Energy for generations

EMERGING TECHNOLOGY INSIGHTS 2024

ESB Innovation

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Executive Summary

ESB's strategy 'Driven to Make a Difference: Net Zero by 2040' commits ESB to Net Zero by 2040. Established technologies, such as wind energy (onshore and offshore), solar PV and Li-ion batteries will be critical to achieving a Net Zero energy system, but we will also need additional emerging technologies to reach our goal.

ESB is exploring and investing in many emerging energy technologies, as outlined in this report. A selection of recent ESB activities in relation to emerging technology are given below.

- ESB is developing an innovative 100 MW floating offshore wind project in the Malin Sea, called Malin Sea Wind.
- ESB is developing the Saoirse Wave Energy project, a 4.9 MW wave farm pilot off the coast of County Clare, partnering with CorPower technology.
- ESB currently owns two 250 kW Hydrogen Fuel Cells. This is one of a large number of hydrogen production, storage and power generation projects ESB are engaging in.
- ESB Innovation signed a Memorandum of Understanding (MOU) with Form Energy, to explore how their '100-hour battery' technology may assist ESB's Net Zero targets.
- ESB delivered an 870 kW Industrial Heat Pump with 65°C water output to ABP Food Group.
- ESB Networks has recently commissioned three STATCOM systems in Ireland on the 110 kV transmission system.

Overview

Purpose

The purpose of this report is to provide an update on emerging energy technologies in Ireland and ESB's interactions with these technologies.

Scope

The scope of this report is to review emerging energy technologies. Established and commercially mature technologies, such as onshore wind or Li-ion batteries, are not emerging and therefore not considered in scope.

Technologies are principally evaluated using the Technology Readiness Level (TRL) scale and estimated time to commerciality.

Technology Readiness Level (TRL)

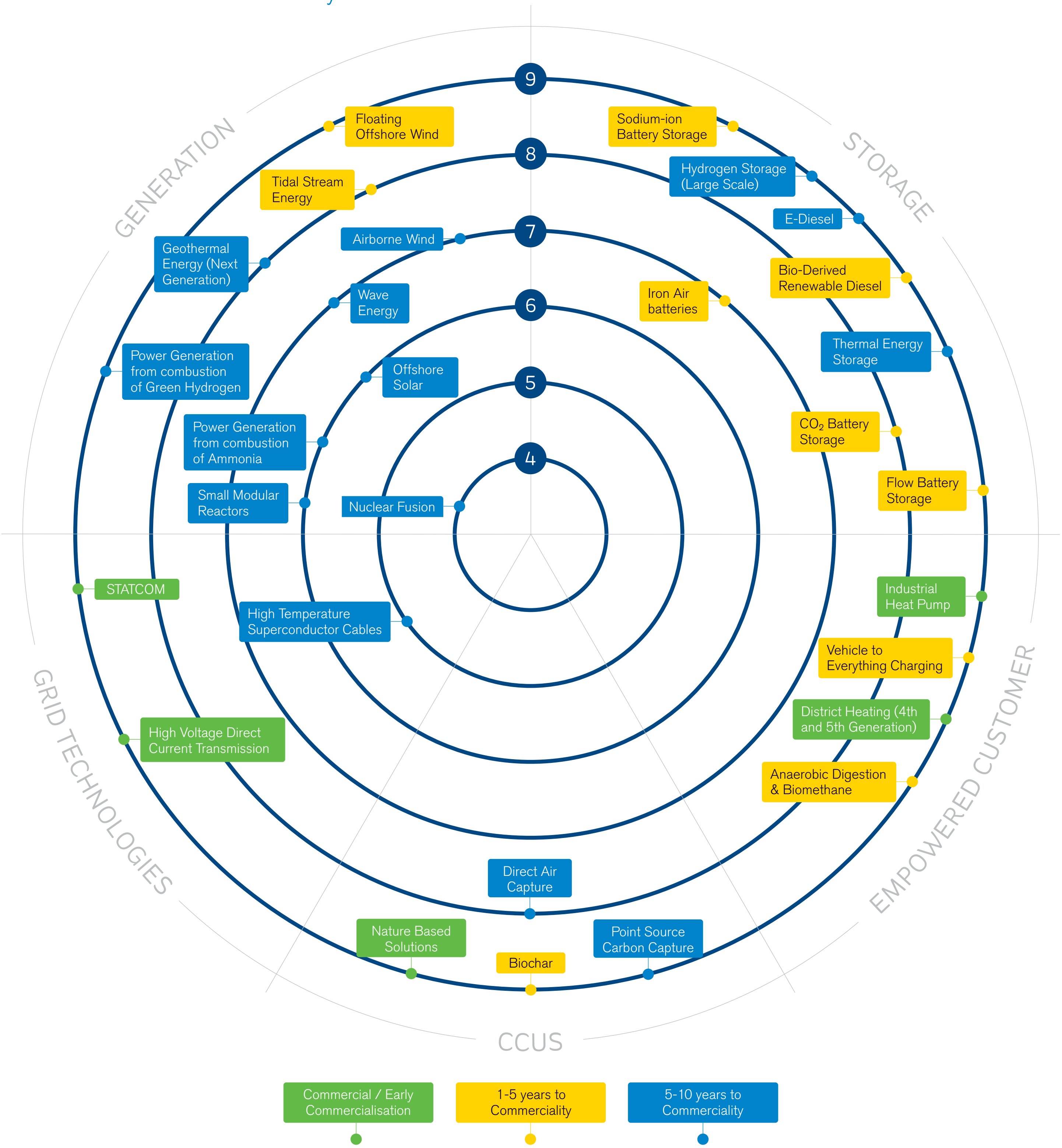
TRL 1-2	Concept phase / research
TRL 3-5	Small scale prototype deployed in lab / controlled environment
TRL 6-7	Large scale prototype or subsystems deployed in controlled environment
TRL 8	Large scale prototype deployed in commercial type environment
TRL 9	Mature technology, deployed at scale in commercial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

