ENERGY ISLANDS
Developing Renewable Energy Hubs
EXECUTIVE SUMMARY REPORT

Webinars on 29 September 2020, organised under the auspices of the
IEA Experts' Group on R&D Priority-setting and Evaluation (EGRD).
Hosted by the Danish Ministry of Climate, Energy and Utilities

On 29 September 2020, EGRD organised two sequential webinars on renewable energy islands or hubs in cooperation with the Danish Ministry of Climate, Energy and Utilities. With ambitious national targets to achieve a combination of renewable energy and cuts in CO_2 emissions, countries face the challenge of how to effectively deploy and integrate large-scale renewable energy in the energy system that go beyond traditional flexibility measures and cross-border transmission lines. Ambitious infrastructure projects are under development in the North Sea, coupling offshore wind energy to gas-storage facilities and power-to-gas grids, and combining offshore power connections, interconnected energy markets and smart integration in the onshore energy grid. Some of these projects are envisaged to be inshore, others further offshore, while others involve building an artificial island, thus combining inshore and offshore aspects. The concept also covers the development and smart integration of power-to-gas technologies in the system, something that is being developed in onshore renewable hubs around the world.

The webinars therefore addressed four overall questions:

1. What are the rationales, concepts and lessons learned so far regarding different energy islands?

2. What are the technological, regulatory, environmental and economic challenges of the island or /hub, and what unknowns remain to be addressed?
3. What are the knowledge gaps and gains in power-to-gas technologies and their integration into the system?
4. How can RD&D policies accelerate the further development of these concepts, systems and technologies?

All presentations are available here

The first webinar focused on energy islands. **Ms. Janni Torp Kjærgaard**, of the Danish Energy Agency, presented Denmark's climate plan to build two energy islands with a capacity of 5GW by 2030 - one in the North Sea and one by the Municipality of Bornholm in the Baltic Sea. They constitute a paradigm shift from radial connections linking offshore wind farms and the nearest onshore landing points to an interconnected energy island that couples wind farms and multilateral interconnections. After 2030, the plan also envisages converting surplus power into hydrogen and climate-neutral fuels (power-to-x) at different nodes, both offshore and inshore. Key challenges include offshore physical planning, which is subject to multiple interests, such as shipping routes, environmental and nature protection, and existing oil and gas infrastructure. The technological challenges are first and foremost related to the integration of large-scale renewables in the grid(-s), but also include assessments of different island concepts such as sand islands, caisson island or steel platforms. The regulatory challenges are related to the cross-border nature of islands, whether subject to separate price zones or merged into existing ones. The issues of financing and ownership are also being investigated. The lessons learned so far are that energy islands rely on a multi-disciplinary, collaborative approach with close cooperation between the regulators and TSOs of the countries involved.

Mr. Ernst van Zuijlen, of Offshore Service Facilities, described the IJVER energy island, the goal of which is to build an artificial pilot island at the Ijmuiden Ver area, which is designated for wind farms. It will be multifunctional, combining electrical infrastructure (HVDC-statin and interconnection), hydrogen production facility feeding into the existing gas grid, operation and maintenance for e.g. neighbouring windfarms, as well as other facilities such as aquaculture, fisheries and marine research. The business case is based on the project's energy functions, including the offshore grid hub, hydrogen production and O&M, and it relies on the engagement of all stakeholders. Different island concepts are considered, taking into account the metocean conditions. These include rock revetments protecting sand fill, caisson protection, and an artificial reef protecting a water area and sand fill for the actual island. Another innovative concept is the Hybrid Enersea Hub, which explores floating elements with breakwaters. Some basic studies have been made of the electrical infrastructure, which can be designed with a conventional DC connection grid with different variations. The hydrogen production is designed with water purification, alkaline electrolysis, compression and storage in mind. Being a pilot island is by definition associated with further development, including the optimisation of individual components and the overall system. Further R&D is related to the ecological synergies between the island and nature, tidal properties and morphology, legal issues related to international law, ownership and the regulatory framework.

