Energy for generations

EMERGING TECHNOLOGY INSIGHTS 2023

ESB Innovation

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Contents

Energy for generations

Glossary

A-CAES	Adiabatic Compressed Air Energy Storage
AD	Anaerobic Digestion
AI	Artificial Intelligence
AWED	Airborne Wind Energy Device
BCM	Billion Cubic Metres
BESS	Battery Energy Storage System
BNEF	Bloomberg New Energy Finance
CAP	Climate Action Plan
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CCUS	Carbon Capture Utilisation and Storage
CHP	Combined Heat and Power
COD	Commercial Operations Date
COP	Coefficient of Performance
DA	Digital Accelerator
DDHS	Dublin District Heating System
DECC	Department of Environment, Climate and Communications
DH	District heating
DSO	Distribution System Operator
EMEC	European Marine Energy Centre
EPRI	Electric Power Research Institute
ETRD	Emerging Technology and R&D
EV	Electric Vehicle
FPV	Floating PV (solar photovoltaics)
GHG	Green House Gases
IHP	Industrial Heat Pumps
I-SEM	Integrated Single Electricity Market
LAES	Liquid Air Energy Storage
LCOE	Levilsed Cost of Energy
LCOS	Levelised Cost of Storage
LV/MV/HV	Low Voltage / Medium Voltage / High Voltage
MAC	Maritime Area Consent
MCB	Miniature Circuit Breaker
ML	Machine Learning
NREL	National Renewable Energy Laboratory
OEM	Original Equipment Manufacturer
OREDP	Ocean Renewable Energy Development Plan
P2P	Peer to Peer
RESS	Renewable Energy Support Scheme
SC	Synchronous Compensator
SEAI	Sustainable Energy Association of Ireland
SMR	Small Modular Reactors
SSRH	Support Scheme for Renewable Heat
TRL	Technology Readiness Level
V2B	Vehicle to building
V2G	Vehicle to Grid
WEC	Wave Energy Converters

Introduction to Emerging Technology Insights Report - 2023

Climate change is one of the defining challenges of our generation. Its impact is evident in increasingly extreme weather patterns, rising sea levels, water shortages and disruption to biodiversity and ecosystems. Electricity has a transformative role to play in tackling climate change by eliminating carbon and other harmful greenhouse gas emissions from the energy sector, enabling the broader decarbonisation of energy in all sectors.

Achieving net zero will require the deployment of new energy technologies at massive scale capable of providing reliable, affordable, low-carbon energy when intermittent renewable power from the wind or the sun is unavailable. Electricity networks are playing an increasingly important role in enabling the mass adoption of low-carbon technologies including heat pumps, electric vehicles and microgeneration, and the connection of large volumes of renewable generation. Digital and data-driven technologies are also transforming the electricity sector, underpinning the development of smarter networks and giving rise to new business models, including digital only suppliers offering an enhanced customer experience at a lower cost to serve.

It is important therefore that ESB understands new technologies that are under development in order to position itself to respond and take advantage of these emerging technologies. The Emerging Technology and R&D team carries out this function on an on-going basis and publishes an annual Emerging Technology Insights report to capture, analyse and summarise recent developments in Emerging Technology. In doing so they engage with external stakeholders, technology developers, consultants, energy start-ups, third-level and research organisations and of course gain valuable insights from staff across all business units in ESB.

This year's Emerging Technology Insights report analyses 24 different technologies across power generation, storage and flexibility, hydrogen, CCUS, empowered customer and digital technologies. The report assesses each of these technologies under the headings of technology, commercialisation, ESB activities and policy in each technology sector. A key objective associated with this year's report is to organise a series of webinars, creating a greater awareness and understanding of these new and emerging technologies and to facilitate technical conversations in each business unit.

I hope you find this report to be both informative and useful in supporting you to play your part in achieving our net-zero goals.

Donal Phelan

Head of Innovation,
Strategy, Innovation & Transformation

Energy for
generations

1.0 OVERVIEW OF EMERGING TECHNOLOGY

The purpose of this report is to provide an update on the status of various emerging energy and digital technologies and, where relevant, an update as to the status of ESB interaction with these technologies. Broadly speaking, most (but not all) technologies examined have the potential to assist with ESB's Net Zero by 2040 target.

Between one-third and half of the cumulative emissions reductions in the IEA's net zero scenarios stem from technologies that are in development but not yet commercially available today. The successful development and deployment of these innovative emerging energy technologies will be key to enabling the net zero energy system of the future.

This report comprises technologies that the Emerging Technology and R&D (ETRD) team are currently evaluating or has evaluated over the last number of years. The technologies are categorised in the report as follows:

- Power Generation Technologies
- Storage and Flexibility Technologies
- Hydrogen
- Carbon Capture Utilisation and Storage (CCUS)
- Empowered Customer
- Digital Technologies

An update is provided on each technology under the following headings:

Technology Readiness Level (TRL)

TRL assessment and score. Basic outline of TRL below including traffic light indicator:

TRL 1 to 2	Concept phase / research
TRL 3 to 5	Small scale prototype deployed in lab / controlled environment
TRL 6 to 7	Large scale prototype or subsystems deployed in controlled environment
TRL 8	Large scale prototype deployed in commercial type environment
TRL 9	Mature technology, deployed at scale in commercial type environment

Commercialisation

Time to commercialisation and costs for Ireland / UK markets (in the case of emerging generation technologies it is assumed that commercialisation is achieved when technology reduces LCOE to <€100/MWh for Irish / UK market):

+5 years to commerciality
1-5 years to commerciality
Currently commercial or commerciality imminent

Prices quoted in this report are from publicly available sources and are intended to be indicative only.

ESB Activity

ESB's interaction with the technology is broadly categorised as below.

Review to be completed
Review completed and watching brief being maintained
Current project active or project completed

Policy

Overview of the Policy environment, with a focus on the Republic of Ireland and the 2023 Climate Action Plan (CAP).

Summary

An overview of the technology, with a view presented on the future outlook for the technology within an Irish context.

Emerging Technology Reports

Certain chapters have associated technology reports which go into greater detail on the chapter topic. For ESB readers, links to these reports are found at the end of the relevant chapters. For readers external to ESB who are interested in more detailed reports, please contact desmond.lalor@esb.ie

This document, and the associated technology reports, have been compiled with a view to further enhancing collaboration across ESB and our research, innovation and industry partners. A number of technology experts from different ESB business units have contributed to the report and we very much welcome input and feedback from all staff across ESB.

Updates in 2023

This is the ninth publication of this report. Three new chapters have been added for the 2023 report, namely:

- CO2 batteries
- Hydrogen fueled turbines
- Metaverse

In addition, the following chapters have been expanded.

- Floating solar, expanded to include marine floating solar
- Thermal storage – expanded to include bricks.
- CCUS – an expanded chapter, which was previously 'negative emissions'.

As technologies reach commercial maturity (such as grid scale battery storage) or are deemed to be no longer a priority (such as airborne wind), they are removed from the report.

For the 2023 update, the following chapters have been removed:

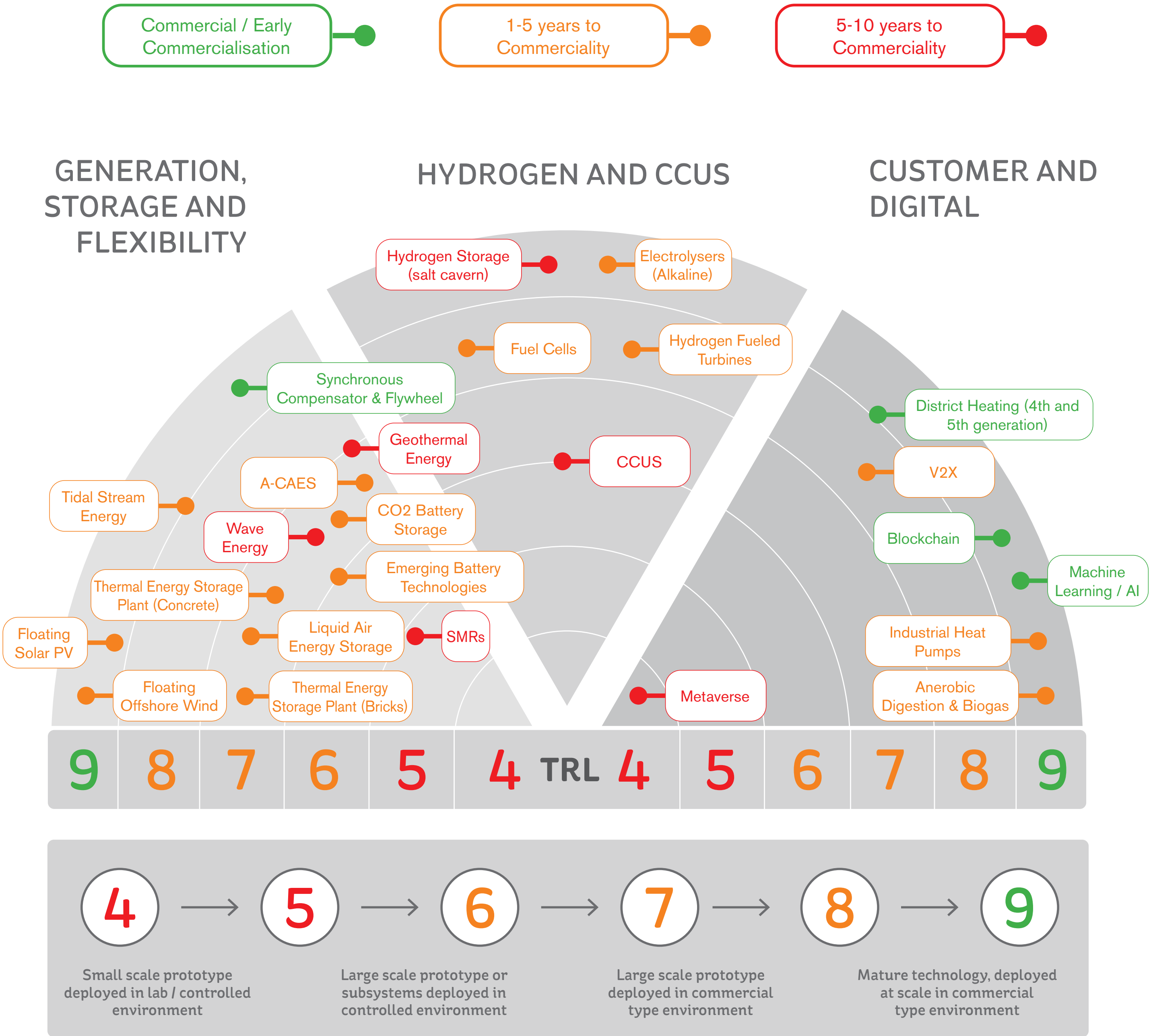
- Gasification
- Airborne Wind
- Battery Storage - grid scale

Emerging Technologies – Five to watch!

Of the emerging technologies reviewed in this report, the ETRD team considered what technologies can make a material contribution to Irelands Net Zero 2050 ambitions. The 'five to watch' are as below.

- Floating Offshore Wind
- Green Hydrogen
- Industrial Heat Pumps
- Flow Batteries
- Biogas / Biomethane

An overview of the status of all technologies in terms of TRL and commerciality is shown below.



Energy for generations

2.0 POWER GENERATION

2.1 FLOATING OFFSHORE WIND

Technology

TRL 9 (semi submersibles)

Floating Offshore Wind energy consists of wind turbines mounted on floating structures that are attached to the seabed using various mooring arrangements. There are greater than 70 different floating wind platform designs in various stages of development. The four principal categories are semi- submersible, spar, barge and tension leg platform. Semi-submersible designs made from steel and/or concrete are most advanced with approximately two-thirds of projects using this design type.

Mooring arrangements of platforms are broadly divided into catenary (free hanging), taut (tensioned), or semi taut mooring. Leading anchoring solutions include drag anchors and suction anchors.

Floating platforms are suitable for large wind turbines. For example, the Kincardine phase 2 project employs MHI Vestas 9.5 MW turbines. Bloomberg New Energy Finance (BNEF) predicts future turbine sizes of 16 MW in 2030, 25 MW in 2040 and 35 MW in 2050.

TRL is defined as 9 for leading semi-submersible and spar platforms.

Commercialisation

1-5 years

Hywind Scotland floating wind project, developed by Equinor, was commissioned in 2017. The Project location is 25km off Peterhead, Scotland. The project consists of 5 x 6 MW turbines with a Capex of circa €8m/MW. Performance of the Hywind wind farm over 12 months has shown an average capacity factor of 56%, which is at the upper level of typical offshore wind capacity factors of between 45% to 60%.

Principal Power's 25 MW (3 x 8.3 MW) Windfloat Atlantic project was installed in June 2020 off the coast of Portugal. This project was developed by EDP, Repsol and Principle Power.

The 50 MW Kincardine phase 2 floating offshore wind farm, 15km offshore from the Scottish coast of Aberdeen, was commissioned in 2021. It features 5 x 9.5 MW turbines installed on semi-submersible floating structures designed by Principle Power. The project is located in water depths ranging between 60 and 80 metres.

The Carbon Trust estimated in a report for the Scottish Government that an LCOE below £100/MWh for floating platforms is achievable by 2030.

In early 2022, Scotland awarded seabed lease rights to 17 offshore wind projects totalling almost 25 GW in capacity through the ScotWind auction process. Of these, over half were for floating projects.

RenewableUK reported in 2022 that the total worldwide pipeline of floating wind projects is now 180GW.

ESB Activities

GT currently developing sites

As part of the ScotWind process, ESB was offered, and have executed, a lease option for a 500MW floating offshore project off the east coast of Shetland. The name of the planned wind farm is Sealtainn Offshore Wind.

ESB has invested in Dublin Offshore Technology (DOT), a company specialising in innovative floating offshore wind mooring technology.

Crown Estate Scotland's conducted a seabed leasing process focussing on Innovative floating technologies, termed 'INTOG'. As part of this process, ESB were offered exclusive rights to develop an innovative 100MW floating offshore wind project in the Malin Sea, called Malin Sea Wind. It will be a collaborative project including ESB and leading technology developers Dublin Offshore Technology and Belfast-based CATAGEN.

ESB is actively progressing several floating off-shore wind projects off the south and west coasts of Ireland. These projects are at early concept stage. A key flagship project is the planned Moneypoint Offshore wind project, with a planned capacity of up to 1.4GW. This project forms a key part of a broader project known as 'Green Atlantic @ Moneypoint', which in addition to Moneypoint Offshore wind project, will include a synchronous condenser (already completed), a wind turbine construction hub and green hydrogen production facility.

Policy

CAP23 has a target of 5 GW of Offshore wind developed by 2030, with an additional 2 GW of Offshore wind earmarked for green hydrogen production.

The Irish Programme for Government (2020) aims to take advantage of the "at least 30 GW of offshore floating wind power" off Ireland's Atlantic coast.

The Maritime Area Planning (MAP) Act 2021 was signed into law in December 2021. This will streamline the development of Offshore energy on the basis of a single consent principle. A new agency, Maritime Area Regulatory Authority (MARA), has been formally established in Summer 2023, and will be responsible for maritime consenting.

Summary

The outlook for Floating Offshore Wind energy in Ireland is extremely positive, with at least 30 GW potentially available. These projects may be grid connected or used for Green Hydrogen/ Ammonia production. As well as being a great domestic opportunity, floating off-shore wind offers a very promising export opportunity, possibly via interconnectors or e-fuels such as Hydrogen or Ammonia.

Reports (ESB staff access only)

Floating Offshore Wind_2020

Semi-submersible floating offshore wind farm.

2.2 FLOATING SOLAR PV

Technology

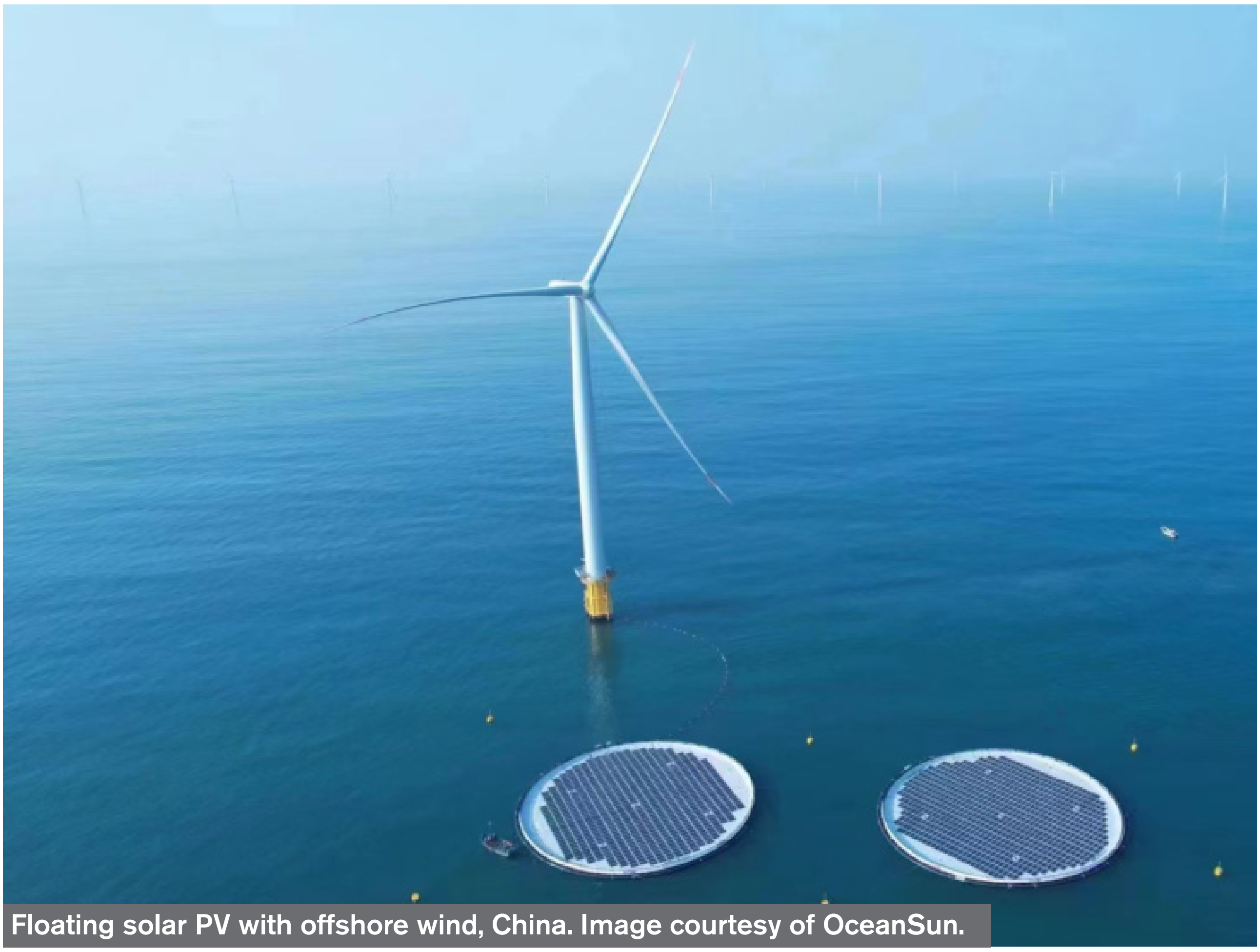
TRL 9 (in-land waters)

Floating PV (FPV) consists of traditional solar photovoltaic panels mounted on buoyant devices floating on in-land or offshore waters, tethered to a fixed point by means of anchoring or mooring structures. FPV on in-land waters is far more advanced than offshore FPV and makes up nearly all projects globally. The solar panels used in floating PV are the same as traditional ground or roof mounted PV. Floating PV (in-land) has been deployed at full commercial scale, thus is TRL 9. The novelty of floating PV lies in the floating structures and the anchoring or mooring technique which varies according to the local environment.