Commercialisation

Time to commercialisation and costs are estimated for the Ireland and UK markets. Prices quoted in this report are from publicly available sources and are intended to be indicative only.

Technology Radar

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



1. GENERATION

1. Generation (continued)

TRL
9

Floating Offshore Wind

Floating Offshore Wind (FLOW) energy consists of wind turbines mounted on floating structures that are attached to the seabed using various mooring arrangements. There is a wide variety of platform designs. Some are more mature and developed than others. DNV have defined the TRL as 9 for leading semi-submersible and spar platforms.

WindFloat project, Portugal

Sample project

Kincardine is a 50 MW project, 15 km off the coast of Aberdeen. It features 5 x 9.5 MW turbines installed on semi-submersible floating structures designed by Principle Power. It was commissioned in 2021.

Cost

The UK Contracts for Difference (CfD) allocation round (AR6) cleared at £139.9/MWh (2012 prices) for floating offshore wind. The Green Volt project (400 MW) was the only floating wind project to be awarded a contract in AR6. The 250 MW FLOW auction off South Brittany had a winning bid price of €86/MWh (grid connection costs excluded). However, the industry has cautioned this low price should not yet be considered a benchmark.

Timelines

In Ireland, FLOW is in the 10+ year time horizon. In GB, FLOW has already significant projects developed such as Kincardine and Hywind. Norway also has deployed a floating wind project to power oil and gas fields (Hywind Tampen). In France, the 25 MW Provence Grand Large wind farm is nearing completion.

Potential to scale

FLOW has great potential to scale in Ireland, particularly off the west coast, with at least 30 GW potentially available.

ESB Activity

ESB has many FLOW projects under development. Some examples include:

- ESB is developing the 500 MW Stoura floating offshore project off the east coast of Shetland.
- ESB is developing an innovative 100 MW floating offshore wind project in the Malin Sea, called Malin Sea Wind.
- ESB, with EDF Renewables UK and Reventus Power, is co-developing the 1 GW Gwynt Glas Offshore Wind Farm, off the coasts of Devon and South Wales.
- In Ireland, ESB is progressing plans at Moneypoint to create a hub for floating wind projects. ESB are also awaiting updates from the Department of Environment, Climate and Communications (DECC) with respect to plans for a floating demonstrator project.

Leading OEMS

Leading OEMs (by installed capacity) include Principal Power for semi-submersible platforms and Equinor for spar platforms.

Summary

FLOW has a positive outlook in Ireland, with a very large potential for significant scaling. Ireland's energetic sea states may pose technical and cost challenges. However, the average significant wave heights off Irelands south coast are roughly equivalent to the seas off Brittany, where successful recent auctions for floating wind have taken place.

TRL 1-2 Concept phase / research	TRL 3-5 Small scale prototype deployed in lab / controlled environment	TRL 6-7 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

TRL 3-6

Offshore Solar

Floating Solar PV consists of traditional solar photovoltaic panels mounted on buoyant devices floating on either in-land or offshore waters, tethered to a fixed point by means of anchoring or mooring structures. Offshore Solar refers specifically to projects in the offshore marine environment. Floating solar on in-land waters has been deployed at full commercial scale and is far more advanced than Offshore Solar, which is at an early stage of development. The European Technology and Innovation Platform for Photovoltaics (ETIP PV) have defined the TRL for Offshore Solar as 3-6 depending on the wave climate.

Pilot project in Risør, Norway. Credit: Fred. Olsen 1848

Sample projects
The 275 kW BOOST floating offshore solar demonstrator project is in the Canary Islands, uses Ocean Sun technology and came online in late 2023. The Nautical SUNRISE consortium, including SolarDuck, RWE, and others is developing a 5 MW solar system within RWE's OranjeWind offshore wind farm and is part funded by Horizon Europe.

Cost
Offshore Solar is pre commercial, and at demonstration stage. For example, the BOOST project above has an estimated cost of €4m, with most of the funding coming from the EU Horizon fund.

Timelines
Offshore Solar is estimated to be perhaps 5 + years from commerciality. Projects in calmer waters, such as bays and inlets, will be earlier to commercialise than those in the open sea.

