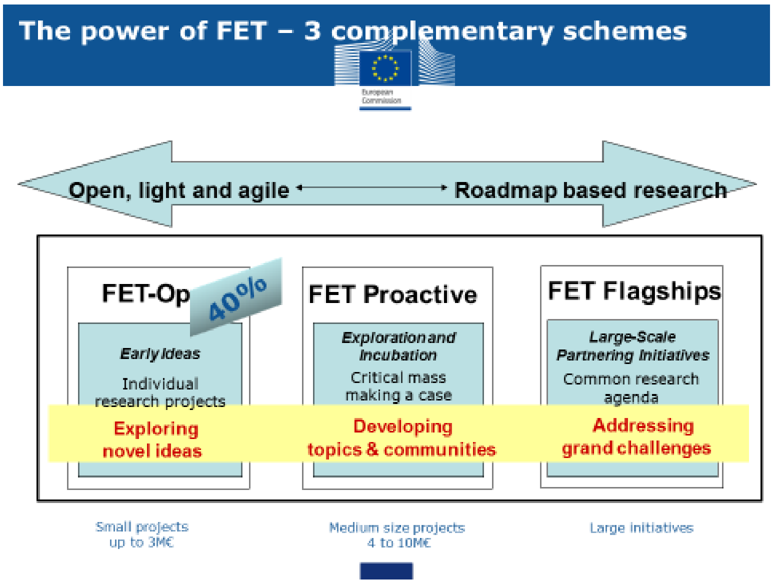


Figure: FET's three complementary schemes

FET has three complementary schemes: FET Open, FET Proactive, and FET Flagships (Figure:). FET Open tends to fund research that is smaller-scale, bottom-up, and open to novel ideas and technologies. No specific technology or type of research is given preference. FET Proactive groups the projects around more structured and thematic areas, and the FET

Flagships focus on the grand challenges. The FET programme original supported only ICT but now covers all advanced technologies, with many on life science research. However, about 10% of the proposals from the first FET open call in H2020 were from the energy, transport, and environment sector.

LiRichFCC is one of the interesting projects that is receiving funding from FET in the energy sector. The goal of the project is to explore a new class of material for electrochemical energy storage characterized by a very high concentration of lithium atoms organized in a cubic dense structure. To achieve this, researchers are exploring and optimizing Li-rich face-centred cubic (FCC) materials (structure and composition) as cathodes in electrical energy storage, understanding and optimizing the chemistry and processes at the interfaces, and studying the charge transport at the interface and in the bulk. The research is expected to have a meaningful impact on technology, environment, and the economy. From a technology perspective, the research is expected to develop revolutionary storage materials with energy densities of 7500 Watt-hours/liter. From an environment perspective, project results will boost existing technologies that rely on compact electric energy storage (electric vehicles). And by developing a new storage concept, the project can potentially have a disruptive effect on the battery market in Europe.

GOTSolar, another project funded by FET, has the goal of achieving disruptive approaches for the development of highly efficient, long-lasting, and environmentally safe perovskite solar cells (PSCs). GOTSolar aims at reaching the ambitious goal of 24% efficiency and stable PV cells by developing highly efficient and stable materials, hermetic encapsulation, and relevant know-how for future upscaling. Scope includes development and physical characterization of new pigments, synthesis of hole-transport materials with enhanced charge transport properties, novel structures of oxide scaffold materials, innovative laser-assisted sealing, development and optimization of graphene-based films to be used as transparent counter-electrodes, accelerated aging tests for stability assessment, and long-term vision for PSC technology to make it profitable. GOTSolar is expected to have a long-term impact on the built environment.

ALEAF is another innovative project with the goal of creating an artificial photosynthesis device that uses sunlight to convert water and carbon dioxide into fuels and other chemicals, mimicking the action of plant leaves. Researchers are conducting theoretical and experimental studies of CO_2–water reactions at surfaces to make fuels, ooptimizing results and transferring to photo-electrochemical cells, and scaling up results in a photoelectron-catalytic device. The project has potential to create photoelectron-catalytic devices for solar energy capture.

The AMADEUS project is investigating the next generation of materials and devices for latent heat thermal energy storage at ultra-high temperatures of up to 2000°C (well beyond today's maximum operation temperatures of ~1000°C). The final goal of this project is to demonstrate the proof of concept of this idea and to kick-start an emerging research community around this new technological option.

LIAR is a project that will have an impact on improving the environmental performance of living spaces. The project goal is to design and develop a programmable modular bioreactor wall capable of extracting valuable resources from wastewater and air and generating oxygen, proteins, and biomass for energy production.