One leading design consists of stiff High Density Polyethylene (HDPE) modular floating structures on which panels are fastened, generally at an incline. Ciel et Terre, a leading FPV OEM, offer this solution. An alternative design consists of a large flexible membrane with rails. The panels are slid into the rails and laid horizontally. Ocean Sun offer this membrane style solution.

There are many potential advantages of floating PV including:

- Reduces land requirement
- Greater efficiency due to cooling effect of the water on the PV panels



Floating solar PV with offshore wind, China. Image courtesy of OceanSun.

- Reduction of water evaporation in hot climates.
- Lower losses due to lower shading impacts.
- Easier maintenance due to less dust pollution

Commercialisation

1-5 years

FPV technology is already at commercial level in many countries with the majority of floating PV farms located in China, Japan and South Korea. Estimates put current floating solar deployment at around 3GW globally. However, in Ireland, there are no FPV plants and the technology is considered to be several years from commercialisation in Ireland due to a lack of suitable sites and low solar resource.

In 2017, Thames Water with Lightsource Renewables developed a 6.3MW floating PV project on the QEII reservoir in Surrey, UK. The electricity generated is exclusively used by Thames wastewater treatment plant at a fixed price for 25 years.

In 2021, German developer BayWa Re and Dutch partner GroenLeven built three floating solar parks totalling 100MW in the Netherlands. The solar parks received subsidies of 8 to 12 € cents per kWh over a period of 15 years.

In March 2021, DNV published the world's first recommended practice (RP) for floating solar power projects (DNV-RP-0584) following a collaborative joint industry project (JIP) involving 24 industry participants

Offshore FPV projects are at demonstration, rather than commercial, stage. The world's first offshore wind and floating solar powerplant has been commissioned in Shandong, China. The project consists of 0.5MW of FPV connected to an offshore wind turbine. In Europe, 'Oceans of Energy' have installed a small scale offshore FPV pilot in the North Sea.

ESB Activities

Exploring a pilot project

In 2022, ESB, commenced a new analysis to investigate FPV possibilities on ESB hydro assets. A detailed electrical review was completed, which identified that several of ESB's hydro power reservoirs would be suitable for multi-MW scale FPV deployment from an electrical perspective. Membrane FPV technology appears to be the most suitable for deployment on ESB's reservoirs and investigations are ongoing.

Policy

Floating solar does not feature in the CAP 2023, reflecting its status as a pre-commercial technology in Ireland.

In the Netherlands, the Climate and Energy Ministry says the country will add 3 GW of offshore solar energy as a target to be achieved by 2030. If this is enacted, it would represent a great step forward for Europe.

Summary

The global outlook for FPV is positive. Fitch predict 10GW of FPV will be installed by 2025. The majority of this growth is expected in high irradiance countries. In Ireland and GB, potential is more limited in the medium-term. It is expected viable projects will likely be private wire installations such as water treatment plants. In ESB, there is an opportunity to deploy FPV due to the large number of hydro power reservoirs owned by ESB, which is being explored currently.

Reports (ESB staff access only)

Floating PV Technology Status_2019

2.3 WAVE ENERGY

Technology

TRL 7

Wave energy is energy harnessed from the ocean waves. The motion of surface ocean waves contains a lot of kinetic energy that is captured by Wave Energy Converters (WEC). The energy is converted to electricity through power take-off systems by pitch, heave or surge responses to incident waves. There are over 50 different WEC designs under development with no clear convergence towards a preferred established wave energy conversion technology yet.

Depending on distance to shore and water depth, a short list of leading technologies has been identified by ESB. That list identifies CorPower as leading the market for floating WECs. EcoWave power is considered the leading developer of shore-mounted WECs, with projects in Jaffa, Israel, and Los Angeles, USA. OEMs including Floating Power Plant, Marine Power System and Bomborra are developing hybrid floating platforms for wind turbines with embedded WEC systems, aiming at lowering the LCOE when compared to floating wind only. Hybrid platform benefits are still to be proven with a large-scale demonstrator and are currently at TRL5.

A key challenge for WEC is survivability, especially when deployed off the west coast of Ireland where sea states are among the roughest in the world. Most OEMs have a built-in survivability state where the device de-tunes (switches off) in extreme conditions to protect the device itself. One advantage of wave energy is that the production profile is complimentary to that of wind energy.

Over 10 Wave Energy Converter (WEC) developers have achieved TRL 6 and above and a small number of leading technologies have achieved TRL 7.

Commercialisation

+5 years

According to the Ocean Set third annual report published in March 2022, the average LCOE among 13 wave energy projects in Europe is €272/MWh. This figure, collected from developers, has not been independently verified and the reality may well be higher. The EU commission has a target to reduce LCOE to €100/MWh by 2035 when it is expected that more than 1GW will be installed.

The most significant progress in wave energy deployment in 2022 has been in China where the 1MW (2x500kW) Wanshan Sharp Eagle wave energy demonstrator, a semi-submersible fitted with attenuators WEC, has been fully deployed and is now heading towards demonstration operation in 2023. In Europe, 12.7 MW of wave energy has been installed since 2010 with only 400kW currently in the water.

Following a 12 month dry testing campaign, CorPower are currently deploying their C4 device (300 kW) at the WavEc test site in Agucadoura Portugal to start open water testing in 2023. There have been numerous delays in deployment.

In March 2023, ENI deployed their 250kW Inertial Sea Wave Energy Converter (ISWEC) 800m off the coast of the Island of Pantelleria in Italy. The floating rotating mass type WEC is connected to the island's grid and a testing campaign is ongoing.

ESB Activities

Development of a pilot

In December 2022, Simply Blue Group (SBG) and ESB signed an MoU to co-develop Saoirse, a wave energy pilot. Project Saoirse is a planned first-of-a-kind 5MW development, consisting of an array of 14 WECs using CorPower Ocean technology. The project site is located between 4-6km off the coast of Co. Clare. Since 2020, SBG has been developing this project and applied for a Foreshore licence in June 2021 for site investigation work. The site is approximately 9km northeast of ESB's former wave project known as "Westwave".

In July 2023, Saoirse Wave Energy Ltd was successful in an EU Innovation Fund application to develop the Saoirse Wave Energy project. ESB supported SBG on the grant application to the EU Innovation Fund.

Policy

The Maritime Area Planning (MAP) Act 2021 was signed into law in December 2021 and will streamline the development of Offshore energy on the basis of a single consent principle. The Act includes key consents required for the development of an offshore renewable energy project including the legal right to occupy a particular area (effectively a lease of the seabed) called a Maritime Area Consent ("MAC").

In Q1 2023, a draft of the Offshore Renewable Energy Development Plan 2 (OREDP2) was issued by DECC for consultation. This plan sets out the principles by which offshore energy will be developed in the long term. The draft OREDP2 states that "Ireland's large maritime area offers significant potential to develop renewable energy from wind, wave and tidal sources." but does not offer a clear route to market for wave energy.

The European Commission set a target of 100MW by 2025, 1GW by 2030 and 40GW by 2050 of wave and tidal energy installed capacity. With the highest wave resource in the European Union, Ireland is well positioned to be contribute to the delivery of this target. To support the delivery of these targets, the Horizon Europe 2023-2024 Work Programme plans to offer between €18m to €20m of grant aid to two wave pilot farms in Europe.

The Renewable Energy Directive revision published in March 2023 setting an indicative target for innovative renewable energy technology of at least 5% of newly installed renewable energy capacity should enable further wave energy deployment.

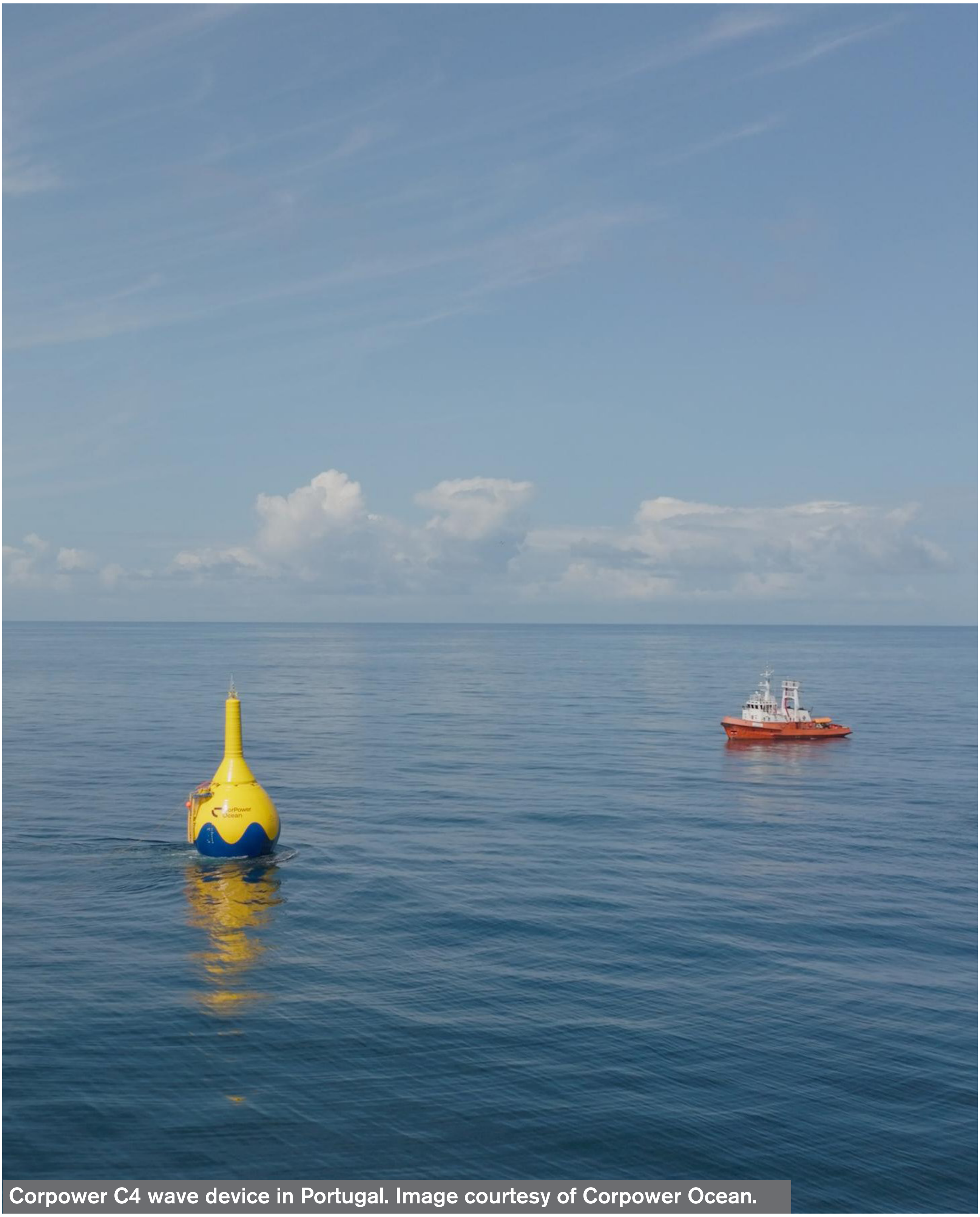
Summary

Wave energy has been under development for decades but has still not reached commercial maturity due to the lack of technology convergence and the harsh environment in which it operates. Many OEMs like Pelamis and Wave Star and utilities such as Scottish Power and SSE built and deployed large demonstrators more than 10 years ago but failed to get to commercial operation due to technical problems or lack of funding. There is now a renewed interest in developing this form of renewable energy, with new technologies completing successful testing and ambitious European target. In addition, the rapid growth of offshore wind should benefit wave energy as wave energy can act as a 'companion technology' to offshore wind energy and can realise economic benefits for local communities thus easing the consenting path for larger offshore wind projects. .

Reports (ESB staff access only)

20220215 - TECHNICAL REVIEW OF WAVE ENERGY CONVERTERS (WEC) – INITIAL FINDINGS

Wave Energy Status 2020



Corpower C4 wave device in Portugal. Image courtesy of Corpower Ocean.

2.4 TIDAL STREAM ENERGY

Technology

TRL 8-9

Tidal stream generators make use of the kinetic energy of moving water to power turbines. Two principal technology types exist; seabed mounted turbines or floating turbines. An example of a seabed mounted turbine is the Simec Atlantis device while an example of a floating turbine is the Orbital Marine Power device.

Tidal turbines can be thought of as 'underwater wind turbines' in that the same power law applies to both wind and tidal energy; namely that power output in proportional to velocity cubed. However, as sea water is 800 times denser than air, there is significant power generation potential at high-velocity tidal sites.

Tidal energy development has focused on areas with fast moving water (> 2 m/s) with laminar flow and minimal wave loading, such as the Bay of Fundy in Canada, Naru island in Japan, and specific sites in Scotland.

Tidal energy is classified as TRL 8 – 9 depending on the technology.

Commercialisation

5 years (UK) >5 years (Ireland)

The first large scale tidal stream array was the Meygen Project located in Pentland Firth between the Scottish mainland and Orkney Islands. Phase 1 was developed by Simec Atlantis in 2018 and is currently in operation. It consists of 4 x 1.5 MW turbines.

In April 2021, Spanish tidal energy developer Magallanes Renovables has reinstalled its second-generation ATIR 2-MW tidal platform at the European Marine Energy Centre (EMEC) in Orkney, Scotland.In August 2021, Orbital Marine Power's O2 (2 MW) turbine started grid-connected power generation at EMEC in Orkney. Orbital Marine reported a Capex of £5m/MW.

Tidal energy took a significant step forward in 2022, with the Orbital Marine Eday 1 & 2, Morlais Magallanes and Meygen Phase 2 projects all successful in Contracts for Difference (CfD) auctions. In total, 41MW of tidal will be brought online via the round, at a strike price of £178.54/MWh ($213.82/MWh).

ESB Activities

Currently monitoring sector

There was significant ESB interaction with tidal energy from 2008-2011 when ESB invested in tidal energy company Marine Current Turbines which developed the first grid-scale tidal energy device SeaGen (1.2MW) at Strangford Lough. This technology was subsequently acquired by Simec Atlantic. Investigations were carried out as to possible development of tidal stream arrays by ESB in Ireland. The only locations deemed viable were the coast of Co. Antrim and at Strangford Lough. No large high speed tidal resource exists in the Republic of Ireland. Given high development costs of such projects and limited tidal resources, it was decided to focus on the development of wave energy and discontinue tidal energy activities. A watching brief has been maintained on the industry since.

Policy

The Climate Action Plan (CAP) 2019 included an action to support emerging marine technologies (wave, tidal, floating offshore wind). As part of this action, it outlines steps to be taken by SEAI regarding funding for early-stage wave and tidal devices. CAP 2023 does not specifically mention tidal energy.

In a boost to the tidal industry in the UK, the British government is investing £20 million a year in tidal power via its renewable energy auction scheme.

Summary

Tidal stream technology is close to maturity and is ahead of wave energy by several years. However, costs remain high and suitable sites are limited. In the Republic of Ireland, the opportunities for development are limited due to a lack of high resource sites. In Northern Ireland and GB, the outlook is more positive due to better resources and recently announced government supports.

Orbital Marine 2 MW tidal turbine. Image courtesy of Orbital Marine Power.

2.5 GEOTHERMAL ENERGY

Technology

TRL 6-9 depending on specific technology and location

Geothermal energy is heat derived within the sub-surface of the earth. Geothermal energy can be used for heating and cooling purposes or be harnessed to generate clean, consistent electricity.

The principal technologies for geothermal electricity generation are as below:

Dry steam - The first and simplest type of geothermal power generation plants built. The subsurface steam travels directly to a steam turbine. (TRL 9)

Flash steam - High temperature fluid is pumped under high pressure into a tank at the surface held at a much lower pressure, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a steam turbine (TRL 9)

Binary cycle - Utilisation of geothermal resources to heat a chemical working fluid with a low boiling point (with respect to water) to produce steam. (TRL 7 – 8)

Enhanced geothermal systems (EGS) - Artificial creation or enhancement of ground conditions to make them suitable for binary generation. Process involves the creation of artificial reservoirs via injection of pressurised water to create fractures in subterranean "hot dry rock." (TRL 6 – 9).

Advanced geothermal systems (AGS) – Closed loop system, where fluids circulate underground in sealed pipes and boreholes, picking up heat by conduction and carrying it to the surface. An example is the 'Eavor-loop' technology, from the Canadian company, Eavor. (TRL 7 – 8)

The principal technology for geothermal heating and cooling is a Ground Source Heat Pump (GSHP). Boreholes act as collectors for the GSHP and may be shallow (<200m) or deep (up to several kilometres), closed loop or open loop. Heat may be used for residential, commercial, industrial or District heating (DH) purposes. (TRL 9)

Commercialisation

+5 years (Irish context)

No Geothermal plant for electricity production exists at present in Ireland or the UK. However, the Eden Project in Cornwall (under ownership of UK educational charity the Eden Trust, in partner with EGS Energy) is currently developing the first EGS power station in the UK. Therefore, price data from Ireland and UK is difficult to obtain at present.

In Germany, the Eaver-loop system has announced its first commercial project. This project will receive a fixed power price of €227/MWh until 2042. In addition, this project received a €91,6 million grant from the European Innovation Fund.

ESB Activities

Current project active

In 2010 / 2011, ESB explored the possibility of Geothermal for electricity production, but did not proceed due to a lack of commercial supports.

In 2018, ESB International was awarded a contract by Philippines geothermal generation developer Energy Development Corporation (EDC) to provide operational and maintenance advisory services on their fleet of 40 Flash steam geothermal assets. This has included increased digitisation and integration of EDC business systems and processes. This project is still ongoing.

ESB installed a GSHP system at the ESB Head Office in Fitzwilliam Street. This system includes 32 no. 150m deep closed loop boreholes and provides approximately 300kW of heating and 250kW of cooling. The system also includes Air Source Heat Pumps (ASHP) that provide additional heat when required.

Policy (ROI)

In November 2020, the Department of Environment, Climate and Communications (DECC) published the following reports:

"An Assessment of Geothermal Energy for District Heating in Ireland"

"Geothermal Energy in Ireland: A roadmap for a policy and regulatory framework""

In December 2021, the Department of Environment, Climate and Communications (DECC) released a draft policy statement for consultation entitled 'Geothermal Energy for a Circular Economy'. ESB submitted a response to this consultation and is a on an expert committee to develop the policy. Publication of this policy statement is a key geothermal goal in CAP 2023.

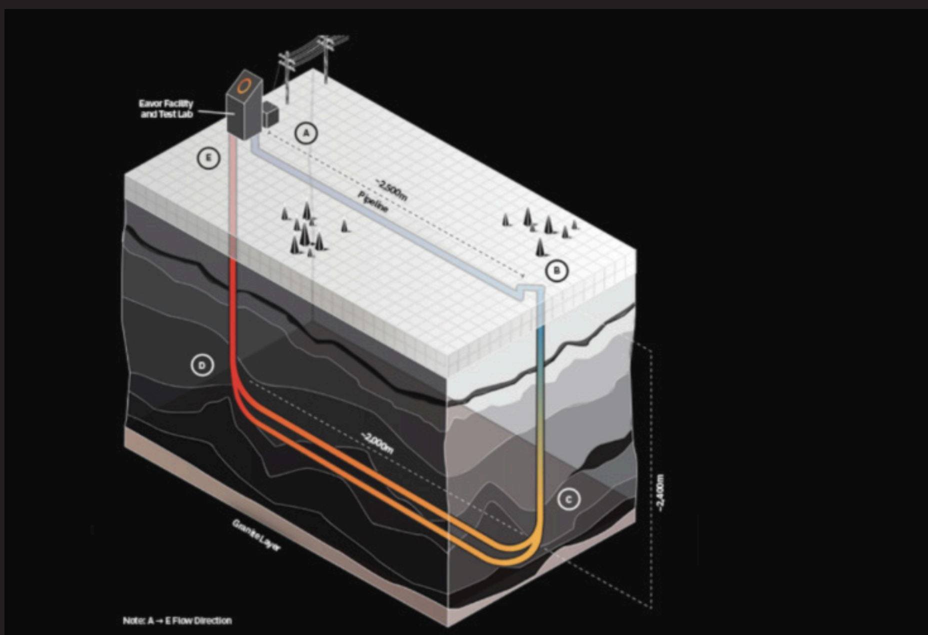
Summary

Geothermal energy for electricity generation in Ireland and the UK has limited potential due to the lack of high-quality heat resources. However, technological advances in drilling (such as those deployed by 'Eavor') may change this outlook in upcoming years.