Resources
Ireland has a comparatively poor solar resource. However, Offshore Solar may still be of interest if costs continue to fall as they have done for onshore solar.

Potential to scale
Assuming technology develops and costs fall, offshore floating solar has the potential to scale in Ireland, due to our large maritime area and many sheltered inlets. Our sea states tend to be energetic however, which would be a disadvantage for Offshore Solar in open waters. Internationally, the potential to scale is very large. In Shangdong, China General Nuclear Power Group (CGN) started building an ocean-based solar farm with a capacity of 400 MW and Shangdong has plans to build GWs of capacity.

ESB Activity
No current project activity. Maintaining a watching brief.

Leading OEMS
Leading OEMS include Solar Duck, Oceans of Energy, Fred. Olsen 1848, Swimsol and OceanSun.

Summary
Offshore Solar is still at an early stage of development. In addition, Ireland has comparatively poor solar resources and energetic seas. Therefore, offshore floating solar has a challenging outlook in an Irish context at present.

1. Generation (continued)

TRL
6-7

Wave Energy

The motion of surface ocean waves contains significant amounts of kinetic energy that can be 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. The TRL for wave energy is 6 to 7 with some full-scale demonstration trials underway.

Wave energy converter, deployed in Portugal. Credit: Corpower

Sample project

CorPower Ocean deployed a full-scale prototype off the coast of Portugal in late 2023, successfully exporting power to the grid and surviving two major storms.

Cost

The UK Allocation Round 6 published in March 2024 has an administrative strike price for wave energy of £257/MWh (2012 prices). There were no successful bids in AR6. To date, no wave project has been successful in UK allocation rounds.

Timelines

The EU Green Deal set a target of 100 MW of Ocean Energy (Wave + Tidal) to be deployed by 2027 and 1 GW by 2030. According to Ocean Energy Europe, only 1 MW of wave energy is currently in the water in Europe and the UK, indicating that most of the 2027 target is expected to be achieved with tidal capacity.

Potential to scale

Ireland has some of the best wave resources in the world, with the potential for GW's of deployment in Irish waters. However, very significant technology development and price drops will be required for wave energy to be deployed at scale.

ESB Activity

ESB is developing the Saoirse Wave Energy project which will be a 4.9 MW wave farm pilot off the coast of County Clare using CorPower technology. The project is supported by the EU Innovation Fund through a €39.5m grant agreement signed in December 2023. The wave farm is due to enter operation in Q1 2030.

Leading OEMS

CorPower Ocean is leading the offshore wave energy technology development, with a full-scale deployment operational in Portugal. Others like WavePiston, OceanEnergy, ISWEC and the Guangzhou Institute of Energy Conversion (GIEC) have deployed full scale prototypes in relevant environments. EcoWave Power is leading the development of shore mounted WEC.

Summary

Following decades of technology development with high rates of failure, wave energy is getting closer again to commercial maturity. Technology development led by CorPower & Ocean Energy and projects like Saoirse Wave Energy are attracting public and private funding, highlighting the high potential of wave energy. Many technical and scaling challenges remain however for wave energy to unlock its potential.

TRL 1-2 Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 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

TRL 8

Tidal Stream Energy

Tidal Energy Converters harness the kinetic energy of horizontal tidal water flow to power turbines. Three principal technology types exist; seabed mounted turbines, floating turbines and tidal kites. The International Renewable Energy Agency (IRENA, 2020) report Tidal Stream as TRL 8 for leading technologies.

Tidal energy converter, deployed in Scotland. Credit: Magallanes Renovables

Sample project

Magallanes installed the 1.5 MW floating tidal turbine "ATIR" in the European Marine Energy Centre (EMEC) in Orkney, Scotland for a period of 5 years. In August 2021, Orbital Marine Power's O2 turbine (2 MW) started grid-connected power generation at EMEC.

Cost

UK AR6 auction cleared at £172.0/MWh (2012 prices) for tidal stream. 28 MW worth of Tidal projects were successful in the auction.

Timelines

In the UK, the industry can be described as at an early commercial stage. The UK Tidal industry is targeting 1 GW of deployments by 2035.

Potential to scale

In the Republic of Ireland, the potential to scale with existing technology is low due to a lack of high resource sites. In Northern Ireland, there is better resource potential with the opportunity for hundreds of MWs of tidal energy. However, policy with respect to Marine Planning is currently not in place. The UK and France each have the potential to achieve a >1GW scale pre 2040 and multiple GWs post 2040.

ESB Activity

ESB has recently conducted a detailed review of options in relation to tidal energy and based on this analysis will maintain a watching brief on tidal energy.

Leading OEMS

Leading OEMS include Magallanes Renovables, and Orbital Marine Power (floating), SIMEC Atlantis Energy/SAE (seabed mounted) and Minesto (tidal kites).