FET Proactive has a new Call in 2018 and includes a topic on disruptive micro-energy and storage technologies seeking radically new approaches to energy for embedded, personal, or local use. It is anticipated that the impacts of this call will be to build a foundation for a radically new future technology, spread excellence and build leading innovation capacity across Europe, build up a goal-oriented interdisciplinary community, and create an innovation ecosystem around a future technology. There is tremendous potential for future returns in terms of societal or economic innovation or market creation.

Websites:

- www.ec.europa.eu/horizon2020/fet
- http://www.lirichfcc.eu/
- http://gotsolar.eu/general-info/
- http://www.a-leaf.eu/project/
- http://www.amadeus-project.eu/
- http://livingarchitecture-h2020.eu/

Session 6. Discussion and Conclusions

Chair: Johannes Tambornino, PtJ, Germany

Innovation is increasingly being recognized as the engine for economic growth, with growing acknowledgement of the value creation realized through transformative R&D. To spur the next generation of advanced technologies and establish a competitive edge, countries are emphasizing the importance of public sector R&D investments—both blue sky and applied research - to address 21st century challenges and provide significant benefits to society. Energy innovation is equally important for both developed and developing economies. In addition to driving economic growth, new energy technologies are essential for reducing emissions and upgrading legacy infrastructure in developed countries, and sustainably expanding electrification and energy availability in developing economies.

Blue sky and applied research are complementary elements of innovation. Innovation tends to be non-linear and iterative, with failures occurring at each stage of development, with possible spin-offs that are reintroduced to development, before leading to an outcome. While blue sky research generates ideas and discovery, applied research is necessary to integrate discoveries and create the products and technologies that are ready for market deployment. Such a complex innovation ecosystem must be supported by an enabling framework that fosters both types of research.

Gaining insight into blue sky research and innovation can help policymakers provide an environment that will increase the chances of achieving positive outcomes. Unlike applied research, blue sky research is funded almost exclusively by the public sector. To provide blue sky research with a supportive and enabling environment, governments need to examine not only the potential of the technology but also the innovation landscape. Policies and incentives are needed to ensure that the social value of innovation is consistently realized in all sectors.

Challenges

Communicating benefits of blue sky research to the public

Encouraging and enabling greater investment in blue sky research requires overcoming multiple challenges, most importantly the lack of funding. Because of its early, exploratory and pre-commercial nature, blue sky research receives funding primarily from the public sector. The benefits that blue sky research provides to society are often indirectly connected to the research itself, and therefore non-obvious and difficult to communicate. As a result, policymakers often lack the understanding of the value of blue sky research and the importance of public sector funding to continue supporting it. For example, it is not widely known that government funding for R&D led to the iPod, iPhone, and iPad. A research study by Mazzucato in 2013 found that publicly funded blue sky research was also the origin of GPS, touch screen, and voice-activated virtual assistance (e.g., 'Siri'), despite credit for these innovations often being attributed to the private-sector companies that commercialized the technologies. Early public-sector support for R&D helped make these products commercially reliable and affordable.

Recommendation: Researchers, institutions, and others reliant upon public financing must consistently communicate to policymakers the importance of providing resources in support of blue sky research. Concrete efforts must be made to better document and measure the value that blue sky research produces for society. Developing processes and methodologies to measure and document the value of blue sky research can help build the case for such research and enable greater public and private sector investment.

Reducing risk

Blue sky research is related to a competence rather than an outcome. It may deliver results that are useful, but not necessarily in the way that was initially expected. For example, the Haloclean technology was initially intended to address electronic waste, though researchers realized that it was more effective in converting biomass to biofuels.

Blue sky research requires longer timeframes and patience to yield benefits.

Decision makers may find it is easier to support funding that results in specific outcomes within a shorter, pre-established timeframe. Industries may prefer to support research that generates profits in the near- to short-term.

Structuring organizations and institutes so that discoveries are not abandoned simply because they are not directly applicable to a specific research goal can prove extremely valuable for BSR. Evidence of value added of BSR is needed. Most BSR is funded by public money and the quest for providing evidence of the societal benefit is perhaps even larger than for near-market research. Energy research is a low priority (only 4% of annual R&D budgets). Providing evidence of the impacts and societal benefits will enable policy-makers to understand the value added of BSR.

However, we need better measurements and examples of such value added. Also, the research-based teaching of future generations of engineers and professionals should be highlighted as an important output of basic and blue sky research.