Perspectives on offshore wind and its integration into energy systems were presented by **Mr. Halvor Hoen Hersleth**, of Equinor. With more than 60GW worth of offshore wind auctions expected in the coming years, the North Sea and the Baltic Sea constitute a strong growth platform in Europe. The North

Sea power hub benefits from abundant wind resources and the ability to link supply and demand in an integrated, cross-border system. This requires a long-term cooperation agreement between the regulators involved and TSOs. Offshore wind energy may also be integrated with existing infrastructure. The Hywind Tampen, a floating offshore wind farm, is currently under construction. It consists of 11 wind turbines with a capacity of 88MW and is expected to deliver power to two oil and gas fields in the North Sea and thereby avoid 200,000 tonnes a year in CO_2 emissions. Also, the Northern Lights CCS value chain may be included to provide future options for deep carbonization. The further development of the North Sea energy hub will rely on the ability to maximize the revenue of the offshore wind portfolio. This means that it has to be competitive in the market while also being able to bring the storage and hydrogen business case to maturity for its offshore wind portfolio and to influence and leverage future (hybrid) interconnections. The overall rationale is for Equinor to be a holistic 'broad energy company' combining offshore wind, oil and gas assets and CCS. Hybrid projects for connected countries are key, but they face regulatory challenges such as market design, grid investments, and operation and ownership (who pays and gains, and how to split?).

In sum, there are many unresolved issues concerning the planning, construction and operation of energy islands. It is a highly complex infrastructure that needs to withstand natural forces and also potentially attacks from the point of view of ensuring resilience. As for the artificial island concept, the North Sea is an excellent testbed due to its wind resources, shallow waters and the commitment of key players, as well as being somewhere where important experiences can be harvested, thus becoming a model for other regions and countries.

Key messages were issued to accelerate the introduction of such energy islands:

- **Island design.** Different design models can be developed, but the questions remains whether the design should be decided by the regulator or be open to developers to decide?
- **Ownership.** Infrastructure is considered a sensitive topic, but several organizational and legal models may be proposed (state-owned limited company, public-private limited company, joint undertaking etc.).
- **Regulatory framework in a cross-border setting.** The environmental assessment[1] and market design for the multilateral interconnections have to be explored, negotiated and decided at intergovernmental level.
- **Alignment with public RD&D programmes** is required, as the combination of PtX, hydrogen infrastructure and electricity infrastructure at these scales has not been properly tested before and therefore needs to be further researched and tested.

The second webinar provided a deep dive into key technologies that will be central to renewable energy hubs in general, going beyond energy islands, namely power-to-gas, power-to-X and system integration. **Mr. Eiji Ohira**, of the Fuel Cell and Hydrogen Technology Group, NEDO, Japan, described the Japanese Hydrogen strategy, launched in 2017 and including a vision towards 2050 and an action plan for 2030. Based on this strategy, Japan has ambitiously and continuously pursued a hydrogen economy by means of dedicated RD&D and favorable frameworks. With regard to electrolysis, which is a key technology of power-to-gas, Japanese actors must reduce costs, increase efficiency and improve reliability. For this

[1] The ESPOO Convention sets out the obligations of the Parties to assess the environmental impact of certain activities at an early stage of planning. For more on this, see: https://www.unece.org/environmental-policy/conventions/environmental-assessment/about-us/espoo-convention/enveiaeia/more.html

reason, NEDO has been working on the development of basic technologies such as the elucidation of reaction mechanisms and the evaluation of electrolysis to accelerate material and CCM development. Also the system should be optimized and improved regarding its overall design, data management, O&M, upscaling etc. NEDO is taking on this challenge through small-scale and MW-scale PtG cases. In order to succeed, government leadership is required to reduce uncertainly for key players. This includes a combination of market pull policies and technology push policies.

Mr. Klemens Kaar, of Oersted, explained how renewable hydrogen may decarbonise areas that are currently not being addressed and are difficult to electrify. Without adding additional flexibility or supply by direct electrification, large amounts of electricity will have to be discarded. An ideal candidate for this flexible consumption is electrolysers, as they can respond quickly to the fluctuating RES production, absorb large volumes of electricity, and enables the conversion of electricity into hydrogen allowing for long term storage compared to electrical storage in batteries. When natural wind resources exceed what can be technically and economically transmitted to demand centres, electrolysis can convert the produced wind energy to hydrogen and give the high production hours monetary value. This, in turn, enables a continued build out of wind energy capacity, along with more electrolysis (a potential 450GW in Europe according to a recent study). Westküste100 or Hydrogen Region West Coast consists of GW offshore wind and multi-MW onshore wind power in combination with local industrial demands for hydrogen and possibly its on-site storage. This involves a holistic/complete sector ranging from renewable power production via fuel production and distribution to industrial or aviation end-use. A joint venture consisting of ten partners has the task first to operate a 30MW electrolysis system, including storage and infrastructure, and then to build a >100MW pilot plant with new applications in refineries, mobility and gas grids before being scaled up to a ~700MW electrolysis system with green hydrogen and e-fuels in all sectors. In order for this to happen, legal uncertainly has to be removed. A favourable regulatory framework of this sort should incentivize the demand side while on the supply side making it mandatory to produce hydrogen from renewable power and to exempt it from the German EEG[2] renewables levy as envisioned in the German national hydrogen strategy.