Summary

In the Republic of Ireland, the outlook is challenging as there are no sites suitable for utility scale development using existing technology. In Northern Ireland, the outlook is more mixed as suitable sites exist off the Antrim coast, but the route to market and grid connection solutions remains unclear. In Great Britain, the outlook is positive with a clear route to market and numerous good sites.

1. Generation (continued)

TRL
7-8

Geothermal Energy (Next Generation)

Geothermal energy is thermal energy derived from 'hot rocks' 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.

Geothermal may be broadly categorised as 'Conventional' or 'Next Generation', 'Next Generation' geothermal includes Enhanced Geothermal Systems (EGS) and Advanced Geothermal Systems (AGS). In conventional geothermal systems, fluids circulate through naturally occurring fissures. However in EGS, fluids circulate through engineered fissures. AGS are closed loop systems that act as large heat exchangers. Leading Next Generation Geothermal technologies are at TRL 7-8.

ESB Head Office uses Ground Source Heat Pumps

Sample projects:

- **EGS** - In July 2023, US based Fervo announced the successful full-scale test of their Nevada 3.5 MW test plant called "Project Red."
- **AGS** – Canadian startup Eavor has been operating an AGS demonstration project since 2019 in the province of Alberta. They are also developing a larger project in Gerestried in Germany, which aims to deliver 65 MW of thermal energy and 8 MW of electrical energy. The project is planned for completion in 2027.

Cost

Costs for geothermal energy are hugely variable depending on location and technologies. Taking the Eavor project above as an example of Next Generation geothermal, the 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.

Timelines

A number of demonstrators are now in place for the Next Generation of geothermal plants. Commercial projects are due to come online in the late 2020s.

Potential to scale

One attractive feature of Next Generation geothermal is that is can be sited, in theory, almost anywhere. Therefore, if the technology progresses and the costs come down, the potential to scale is enormous.

ESB Activity

In relation to Next Generation Geothermal, ESB is keeping a watching brief.

Leading OEMS

Eavor, Fervo Energy and Sage Geosystems.

Summary

Globally, the outlook for Next Generation Geothermal is positive. In Ireland, which has comparatively low geothermal resources, the outlook is less positive. However, there is potential for deployment in future if the technology develops further and prices decrease.

TRL 1-2 Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 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

TRL 6

Small Modular Reactors

Small Modular Reactors (SMRs) are advanced nuclear reactors that have a power capacity of between 20 MWe and 400 MWe per unit. The small modular design allows this form of energy generation to have multiple uses including electricity production for the grid, generating electricity and heat for industrial applications, or the waste heat can also be recovered for district heating. The concept is still at an early stage (TRL 6) with more than 80 commercial SMR design currently in development in over 19 countries using a variety of designs including Pressurised Water Reactor (PWR), or Boiling Water Reactor (BWR) which are based on existing conventional nuclear power while designs for an Advanced Modular Reactor (AMR) are still emerging.

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

Sample project

In Hainan Island, China, the construction of a 125Me PWR prototype ACP100 started in July 2021 and is due to take six years to complete. This reactor, which is known as 'Linglong 1', is expected to be the world's first commercial SMR once it is commissioned. The CAREM-25 project in Argentina is due to be commissioned in the late 2020's.

Cost

The costs of SMRs are unknown and subject to high degree of uncertainty due to the lack of demonstration projects. The costs of certifying new designs and the cost of factories yet to be built are also subject to a high level of uncertainties.

Timelines

The first SMRs are expected to be built this decade, followed by accelerated deployment in the 2030s.

Potential to scale

Globally, SMRs have attracted a lot of interest as a source of zero carbon electricity and the technology has the potential to scale to deliver large volumes of zero carbon electricity.

ESB Activity

ESB has no direct involvement in SMR. 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).

Leading OEMS

NuScale Power, TerraPower, Westinghouse Electric, Nuward (EDF), GE Hitachi, Holtec International Rolls-Royce, Moltex.

Summary

Globally SMRs hold the promise of zero carbon dispatchable energy and could play a crucial role in providing reliable, firm and low carbon energy. They have attracted a lot of investment and attention; however, the concept and technology currently remain unproven due to a lack of demonstration projects.

1. Generation (continued)

TRL
7-9

Power Generation from Renewable Hydrogen

Hydrogen may be used as a fuel to generate electricity and if the hydrogen used is derived from renewable energy sources via electrolysis it is classified as ‘renewable hydrogen’. Focusing on the turbine technology (and not the entire project infrastructure), the TRL can be defined as 7-9, depending on blend of hydrogen and the scale of the system. Another option to combust renewable hydrogen is by using a reciprocating engine, which is already at TRL 9.

Hydrogen can also be converted into electricity using fuel cells, which combine oxygen from the air and hydrogen to produce power and water. Fuel Cells are currently at TRL 9.

ESB Fuels cells at the Amgen Irish Open

Sample project
In 2023, the Hyflexpower pilot project in France saw the world’s first successful demonstration of an integrated industrial electricity-to-hydrogen-to-electricity solution using 100% renewable hydrogen to generate zero carbon electricity. The turbine manufacturers were Siemens Energy and the output of the system was 12 MW.