Geothermal energy for heating and cooling has a moderately positive outlook in Ireland, with many potential applications from residential to utility scale. However, high Capex costs remain a challenge. Also, in many applications, ASHPs can provide a simpler and cheaper alternative, and may prove a more competitive technology.

Reports (ESB staff access only)

Geothermal Generation



Graphic of geothermal technology from Eavor. Image courtesy of Eavor.

2.6 SMALL MODULAR REACTORS (SMR)

Technology

TRL 4-7

Small modular reactors (SMRs) are advanced nuclear reactors that have a power capacity of circa 20 MWe to 400 MWe per unit. The underlining concept is that prefabricated units of SMRs can be manufactured offsite and then shipped and installed on site, making them more affordable and faster to build than large power reactors, which are often custom designed for a particular location. Additional potential benefits include a small plant footprint.

SMR's have potentially multiple use cases, including electricity production for the grid, industrial applications, waste heat can be recovered for district heating or industry applications. Nuclear energy can also be used for hydrogen production.

More than 80 commercial SMR designs are being developed in 19 countries. SMRs using Pressurised Water Reactor (PWR) or Boiling Water Reactor (BWR) are based on existing conventional nuclear power while Advanced Modular Reactor (AMR) is still emerging.

TRL definition depends on the SMR design type. Broadly speaking, SMR technology can be said to range from TRL 4-7, depending on the technology.

Commercialisation

+5 years (European perspective)

Commercialisation barriers for SMR are multiple, including concerns over nuclear proliferation, waste management (SMRs produce more waste than conventional nuclear energy on a pro rata basis), vulnerability to terrorist attack or natural disaster and overall safety of operation. Lower enriched/ recycled fuels combined, underground sealed reactors, and passive safety features are some of the strategies used by SMR designs to overcome these challenges.

Commercialisation of SMR's varies depending on technology type and jurisdiction, Russia's Akademik Lomonosov, a floating nuclear power plant that began commercial operation in 2020, is producing energy from two 35 MW(e) PWR. The project location is in Kamchatka in the Russian far east. There is debate as to whether this project constitutes a modern SMR as it doesn't fit the 'modular' definition of serial factory production.

In 2021, in Shandong province, China, a 210 MW High Temperature Gas-Cooled Reactor-Pebble-bed Module (HTR-PM) reactor was commissioned and connected to the grid. It reached full power in December 2022 with two reactors driving a single turbine. It is the world first HTR. However, again there is debate as to whether this constitutes an SMR.

In Hainan island, China, the construction of a 125MWe PWR prototype ACP100 started in July 2021 and is due to take 58 months to complete. This reactor is referred to as 'Linglong-1'. On completion, it is expected this will be the world's first commercial SMR.

Graphic of planned SMR. Image courtesy of Rolls Royce and the BBC.

In North America & Europe, several reactors are at the licensing stage. These include the GE Hitachi BWRX-300 (300 MWe) reactor, NuScale (77 MWe) reactor, Rolls Royce (470 MWe) and Moltex (150 MWe) reactor. Moltex's Stable Salt Reactor - Wasteburner (SSR-W) reactor, which uses low purity recycled radioactive waste as a fuel and producing waste at a lower radioactivity level, is one example on how SMRs can disrupt the nuclear industry. Demonstration plants are expected to be online in the late 2020's or early 2030's.

In March 2023, EDF launched Nuward, a venture dedicated to the development of SMR. Their 2 x 170 MWe PWR, is currently under review by the French, Czech and Finnish safety authorities for pre-licensing. Nuward aims at building a reference plant in France by 2030.

IEA SMR energy cost estimations are between $45 and $110 per MWh, depending on the degree of technology maturity The costs of certifying new designs and the cost of factories yet to be built are subject to high uncertainties.

To take one case study for pricing, the planned 462 MW Nuscale Carbon Free Power Project in Idaho, US, is planned for operation in 2030. The target price for power is $89/MWh with subsidies of $30/MWh. ($119/MWh without subsidies). The Capex estimates have risen from $5.3 to $9.3 billion dollars.

ESB Activities

Currently monitoring sector

ESB has no direct involvement in SMR but is monitoring the technology development.

Policy

The production of electricity for the Irish national grid by nuclear fission, is prohibited in the Republic of Ireland by the Electricity Regulation Act, 1999 (Section 18). The European commission has officially named nuclear energy as a sustainable energy source that could contribute to Europe's transition to climate neutrality, enabling investors to label and market investments in them as green.

Nuclear energy generation in the Republic of Ireland is prohibited and there is no indication that this position will change in the short or medium term.

Globally, SMR's have attracted a lot of investment and attention. However, the concept and technology remain unproven due to a lack of demonstration projects.

Energy for generations

3.0 STORAGE AND FLEXIBILITY

3.1 SYNCHRONOUS COMPENSATOR AND FLYWHEEL

Technology

TRL 9

A synchronous compensator (SC), also known as synchronous condenser is similar to a generator in its design and behaviour but produces only reactive power and no active power. It neither acts as a motor, as nothing is driven on the other side, nor a generator as there is no prime mover.

Its purpose is not to convert electric power to mechanical power nor vice versa, but to offer immediate inertial response to grid fluctuation in supply or to absorb reactive power. Synchronous compensators were once widely applied as a means of providing reactive power compensation in power grid prior to the introduction of power electronic-based devices.

Under utilised turbines can be retrofitted to act as synchronous compensators, by installing a synchronous self-shifting clutch between the turbine and the generator.

A synchronous compensator can provide grid system services such as inertia, increased short circuit contribution, dynamic voltage recovery and reactive power. If a flywheel is added, the system increases the overall inertia provided to the power grid. A flywheel operates by accelerating a rotor to a very high speed and maintaining the energy in the system as rotational energy.

SCs are tailored on the basis of network studies, and they are strategically sited for optimal results according to grid characteristics.

Commercialisation

Currently commercial / early commercial

Synchronous compensators and flywheel systems are readily available on the market from major OEMs such as Andritz AG, Ansaldo, Siemens, GE and ABB.

In GB National Grid ESO have developed “Stability Pathfinder” competitions to incentivise the development of system stability devices for inertia and short circuit provision. Contracts have been awarded to projects including synchronous compensator projects. In 2020, National Grid ESO ran phase 1 of the Stability Pathfinder competition in which a number of synchronous compensator projects won long duration contracts. Following this process for example, in February 2021, ABB was awarded a contract by Statkraft, Europe’s largest renewable energy producer, for two SCs for the Lister Drive Greener Grid Park in Liverpool, England. This couples a 67MVAr SC with a 40-tonne flywheel that increases the instantaneously available inertia by 3.5 times. The two SCs in Liverpool are now operational and provide a total of more than 900 MWs inertia.

In Ireland, Eirgrid has developed the DS3 programme which includes the development of financial incentives for a range of services including inertia and voltage stabilisation. In this context, ESB and Siemens have built the biggest SC and flywheel unit worldwide. Details are reported in the following section.

Globally, advisory firm Devlins, estimate that the SC market will grow from a value of $615.2 million in 2022 to $947.1 million by 2030.

ESB Activities

Moneypoint Synchronous compensator and Flywheel Project

As part of the ESB's Green Atlantic @ Moneypoint project, a synchronous compensator coupled with a flywheel at the Moneypoint station has been installed. The aim of the project is to increase the mass of the system and provide increased inertia and voltage stabilisation to the transmission system under the EirGrid DS3 market. The system shares a grid connection with Moneypoint Unit 2 connecting into the 400 kV transmission station.

The 177 tonne flywheel is fabricated from forged steel. The development will generate reactive power c. 371 MVAr (+260/-111) range and inertia c. 4,000 Megawatt-seconds (MWs) to the transmission system (equivalent inertia contribution as two of the Moneypoint units).

ESB is reviewing opportunities at the Midlands Stations, in Northern Ireland, the Dublin area and the North-West for additional deployments.

Policy

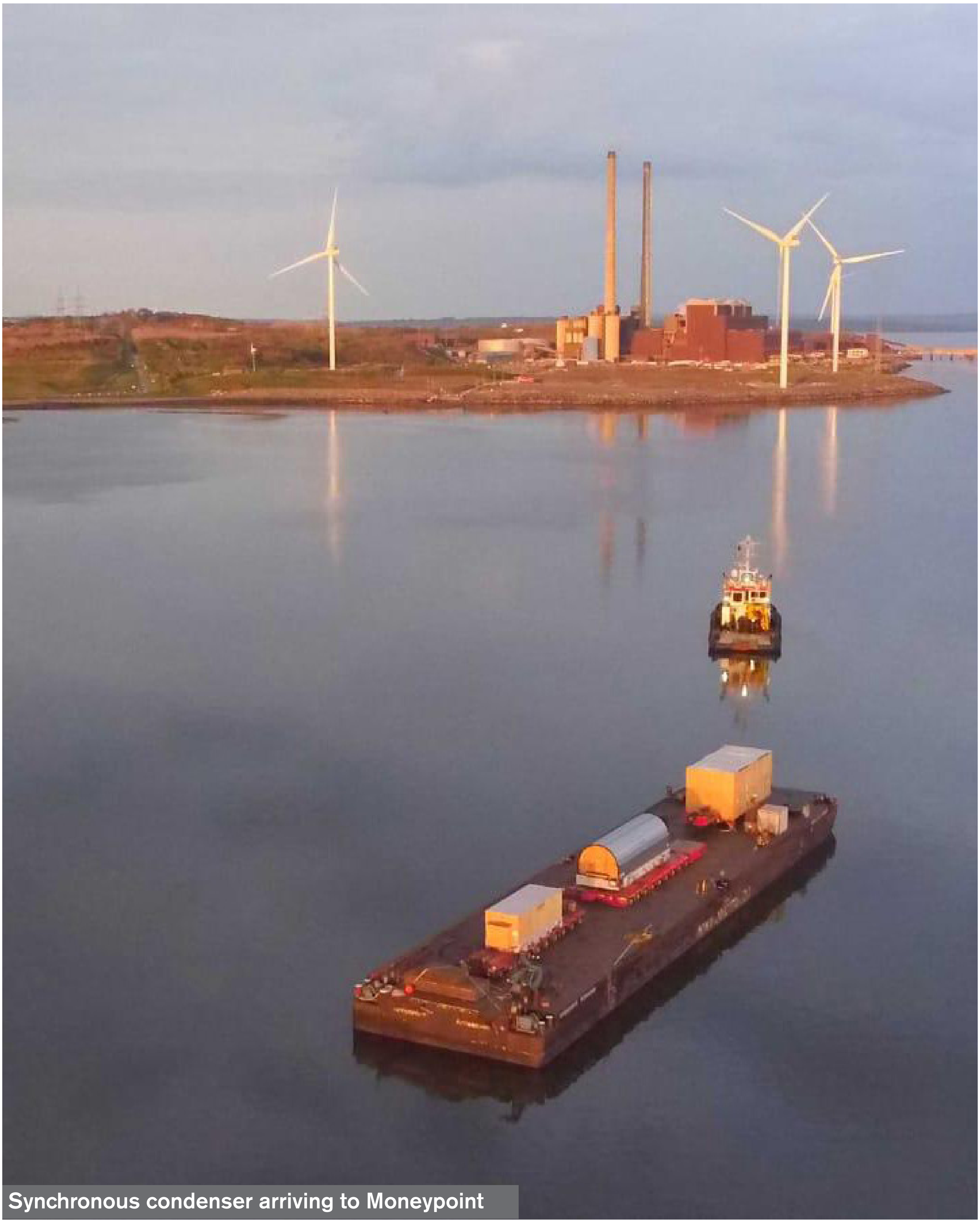
EirGrid has developed a Power System Operational Policy Change Roadmap, setting out how power system operational policy will need to evolve to facilitate the integration of high-levels of intermittent, non-synchronous renewable generation. The Eirgrid DS3 programme has been supporting those technologies that deliver frequency balancing, ramping, voltage, and inertia services on the grid. EirGrid has been able to increase the limit of system non-synchronous penetration (SNSP), including wind, solar and interconnectors, from 50% to 75%. By 2030, the SNSP is set to increase to 95% in order to achieve Government renewable energy targets where operational grid constraints such as frequency and voltage stabilisation, SNSP limit, and inertia floor of the grid will need to be managed.

By 2030, Eirgrid has planned to reduce the Inertia floor from 23,000 to 17,500 MWs and reduce the minimum number of thermal stations online from 8 to 4 or less in the all-island system. SC and flywheels are able to provide low carbon inertia and voltage stabilisation which can reduce the minimum number of stations online and facilitate penetration of renewables on the grid.

Leveraging off the Moneypoint synchronous compensator experience, EirGrid announced their intention to run a “Low Carbon Inertia Service” competition in late 2023, awarding long term contracts to system stability devices such as synchronous compensators in Ireland north and south.

Summary

SCs coupled with flywheels are going to play an increasing role along with the increase of renewables. The technology is undoubtedly necessary in order to allow thermal stations to retire and bring more renewables on the system. A support mechanism is still needed as the technology is relatively expensive, considering that no active power is generated.



Synchronous condenser arriving to Moneypoint

3.2 EMERGING BATTERY TECHNOLOGIES

Technology

TRL 4-9

Alternative battery chemistries to Lithium ion are commercially proven for certain static storage applications. Sodium, Nickel, Lead Acid, and various flow technologies (Vanadium, Zinc and Iron) are the most advanced. Some examples are given here and a more detailed overview of the various technologies available can be found in the report linked below.

Iron air (TRL 5-6):

Form Energy's iron air battery claims an ability to store electricity for 100 hours, compared to about 4-6 hours for a lithium battery. This battery consists of a metal anode which is exposed to air to form a rust coating. This works by reversing the oxidation of iron. In discharge mode, thousands of tiny iron pellets are exposed to the air, which makes them rust (ie, the iron turning to iron oxide). When the system is charged with an electric current, the oxygen in the rust is removed, and it reverts to iron. Some drawbacks are the poor efficiency and short life spans, although iron air batteries have a very high energy density compared to Li-ion batteries and can store energy for days. It has a slow discharge characteristic and is not suitable for a high-power boost requirement.

Vanadium Redox Flow Batteries (TRL 8-9):

Vanadium is the current market leader in terms of installed capacity for Flow Batteries. Vanadium as a material offers reasonable energy yield, however it is currently significantly more expensive when compared to Lithium. An important differential of this technology is that unlike many other flow batteries, Vanadium Redox Flow Batteries (VRB) utilise vanadium for both positive and negative electrolyte solutions. This has the advantage of limiting the effect of cross contamination of solutions and results in low levels of self-discharge, which is potentially an advantage for long duration storage.

Sodium Batteries (TRL 7-9):

Sodium based batteries have been around for decades and are one of the more prominent alternative battery chemistries in recent years. Sodium is inexpensive and has potential cost advantages on the raw material side compared with lithium. The electrochemical performance of sodium batteries is relatively stable and safer than Li-ion batteries and can adapt to high and low temperatures between -30 and 80 degrees Celsius without much energy attenuation. However, sodium batteries have a lower energy density than Li-ion and can only reach about 2000-4500 cycles at 100% depth of discharge.

Lithium-ion Capacitors (TRL 4-5):

Lithium-ion Capacitors (LICs) combine the high power capability and long lifetime of Electrical Double-Layer Capacitors (EDLCs) with the high energy density of Lithium-ion Batteries (LIB). These characteristics make them very attractive for traction applications that need a high peak power, such as hybrid buses, trams, trains, etc. LIBs have relatively low power density (circa 0.1 - 1 kW/kg) whereas LICs have a very high power density (10kW/kg). However, LIBs have a high energy density (circa 260 wh/kg) and LICs have a low energy density (<100wh/kg). Therefore, LIC are primarily suited to high power, very short duration use cases.

Commercialisation

1-5 years

One of the leading lithium-Ion chemistries is Lithium Iron Phosphate (LFP). The Chinese firm, EVE, have designed a new LFP battery cell with a large capacity of 560Ah. A single battery can store 1.792kWh of energy, and the cycle life exceeds 12,000. This is the largest energy storage battery cell ever produced, with twice the energy capacity of the 280Ah prismatic cell.

Altech Chemicals and research institute Fraunhofer-Gesellschaft have progressed plans for a 100MWh plant in Germany to produce sodium solid state battery technology.

Invinity Energy Systems and chemicals company BASF have announced the first deployments of their non-lithium battery storage technologies in Hungary and Australia respectively. Invinity makes its own vanadium redox flow battery (VRFB) energy storage systems, while BASF has the license to distribute the sodium-sulfur (NAS) battery storage technology developed by Japan's NGK Insulators.

Form Energy in a first-of-its kind pilot project with Great River Energy plans to install a 1.5 MW iron-air battery pilot project next to its natural gas peaking plant in Cambridge, Minnesota. Form Energy has started the construction of its 800,000-square-foot manufacturing facility in West Virginia. Operations are scheduled for late 2024.

Australia-based Redflow, has finished the installation of a 2MWh zinc-bromine system in California.

EDP has received clearance to deploy a 1MWh vanadium flow battery system as part of a hybrid energy storage project at the site of a retiring thermal plant in Asturias, Spain.

German utility company RWE has been awarded a long-term contract for a 50MW/400+MWh (8 hour) battery storage project in New South Wales, Australia. This is one of the longest duration lithium battery projects in the world.

In early 2023, the first generation of mass-produced sodium-ion batteries has been installed in a production electric car for the first time. The small car is part of VW's joint venture Sehold brand in China and can cover 200 kms on a charge.

ESB Activities

Currently monitoring sector

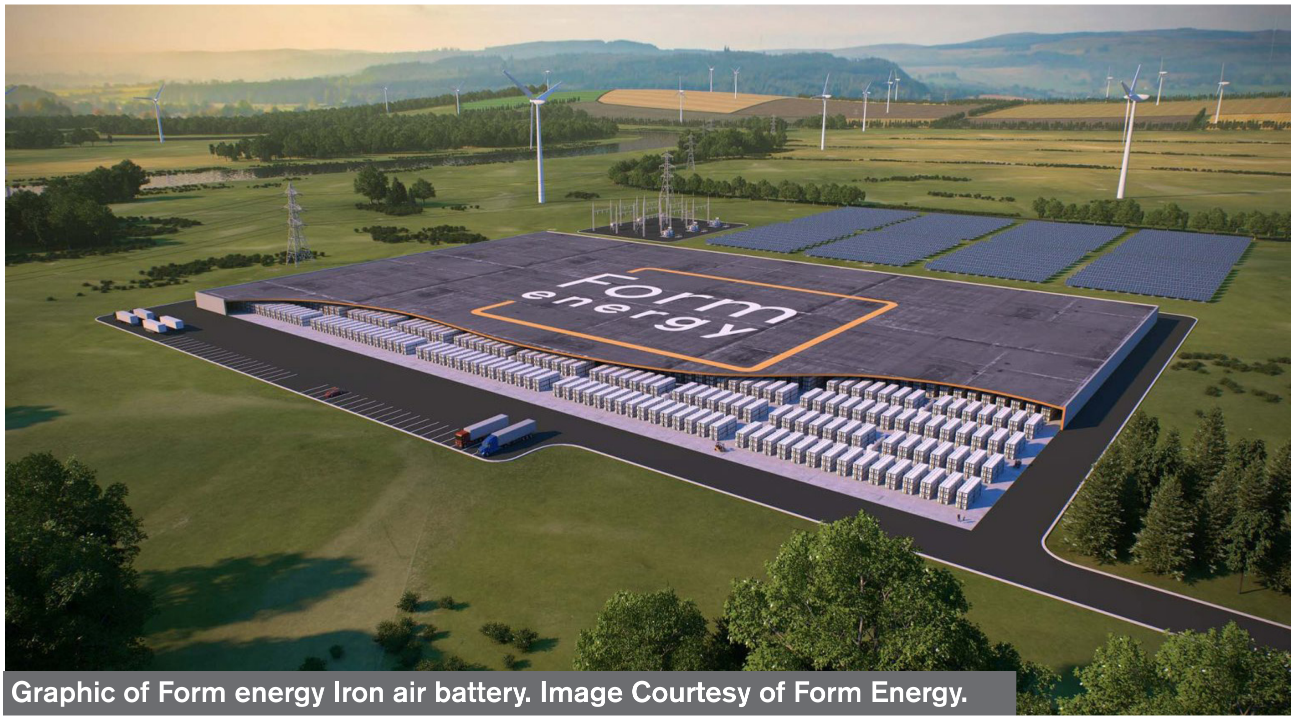
ESB is currently assessing the potential for alternatives to Lithium chemical storage, including the viability of long duration storage for energy arbitrage under I-SEM and network services. Multiple sites and a full battery technology assessment is being carried out by ESB to establish potential alternatives to Li-ion batteries.