Recommendation: To fully capture the benefits of BSR, policymakers and industry must have the flexibility to allow for unintended results which may have longer time horizons. This can be supported by better documentation and evidence of the value-added of BSR, including the education of the next generation of engineers and scientists.

Reducing institutional barriers to

Researchers are also subject to constraints which may reduce a researcher's capacity to conduct BSR such as expectations created by the funding agencies and the associated management, multiple hierarchical reporting, tight deadlines, and pressure to produce journal articles. The current research environment often rewards those who produce successful (often publishable) results, while undervaluing the equally important knowledge acquired through 'failures'. This deters dedicated researchers who may be focused on riskier topics that, if successful, could yield significant benefits. For example, Isamu Akasaki, one of three scientists who won the 2014 Nobel Prize in Physics for inventing the blue-emitting diode, attested to the importance of institutional support. He attributed his success primarily to his keen focus on blue-emitting diodes, a strong belief that he could succeed in spite of failures, and a management structure that supported his venture.

Several research entities are restructuring their selection processes to inspire creativity and out-of-the-box thinking. The Research Council of Norway evaluated existing processes for awarding funding for research and recommended establishing mechanisms that support basic and applied research. In response, the ENERGIX programme restructured its selection criteria for awarding grants to factor in creativity and risk taking, prioritizing 'stimulating new ideas and pathways of thinking'. The results of the programme showed that changing the behaviour of researchers was the biggest challenge as they may be accustomed to a system that rewards outputs rather than one that stimulates and encourages new thinking and acceptance of failures. Another example of an evolving model is Japan's NESTI, which has established clear goals while including innovativeness and long-term investment in the selection criteria.

As digitalization is increasing in a rapid pace, research on (big) data is primairaly done by the private sector as part of their day-to-day business. Faced with privacy rules and the reluctancy to enter this research field from a policy prespective limits the role it should play in basic research.

Recommendation: Research institutions should be flexible with structures that incentivize risk-taking and are able to manage the unintended results of BSR. Designing projects with selection criteria and evaluation processes that incentivize innovation accelerates this process. When designing R&D initiatives, the key criteria for selection should foster innovation. An enabling environment should be provided that has a simple management structure and is not wrought with funding concerns or the pressure to publish.

Increasing private sector funding

Engaging industry to provide funding and supplemental support for BSR can be challenging. The ultimate realization of its value is inherently indirect; only when discoveries generated by BSR are applied to targeted R&D and reach commercialization will industries achieve a return on investment. As a result, industry prefers to fund technologies that are closer to market-ready. Even for early-stage technologies that show clear promise for a targeted application, there is a lack of risk-taking by industry which results in the failure to reach markets (the so-called 'valley of death'). While BSR is necessary for innovations that drive private-sector actors, direct involvement in such early-stage efforts is high-risk.

Structural barriers increase the risk associated with private sector investment in BSR. Research collaborations in which the private sector makes in-kind or cash contributions are invaluable, as industry not only provides material support but also plays an advisory role. However, such collaborations can result in steering the research toward a particular pathway that benefits the industry sponsor. Determining how best to pursue unbiased research while securing industry support will be important going forward.

The private sector responds to the regulatory landscape, and crafting policies that incentivize the private sector to engage in the innovation process can have a significant impact. Similarly, policies that force the retirement of older and dirtier technologies, as seen in the case of incandescent light bulbs, can incentivize blue sky research that enables the creation of new technologies decades down the line.

Research organizations can also play a role in shepherding early technologies along the innovation pathway. Such entities can develop structures to help reduce the risk that is inherent in newer technologies and bridge the valley of death. Examples include Fraunhofer UMSICHT, which takes its innovative technologies to market by spinning off a start-up, and TU Darmstadt, which works closely with industry to address an emerging technology's issues with commercialization.

Recommendation: A clear understanding is needed of how the ownership and benefits associated with jointly funded research are to be shared between the private and public stakeholders. Policymakers must craft policies to support and incentivize private sector engagement in blue sky research. Research organizations can also contribute by developing supportive structures that help emerging technologies bridge the valley of death.

Increasing collaboration to foster innovation to accelerate results

There are few organizations which actively foster the elements that spur innovation: cross-fertilization of ideas, a whole-systems approach, or cross-sectoral partnerships. Collaborations enable knowledge sharing which can in turn maximize the benefits for all. These advantages were recognized in the development of ITER, where involves 35 governments join forces to build and operate the international fusion prototype (a large-scale scientific device. The U.S. Department of Energy and the National Science Foundation determined 'rules of engagement' which allows researchers reasonable flexibility to operate and interact with peers. This framework encourages both individual and collaborative activities.