Cost
In late 2023, the UK held its first Hydrogen Allocation Round (HAR1) for renewable hydrogen projects. The average price was £8/kg which are the are costs for the fuel (hydrogen) rather than full system cost for producing electricity from renewable hydrogen.

Timelines
GE and Siemens Energy have both pledged to make all their new turbines capable of burning 100% hydrogen by 2030. The development of utility scale projects that would include renewable hydrogen production, storage, transportation, and combustion of 100% hydrogen is expected to occur post 2035.

Potential to scale
There is a very large potential to scale in Ireland and renewable hydrogen could enable the storage of terawatt hours (TWh) of energy, providing a seasonal storage solution.

ESB Activity
ESB has been developing a number of projects for power generation from hydrogen. Some examples include the HyNet project in Northwest England, which will use hydrogen as part of a fuel blend in Carrington power station.

ESB recently acquired two 250 kW Fuel Cells, which have been tested at Cliff Hydro Station and are currently being used for demonstration purposes. The deployment of the fuel cells is the first phase of a demonstration-scale renewable hydrogen lighthouse project. The second phase will involve the deployment of an electrolyser at ESB’s Aghada Power Station in Co Cork – the overall project will be completed in 2025.

In addition to the recently acquired fuel cells, ESB is exploring the demonstration of other hydrogen to power technologies such as hydrogen-fuelled reciprocating engines and turbines.

Leading OEMS
Siemens and GE are two of the leading turbine OEMs

Summary
Hydrogen can be used to store energy over weeks, months, and seasons at scale and can be used as a renewable fuel to provide dispatchable generation’. Hydrogen power generation is currently the leading solution for Net Zero seasonal storage in Ireland. However, considerable cost and technical challenges exist which need to be overcome in order to scale this technology.

TRL 1-2 Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 Large scale prototype or subsystems deployed in controlled environment

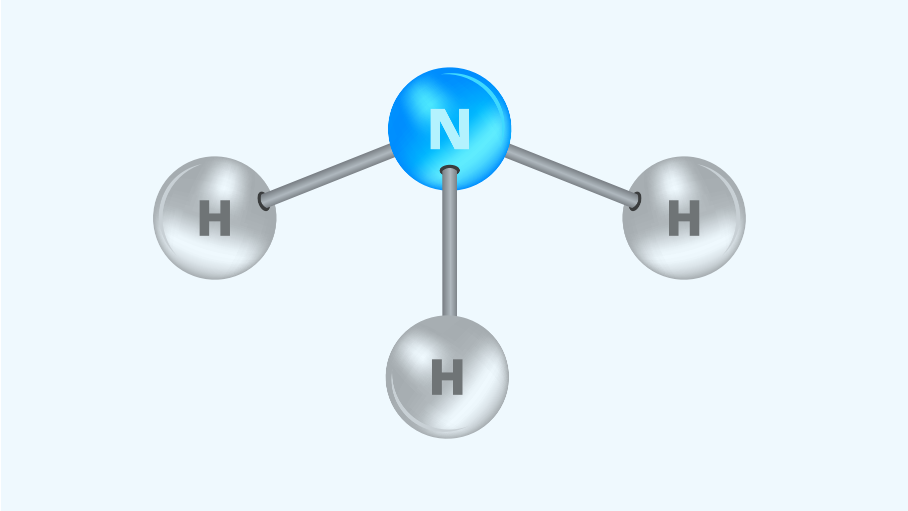
TRL 8 Large scale prototype deployed in commercial type environment

TRL 9 Mature technology, deployed at scale in commercial type environment

TRL 5-6

Power Generation from Combustion of Ammonia

Ammonia is the second most traded chemical in the world and 85% of the worlds current production of hydrogen is used to manufacture ammonia. 80% of the manufactured ammonia is used for fertilizer manufacturing, and the other 20% mostly in explosives and as an industrial refrigerant. However, ammonia has gained interest in the electricity industry as a potential zero carbon fuel. When ammonia is produced using nitrogen captured from ambient air and renewable hydrogen, it is considered to be a renewable fuel. The shipping industry is also interested in ammonia as an energy source to decarbonize maritime travel. Reciprocating engines (TRL 5-6) and gas turbines (TRL 5) that use renewable ammonia are under development for electricity generation.



Ammonia molecule

Sample project
Mitsubishi has been developing a 40 MW 100% ammonia-firing gas turbine based on their H-25 design. On a combined cycle they claim that the turbine could produce up to 60 MW. So far, they have tested a single burner of 0.5 tonnes/hour capacity demonstrating the complete combustion of the ammonia and suppression of NOX emissions thanks to their burner design. They are expecting to test a 4 tonnes/hour burner as a following step.

Cost
Renewable ammonia produced from renewable hydrogen is currently more expensive than grey ammonia (produced from natural gas). According to IRENA the cost of renewable ammonia is around USD 720 per tonne in locations with the best renewable resources compared to typical grey ammonia prices which range from USD 110 to 340 per tonne.

Timelines
Mitsubishi is expecting to have their first ammonia gas turbine running by 2025 followed by in-plant validation tests.