Policy

Storage will be vital in helping to meet our Climate Action Plan objectives of increasing the proportion of renewable electricity to 80% by 2030 and ultimately in decarbonising the electricity system.

Towards the end of 2022, DECC issued a consultation document on developing an electricity storage policy framework for Ireland. ESB gave input into this consultation. The combined storage capacity connected to the grid in Ireland today is approximately 792MW, including lithium-ion batteries with a total charging and discharging capacity of approximately 500MW. An array of storage technologies at various durations, will be required to support the transformation of the electricity system as the level of renewable penetration increases.

At European level, in March 2023, the European Commission published a proposal to reform the EU electricity market. The proposal follows a public consultation period from 23 January 2023 to 13 February 2023, during which a variety of stakeholders provided a response sharing their views. The intention is for the market send investment signals and enhance market conditions for flexibility which will include energy storage. This change will have to considered and implemented at Irish level which may take some time.



Graphic of Form energy Iron air battery. Image Courtesy of Form Energy.

Summary

The decision to deploy a specific type of storage system for a particular application depends not only on the technology but also on its economic feasibility. It is worth noting that the techno-economic evaluation of storage systems, especially for portable application and transportation, has been widely assessed. Yet, this is not the case for a utility-scale stationary application and especially when it comes to grid services. There is a significant lack of data and information on cost parameters and the techno-economic feasibility of energy storage systems (ESS) for grid-scale stationary applications.

Future investment in non-lithium technologies carries more risk as technologies are still relatively immature and may present inadequate performance or life span challenges. This may greatly impact the services contracted to the System Operator. The existing grid code requirements for batteries is largely treated as a power plant and is extremely rigorous in nature. In order for traction in the market using other battery and storage technologies, new policies of how energy storage is treated will need to be developed and implemented.

Reports (ESB staff access only)

Non-Lithium Chemical Battery Storage Overview 2018

3.3 LIQUID AIR ENERGY STORAGE

Technology

TRL 7-8

Liquid Air Energy Storage (LAES) is a thermo-mechanical energy storage system, specifically cryogenic energy storage. Grid electricity is used to compress and cool atmospheric air until liquid at cryogenic temperature of -196°C. When active power is required by the grid, liquid air is released to turboexpanders where electricity is generated. If the electricity used to liquify the air is sourced by renewables, the process is carbon neutral.

This technology allows the storage of large quantities of energy above ground without geological constraints. LAES allows for discharging times of several hours (<6 hours). Roundtrip efficiency (electricity to electricity) could reach 60-70% if waste heat is used in the process. Also, it can provide synchronous inertia, short circuit, and dynamic voltage control to the grid supporting more renewable penetration. The projected lifetime of a LAES plant is >30 years with no major performance degradation due to cycling.

Drawbacks of LAES include long construction times (18 – 24 months) compared to battery storage, H&S issues related to handling of liquids at cryogenic temperatures, and the homogeneity and purity of the liquid stored at cryogenic temperatures is critical to avoid boil-off.

LAES has been demonstrated at small scale and in a commercial environment (TRL 7-8).

Commercialisation

1-5 years

LAES technology leader and project developer is the UK company Highview Power. In October 2019, Highview Power teamed up with Carlton Power for a 300 MWh (50MW) system in Trafford Energy Park, Manchester, UK. It is currently under construction and is expected to cost c. £ 85m. In 2023, Highview announced a 250MWh (50MW) development in Yorkshire, UK.

In 2021, Highview Power announced the development of up to 2 GWh of LAES projects across Spain with an estimated investment of around $1 billion. The plan is to develop up to seven projects starting at 50 MW/300 MWh in Asturias, Cantabria, Castilla y Leon, and the Canary Islands. Highview Power stated that its global pipeline of projects is roughly 400MW/4GWh however none of this capacity has completed construction or is in operation. In April 2023, Highview Power announced a partnership with Ørsted to investigate hybrid offshore wind and LAES technical feasibility.

Highview Power has reported a levelised cost of storage (LCOS) at approximately £110/MWh for large applications of a 10-hour, 200MW/2GWh system.

Large LAES systems require high upfront investment and securing funding can be a challenge due to uncertain future revenue streams. All these developments have the potential of bringing the technology to TRL 9 and commercial readiness by 2025. However, some industry experts remain pessimistic on the ability of the technology to become commercial before 2030, mainly due to market challenges and low competitiveness compared to other storage technologies such as batteries. For comparison, battery cells cost $270-300/kWh (based on estimates for a 4-hour battery, excluding grid and development costs).

The energy storage market is currently highly uncertain. Nevertheless, the economic feasibility of storage is increased when it is used for multiple purposes in the market such as energy shifting, provision of capacity and system services (DS3 program in Ireland). Energy shifting is the main driver for utility-scale energy storage deployments, generally paired on-site with renewables. However, high capital costs and uncertain revenue streams on long lifetimes make the business case for LAES challenging.

ESB Interaction

Technology ranking exercise

ESB is working on a detailed technology ranking exercise for long duration energy storage (LDES), which will include reviews of LAES technology.

Policy (ROI)

Several studies in Ireland and UK published recently have highlighted that large-scale LDES (over 4 hours) will be essential to ensure resilience and security of supply in a high renewable penetration scenario by 2030. However, no policy or market mechanism supports it.

CAP 2023 mandates ESB Networks and Eirgrid to introduce flexibility market arrangements to incentivise commercial storage facilities at scale. Key Performance Indicators (KPIs) are in place for 2025 and 2030 to introduce LDES (4hr+). The Commission for Regulation of Utilities (CRU) is mandated to undertake a review of regulatory treatment of storage, including licensing, charging and market incentives that support the achievement of electricity emissions reduction targets. In 2024, DECC have stated an intention to develop a storage policy framework supporting the 2030 targets in 2024 and aligns with our renewable gas ambition, security of supply, and flexibility policy drivers.

In 2022, the UK government published a report detailing the facilitation of large scale, LDES deployment, anticipating 30GW of low carbon flexible assets by 2030. The report mentions LAES as an emerging technology of interest. The UK government have set an ambition to develop appropriate policy to enable investment in long-duration energy storage in 2024.

Summary

LAES is well suited to provide bulk energy shifting, grid services as well as capacity. The main challenge is the competition with other storage technologies such as batteries. LAES requires higher upfront investments while offering potentially lower LCOS than batteries, due to longer lifetimes. However, for storage systems the revenue streams are uncertain over such a long lifetime. Therefore, a market mechanism specific for long duration and large energy storage is necessary to make these technologies commercially viable. Furthermore, as this process uses equipment already available on the market, it is unlikely there will be a dramatic reduction of costs in the future.

Reports (ESB staff access only)

Thermal Energy Storage 2020

3.4 ADIABATIC COMPRESSED AIR ENERGY STORAGE

Technology

TRL 7-8

Compressed air energy storage (CAES) stores energy for later use by compressing air. Heat is generated during compression and heat is required before air expansion. Conventional CAES, called Diabatic CAES (D-CAES, TRL 9) uses fossil fuels for compression and expansion. The heat generated during compression is normally dissipated. Adiabatic CAES (A-CAES, TRL 7-8) compresses with renewable sources and stores the heat for reuse during expansion. No emissions from burning fossil fuels are generated in the process.

Theoretically, efficiency of A-CAES approaches 100% with perfect insulation, however, in practice round trip efficiency (RTE) (AC-to-AC) is ~70%.

There are several designs of A-CAES systems. Hydrostor is the leading design at TRL 7-8. The air is stored in purpose built underground storage caverns, connected to a water reservoir. A constant pressure is maintained by varying the reservoir water level. A 250-MW, 8-hour A-CAES system requires about 0.4 million m3 of water. For comparison, Turlough Hill upper reservoir has 2.3 million m3 capacity. The mined-rock air storage caverns are typically at a depth of 300-600m. The greater the storage requirements (MWhs), the larger the cavern. Under development by Hydrostor is an underwater CAES (UW-CAES) system using large inflatable balloons placed on a seabed or lake floor for air storage under natural (and constant) hydrostatic pressure. Hydrostor has developed their own proprietary thermal storage, the operating temperature of the hot tank is ~150^{o}C. The fluid used is most likely water.

Hydrostor's A-CAES system provides long-duration (4-24 hours), non-emitting, long-asset life (50+ years) bulk energy storage for applications including direct replacement of fossil generation, renewables load balancing, grid reserve and ancillary services, and the relief of grid congestion. Hydrostor A-CAES systems' steady-state RTE, AC-to-AC, including all auxiliary loads and assuming daily cycling, is projected to be around 60% with a start-up time of 5 minutes and an operating ramp time of 5%/second.

Commercialisation

1-5 years

In 2015, Hydrostor completed a demonstration site in Toronto which was decommissioned in 2020. Hydrostor commissioned a 1.75MW (10MWh) facility in Goderich, Ontario and has been in service since 2019. The facility provides dispatchable capacity in an area of high wind penetration and stores air in an existing salt cavern. Hydrostor has several projects under development. One leading example is Willow Rock, California (500MW / 4GWh), with a planned operation date of 2026. This project has a 25-year PPA in place with Central Coast Community Energy.

Hydrostor has a supply partnership and equity sponsorship with Baker Hughes for the turbo-machinery. In 2022, a consortium of EDF, io Consulting and Hydrostor has won £1 million from the UK Government to develop storage of electricity as compressed air. This could use mothballed EDF gas cavities in Cheshire, UK.

BloombergNEF has reported an LCOS for Hydrostor between $100-150 /MWh (2025) for a lifetime of a plant of 50 years. This is comparable with Li-ion costs. Hydrostor estimates that the capital cost of a commercial A-CAES plant in the 50 MW to 500 MW range, with 10 hours of storage capacity, will be $1500–3000/kW. These figures are comparable with pumped hydropower technology. The marginal cost to add energy capacity (discharge duration) is approximately $40-60/kWh. However, costs are dependent on geological site specifics.

ESB Activities

Under review

No active projects are being developed in ESB featuring A-CAES at present. A technology watch is kept by the ETRD team.

Policy (ROI)

Several studies in Ireland and UK published recently have highlighted that large-scale and long-duration electricity storage (over 4 hours) and system services solutions will be essential to ensure resilience and security of supply in a high renewable penetration scenario by 2030. However, no policy or market mechanism supports it as yet.

CAP 2023 mandates ESB Networks and Eirgrid to introduce flexibility market arrangements to incentivise commercial storage facilities at scale. Key Performance Indicators (KPIs) are in place for 2025 and 2030 to introduce LDES (4hr+).

The Commission for Regulation of Utilities (CRU) is mandated to undertake a review of regulatory treatment of storage, including licensing, charging and market incentives that support the achievement of electricity emissions reduction targets. In 2024, DECC will develop a storage policy framework that supports the 2030 targets and aligns with security of supply, and flexibility policy drivers.

Summary

The outlook of A-CAES is positive, however is highly dependent on availability of geological storage and the market conditions. A-CAES leverages traditional CAES, which has been operational since late 1970s, and uses readily available components. This technology is expected to offer a comparable scale to pumped hydro by the mid 2020's.

Hydrostor A-CEAS storage facility, Canada. Image courtesy of Hydrostor.

3.5 CO2 BATTERY STORAGE

Technology

TRL 7-8

A CO2 Battery is an energy storage system using carbon dioxide as a working fluid. The leading OEM is Energy Dome whose proprietary technology utilizes a closed thermodynamic cycle and has a planned 4-24 hour duration.

The CO2 battery is made primarily with off-the-shelf industrial parts such as compressors and turbines along with standard piping and instruments. The CO2 is stored in a dome with a PVC coated polyester fabric. CO2 is stored in the dome in gas form slightly above atmospheric pressure. It allows for high-density energy storage without the need to go to extremely low temperatures.

To charge the battery, the CO2 changes from a gaseous to a liquid state. The system pulls CO2 at near atmospheric pressure and temperature from the dome and compresses it down to a liquid form which is stored in multiple tanks at high pressure at approximately 70 bar. As the system is charging, the inner membrane collapses down to the floor of the dome as the gas is expelled. The heat that is generated during the compression stage is stored as thermal energy in the Thermal Energy Storage (TES) tanks and is used in the discharge cycle.

To discharge, the liquid is heated up from the previously stored heated energy in the TES to turn it back into a gas. As the CO2 expands from a liquid to a gas, it turns a turbine to generate electricity onto the grid. During the discharge stage over a long period of time, the high-pressure CO2 gas is transferred from the liquid tanks back into the dome at just above atmospheric pressure. During this process the inner membrane rises as the gas expands to fill the dome volume to be ready to recommence the charging cycle when required.

The CO2 Battery can store renewable energy with 75% RTE (AC-AC) and can potentially compete with price of lithium-ion batteries. Unlike lithium-ion batteries that suffer significant performance degradation, the CO2 Battery maintains its performance during its expected 25-year operational lifetime.

Commercialisation

Under review

In June 2022 Energy Dome launched its first CO2 battery facility in Sardinia and entered the commercial scaling phase. The company's first major project, a 2.5MW/4MWh CO2 Battery facility is now fully operational and the bridge financing will allow it to accelerate the development of its larger, ten-hour duration 20MW/200MWh system. This full-scale project is being constructed close to the existing demo site in Sardinia.

In September 2022 Energy Dome and Ørsted signed a Memorandum of Understanding, to run a feasibility study on the deployment of a 20 MW / 200 MWh energy storage facility using the CO2 Battery technology.

In December 2022, Energy Dome was awarded €17.5 million in funding from the European Innovation Council (EIC), the largest amount made available by the program. Energy Dome was selected through a highly competitive process from more than 1000 companies that submitted a full application.

In April 2023 Energy Dome closed a €40 million funding round – bringing the total raised for its novel energy storage solution to €54 million. The round was co-led by Eni Next, the corporate VC arm of Italian energy giant Eni; along with Neva SGR, the VC company owned by European banking group Intesa Sanpaolo.

Energy Dome CO2 battery, Sardinia

ESB Activities

Under review & Site visit for Demo project

In October 2022, ESB visited the Energy Dome's demonstration plant which is situated in the centre of an industrial area on the island of Sardinia in Italy. It was commissioned in May/June 2022 and is currently connected to the local distribution power grid. It can export up to 2.5 MW with an energy capacity of 4MWh. Fichtner Consulting were engaged with the demo plant site testing and are validating the technology and the performance of its operation. The Emerging Technology team completed a Technology Spotlight report on the CO2 battery at the end of 2022 and plans to visit the full-scale project on completion in 2024.

Policy (ROI)

Several studies in Ireland and UK published recently have highlighted that large-scale and long-duration electricity storage (over four hours) and system services solutions will be essential in order to ensure resilience and security of supply in a high renewable penetration scenario by 2030. However, there is no policy or market mechanism that incentivises it at present.

Storage will be vital in helping to meet our Climate Action Plan objectives of increasing the proportion of renewable electricity to up to 80% by 2030 and ultimately in decarbonising the electricity system. Towards the end of 2022 DECC issued a consultation document on developing an electricity Framework for Ireland. ESB gave input into this consultation.

At European level, in March 2023, the European Commission published a proposal to reform the EU electricity market. The proposal follows a public consultation period from 23 January 2023 to 13 February 2023, during which a variety of stakeholders provided a response sharing their views. The intention is for the market send investment signals and enhance market conditions for flexibility which will include energy storage. This change will have to considered and implemented at Irish level which may take some time.

Summary

The potential use case for CO2 batteries may be timely as the DECC is developing a new policy on the role of electricity storage in Ireland. ESB need to be ahead of the curve and have storage technologies selected that can be bid into future DS3 and capacity auctions. It also aligns with Eirgrid's FlexTech activities where energy storage is a key part of. Further financial incentives are likely to enable these investments. The CO2 battery, with its proven and mature technology should be selected for further evaluation as one of the potential technologies to deliver ESB's energy storage solutions.

Reports (ESB staff access only)

CO2 battery Spotlight.pdf

3.6 THERMAL ENERGY STORAGE - BRICK & CONCRETE

Technology

TRL 5-7

Brick and/or Concrete thermal energy storage is a form of thermal storage where excess energy is used to increase the temperature of a heat transfer fluid (air/water/steam/oil) which heats a brick/concrete mass to a high temperature. The mass stores heat which is discharged to produce heat or electricity when needed. Brick and concrete represent similar storage mediums. A high temperature heat source or electric heating coils are required. There are several designs operating at different temperatures, using different storage media or heat transfer fluids including:

- Rondo Energy (TRL 6-7) technology uses thermal radiation from an electric heating element to heat clay brick stacks, operating at 1000-1500°C with discharge times of up to several days.
- EnergyNest (TRL 7) uses either synthetic oil (Dowtherm-A) or water / steam as heat transfer fluid to transport high-temperature heat (up to 400°C) to cast concrete cylinders. The main innovation of EnergyNest's design is their proprietary concrete mix called Heatcrete.
- Storworks Power (formally Brighter Energy) design operates at high temperatures (up to 600°C). Therefore, supercritical steam can be used as heat source (TRL 5). This design can be used to tie in with power generation steam cycles, due to the high temperatures involved.

The use of thermal storage technology in industrial processes can reduce waste heat and increase flexibility. These technologies allow for long discharging times (four hours up to a few days with 1-2% losses per day) and long lifetime with negligible performance degradation due compared to lithium-ion batteries. Furthermore, the stability of the tube-concrete interface given the potential for differential expansion and associated mechanical stresses is still to be determined.

Heat to electricity roundtrip efficiency is relatively low (40%), so the technology is best suited for applications where heat is charged and discharged (heat roundtrip efficiency up to 90-98%).

Commercialisation

Industrial application: 1-5 years
Grid application: > 5 years

As of March 2023, Rondo has deployed a 2MWh system in California at Calgren's production plant (biofuels producer). The system supplies heat at 1000°C.

The EnergyNest solution finds better applications in the industrial sector rather than integrated in steam cycles for power generation.

EnergyNest partnered with Yara International (crop nutrition company) and AC Boilers S.p.A on their first commercial project, operational as of 2022. A 4 MWh thermal battery directly connected to the steam grid at their production facility in Porsgrunn, Norway. The system provides increased flexibility to the plant by balancing local steam production and reducing dumped excess steam. This plant is one of the largest of its kind in Europe, and it is expected to help reduce GHG emissions by around 5,000 t/annum.