Recommendation: Research institutions should structure their programs to encourage both individual and collaborative endeavors, striking the balance between providing structure while at the same time allowing for flexibility.

Reducing costs of laboratory facilities

BSR often requires world-class, modern laboratory facilities, which can be cost-prohibitive. Partnerships can enable not only cross-fertilization of ideas but also cost-effective facility sharing. The advantages of collaboration were acknowledged in the establishment of two multilateral, groundbreaking nuclear fusion devices, the Joint European Torus (JET) and ITER. Initially, countries worked in isolation, but the high costs of research facilities led countries to pursue these international collaborations – with success.

Recommendation: Collaborations among governments should be explored to leverage resources, sharing the cost burden of expensive cutting-edge research facilities and fostering knowledge exchange.

Appendices

Appendix A. Acronyms

BEC	Breakthrough Energy Coalition
CCS	Carbon Capture and Storage
Cd	Cadmium
CERT	Committee on Energy Research and Technology
CIA Triad	Confidentiality, Integrity, and Availability
CIGS	Copper Indium Gallium Selenide
CO_2	Carbon Dioxide
COP	Conference of the Parties
CSER	Centre for Solar Energy Research
DAC	Direct air capture
DMF	Dimethylfuran
DOE	U.S. Department of Energy
EGRD	Experts' Group on R&D Priority Setting
EPSRC	Engineering and Physical Sciences Research Council
ETI	Energy Technologies Institute
EU	European Union
FCC	Face-Centred Cubic
FET	Future and Emerging Technologies
FP7	European Union Seventh Framework Programme for Research and Technological Development
Ga	Gallium
GPS	Global Positioning System
GW	Gigawatt(s)
HDO	Hydrodeoxygenation
ICT	Information and Communications Technology
ICS	Industrial Control System
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers

ImPACT	Impulsing Paradigm Change through Disruptive Technologies Program
ITEMA	International Thermal Energy Manufacturing Accelerator
ITER	International Thermonuclear Experimental Reactor
JCESR	Joint Center for Energy Storage Research
JET	Joint European Torus
JPY	Japanese Yen
kg	Kilogram(s)
LED	Light-Emitting Diode
Li-ion	Lithium-Ion
Li-S	Lithium-Sulphur
MAXIEM	Maximierung der Energieeffizienz Spanender Werkzeugmaschinen
MI	Mission Innovation
mm	Millimetre(s)
MW	Megawatt(s)
MWh	Megawatt-hour(s)
NESTI	National Energy and Environment Strategy for Technological Innovation
NIS	Networking and Information Security
PLC	Programmable Logic Controller
PSC	Perovskite Solar Cell
PV	Photovoltaic
RAT	Remote Access Trojan
RITICS	Research Institute in Trustworthy Industrial Control Systems
R&D	Research and Development
RD&D	Research, Development, and Demonstration
S7	(Siemens SIMATIC) Step 7
SEI	Solid Electrolyte Interphase
SME	Small and Medium Enterprise
SPARKS	Smart Grid Protection Against Cyber Attacks
SuRo	Sulzbach–Rosenberg
TCP	Technology Collaboration Programme
TCR	Thermo-Catalytic Reforming

Te	Telerium
THAI	Toe-to-Heel Air Injection
TRL	Technology Readiness Level
TU	Technische Universität
TWh	Terawatt-hour(s)
UK	United Kingdom
UKSAP	United Kingdom Storage and Appraisal Project
US or U.S.	United States
USD	United States Dollar
V	Volt(s)

Appendix B. List of Participants

Name	Organization	Country
Ryan Bayliss	Oxford University	United Kingdom
Kai Bongs	UK Quantum Technology Hub, University of Birmingham	United Kingdom
Ian Chapman	United Kingdom Atomic Energy Authority	United Kingdom
Mike Colechin	Energy Technologies Institute	United Kingdom
Martin Freer	University of Birmingham	United Kingdom
Ann-Christin Frensch	TU Darmstadt	Germany
Nelson Mojarro Gonzalez	Energy Sustainability Fund for Europe	Mexico
Herbert Greisberger	eNu	Austria
Gavin Harper	Birmingham Energy Institute	United Kingdom
Tone Ibenholt	Research Council of Norway	Norway
Stuart Irvine	Centre for Solar Energy Research, Swansea University	United Kingdom
Birte Holst Jørgensen	Technical University of Denmark	Denmark
Rob Kool	EGRD Chair, RVO.nl	The Netherlands
Atsushi Kurosawa	Institute of Applied Energy	Japan
John Magan	Directorate-General CONNECT	European Commission
Alexander McLean	U.S. Department of Energy	United States of America
Miloud Ouadi	Fraunhofer UMSICHT	Germany
Carrie Pottinger	International Energy Agency	France
Jonathan Radcliffe	University of Birmingham	United Kingdom
Jaime Gomez Rivas	Technical University Eindhoven	Netherlands
Peter Slater	University of Birmingham	United Kingdom
Johannes Tambornino	Projektträger Jülich	Germany
Richard Thomas	University of Birmingham	United Kingdom
Joe Wood	Birmingham Energy Institute	United Kingdom