Potential to scale
Very large potential to scale. In countries with low availability of underground hydrogen storage, an alternative for seasonal energy storage requirements and dispatchable thermal generation might be achieved using renewable ammonia solutions.

ESB Activity
ESB is currently evaluating ammonia storage and power solutions for Moneypoint at small, medium and large scale.

Leading OEMS
Mitsubishi, Jenbacher, MAN.

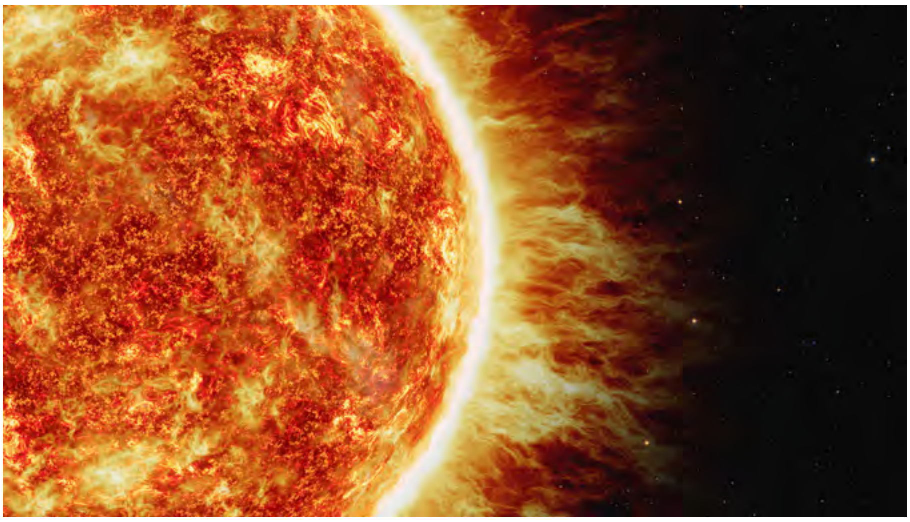
Summary
Power generation from ammonia combustion is still at low a TRL but is advancing at a rapid pace. Safety challenges remain in ammonia combustion for power generation and currently the cost of renewable ammonia is not competitive with grey ammonia. The first ammonia gas turbines should be deployed within the next decade and this may create an option for Ireland's zero carbon dispatchable portfolio.

1. Generation (continued)

TRL 4

Nuclear Fusion

Nuclear fusion combines light atomic nuclei to form heavier ones releasing large amounts of energy in the process. Unlike nuclear fission (used in existing nuclear power plants) where atoms are split, fusion involves bringing atomic nuclei together. Fusion is the process that produces energy in our sun and stars. The most promising combination for fusion on Earth involves fusing together Deuterium and Tritium (both isotopes of hydrogen) to produce energy in the form of heat. This process requires extremely high temperatures (100 million °C) which is a challenge to achieve and maintain.



The sun generates its energy by nuclear fusion

Sample project

Current demonstration projects at the ITER facility in the south of France include the DEMOnstration power plant which is ITER's successor, it aims to operate with a closed fuel cycle and to produce electricity.

Cost

For fusion to be cost competitive with other forms of energy generation its capital costs need to be significantly reduced. There are several companies which are commercialising fusion power generation and planning to reduce its cost through innovative designs of the magnetic containment field.

Timelines

Hard to forecast but unless there is a technology breakthrough it is at least a decade away from commercial viability.

Potential to scale

Globally, nuclear fusion offers the potential for clean and virtually limitless electricity generation.

ESB Activity

ESB has no direct involvement in nuclear fusion.

Leading OEMS

Commonwealth Fusion Systems, TAE Technologies, Helion Energy, General Fusion, Neo Fusion, Zap Energy, Tokamak Energy, First Light Fusion, Kyoto Engineering, Focused Energy.

Summary

Nuclear fusion holds the promise of a clean and plentiful energy source. However, to become commercially viable it will need to overcome several engineering and financial challenges. Significant public and private investment is being used to make this a reality. However it remains at least a decade away unless there is a technology breakthrough.

TRL Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 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

TRL 7

Airborne Wind

Airborne Wind Energy Devices (AWED) are towerless wind turbines, generally either aircraft or kite type devices, which are tethered to the ground or to a portable station. AWED are designed to be flown at altitudes of several hundred metres to harness higher wind speeds. AWED sizes are variable, but as a representative example, the Kitepower 'Falcon' device is rated at 100 kW. National Renewable Energy Laboratory (NREL) have reported the leading technology types as TRL 7.

Sky sails Mauritius. Courtesy of the SkySails Group

Sample project

The OEM 'Kitepower', with leading renewable developer, RWE, is testing the 100 kW 'Falcon' device in County Mayo, Ireland. Testing commenced in 2023 and is ongoing.

Cost

No reliable price data is available yet for AWED. NREL reports LCOE estimates of €120/MWh in 2030. These are just projections at this stage.

Timelines

As most technologies are at the stage of testing and demonstration, commercial deployment at scale is most likely 5+ years in the future.