Installation was completed in early 2023 of an EnergyNest battery on Avery Dennnison's plant in Belgium. The system will use excess concentrated solar thermal (CST) energy to keep the plant running at night. The project received funding under Horizon 2020. EnergyNest has announced projects with Italian oil company Eni and brick maker Senftenbacher;

In the power sector, the Electric Power Research Institute (EPRI) is leading a pilot project to test the Storworks concrete thermal energy storage at the Alabama Power's E.C. Gaston Steam Plant in Wilsonville, AL, USA. The aim of the project is to evaluate how concrete thermal storage can assist coal plant thermal fluctuations and for electricity production. The 10 MWhe pilot was constructed in 2021 and became operational in 2022.

ESB Activity

Under review

ESB engineering teams completed a technology review of grid-scale thermal energy storage including concrete thermal energy storage.

Rondo Energy is currently short-listed as part of the Free Electrons programme. Rondo and concrete storage technologies will also feature in a 'storage technologies ranking' exercise being undertaken.

Policy (ROI)

In CAP 2023 there is no specific mention of thermal storage technologies for industrial heat, reflecting its status as a pre-commercial technology in Ireland.

Summary

The outlook for brick/concrete thermal energy storage is positive as these systems are easy to manufacture, build and operate. They are best suited to situations where heat is stored for later use as heat, rather than heat stored for later conversion to electricity. Therefore, applications are expected to be largely in the industrial sector.

Reports (ESB staff access only)

Thermal Energy Storage 2020

Rondo Brick storage facility, California. Image courtesy of Rondo.

Energy for generations

4.0 HYDROGEN

4.1 HYDROGEN / ELECTROLYSIS

Technology

TRL 7-9

Electrolysis is the process of splitting of water into hydrogen and oxygen by using electricity. The process is carbon-neutral if renewable energy is used to power the electrolyser. This is a well-established process for production of hydrogen for industrial applications. The three most advanced types of electrolysis are:

- Alkaline Electrolysis (AEL) – TRL9. This is the most established technology but not flexible in operation c. 60% efficiency. This technology avoids the use of precious metals, the electrolyte is generally a solution of potassium hydroxide or sodium hydroxide.
- Proton Exchange Membrane (PEM) – TRL 7-8. Currently, 63% efficiency but room for improvement possible by 2030. The electrolyte is a solid specialty plastic material (referred to as the membrane).
- Solid Oxide Electrolysis (SOE) – TRL7. The least maturewith c.70% efficiency. SOE utilises solid ceramic electrolytes. The process requires the use of high temperature steam as a feed source and generally operates at temperatures in the range between 700-1000°C.

Commercialisation

1-5 years

Globally, installed capacity of water electrolysers for hydrogen production was more than 500 MW by the end of 2021. The manufacture of electrolysers is set for massive growth, with predictions of 47GW annually by 2030. The preferred technology for bigger projects (100s MW) is alkaline due to low costs and maturity.

The most active OEMs for PEM technology are Plug Power, Siemens and ITM Power while Nel, McPhy, Green Hydrogen Systems, HydrogenPro are the most active for alkaline technology.

The world's largest green hydrogen project, with a 150MW alkaline electrolyser, is in China, powered by a 200MW solar array. It was developed by Ningxia Baofeng Energy Group.

The IEA reports that electrolyser CAPEX costs are currently in the range of $500-1400/kWe for alkaline electrolysers and $1100-1800/kWe for PEM electrolysers, while estimates for solid oxide electrolyser cell (SOEC) electrolysers range across $ 2800-5600/kWe. Costs are expected to decline significantly as manufacturing scales up.

Depending on where the electrolyser is located and thus cost of renewable electricity, hydrogen production via electrolysis would cost €3-9/ kgH2, green hydrogen costs are highly variable and may be outside this range in certain cases.

ESB Activities

ESB actively assessing potential projects

- In 2022, a revision of the ESB Brighter Future Strategy sets the challenge for ESB to reach net zero by 2040. This will require renewables, energy storage, hydrogen and new zero-carbon dispatchable generation.
- ESB is developing its first hydrogen project 'Fast Track' consisting of a c.0.9MW alkaline electrolyser which will produce hydrogen for use in mobile fuel cells. Mobile storage will also enable industrial and transport operators. First hydrogen production targeted in Q2 2024
- A pipeline of Lighthouse projects are under development which will target industrial, data centre and transport offtakers. Opportunities for directly co-locating an electrolyser at a wind farm are being assessed.

- The Green Atlantic project at Moneypoint, announced in April 2021, is ongoing. This is a multi-billion-euro project with the aim of repurposing the coal station site into a green energy hub. Amongst different phases, it includes a 1,400 MW floating offshore wind farm coupled with green hydrogen production, storage and generation facility.

Policy (ROI)

In 2020, the European Union set a target for electrolyser capacity to reach 6 GW by 2024 and 40 GW by 2030.

The Inflation Reduction Act (IRA) in the US offers generous supports for hydrogen production of up to $3 per kilogram of clean hydrogen produced.

The Hydrogen Strategy for Ireland was published in July 2023. ESB contributed extensively to the consultation process.

CAP 2023 plans for 2 GW of offshore wind energy for green hydrogen production

Summary

Globally, the outlook for electrolyser technology is extremely positive, with very large growth expected. As manufacturing scales up, significant price falls are expected.

Reports (ESB staff access only)

Low Carbon Hydrogen 2021

4.2 HYDROGEN / FUEL CELLS

Technology

TRL 7-9

Fuel cells are electrochemical conversion devices which convert gaseous fuel (including hydrogen or hydrogen rich fuels) and an oxidant (air or pure oxygen) directly into electricity in the presence of an electrolyte, by a process other than combustion.

The reaction process is facilitated by a catalyst. Technologies vary in terms of type of electrolyte, operational temperatures, and efficiencies.

- Proton Exchange Membrane Fuel Cells (PEMFC) use a solid polymer-based, proton-conducting membrane as the electrolyte. These are susceptible to fuel impurities, have low operational temperatures (50 – 250°C) and use platinum as the catalyst. The efficiencies range between 40 – 60%. For mobile applications, PEMFC are a mature technology (TRL 9).
- Phosphoric Acid fuel cells (PAFC) use liquid phosphoric acid as electrolyte and platinum as the catalyst. These operate at temperatures between 15-200°C. The electrical efficiency is circa 37-42%. They can operate with hydrogen as well as natural gas, biogas, and Liquefied Petroleum Gas (LPG). Due to their relatively low energy densities and long start-up time, these fuel cells are generally used for stationary applications (TRL 9).
- Technologies that utilise non-platinum catalysts, such as the Solid Oxide fuel cells (SOFC) use non-porous ceramic compounds as electrolyte, have higher operational temperatures (600 – 1,000°C) and improved efficiencies (50 – 65 %). This technology is generally used with natural gas (TRL 9). Application of SOFC with hydrogen is still limited due to the high cost of hydrogen (TRL 7). The start-up times are quite long (> 24 hours) and therefore more suited for stationary, base load applications.

Commercialisation

<5 years for mobile applications
>10 years for stationary grid applications

The largest markets for stationary fuel cells are currently the USA and South Korea. Numerous small-scale grid applications have been reported, with typical applications as part of CHP plants and data centres, both as a storage solution and to diversify generation.

A key challenge to the viable implementation of wide scale fuel cell adoption is the sourcing of economic hydrogen, as well as the implementation of suitable storage and transport infrastructure. For stationary grid-scale installations, typical uses tend to favour high-energy, low-power applications (typically 1–5 MW, 5–25 MWh). The average capital expenditure of large-scale fuel-cell power plants is at around $5m/MW (2020), which is at least three times that of coal- or gas-fired power plants.

The world's largest hydrogen fuel cell power plant (78.96 MW) is in South Korea's western port city of Incheon. The project cost about $292 million.

Utilisation of fuel cells for transport is a more mature application of the technology. Compared to battery electric vehicles (BEVs) fuel cell electric vehicles (FCEVs) have improved driving ranges and much quicker refuelling times (3 – 5 mins). However, due to efficiency losses in the production of hydrogen and fuel cell operation, BEV will always have lower running costs compared to FCEV. Globally there are 740 hydrogen refuelling stations but over 8m of charging points for battery electric vehicles. Nevertheless, FCEV have potential applications whereby vehicles have high utilisation rates such as logistic vehicles and intercity bus fleets, high vehicle weight (HGV) and where direct electrification of transport is not possible (aviation, maritime).

The JIVE 2 (Joint Initiative for hydrogen vehicles across Europe) project plans to facilitate the deployment of over 150 fuel cell electric buses across 14 European cities.

Translink, together with the Energia Group, formed a consortium which successfully bid for part funding for the supply of three hydrogen fuel cell buses. The buses are being supplied by Wrightbus, with the first entered operation in Belfast, in December 2020. The overall capital investment is around £4 million. This is part of the Gencomm project with partners including NUIG and Hy Energy, funded by the Interreg North-West Europe (NWE) Programme.

ESB Interaction

Exploring possible projects

In 2020, ESB took part of a new, in-service, trial of a fuel cell electric bus in the Dublin area powered by hydrogen produced by renewable electricity from ESB's Ardnacrusha power station via certificates of Guarantees of Origin. Co-ordinated by Hydrogen Mobility Ireland, this was the first FCEV put into public service in the Republic of Ireland.

As part of 'Fast Track' project – the re-electrification of hydrogen via fuel cells is targeted for demonstration beginning Q4 2023. The fuel cells are rated for c.100kW with a 250kW peaking output capability via batteries (40mins). These fuel cells are mobile and intended to displace diesel generators for peaking, off grid and temporary power applications.

Policy

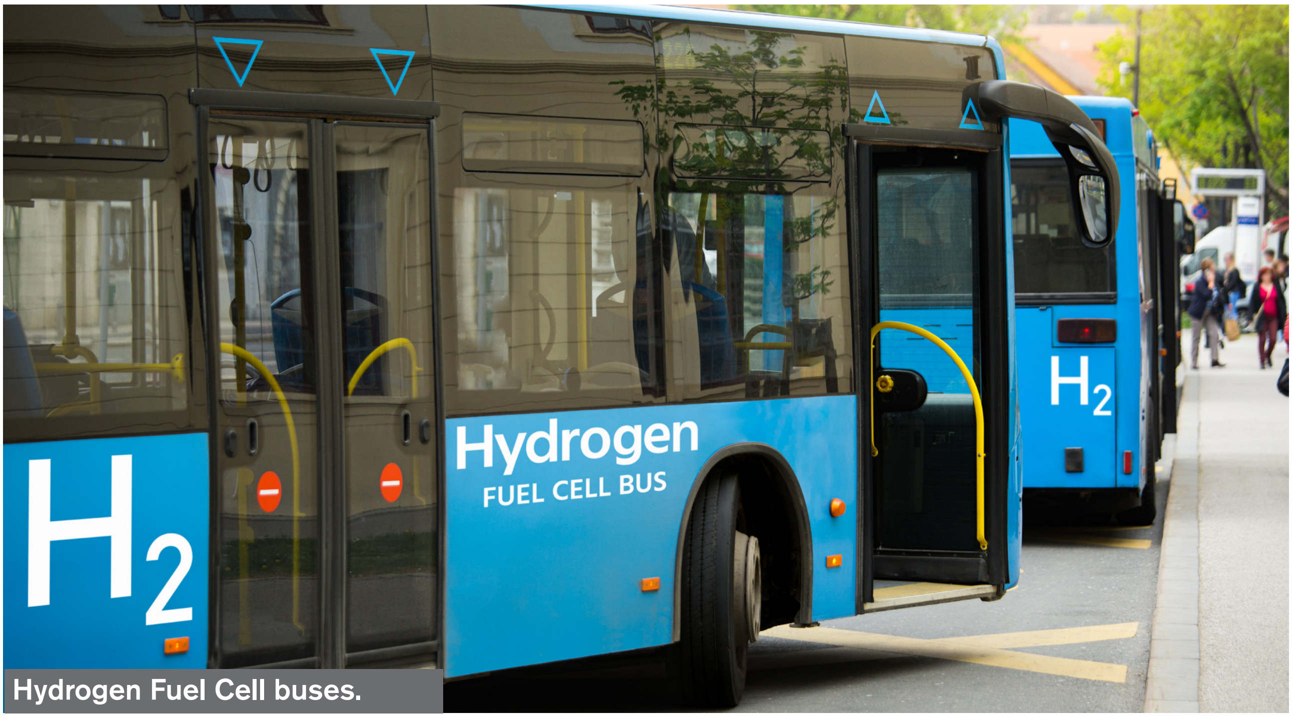
The Hydrogen Strategy for Ireland was published in July 2023. ESB contributed to the consultation process.

Summary

Globally, the outlook for fuel cells is positive, with high growth forecast. Fuel cells for mobility will have to compete with electrical transport solutions and are most likely to succeed where electrical solutions are not feasible. Stationary fuel cells offer an attractive option of producing electricity from hydrogen without combustion or NOX emissions. However, price challenges remain.

Report (ESB staff access only)

Low Carbon Hydrogen 2021



Hydrogen Fuel Cell buses.

4.3 HYDROGEN STORAGE

Technology

TRL 2-9

The technology options for storing hydrogen vary depending on the scale required. The main ways to store hydrogen are:

- Compressed hydrogen in pressurised tanks (TRL 9). Pressure of the tanks ranges from 170 bar (aluminium material) up to 1,000 bar (advanced composite materials). The main technical issues for pressure vessels are the resistance to expansion and contraction and hydrogen embrittlement. Pressurised tanks are mainly used for hydrogen transport with tube trailers or for fuel cell vehicles. The energy stored is low MWh scale.
- Compressed hydrogen can be stored in underground caverns (aquifers, salt caverns, depleted gas field). Salt caverns are considered the most mature for hydrogen storage (TRL 9), other geological formations are still under investigation (TRL 2-3). Salt caverns are man-made underground holes created by washing salt out of large geological structures made of almost pure salt. The hydrogen pressure varies between 100-150 bar and may exceed 250 bar for very deep reservoirs or aquifers. The energy stored is at TWh scale. Four hydrogen salt caverns sites are currently operational in the world, however these are not yet coupled with a green hydrogen production facility. The first was commissioned in 1972 at Teesside (UK) by Sabic Petrochemicals, this stores almost 1million Nm3 of nearly pure hydrogen (95% H2, 25 GWh) in three salt caverns at a depth of circa 400m. The other three operational caverns are in Texas, including Spindletop (commissioned in 2016), the world's largest hydrogen storage facility (>120 GWh). While pressurised containers are the best option for transport applications, geological storage of hydrogen is the best option for seasonal back-up of wind and other renewable energy. A future typical salt-cavern facility is expected to be made of multiple caverns each storing in the range 150-250 GWh of Hydrogen, and these may be onshore or offshore.
- Compressed Hydrogen in a lined Cavern Storage facility. High pressure hydrogen is stored in steel lined cavities underground, typically for large scale buffer stock. Geostock is developing a pilot in France currently
- Liquefied hydrogen in cryogenic tanks is obtained by cooling to below -253°C (TRL 9). 25-40% of the energy stored is used for hydrogen liquefaction. There are challenges with storing hydrogen in liquid form including evaporation losses caused by thermal leakage (boil-off), the tank's resistance to expansion and contraction and resistance to structural degradation due to hydrogen embrittlement. Cyrogenic tanks offer a GWh scale solution.
- Chemical conversion of hydrogen to ammonia (TRL 9) or LOHC (Liquid Organic Hydrogen Carrier, TRL 6-7). Circa 25-28% of the initial energy is lost when converting hydrogen to ammonia. Ammonia is a toxic substance and the storage of ammonia poses high health and safety risks. However, Ammonia is an established industry and facilitates solutions for both storage and transportation of green energy using proven existing technologies.
- Storage of hydrogen in solid form, by absorption or by adsorption to a variety of potential materials such as metal hydrides, is not a mature technology yet and its development is still at early stages (TRL 6-7).

Commercialisation

Pressurised vessels: commercial
Other solutions: >10 years

Pressurised hydrogen in vessels is the only commercial option at present at a levelized cost of storage (LCOS) of c.$0.19 /kgH2. These are suitable for small volumes (< 1000 kgH2) and daily cycling.

At large-scale and long-term scale, Bloomberg NEF found that the cheapest way to store hydrogen is using salt caverns (if geologically available) with LCOS ranges between $0.23-0.97 /kgH2, depending on cycling. Technologies with high capex, such as pressurised tanks, need to cycle often to be economical. On the other hand, geologic storage technologies cost less per unit of capacity and can store hydrogen at a relatively low cost even when cycling once per month.

Announced in 2021, the Hypster project by Storengy (subsidiary of Engie) aims to demonstrate the coupling of hydrogen produced by electrolysers and the storage in salt caverns on the French site of Etrez (located between Geneva and Lyon). The project is currently in the construction phase.

The next best options are rock caverns and depleted gas fields with LCOS which varies from $0.71 to $1.90 /kgH2.

If geologic options are not available, hydrogen can be stored in the form of ammonia (2.83 $/kgH2). This option has high costs related to the conversion of hydrogen to ammonia and vice versa. A possible reduction in costs is achievable if a more efficient way of synthesizing is developed and if ammonia is used directly instead of hydrogen.

Liquified hydrogen has the highest cost at $4.57 / kgH2, however due to the very high energy density achievable, this can be a solution for transport of hydrogen.

Storage of hydrogen will be always more expensive than natural gas storage regardless of the technology or scale. Hydrogen requires three times the amount of volume to store the same amount of energy as natural gas.

ESB Activities

ESB active projects

ESB has a partnership agreement with dCarbonX, a geological company which develops subsurface assets for hydrogen and carbon storage. dCarbonX is part owned by Snam, Europe's largest gas storage provider and gas infrastructure company. The aim of the collaboration is to assess the Irish potential for offshore salt caverns for energy storage in Moneypoint (Green Atlantic at Moneypoint project) and off Poolbeg peninsula (Green Hydrogen Valley project) and re-development of the decommissioned gas reservoirs at the Kinsale Head field, ultimately, for green hydrogen storage (Kestrel project). Initial analysis has identified thick salt sections off Poolbeg and Moneypoint with the potential of storing 2.1 TWh and 6 TWh of hydrogen respectively while the depleted gas field off Kinsale may have storage potential of 4 TWh. To give an idea of the scale of these projects, Turlough Hill is Ireland's largest low carbon storage facility and consists of 4 x 73 MW units with six hours electricity storage, for a total of just 1.75 GWh of energy storage. Salt cavern storage on the West coast is 150km offshore and may not be practical. Ammonia storage on the west coast is expected to be more feasible which would also facilitate transportation to western Europe.

Small scale pressurised vessel storage will be demonstrated as part of 'Fast Track' project. Four 300bar c.300kg storage capacity Multi Element Gas Containers (MEGC) will be delivered to support two mobile fuel cells.

Policy (ROI)

The Hydrogen Strategy for Ireland was published in July 2023. ESB contributed to the consultation process.

Summary

Hydrogen, and derivatives such as ammonia, are considered the leading options for seasonal storage of electrical energy at TWh scale. As such, development of this technology will be critical to the achievement of net zero power.

Hydrogen Storage

4.4 HYDROGEN POWER GENERATION

Technology

TRL 7-9 (depending on blend and scale)

Hydrogen may be used as a fuel for the purposes of generating electricity. If the hydrogen used is derived from renewable energy sources via electrolysis it is classified as 'Green Hydrogen' and it can be used to fuel dispatchable renewable generation. The principal methods by which hydrogen fuel can be used for power generation are via Fuel Cell technology or Gas Turbine technology. The combustion of hydrogen in gas turbines is the focus of this note as it is considered a more viable option for utility scale power production.