Appendix C. Agenda

DAY 1 – Wednesday, 14 June 2016

Session 1: Introduction

The Session provides background and context for the workshop. It reminds participants of the purpose, interactive nature of presentations, dialogue and social interactions, and the expected outcomes, and post-meeting activities and communications.

Chair: Gavin Harper			
08:30	Registration		
9.00	Welcome		Prof. Martin Freer, University of Birmingham
9:15	Introduction		Rob Kool, Chair, EGRD
9:30	1	Blue Sky Research	Ryan Bayliss, Oxford University
10:00	2	Disruptive Innovation	Carrie Pottinger, IEA
10:30	Coffee break		

Session 2: From Blue sky research to new emerging technologies – and beyond

This session reviews the contribution of BSR on long-term sustaining technologies and/or shorter term disruptive technologies and the prospects for breakthrough innovation.

Chair: Birte Holst-Jorgensen			
11:00	3	Sustainability in turbulent times	Mike Colechin, Energy Technologies Institute
11:30	4	Battery technology and basic science	Prof. Peter Slater
12:00	Lunch		
13:30	5	UK cyber programme	Richard Thomas, Cyber Security, University of Birmingham
14:00	Discussion		

Session 3: Converging and enabling technologies for energy

This session reviews the elements and mechanisms of BSR and disruptive innovation and how they may play a role in future energy paradigms.

Chair: Herbert Greisberger			
14:30	6	Reducing critical materials through chemical catalysis	Prof. Joe Wood, Birmingham Centre for Strategic Elements and Critical Materials
15:30	7	Foresight applied to energy	Miloud Ouadi, Fraunhofer UMSICHT
16:00	Coffee break		
16:30	8	Welcome to the ETA-Factory	Ann-Christin Frensch, TU Darmstadt
17:30	Discussion		
18:00	Close day 1		

DAY 2 - Thursday, 15 June 2017

Session 4 : Use-inspired basic research and innovative processes

This session focuses on innovative processes and successful examples of use-inspired basic research, its constituting technological components and the prospects for breakthrough innovation.

Chair: Alexander Mclean			
9:00	9	The promise of fusion	Prof. Ian Chapman, CEO, United Kingdom Atomic Energy Authority
9:30	10	Spin-offs from space	Prof. Stuart Irvine, Centre for Solar Energy Research, Swansea University
10:00	11	Innovations in Japan and negative CO_2 emission technology	Atsushi Kurosawa, Institute of Applied Energy
10:30	Coffee break		
11:00	12	The quantum technologies hub	Prof. Kai Bongs, UK Quantum Technology Hub
11:30	13	Bringing nanotechnology into LEDs	Jaime Gomez Rivas, Technical University Eindhoven
12:00	Discussion		
12:30	Lunch		

Session 5: Policy and regulatory frameworks

The session will review best practice in establishing BSR programmes, including calls for tender, organisation, management, reporting and evaluation.

Chair: Rob Kool			
13:30	14	Integrating disruptive innovation into energy foresight	Jonathan Radcliffe, University of Birmingham
14:00	15	Mission Innovation Materials Challenge	Nelson Mojarro Gonzalez, Energy Sustainability Fund for Europe, UK
14:30	16	New concepts in energy research, a pilot call for innovative projects	Tone Ibenholt, Research Council of Norway
15:00	17	Energy research under future and emerging technologies (FET)	John Magan, Directorate-General CONNECT, European Commission
15:30	Coffee Break		

Session 6: Synthesis and takeaways

The session will summarize the workshop, including conclusions and possible recommendations to policymakers and members of the IEA Committee on Energy Research and Technology (CERT).

Chair: Johannes Tambornino	
16:00	Panel discussion *Moderators: Birte Holst-Jorgensen, Herbert Greisberger, Alexander McLean, Rob Kool*
16:30	Workshop conclusions
17:00	Meeting close