Potential to scale

Theoretically, the potential to scale is large in places where there is an abundance of space, such as offshore environments, or low populated areas, such as deserts.

ESB Activity

ESB visited the KitePower Mayo test facility in 2023 and keeps a watching brief on the technology.

Leading OEMS

Kitepower, SkySails, Kite mill.

Summary

The outlook for this technology is challenging due to technical, safety and cost issues to be overcome. However, the technology does have attractive features such as an extremely light weight design (for kite type systems) and access to high winds. In addition, the industry received a significant boost in April 2024, with the announcement that airborne wind energy will receive a specific tariff within the German Renewable Energy Act.

2. STORAGE

2. Storage (continued)

TRL
8-9

Sodium-ion Battery Storage

Sodium-ion batteries (NIBs) use Sodium ions (Na+) as their charge carriers and are much better than Lithium-ion (Li-ion) batteries in terms of their impact on mineral resource scarcity. Sodium, the key component, is extremely abundant in comparison to lithium. NIBs have a superior safety profile and are less dense compared to conventional Li-ion batteries having a longer deep discharge cycle life. NIBs are largely at the advanced research and development stage for stationary storage (TRL 8/9) and not yet widely deployed in grid applications.

Sea salt harvesting

Sample projects

China Southern Power Grid has deployed a 10 MWh NIB battery in China's Guangxi Zhuang region. It is the first phase of a 100 MWh project. A large 50 MW/100 MWh Battery Energy Storage System (BESS) project in Hubei, China, using NIB technology was completed in June 2024, making it the world's largest operating NIB BESS.

Cost

NIBs are constructed from less expensive materials than Li-ion batteries and need fewer critical materials. Current costs, according to EPRI are roughly €300-400/kWh, considerably higher than Li-ion but should reduce as the technology scales.

Timelines

NIBs need to significantly scale- up supply chains and production. This could facilitate their wider deployment, especially in compact urban vehicles and storage applications over the next 5 years.

Potential to scale

NIBs can be manufactured using similar manufacturing facilities as Li-ion batteries. This could facilitate their wider deployment, especially in compact urban vehicles and storage applications. However, the need to scale up supply chains, particularly for the hard carbon anode, is currently a significant constraint on production.

ESB Activity

ESB has recently completed a long duration energy storage technology ranking study and NIBs were shortlisted as a key battery technology to explore in more depth.

Leading OEMS

CATL (China), Natron (US), Northvolt (Sweden), Faradion (UK), BYD (China), HiNa (China)

Summary

Improvement in energy density and production scale-up could make NIBs competitive with Li-ion batteries. Batteries based on abundant raw materials could reduce geopolitical risks and dependencies on specific regions, both for battery manufacturers and countries. According to the European Commission's Critical Raw Materials Act, the demand for critical raw battery materials is expected to increase exponentially as EU countries transition to renewable energy systems and electric vehicles. However, it remains to be seen whether NIB batteries can develop a competitive advantage over Li-ion batteries.

TRL 1-2 Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 Large scale prototype or subsystems deployed in controlled environment

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TRL 9 Mature technology, deployed at scale in commercial type environment

TRL 9

Flow Battery Storage

A flow battery is a rechargeable battery in which electrolyte flows through the electrochemical cells from one or more tanks. There is a growing market in flow batteries for grid scale applications, particularly in the 4-24 hour duration range. Unlike Li-ion batteries, flow batteries have liquid electrolyte stored in external tanks rather than in each battery cell which decouples their power and energy. There are several different flow battery technologies being developed using different electrolyte chemistries and the different chemistries are at different TRL levels. Some examples include iron flow, iron-chromium, organic flow, zinc bromine & hydrogen/bromine batteries. Vanadium Flow Batteries (VFBs) are currently the most mature (TRL 9) and are already commercially available.

Vanadium Flow Batteries in Oxford, UK. Credit: Invinity

Sample project

A 100 MW/400 MWh VFB system, the largest of its kind in the world, was successful brought into operation in Dalian in northeast China in 2023 by Rongke Power Company.

In 2022 Sumitomo installed a 51 MWh VFB for the Hokkaido Electric Power Co. in Japan. A 14.4 MWh new generation VFB will be installed by Invinity at a utility site in Taiwan.

Cost

According to EPRI, the current cost is in the region of €400-800/kWh for VFBs which is considerably higher than Li-ion. However, the costs greatly depend on the location and scale of the project. The costs are projected to reduce significantly in the next few years to compete with Li-ion particularly in the 8hr+ market.

Timelines

VFBs are already available but are expected to scale up in production in the next 2-3 years to meet the growing demand. An example is Invinity, who have recently expanded their manufacturing capacity in Scotland to create the production capacity needed for their next generation VFBs.

Potential to scale

VFBs are now being deployed at much larger grid scale applications and their energy density is improving. Iron flow batteries have not scaled to the level of VFBs yet but have the potential to be much cheaper.