The Hydrogen Initiative Energy Model Region Austria Power & Gas (WIVA P&G) was presented by **Ms. Martina Ammer**. It is one of three energy model regions supported by the Austrian Climate and Energy Fund and aims to develop and demonstrate showcase solutions for intelligent, safe and affordable energy and transport systems. The partnership of companies, utilities and research institutes focuses on power-to-gas (H_2 and SNG) from the production of green energy sources, the coupling of the power and gas grids, long-term chemical storage and the decarbonisation of specific industrial processes. A portfolio of R&D projects is carefully being developed and selected with reference to existing knowledge gaps and R&D needs, covering the three main sectors: transport, industry and energy. The findings so far are that, while the core activities deal with the research, development and demonstration of a hydrogen-based system, further implementation is subject to integration into the national and international legal system. The research portfolio needs to cover the major part of the knowledge value chain, relying on existing RD&D funding mechanisms. A final issue is the alignment of projects and partners beyond the single project, allowing for knowledge exchange, short cuts and better use of results.

[2] Erneuerbare Energien Gesetz) The Renewable Energy Act (EEG), introduced in 2000, has been Germany's main legislative tool for the development of renewable power, guaranteeing all renewable power producers an above-market fixed price for 20 years, as well as grid priority.

The game changers for PtX and PtX infrastructure were presented by **Mr. Tor Elmelund**. Power-to-X (PtX) and sectorcoupling are strategic priorities for the Energinet, the national Danish TSO. The development of PtX is driven by the sharply falling costs of renewables, the emerging large-scale industrialisation of electrolysis technology, the increasing demand for and value of green PtX products in industry and transportation, and finally also the need to integrate large-scale offshore renewables into the energy system. There are three overall applications for green hydrogen: direct use of hydrogen, e.g. for fuel in heavy transport and refineries; green fuel in the form of ammonia for maritime transport, chemical production and fertilizers; and finally carbon-based fuels for aviation fuels, plastic products and other chemicals. The PtX infrastructure consists of individual infrastructures for heat, CO_2, electricity, offshore, hydrogen and methane. The overall energy system may be optimized with lower unit costs by coupling the H_2-infrastructure to the offshore landing zones. To support this, the European Gas TSOs have made a first vision map for European hydrogen backbone infrastructure, showing that large-scale hydrogen transport over longer distances can be done in an energy efficient way. The use of excess heat from electrolysis and synthesis is also being considered for district heating and heat requirements in industry, biogas plants or direct-air capture, thus improving the overall system efficiency. The key messages are that by using PtX, a 100% decarbonisation of the energy system is feasible, the coupling between wind power and hydrogen is more than simply curtailment, and last but not least we need integrated planning of infrastructure across different sectors, combining both existing and newly build infrastructure, to couple the resources with the demand for electro-fuels..

In sum, hydrogen is a promising energy carrier, a storage option, a fuel for aviation and heavy transport, and also a chemical much in demand by industry. Due to falling hydrogen production costs, increasing demand and possible sector-coupling opportunities, PtX technologies can play a significant role in the green transition.

Revisiting the RD&D recommendations of a recent EGRD workshop on Green Fuels,[3] many of these **key messages** are even more relevant, such as:

- **Hydrogen** and similar gases and their integration in the energy systems should be further researched. This includes a new flexible sector-coupled energy system to provide a match between electricity generation and consumption. Also sector coupling through electrolysis (green hydrogen) ensures that renewable energy can be integrated efficiently with little discarded electricity, by creating synergies across energy sectors, while ensuring security of supply of affordable energy, long term storage and cost savings of energy infrastructure.
- **Consumer needs and acceptance** should be at the centre of such ambitious infrastructure
- **Knowledge exchange** and sound decision-support tools are essential
- **Financial support** is needed across the whole value chain
- **Public-private partnerships** may accelerate knowledge creation
- **International RD&D cooperation** is needed to avoid overlapping R&D activities, and also to fill the gaps in PtX technologies and their integration into the system.

[3] Available at https://userstcp.org/iea-egrd