There are a number of examples of small gas turbines (<100MW) burning hydrogen with volumes up to 100% hydrogen. However, in most cases, these turbines have not been commercialised yet. Commercialisation of 100% hydrogen fuelled, large scale, gas turbines is expected towards the end of the 2020s, with commercialisation of turbines combusting blended mixes expected in the mid-2020s. Fusina hydrogen power station (12 MW), near Venice in Italy, was the first commercial-scale power station in the world that was fuelled with pure hydrogen (note – fossil generated 'grey' hydrogen, not green hydrogen). The power station produced energy from 2016 to 2018 and was operated by Enel. In Korea, a 45 MW gas turbine at a refinery has been operating on gases of up to 95% hydrogen for 25 years. One key challenge with hydrogen combustion is high NOX emissions due to higher combustion temperature of hydrogen compared to that of methane.

Commercialisation

Variable depending on % hydrogen, >5 years for 100% hydrogen

The LCOE of hydrogen power generation considers all costs related to the fuel (Levelized cost of hydrogen – LCOH) as well as costs related to the power generation itself. Hydrogen power generation is a dispatchable, flexible power source, using a fuel that can be stored for months. Therefore, it is important to note that the LCOE of Hydrogen power generation is not comparable with the LCOE of variable renewables such as wind or solar energy as they provide different market functions.

A BNEF study entitled 'LCOE Highlights: Hydrogen, CCS and Small Nuclear Reactors' (2021) is used as the principal reference for costs. This study presents global and continental averages and is therefore an order of magnitude guide, rather than a detailed country specific analysis. The BNEF study makes the following assumptions:

Green hydrogen is the fuel and it is stored in salt caverns.

'Load following' Hydrogen LCOE (Combined Cycle Gas Turbine - CCGT) has a capacity factor of 55%

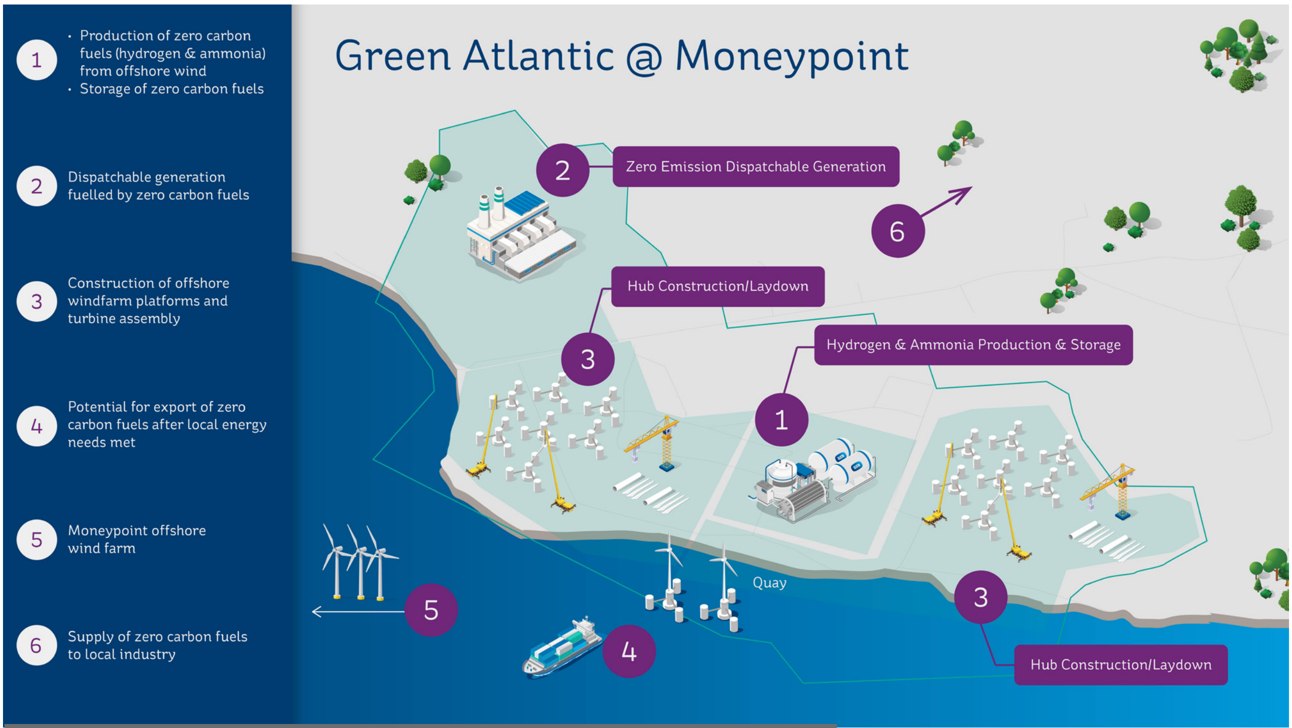
'Peaker' Hydrogen LCOE (Open Cycle Gas Turbine - OCGT) has a capacity factor of 10%

Mid-range green LCOH assumptions are $5.9/kg (2021), $2.5/kg (2030), $1.5/kg (2050)

These assumptions yield the LCOE ($/MWh) estimates as below.

	2021	2030	2050
Hydrogen OCGT	623	342	234
Hydrogen CCGT	363	165	101

A key pilot project is the Siemens 12 MW Hyflexpower project in France, which will use up to 100% green hydrogen at an existing gas-fired co-generation plant that provides power and heat to a paper mill in west-central France.



Schematic of planned 'Green Atlantic@Moneypoint' project

At the Magnum power plant in the Netherlands, a hydrogen conversion project is being planned, which would convert one of the units (440 MW) to fully run on hydrogen by 2023. (Note – hydrogen planned for use will not be green).

ESB Activity

ESB active projects

The ESB Carrington 910MW CCGT is a partner of the HyNet North West UK project which will deliver hydrogen in a dedicated transmission network by ~2027. A feasibility study is underway by assessing the station for upgrades required for hydrogen blend service.

Policy

The Hydrogen Strategy for Ireland was published in July 2023. ESB contributed to the consultation process.

As part of the setting of sectoral emissions targets, DECC has introduced a 2 GW green hydrogen ambition.

Summary

The outlook for hydrogen power generation is positive. Hydrogen can be used to store green energy over weeks, months, and seasons at scale and can be used to fuel dispatchable renewable power generation. Hydrogen power generation is currently the leading solution for net zero seasonal storage in Ireland. Although Hydrogen power generation has many attractive characteristics, there are also technical and commercial challenges andt is expected that utility scale hydrogen power generation will occur at scale after 2030.

Energy for generations

5.0 CARBON CAPTURE UTILISATION AND STORAGE (CCUS)

5.1 CARBON CAPTURE UTILISATION AND STORAGE

Technology

TRL 3-9

Carbon Capture Utilisation and Storage (CCUS) encompasses a broad scope of technologies across the carbon value chain. Capture technologies may be broadly categorised into point source capture, carbon dioxide removal (CDR), and nature-based solutions.

Point source carbon capture may be applied to mitigate a refinery or power station emissions. The removal may take place pre- or post-combustion of the fossil fuel with variations to the process to allow highly concentrated streams of CO2 which are easier to capture.

Carbon dioxide removal (CDR), also known as Negative Emissions Technologies (NET), actively reduce atmospheric carbon by capturing and storing it permanently. Some of the most advanced CDR technologies are as below:

1. Biochar is a type of charcoal that is produced through a process called pyrolysis, which involves heating biomass (carbon captured during growing process), such as wood, crop residues, or organic waste, in the absence of oxygen. Carbon is sequestered by mixing the biochar with soil. TRL 6-7.
2. Biomass Energy and Carbon Capture Storage (BECCS) combines energy (electricity and heat) generated from biomass (generally woody biomass) with CCS. Depending on the feedstock, TRL 6-9.
3. Direct Air Carbon Capture and Storage (DACCS) replicates the role of plant photosynthesis with machinery that is capable of filtering and concentrating carbon directly from the air. TRL 6-9.

Nature-based solutions include land management practices such as:

1. Soil carbon sequestration via various agricultural practices and pasture management. TRL 8-9.
2. Improved forest management, reforestation, and afforestation where we actively protect existing forests, replant trees in deforested areas and other sites. TRL 8-9.
3. Peatland/wetland restoration where lands are rewetted and revegetated. Carbon is stored in the soil. TRL 8-9.
4. Enhanced rock weathering via spreading crushed silicate rocks on land or ocean. TRL 3-4.

It's important to be mindful of the impacts of large-scale land use changes when implementing afforestation and biomass-based solutions as there are potential positive and negative impacts on food/water security and biodiversity.

There are several options for CO2 utilisation including mineralisation, CO2-to-fuel and the food industry. An example is the company Carbfix, which has developed a proprietary technology able to store carbon in minerals. Finding a revenue stream for the CO2 captured is key for business case viability. CO2 is used in enhanced oil recovery (EOR) where it is injected into the oil reservoir to displace the oil. The CO2 remains permanently stored, but the process aids increased fossil fuel extraction.

Carbon storage options include existing geological formations (e.g. salt caverns, depleted oil fields), or through mineralisation as in some of the nature-based solutions of capture and storage.

Commercialisation

5+ years to commerciality (Ireland)

According to the IEA, there are ~35 commercial facilities globally applying CCUS to industrial processes, fuel transformation and power generation capturing 45 Mt CO2 in 2022. The Sleipner CCS project offshore Norway is the oldest and most established CCS project in the world. The project was commissioned in 1996 and has received over 1 million tonnes of CO2 to date. New capture facilities include the Gorgon CO2 injection project in Australia (2019), two facilities linked to the Alberta Carbon Trunk Line in Canada (2020), the first large-scale BECCS project in Japan (2020), and two capture facilities in China at the Sinopec Chemical plant and at the Guohua Jinjie coal power plant (2021). Positive final investment decisions (FID) were seen on 10 CCUS projects in 2022, versus 6 in 2021.

Texas-based Net Power LLC developed a 50MW demonstration pilot to deliver net-zero carbon natural gas which broke ground in 2016 and was operational in 2018. There are economic challenges to the site that may be partially mitigated through tax credits. The demonstration site is not expected to be in operation long term.

BNEF calculates that DACCS costs are approximately $600/t CO2 for First of a Kind (FOAK) projects. This is much higher than CCS at source, which ranges from $15-25/t CO2 for industrial processes producing highly concentrated CO2 streams (e.g. ethanol production or natural gas processing), to $40-120/t CO2 for processes with "dilute" gas streams (e.g. cement production and power generation).

Climeworks DACCS facility in Iceland, called 'Orca', launched in 2021. The full plant capacity is 4,000t CO2 per year, however, due to losses and leaks, the actual CO2 sequestrated is ~3,200t. Canadian company, Carbon Engineering focuses on larger scale projects and plans on building a 1MtCO2/year DACCS plant by 2024. The power required to run DAC systems is very high, which is a key disadvantage.

BECCS has much lower costs than DACCS. Ricardo has estimated a cost for BECCS in the UK of £181/MWh, with a range of £149/MWh-£230/MWh. While the cost of carbon captured and stored ranges from £112/t CO2 to £196/t CO2. The 2023 IPCC report places BECCS as a front running technology.

Drax is the biggest power generator from biomass in the UK. Following two successful pilots, Drax

Forestry – a nature based carbon capture solution

signed an agreement with Mitsubishi to use their proprietary carbon capture technology (Kansai Mitsubishi Carbon Dioxide Recovery) in a proposed large-scale plant permanently removing 8Mt of CO2 from the atmosphere every year by 2030.

Biochar represents a strong area of focus for the research community particularly in China, with momentum developing in EU; Germany, Switzerland, and Sweden have existing demonstration plants. Vow, Carbona, Pyreg and Syncraft are some of the leading biochar pyrolysis technology providers. Biochar uses include as anaerobic digestion feedstock, flood prevention, soil fertiliser and animal feed depending on the grade produced.

ESB Activity

Active

ESB is a partner of the EU funded Realise project. The project brings together industrial partners from the Cork Harbour region, including Gas Networks Ireland, Irving Whitegate and Bord Gais. The objective is to develop a refinery-centred sector-coupling strategy to enable full-chain CCUS implementation, by demonstrating technologies to lower the cost of CO2 capture by at least 30% and increase the overall rate of CO2 capture to 90%. The project is also developing recommendations for policy and regulatory changes to overcome societal, political and socio-economic barriers. Small scale proof of concept in Irving Oil's refinery in Whitegate, Cork.

ESB's C-ink project from 2021 has progressed working with Coillte on a feasibility and early technology review of biochar production by using mainly forestry waste through pyrolysis.

Policy

Modelling by the European Commission shows that the EU will need to capture and utilise or store 300 - 640Mt of carbon dioxide every year by 2050 to meet climate neutrality goals. Ireland's share of this target is 5-10Mt. The EU Commission is to announce strategic vision this year (2023).

CAP 2023 sets an action to conduct a feasibility assessment on CCS in 2023 to announce a policy position in 2024. CCS is mentioned in terms of construction materials and point source capture at industrial and energy production sites as a third carbon budget measure beyond 2030. Peatland restoration is underway as part of the Enhanced Decommissioning, Rehabilitation and Restoration Scheme (EDRRS). EDRSS aims to rehabilitate 33,000 hectares of peatlands over 82 Bord na Móna bogs, previously used for peat extraction for electricity generation. The EDRRS is the largest programme of bog rehabilitation in the State's history and, once completed, it will protect the storage of 100Mt CO2.

The UK's Spring Budget 2023 pledged up to £20billion to fund early deployment of CCUS projects; a shortlist of projects was released in March 2023. The UK's Government's 10-point plan pledged to accelerate deployment of industrial clusters ("SuperPlaces") to reach an ambition of capturing 10MtCO2/annum by 2030. In 2021, Hynet and the East Coast Cluster were announced as Track-1 Clusters.

Summary

CCUS is regarded by many as an essential part of limiting global warming, although almost all technologies are still in early stages of development. Most existing CCUS is used for Enhanced Oil Recovery (EOR). There is currently no existing business case for point source CCUS at power generating sites. Of the suite of additional solutions available at present, Biomass Energy and Carbon Capture Storage (BECCS) and Biochar appear to be among the most promising.

Reports (ESB staff access only)

Negative Emission Technologies 2019

Energy for generations

6.0 EMPOWERED CUSTOMER

6.1 BIOGAS / ANAEROBIC DIGESTION

Technology

TRL 7-9

Biogas is a renewable fuel produced by the breakdown of organic matter under oxygen-free conditions. The chemical makeup is ~60% methane (CH_4) and ~40% carbon dioxide (CO_2) with trace contaminants. Anaerobic digestion (AD) is a proven technology (TRL9) with approximately 19,000 AD biogas plants in operation in Europe. There are three main uses of the biogas generated:

1. Burned in a CHP unit (i.e., reciprocating internal combustion engines) to produce heat and electricity.
2. Upgraded to biomethane (>95% methane) through the removal of CO_2 (which can be a profitable by-product). Biomethane has the same characteristics as fossil methane ("natural gas"). The biomethane may then be:
   A. Injected into the gas grid for heating and power generation or compressed or
   B. Used as a transport fuel in Compressed Natural Gas (CNG) vehicles/farming equipment.
3. Convert cleaned biogas via chemical and biological pathways into methanol, ethanol, hydrogen, diesel, liquefied petroleum gas (LPG), and gasoline.

AD can benefit the agricultural community through decreasing GHG emissions. The digestate output of the AD has improved nutrient content compared to the feedstock (slurry, food waste etc.), when used as an organic fertilizer in place of slurry, nutrient run off to waterways is reduced, reducing the potential for water pollution. Additionally, thr use of digestate as a fertiliser reduces the demand for chemical fertilizers along with the associated emissions from their manufacture.

Industrial sites may be able to use waste heat recovery (via industrial heat pumps) to generate the digester parasitic heat demand, allowing all of the biogas output to be used for energy generation.

A technology development at TRL 7 is methanation. By reacting the CO_2 content of the biogas with green hydrogen (H_2) which increases the biomethane (CH_4) output of the plant up to 98%. This system is known as Power-to-Methane.

Commercialisation

Commercial (Continental Europe and UK) 1-5 years (Ireland)

Existing digesters in Ireland are primarily in wastewater treatment plants with some small-medium scale digesters at farm level. Approx. 8TWh/pa of biomethane production have requested a gas connection. Some Irish sites have achieved planning permission. However, there is significant community opposition delaying the projects going forward with construction. Community concerns include truck movements, odour, and pollution. This signifies the need for a wider community engagement package of work to disseminate the environmental benefits of an AD, especially around their potential to improve local water quality.

Renewable Gas Forum Ireland (RGFI) claims a potential for biomethane to cover c. 12% of Ireland's current natural gas demand, which corresponds to 6.8TWh/a of thermal energy from renewable biomethane gas by 2030. Comparatively, KPMG estimates the resource is closer to 9.5TWh/a. In Ireland the 2022 purchase price of biomethane is estimated to be 7-12c/kWh

A renewable gas injection point commenced commercial flows in May 2020 in Cush, Co. Kildare. A new facility in Mitchelstown, Co. Cork, set to begin construction in Summer 2023, has been delayed to 2025.

There are ~100 farm-scale AD plants in Northern Ireland due to Renewable Obligation Certificate (ROC) payments. However, this support has since closed to new entrants, presenting challenges to further build out of AD in Northern Ireland.

According to the European Biogas Association, 18.4bcm (32TWh) of biogas/biomethane is produced in Europe today. Germany, France, and the UK have the highest number of biogas/ biomethane plants in Europe.

AD technology is commercially viable when suitable support mechanisms are available. There are two principal business models based on the feedstock used. In the case of food/industrial waste, the AD plant operator charges a gate fee. In the case of agri-crops, the AD plant operator pays for their feedstock.

The Power-to-Methane system is unlikely to be commercial before 2030, due to high costs of hydrogen and biogas facilities, especially in Ireland. Commercial size demonstration plants are available in continental Europe, including the BioCat project in Denmark and the Store&Go project in Switzerland.

ESB Activity

Exploring project possibilities

ESB's 2022 X-Potential project, Agcelerate, is assessing ESB's role to enable and support the future development of AD plants in Ireland. Supporting farming communities to decarbonise is a key strategic outcome of this project. The project team is in collaboration with ESB, Kerry Group, Teagasc, Coillte, and others. The scale of opportunity and the best route to market is under development.

There is growing industrial demand for renewable gas with several potential off-takers identified by ESB. Future business models may involve the production of biogas and upgrading to biomethane or purchasing from a third-party developer.

Anaerobic digestion plant in Timoleague

Policy

CAP23 has increased the 2030 national target for the generation of biomethane from 1.6TWh to 5.7TWh and introduced an intermediate target of 1TWh by 2025. AD is commercially challenging without supports; however no meaningful supports exist for AD/biomethane in Ireland at present. Existing supports for biogas powered CHP include REFIT 3 and the Support Scheme for Renewable Heat (SSRH) for small scale AD systems. The Renewable Heat Obligation Scheme details are yet to be announced but may have a profound effect on the domestic AD market. Government has released early signals regarding capital investment scheme consultation planned for 2024.

The REPowerEU plan sets a goal of achieving a European biomethane production of 35bcm (~360 TWh, <7% of EU Gas Demand) by 2030.

Summary

Biogas/biomethane represents a proven way to decarbonise parts of the energy system using a well understood and widely used molecule requiring no gas grid or end user changes. The low take up in Ireland is due to a lack of financial and regulatory supports. 2022/2023 has seen continued dramatic fluctuation in European natural gas prices. The Russian invasion of Ukraine has highlighted the need for increased energy security, and domestic production. These points strengthen the argument for biogas production in Ireland at scale.

6.2 INDUSTRIAL HEAT PUMPS

Technology

TRL 7 (160°C) TRL 9 (120°C)

A heat pump is a device that can provide heating and cooling for residential, commercial and industrial applications. Residential heat pumps are an established technology at TRL 9 and are used for heating and cooling applications worldwide. Industrial heat pumps (IHPs) may be defined as heat pumps used in an industrial setting that actively recover waste heat. Whereas residential and commercial heat pumps typically provide heating to less than 100°C, IHPs can provide heating up to 160°C in working environments, with lab scale projects providing heating beyond 200°C. IHPs that provide both heating and cooling solutions, as well as efficient waste heat recovery can achieve Coefficient of Performance (COP) of up to 6. This is analogous to an efficiency of 600%. This high COP creates a very carbon efficient solution as the majority of the heat energy is coming from waste heat and/or environmental heat.

The TRL of IHPs varies according to the temperature output, with higher temperature being at lower TRLs. A number of EU Horizon projects exist to accelerate lower TRL IHP technology. For example, Push2Heat and SPIRIT will demonstrate IHP across 7 industrial sites with output temperature of up to 160°C.

Irish company, Astatine, has installed a 1 MW IHP, supplying temperatures of 120°C, at Ahascragh distillery, Galway. Grant funding assisted the project development.

Internationally, companies including ECOP, SPH and Fuji are offering heat pumps solutions delivering water and steam temperatures in excess of 160 degrees, with future plans for temperatures in excess of 200 degrees.

Commercialisation

1-5 years (depending on output temperature)

The degree of commercialisation varies according to the temperature output required. IHPs are in operation across sectors including food and beverage, district heating, sewage treatment and paper production. Specific applications for the IHPs include water heating, process drying, pasteurisation and distillation.

The commerciality of IHPs in the range up to 160^{o}C will vary greatly by site and technology, but as a rough categorisation, can be estimated to be circa 1- 5 years from commerciality.

In Ireland, as well as many other countries, the high cost of electricity relative to gas is a barrier to the roll out of IHP's. In addition, IHPs tend to have high Capital Expenditure (Capex). In Ireland, the principal support system for IHP's is the Support Scheme for Renewable Heat (SSRH), which was launched in 2018 and updated in 2022, offers Capex grants of up to 40% / €1m depending on the IHP temperature output and COP. In GB, the principal support mechanism is the 'Industrial Energy Transformation Fund', based on the principle of Capex supports.

ESB Activities

Current active projects

ESB has deployed the largest capacity heat pumps in the UK (72.5 MW thermal, output temperature circa 50o C) in a landmark greenhouse project. This world-first £120m project covers two large greenhouses in Suffock and Norfolk (total area 29 hectares) and consists of a hybrid heat pump and Combined Heat and Power (CHP) solution. A key component of the design is that waste heat is sourced from a nearby water treatment facility, which increases project efficiency.

ESB completed a heating project at the Dundee V&A museum, which consisted of a hybrid ground and air source solution to provide heating for the museum.

In Ireland, ESB signed a contract with one of Europe's leading food processors, ABP Food Group. As part of this contract, ESB also delivered a 870kW Sabroe ammonia heat pump with 65^{o}C water output.

ESB wrote an 'Insights' paper entitled "Decarbonising Ireland's industrial sector - the role of industrial heat pumps'. This initiative explored the opportunities for IHP usage in Irish industry and was communicated to an external audience via a presentation, paper and video. The paper is available on the ESB website, and a link is given at the end of this chapter.

Policy

CAP2023 details ambitious heat pump targets as below:

"Put heat pumps into 45,000 existing and 170,000 new dwellings by 2025, up to 400,000 existing and 280,000 new dwellings by 2030"

There is no explicit target for IHP's in CAP2023, but the large-scale potential for this technology is mentioned as below:

"Investment in our electricity grid capacity and generation will further facilitate up to 3.5 TWh of new industrial heat pumps"

Summary

The outlook for IHP's in Ireland is positive. The technology is developing and there is a good match with the low temperature heat required in Irelands food and beverage industry. In addition, IHP's may be able to play a role in future district heating schemes, including the Dublin District Heating Scheme. Challenges include high upfront costs and the relatively low cost of gas solutions. Supports will be required to overcome these issues as the industry matures. Finally, ESB has demonstrated expertise in this area, as shown by the UK Greenhouse project deploying heat pumps.

Greenhouse heat pumps at Crown Point Estate, Norwich

Report (ESB staff access only)

ESB Leading Lights

6.3 VEHICLE TO EVERYTHING (V2X)

Technology

TRL 8

V2X is an inclusive term for the utilisation of bi-directional power flow from EVs for non-transport applications in the same manner as static battery storage systems, namely system services, arbitrage, demand time shifting or power back up. Vehicle to Grid (V2G) and Vehicle to Home (V2H) or Vehicle to Building (V2B) systems are prominent examples of this technology. Vehicle to Load (V2L), which is available on most recent EVs, enables the use of the battery to power external devices such as camping equipment or power tools.

V2G and V2B allows charging EVs at off peak times when demand on the grid is low and discharging the EV to the building or grid at peak times when demand on the grid is high. In aggregation, vehicles can act as a virtual power plant. In their Electric Vehicle Outlook 2021, BloombergNEF states that if by 2040, 25% of the vehicle fleet in Germany were V2G capable and 50% of those were available to provide services, the power available could equal 40% of the total peak demand.

CHAdeMO, Tesla's NACS and, CCS are the existing connector standards for DC charging. Currently, V2G and V2H are only available on vehicle using CHAdeMO Nissan (Leaf or e-NV200), Mitsubishi (iMiev or Outlander PHEV), Peugeot iON and Citroën C0 are the only electric vehicles still using CHAdeMO charging in Europe. Car manufacturers are now moving towards CCS charging, and CCS currently has no V2G or V2H capability for now. While V2X charger manufacturers like Wallbox already offers a CCS2 V2G/V2H charger, no cars are commercially equipped with that option. CharIN, promoter of the

CCS, expects V2G capability to be available by 2025. Tesla does not offer bidirectional charging but stated at the 2023 Investors Day that its vehicles will be equipped with that functionality in the next two years. However, it also mentioned it does not see it being used unless the house is equipped with a Tesla Powerwall.

DC-AC bidirectional capability can be built on-board rather than via an off-board DC charger. OEM Nuvve offers AC V2G chargers for heavy duty trucks and school buses.

The impact of V2X on EV batteries is a key concern for vehicle owners. A study conducted by the University of Warwick shows that V2X could extend the life of batteries (through having the battery at a lower average State of Charge). As an example, Nissan maintains the same warranty conditions for cars that provide V2X services.

The electric vehicle needs to be constantly plugged to the V2X when parked to optimise interaction with the grid or building, leaving the system depending on end user's behaviour. OEM WiTricity and car manufacturer Genesis are working towards a wireless V2X pilot. Wireless V2X will ensure availability of car batteries when parked, and address cable management at the same time.

Commercialisation

1-5 years

V2X DC chargers are commercially available in Europe from €5,000 for a wall mounted unit.

According to V2G hub, there has been 114 V2X projects globally with 25 ongoing. Over 6,600 chargers have been installed to date as part of these projects.

Project Sciurus in the UK is one of the largest V2G demonstrators in the world with 325 home units installed. The V2G units were aggregated, optimised and scheduled by the Kaluza Intelligent Energy platform. The project assessed consumer receptiveness and developed a long-term business case, targeted at the residential level. It showed end users were savings £420 per year on energy with an average export of 6.77kWh/day/charger and a 93% customer satisfaction rate. Built on the success of project Scirus, Kaluza, Indra, OVO and VW are running the INFLEXION project which aims at demonstrating CCS V2X, in the world first large CCS V2X trial. Both of these projects have received grant funding from Innovate UK, who is currently running the second phase of the £12m V2X Innovation Programme. In the US, the Ford F-150 combined with Ford Charge Station Pro bidirectional charger, using CCS, is being tested in Florida in a V2H pilot run by Duke Energy.

With commercial offers available in France, the UK, Denmark and the US, Nuvve is the most advanced manufacturer and aggregator. French distribution service operator RTE certified their solution to allow V2G grid services since February 2022. Nuvve and EDF joint venture Dreev deployed more the 200 charging stations to date using ABB V2G chargers.

One key challenge is the readiness of DSO systems to facilitate viable markets with appropriate price signals, along with technical and policy decisions to make V2X an attractive solution.

ESB Activity

RESERVE Project
Dingle Project
CityXChange

ESB Networks installed five domestic V2G chargers from supplier WallBox as part of the Dingle Project in 2021.

As part of the EU Horizon 2020 "CityXChange" Limerick project, ETRD investigated the role of urban VGI (Vehicle Grid Integration). A GoCar EV has been deployed in University of Limerick campus as part of the project, learnings on end user behaviour such as average trip distance and time of use will inform the relevance of V2G for such application as a challenge for shared EV is keeping the battery charged.

ESB Networks installed and operated a V2G installation in Leopardstown as part of the RESERVE Project. The project was being carried out in conjunction with Mitsubishi and Nissan, and utilised a 10 kW DC V2G Charger supplied by Magnum Cap. The aim of the project was to investigate the capabilities the technology for EV charger management and EV battery export capacity for applications such as system services and voltage support.

Policy

In Ireland, V2X installation is falling under the micro generation or mini generation scheme. SEAI grants are available at the same rate as a regular EV charger. The Micro-Generation Support Scheme in Ireland allows for Clean Export Premium at €0.135/kWh for non-domestic applicant but V2X is not included in that scheme.

Currently there is no aggregator offers available in Ireland, so V2X is limited to time shifting electricity demand only.

Summary

V2X commercialisation is impeded by the uneven uptake and shift of charging standards. Deployment is uneven around the world, commercial offers and grid support are available in countries like UK and France, but not available yet in Ireland. With a target of 845,000 electric passenger cars to be on Irish roads by 2030 and cars spending typically 95% of their time parked, V2X has great potential to improve grid flexibility if deployed at large scale. While price, regulatory and public acceptability hurdles remain, the outlook for this technology remains positive

Vehicle to grid (V2G) charger

6.4 DISTRICT HEATING (4th AND 5th GENERATION)

Technology

TRL 9 (4GDH) TRL 8 (5GDH)

District Heating (DH) is a centralised heating system which uses one or more energy centres to generate heat and which the distributes the heat via network of insulated pipes which are then connected to buildings or industrial or commercial premises. On the customer's side, heat exchange units collect heat from the network and distribute it inside the building instead of each building having its own boiler or heat pump. District Heating (DH) is a well-established technology especially in Eastern Europe and USA. The first district heating scheme started operation in 1877 in New York.

First generation district heating (1GDH) relies on fossil fuel to generate heat, using steam or water above 90degC to transport heat. 3GDH uses waste heat recovered from power production and industries, as well as heat generated from biomass boilers and Combined Heat and Power (CHP) Units. It also integrates real time energy monitoring to track energy usage, efficiencies, heat losses and leaks. 4GDH includes solar thermal and geothermal heat, large dispatchable electric boilers, seasonal heat storage and uses heat pumps as the main heat supply, as back up or to upgrade heat from low grade heat source such as data centres. It includes smart monitoring and controls to optimise generation and pumping strategies. 4GDH is at TRL9 with many installations in operation.

5GDH (also called ambient loop), operates at low temperatures (0 to 30degC) and has near zero thermal losses. It enables users to export low grade excess heat which can come from supermarket refrigeration systems, local transformers and sewage plants. Both heating and cooling demands can be covered simultaneously. Users of 5GDH require water source heat pumps to upgrade the heat from the ambient loop to their temperature requirement. 5GDH is a TRL8 technology, with small scale (below 10MW) installations existing in several leading countries.

Commercialisation

Commercial

Tallaght District Heating System (TDHS) is a 4GDH owned by South Dublin City Council and co-developed with Codema. Fortum eNext has been appointed as the Energy Service Company (ESCo) to design, build, operate and maintain the energy centre and heat network. Phase 1 has been completed and is now in operation since end of 2022. It is the first large scale district heating in Ireland. Heat recovered from an Amazon Web Service data centre is upgraded through water source heat pumps and distributed to local authority buildings and the TU Dublin-Tallaght campus. The Energy Centre is also equipped with thermal storage and electric boilers for back up. It benefited from a €4.5m grant coming from the Climate Action Fund.

Toulouse Energy Durable (TED) in the South of France recovers waste heat from a waste to energy facility. A heat recovery system from the Clement Ader research centre's super calculator and data centre used for aerospace research and weather forecast feeds a 5GDH ambient loop with low grade heat. Together, they are delivering heat to 15,000 homes equivalent through 36km of pipework. Because at least 50% of its energy comes from renewables or waste heat recovery, end users benefit from a lower tax rate on heat (5.5% versus 20%) establishing an average cost of heat for the end user of €66 per MWh.

In 2019, a non-exhaustive list of 40 5GDH was established in the study "5th generation district heating and cooling systems: A review of existing cases in Europe". On average, three 5GDH per year have entered the market in the last decade. Pioneer countries in this technology are Germany and Switzerland.

ESB Activity

Dublin District Heating System (DDHS)

Dublin City Council (DCC) is preparing a joint venture procurement for the delivery and operation of the Dublin District Heating System (DDHS). The project is included in Dublin City's Capital Programme 2023-2025. It aims to go to market in 2023, with construction planned from 2024 to 2026 at a cost of €76.9m, with €20m coming from the Climate Action Fund. The primary heat source will come from the Dublin Waste to Energy plant in Poolbeg, where 90MW of waste heat at 120degC is available. A new energy centre equipped with back up/peak boilers and thermal storage will complement the heat generation. The heat will be distributed through 14.5km of flow and return pipes.

DCC has already invested in elements of the DDHS and have installed pipework under the river Liffey, under the LUAS on Mayor Street Upper and under the road beside the 3 Arena off North Wall Quay. Consultant Ramboll established in a 2019 engineering review report that DDHS could deliver 288GWh of heat per annum when fully developed, covering areas in Poolbeg, Irishtown, Ringsend, North Wall Quay and the Docklands.

Policy

CAP 2021 set a 2030 target of up to 2.7TWh of district heat supplied in Ireland. This is an ambitious target of close to ten times the heat demand of DDHS, CAP 2023 added an interim 2025 target of up to 0.8TWh. An SEAI National Heat Study published in 2020 established district heating could deliver up to 50% of the building heating demand in Ireland. A District Heating Steering group was formed under the CAP2021 and is due to report recommendations for the development of the district heating, and the CRU has been appointed as Regulator of District Heat Networks to develop of appropriate regulation of the sector.

Summary

District Heating provides less than 1% of Ireland's heating demand, putting the country in the bottom five of EU countries. The Climate Action Plan 2023 recognises the role district heating can play in decarbonising heat in Ireland, setting an ambitious target. District heating has significant potential as a proven tool to decarbonise a lot of Irelands urban heating emissions. However, policy and financial support are critical.

District Heating pipes

Energy for generations

7.0 DIGITAL TECHNOLOGIES

7.1 ARTIFICIAL INTELLIGENCE

Technology

TRL 7-9

Artificial Intelligence (AI) is focused on simulating human intelligence on computers. Machine Learning (ML) is a key subfield of AI that enables machines to learn from data without being programmed with specific algorithms. ML techniques include supervised (with labelled data), unsupervised (unlabelled data), and reinforcement (trial & error with reward) learning. Neural networks are an advanced architectural support for the implementation of machine learning inspired by the structure of the human brain. The architecture consists of interconnected artificial neurons that can be trained through the adjustment of weights affecting their level of interaction.

Transformer architecture, a further development on neural networks, has emerged as a powerful architecture for natural language processing (NLP) tasks. First developed in 2017, it added the concept of attention, which allows the model to attend to "nearby" information and learn contextual relationships between words or tokens. Generative Pre-Trained Transformers, aka Large Language Models, are trained with large amounts of data and used to create novel human-like content based on the statistical patterns and semantic relationships within language learned during pre-training. ChatGPT, developed by OpenAI, is a conversational chatbot powered by GPT-3.5 that has been fine tuned to optimize for dialogue. GPT4 had a limited release in March 2023. It is expected to have a significant impact on the use of AI across business and industry.

Machine learning (ML) and artificial intelligence (AI) have been around for decades and have reached TRL 9. That said, significant advances have been enabled in recent years by the development of the transformer architecture and the availability of both large publicly available research data sets and more powerful computers / GPUs. Further advances are expected in the short term. Also general access to AI has increased enormously with the inclusion of AI offerings in, for example, MS 365 as well as several other platforms, including Microsoft Azure, Google Cloud, AWS, DeepMind and IBM Watson, that provide AI and ML solutions at scale to the utilities industry.

AI in general use by society include voice recognition, visual recognition and the 'self-driving' car industry. For example, Cruise has recently completed one million self-driving miles in San Francisco with 73% fewer collisions with meaningful risk of injury.

In the energy sector, applications that benefit from ML/AI include weather forecasting, condition monitoring, grid management and maintenance scheduling. Nvidia Omniverse is used by Siemens to train a physics-based AI engine to predict corrosion in their Heat Recovery Steam Generators and by Deutsche Bahn to predict a future automated train network.

Legitimate ethical concerns exist in the field of machine learning and AI, related to issues such as privacy, facial recognition capabilities, inbuilt biases, copyright violation and others. These will have to be managed carefully as the technology advances.

Commercialisation

Early Commercial

ML and AI are already at a commercial level across Europe, the United States and China, with many companies specialising in Data Analytics using ML. In the energy sector, leading companies include NextEra Energy, Duke Energy and Octopus, with applications as outlined below.

NextEra Energy has implemented ML software developed by Space Time Insights to help with diagnostics, troubleshooting and scheduling of maintenance crews. The tool also analyses factors such as weather and traffic to optimise their workload and cut costs. The product also uses grid variable datasets to minimize outages and maintenance costs.

Duke Energy also implemented ML to prevent outages after losing approximately $10 million due to a major power failure. Measuring data from 30,000 sensors spread across 50 plants has improved data monitoring, data processing, diagnostics, and visualisations.

Octopus energy is utilising ML to optimise various customer services offerings. The 'Kraken Technologies' platform is used for the analysis. Kraken Technologies is part of Octopus Energy Group, but it can be licensed to third parties. Good Energy, for example, developed a new platform which was licensed from Kraken Technologies. In the utility sector in general, most companies are focusing on Smart Grid Solutions and Digital Twins. However, AI is also being applied at meters to forecast customer demand. As different datasets are made more available through digital channels it is expected that the commercial value generated through data analytics will increase rapidly over the coming years. Data science will become an increasingly critical skill across ESB's business units. Data scientists will increasingly use machine learning and other advanced techniques to drive out better customer products and services, reduced operations and maintenance costs and faster and better business decisions.

In February 2023 Octopus trialled ChatGPT based customer emails and by the end of April it was answering 34% of all queries, with an 80% satisfaction rating, surpassing the norm of 65%.

Accenture and PwC US announced in 2023 plans to invest $3B and $1B respectively over the next three years to expand and scale their artificial intelligence (AI) offerings

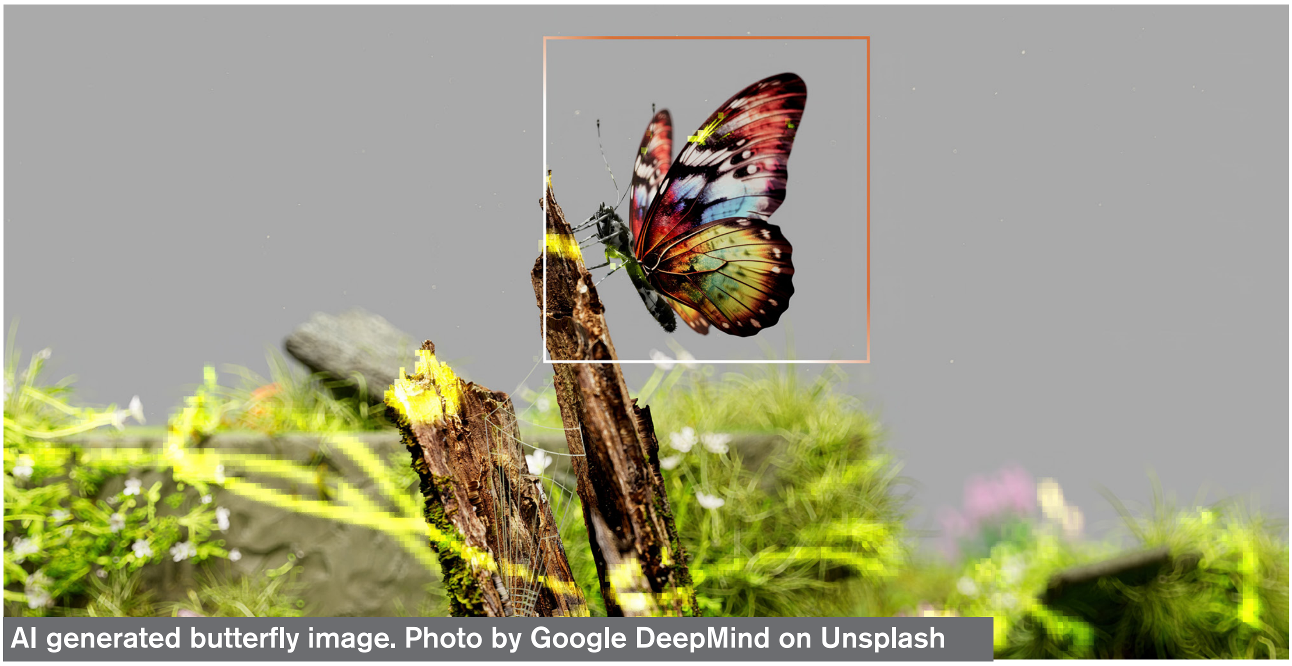
Microsoft CEO Satya Nadella announced at the 2023 World Economic Forum that "every product of Microsoft will have some of the same AI capabilities to completely transform the product". This also applies to Windows 11 and their Security products.

ESB Activity

Currently active in numerous projects

ESB has issued interim internal guidelines on the internal use of generative AI. The policy allows the use of generative AI but highlights several Do's and Don'ts to manage the risks of data breaches, cyber risks, regulatory breaches, bias or prejudice.

ESB has recently set up (June 2023) a Generative AI Focus Group to explore use cases and implications of AI use within and across ESB.



AI generated butterfly image. Photo by Google DeepMind on Unsplash

ESB is exploring the use of ChatGPT for use in the development of internal programming code and is preparing for the availability of Enterprise scale AI across the MS suite of products.

ESB Networks has initiated a Proof of Concept for the use of synthetic data generation for training AI to differentiate and identify insulator stacks on transmission poles to help identify and catalogue the various component types, improving maintenance effectiveness. The PoC has been extended following successful first trials.

Several Free Electrons 2023 entrants presented AI solutions in the areas of digital twin modelling, solar PV forecasting, energy consumption assessments and solar generation location opportunities under consideration at time of writing.

ESB has developed ML models to determine which customers are likely to complain or churn. Repeat Contact Analysis uses sophisticated Bayesian Networks to identify customers and pre-emptively reach out to these customers.

In ESB Generation & Trading there are a number of deep learning neural network models in development and in use to provide traders with predictive movements of energy prices, wind forecast and hydro generation.

Image recognition and computer vision models use cases have been growing steadily. As part of the Smart Metering Project, ESB Networks requires four images to be taken of every smart meter installation. These images are used to check and audit that the installations are completed correctly and that they are compliant with our safety procedures. ESB Networks has conducted various trials in the use of satellite and drone imagery to identify utility pole continuity issues such as damaged transformers, vegetation encroachment and to validate LV mapping.

Policy

In 2021, the European Commission published an AI regulatory proposal. This will restrict certain AI activities that are deemed high risk. In addition the use of data must comply with the existing General Data Protection Regulation (GDPR).

In 2023 the European Union (EU) drafted a new legal framework that aims to significantly bolster regulations on the development and use of artificial intelligence. The proposed legislation, the Artificial Intelligence (AI) Act, focuses primarily on strengthening rules around data quality, transparency, human oversight and accountability. It also aims to address ethical questions and implementation challenges in various sectors ranging from healthcare and education to finance and energy. On 14 June 2023, MEPs adopted Parliament's negotiating position on the AI Act. The talks will now begin with EU countries in the Council on the final form of the law. The aim is to reach an agreement by the end of this year. ESB Data Science team has been monitoring and has proposed Ethical AI strategy and guidelines to be implemented post Act "go live".

Summary

ML is an established technique enabling machines to learn from data. Improvements in the design of neural network based architectures along with access to large data stores and GPU computing power has significantly advanced the abilities of AI in recent months. These advances in artificial intelligence will significantly increase productivity across industry. Major changes across a wide range of sectors are likely.

7.2 BLOCKCHAIN

Technology

TRL 8-9

Blockchain is a distributed ledger of transactional records (blocks) cryptographically secured from tampering and revision. The records on a blockchain can represent transactions associated with any digital asset, for example, the sourcing of a unit of renewable energy or the purchase of a top up to an electric vehicle. An ideal blockchain would excel at security, decentralization, and throughput, but blockchain's "scalability trilemma" requires compromise, normally in the choice of "trust mechanism". There are many trust mechanisms, falling into two categories: permissioned and permissionless. Permissionless trust mechanisms, e.g. Proof of Work, as used in public blockchains, are appropriate where there is no inherent recognition between peers.

The most widely known permissionless blockchain technology is cryptocurrency. In these systems trust is based on a "proof of work" mechanism involving the identification of a hard-to-find but easy to confirm cryptographic value. This process, called mining, is associated with the consumption of significant quantities of energy, estimated to be at least 700kWh per bitcoin transaction, the equivalent of approx. 0.5m VISA transactions.

Enterprise Blockchain is a general term for private blockchains optimised for enterprise use in environments of partial trust. When setting up the blockchain, businesses define the asset types, the consensus protocol and the business rules that apply. They set permissions on who can join the network, and what type of access they have. This approach allows privacy and competing business interests, whilst maintaining a common record set of transactions.

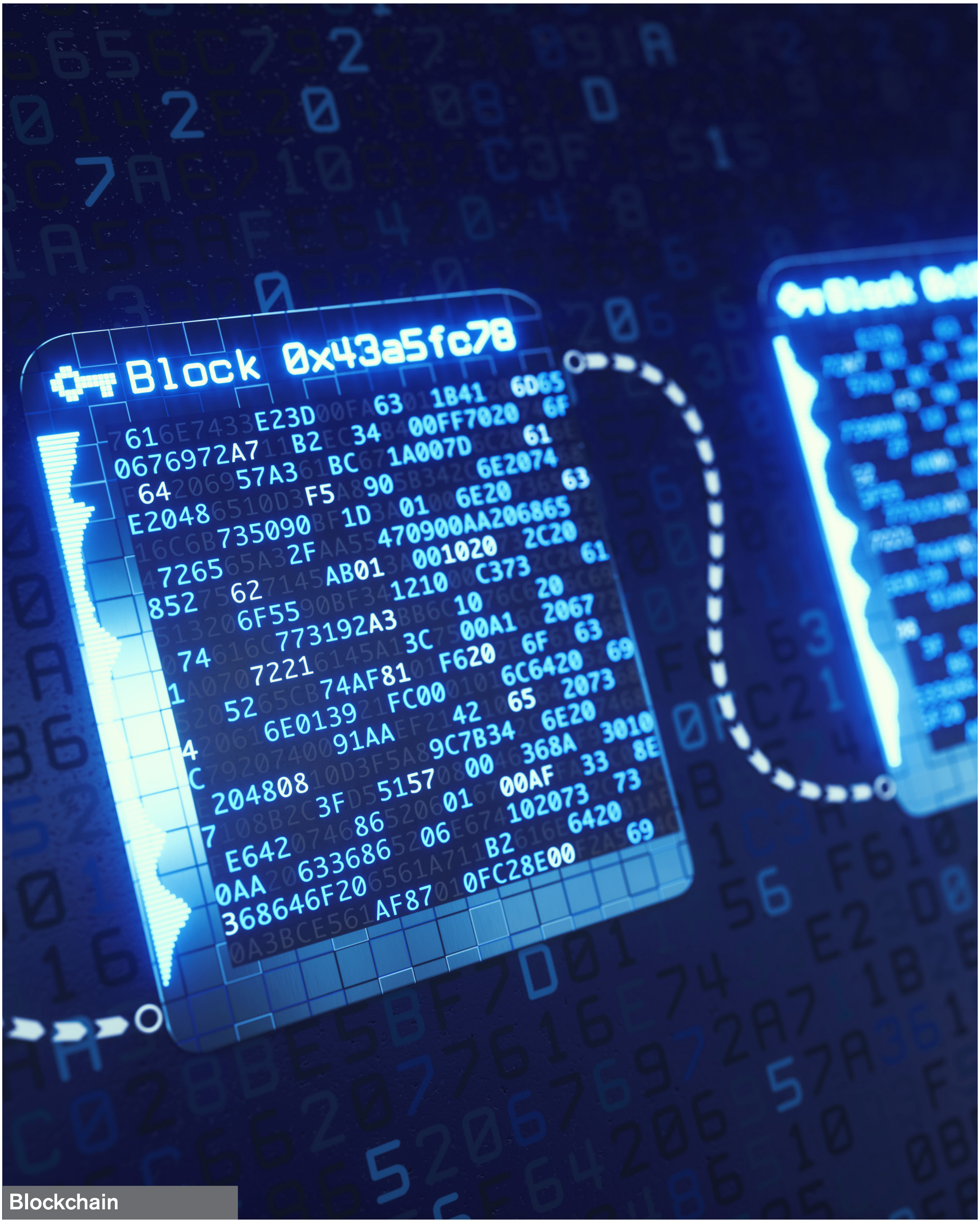
Ethereum's switch to a "Proof of Stake" system in Sept 2022 has proven even cryptocurrencies can be operated with integrity, high volume, and low energy consumption. This is potentially a model for supporting a peer to peer / distributed transactional based energy market.

Commercialisation

Early Commercial

Commercialisation of blockchain technologies has mainly developed in the Decentralised Finance (DeFi) and logistics industries. A wide range of companies in the energy sector have completed small scale pilot projects primarily focused on peer-to-peer energy transaction tracking. Some early projects are scaling up to larger projects, but are not yet commercially deployed in a practical sense:

- Acciona Energia, a Spanish renewable energy company, is installing over 500 blockchain based renewable energy powered EV charge points at IKEA shopping centres supplying real time tracked 100% renewable energy using Acciona Energia's Greenchain blockchain platform. The platform, which is based on the Energy Web chain, also has been adapted for green hydrogen tracking. Some of the chargers will also be fitted with vehicle to grid (V2G) capabilities.
- Granular Energy, a participant in the 2023 Free Electrons programme, provide a platform to support 24/7 Carbon Free Energy using hourly and sub hourly tracked renewable energy. They are also developing a trading platform for hourly 24/7 carbon free energy. In 2022 they launched their GB-Demonstrator pilot project with Elexon and NordPool to support 24/7 Carbon Free Energy (CFE) trading and in May 2023 they initiated a similar pilot with #50Hertz and LichtBlick SE. This solution is designed to support blockchain and non-blockchain transaction recording.



Blockchain

- FlexiDAO is providing a 24/7 electricity and carbon tracking demonstrator system tracking energy supplied to Google and Microsoft in a number of European countries including Ireland since July 2022.
- Power Ledger was founded in Australia in 2016 and its blockchain-enabled platform aims at making energy trading more efficient. Its platform has several configurations. µGrid supports P2P energy trading in India, Australia and Thailand. TraceX supports Renewable Energy Certificate hourly trading as part of the largest voluntary Renewable Energy Certificates (REC) registry in North America, the Midwest Renewable Energy Tracking System (M-RETS). MODE flex supports aggregation for the supply of flexibility services. PowerLedger moved to a permissioned Solana Blockchain in 2022, now promising short block times of 400 milliseconds and fast throughput of more than 50,000 transactions per second using a Proof-of-Stake consensus mechanism.
- PowerLedger has assisted EnergyTag in defining a set of standards for supporting 24/7 CFE accreditation and transactions. These standards are compatible with the EU standards defined for "Green Hydrogen" production. Similar sets of standards have been developed by Energinet, Elia Group and Elering with their "Energy Track and Trace" system. These standards cover geographical and temporal attributions. Elia and PowerLedger have initiated an R&D project on peer to peer energy trading in April 2023.
- Energy Web (a block chain non-profit), Elia Group, the Belgian and German TSO and BMW Group partnered to test and validate the Energy Web Decentralized Operating System (EW-DOS). They developed decentralized identifiers (DIDs) which dramatically simplifies the process of data exchange between EV owners and participants of the energy sector, such as TSOs, energy suppliers, and flexible service providers. A similar test is in development with Volkswagen.
- Six European Transmission Service Operators (TSOs) have developed the trans-national crowd balancing platform EQUIGY. This blockchain-based flexibility platform is being developed to integrate millions of individual electric vehicles, heat pumps and battery storage units in Germany and Europe through aggregation. In this way, these flexible capacities can be used as system services for the stabilisation of the electricity grid. The system has gone live as part of the Italian UVAM (virtually aggregated mixed units) project.
- In the US the Oak Ridge National Laboratory the "Grid Guard" demonstration project has shown the resiliency of blockchain based communication among devices on a smart grid.

ESB Activity

Currently monitoring sector

ESB is actively investigating a Blockchain based guarantee of origin system for a commercial offering of a renewable energy certification. The solution is due to launch to demonstrator status in Summer 2023 and is based on the Verus open-source decentralized blockchain protocol with the "Verus Proof of Power" consensus algorithm which is a 50% proof-of-work and 50% proof-of-stake consensus mechanism.

Granular Energy is part of the 2023 Free Electrons programme.

Policy

In Ireland, there is no blockchain specific legislation or blockchain specific regulatory framework.

Research by the Joint Research Centre (JRC), the European Commission's science and knowledge service notes that "regulatory initiatives would be needed to make the adoption of blockchain an advantage for consumers, to enlarge the community of those participating in the flexibility "energy economy".

If the full potential of blockchain is to be fulfilled, then government buy-in will be required with substantial legislative and regulative implications. Significant progress in standardisation for 24 CFE Energy Attribution Certificates has been made by EnergyTag.

In the absence of a regulatory requirement Blockchain solutions should only be implemented following a thorough cost-benefit analysis. It may prove to be the case that existing systems are more effective and existing database solutions are a better option.

Summary

Blockchain is a potential base technology to support the future highly distributed energy system. However, parallel progress in the areas of standardisation, regulation, market developments, and consumer and manufacturer engagement will be required. The main driver towards a blockchain solution would be a regulatory requirement though there is no strong evidence supporting this direction at present. ESB is monitoring potential regulatory demands for blockchain solutions.

6.3 METAVERSE

Technology

TRL 4

The metaverse is a vision for future social and work experiences that facilitate virtual, fully immersive interactions categorised by a feeling of presence. The full vision is at least 10 years to realisation; requiring developments in a large range of supporting technologies (see below for description of the technologies): Virtual Reality (VR), Augmented Reality (AR), Internet of Things (IoT), 5G, Generative AI, Conversational AI, Edge Services, Cloud Services, Blockchain, Non-Fungible Tokens, Displays, Haptics, Sensory Devices, Spatial Computation, Audio, Artificial Intelligence (AI), Perceptual Science, Avatars, and compute power. While many of these supporting technologies are at TRL level 7 or higher the full metaverse experience requires the combinatorial functionality of the supporting technologies and this functionality is at best TRL 3 / 4. The development of the Metaverse should be seen as evolutionary and not revolutionary. Continuous incremental developments will occur. The experience of the metaverse should also be understood as covering basic interactions to complete immersion.

The functionalities of the metaverse can be usefully categorised as to Transport, Transform and Transact:

- Employees or customers can be transported to a virtual environment facilitating immersive collaboration,
- The physical / real world can be transformed by the addition of digital information / digital assets in augmented realities,
- Commerce and value transactions can be facilitated within the metaverse, and between the metaverse and the real economy.

The metaverse will bring risks associated with identity, at both a personal and enterprise level. The more real and immersive an environment becomes the easier it will become to scam. There is an expectation that the computing power required to generate metaverses will be 10 times the compute power for existing experiences – a potential challenge to ESB's Net Zero Strategy. Other potential issues arise around capital and operational costs, security awareness and device security.

Virtual Reality is the ability to generate a completely fabricated "world" that resembles reality in perception or functionality. Augmented Reality adds elements overlaid on physical reality such that the user experiences reality with additions (objects or information). The Internet of Things (IoT) will facilitate the measurement and collection of data from the physical worlds, making that information available to the realities being created or augmented. 5G is a wireless protocol that will allow the necessary very high-speed data transmission without limiting motion. Generative AI and Conversational AI will allow the realities being created to react in real time to the users' actions and speech with a depth of meaning and understanding. Edge Services allow the necessary computations to be made local to their delivery reducing time delays. Cloud Services will be required to join the distributed users to common worlds. Economic exchanges in a metaverse will require means to exchange items of general value (Blockchain / cryptocurrency) and items of unique value like designer avatars (Non-Fungible Tokens). Displays and Haptics will present visual and touch sensations to users whilst Sensory Devices will interpret user actions. Spatial computational improvements will be required to ensure the computed action of virtual objects appear to move and interact with the real world and the user's 3D orientation in a manner that supports realism / expectation. Spatial effects from enhanced Audio will aid the realism of immersion, while Artificial Intelligence will facilitate autonomous agents to act in the created metaverses. Perceptual Science developments will show how lower resolution (and thus lower computing power) can be utilised without loss of immersion. Avatars allow users to represent themselves in a virtual world. All the above will demand increases in computing power.

Commercialisation

+ 5 years to Commercialisation

Meta has invested $36B on developing a Metaverse. In 2022 shareholders were informed that Metaverse related activities were unlikely to be profitable for 3 -5 years and this year Meta is emphasising artificial intelligence, over its metaverse, activities. Apple has launched a mixed reality headset, called Vision Pro, in June 2023 along with a new operating system visionOS. Microsoft's Hololens is the current market leader in industrial VR sets but this hasn't been developed in 4 years. In 2022 a major Microsoft contract with the US Army ran into significant trouble. Google invested $39.5 million in Metaverse projects as a way of "evolving computing in an immersive way with augmented reality." Google's Starline project (holographic projections) is an example of the highly immersive experiences that the metaverse promises – however the hardware requirements are immense. A number of game companies have also invested heavily, e.g. Epic Games and Roblox. Unity Software has established itself as supporting more than 50% of all real time 3D computation.

For industrial use, Nvidia has developed its omniverse offering. This is focused on the support of digital twins to simulate complex real-world events and operations using large-scale, physically accurate industrial digital twins. Amazon Robotics use Omniverse to optimise warehouse design and train intelligent robot assistants, Ericsson use it to optimize 5G signal propagation in cities, and BMW use it to design, simulate, operate, and maintain automotive plants. Siemens Energy is using Omniverse to predict corrosion progression in power plants thereby reducing maintenance inspection requirements and unplanned downtime by a claimed 70%.

A forecast of five years to commercialisation may be optimistic considering the relatively limited improvements in physical hardware and mobile compute in recent years, despite major investments by many industry leaders.

ESB Activity

Currently monitoring sector

ESB has been involved in a number of demonstrator projects covering remote support (ESBN and GT), immersive learning (Innovation Academy / Portlaoise Training School) and the use of Digital Twins (e.g. Turlough Hill).

Metaverse type experiences can be prototyped in supporting facilities, such as the Dell Customer Solution Centre in Limerick which the ESB has explored virtually.

Policy

The metaverse of 10 years from now may be as fundamental to collaboration, interaction, and commerce as the internet of today. The metaverse is in the early stages of development but the risk of being left behind is present.

Summary

The metaverse promises immersive experiences of virtual environments and augmented real environments. Major developments in technologies are required to allow these technologies combine in an unobtrusive manner to deliver the immersive experiences. Despite major investments by many industry leaders there has been relatively limited improvements in physical hardware and mobile computing in recent years. However useful applications including remote support, immersive training and digital twin simulations are commercially available. Future progress may be slow but it is likely inevitable.

VR Headsets

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