ESB Activity

ESB are engaging with key flow battery OEMs and are conducting a study to access the feasibility of building a pilot or full-scale commercial flow battery storage system in Ireland or elsewhere. As part of the study ESB are carrying out financial modelling to compare flow batteries with Li-ion at longer durations.

Leading OEMS

Invinity, Largo, Sumitomo, Cellcube, VRB and ESS.

Summary

Compared to Li-ion batteries, flow battery technologies offer advantages such as longer output duration, more stable, longer cycle life and low degradation but they also have relatively low round-trip efficiencies and higher upfront cost. Investment in local raw material supply chains, better manufacturing processes and larger scale projects will help lower the risk profile of flow battery technology.

2. Storage (continued)

TRL
7-8

CO_2 Battery Storage

A CO_2 battery is an energy storage system that utilizes compressed CO_2 to store and release energy when needed enabling the long-duration storage of renewable electricity. The CO_2 battery is made primarily with standard industrial components such as compressors and turbines and using CO_2 as the storage medium allows for high-density energy storage without the need for extremely low temperatures. The CO_2 changes between its gaseous and liquid state in the charging and discharging process. This process operates in a closed loop cycle with no CO_2 being emitted into the atmosphere. This technology is suitable for durations of 8, 10 & 12 hours and due to the large size of the system is more suitable in less urban locations. The technology is currently at TRL 7 and OEMs aim to be at TRL8 with a fully commercial scale plant tested at the end of 2024 or early 2025.

Energy Dome CO_2 battery, Sardinia, Credit: Energy Dome

Sample project
Energy Dome have built a 4 MWh demonstration project in Sardina, Italy and a full commercial scale project of 20 MW/200 MWh is currently being built close to the existing site. Alliant Energy in collaboration with Energy Dome and other key stakeholders have also announced a 200 MWh CO_2 battery in Wisconsin, USA.

Cost
Target costs for a full scale 200 MWh project are approximately €200/kWh This may vary depending on market timing and build out costs in specific regions however this cost projection and has not been validated independently.

Timelines
Energy Dome aim for the full-scale 200 MWh plant in Sardinia to be operational by the end of 2024 or early 2025 and for it to be commercially ready to deploy thereafter. The Wisconsin 200 MWh project is planned to be completed in 2026.

Potential to scale
The projected deployment costs appear to be competitive compared with Li-ion and other technologies. As projects are rolled out and performance data is validated the scale and number of projects are likely to increase significantly.

ESB Activity
ESB has recently completed a long duration energy storage technology ranking study which included mechanical storage. Following this study ESB and Energy Dome are conducting a study to access the feasibility of building a full-scale commercial CO_2 battery storage system in Ireland.

Leading OEMS
Energy Dome.

Summary
CO_2 batteries have several advantages including low environmental and fire risk, proven components with reliable established suppliers, and long duration capability in the 8+ hours range. If they can compete commercially with Li-ion, then the outlook is positive. Due to the scale of the projects, obtaining planning permission will be a consideration when choosing project locations.

TRL 1-2 Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 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

TRL 5-9

Thermal Energy Storage

Thermal Energy Storage (TES) is a form of energy storage that uses heat to store energy for prolonged periods of time. TES achieves this by heating or cooling a bulk storage medium such as molten salt, concrete or sand to temperatures as high as 1,200°C. This medium can then be used later to generate electricity or for heating and cooling applications. This technology is most proven for applications with heat as the output, but manufacturers are also beginning to explore the electricity-heat-electricity (AC-AC) capabilities of TES for future integration into the electricity grid. The TRL is 9 for technologies with heat as the output. For AC-AC systems, EPRI have defined leading technologies as TRL is 5-6.

Sample project

The Rondo Heat Battery is an electrified thermal energy storage system that uses refractory bricks to thermally store energy. In 2022, a thermal battery was commissioned in Pixley, CA with a 2 MWhth unit located at a low carbon fuel manufacturing facility. The battery is charged with surplus intermittent electricity and is discharged as heat which is provided directly to the sites steam plant. Rondo plans to begin construction on their first 100 MWh system in 2024/2025. This system is designed to output steam at temperatures up to 1100°C with the potential of integrating a heat engine to convert the stored heat back to electricity at an expected round trip efficiency of around 35-45%.

Rondo Brick Storage California, Credit: Rondo

Cost

In 2022, the US Department of Energy published a Grid Energy Storage Technology Cost and Performance Assessment which predicted that by 2030, thermal energy storage of a 100 MW system (24 hours storage) would have a totalled installed cost of $152/kWh for AC – AC systems. This value is set to decrease with scale and duration over time.

Timelines

As of 2024, several companies have demonstrated the viability of TES in a electricity-heat capacity. However, the integrated AC-AC system is still in the development phase with several companies attempting to develop demo and commercial projects within the next number of years.

Potential to scale

Many TES systems are being deigned in modular configurations with the intention of making scalability easy and efficient. Some preexisting concentrated solar power plants have demonstrated heat to electricity capacities of up to 110MWe.

ESB Activity

In 2023, Rondo featured in the top 15 in the Free Electrons Programme of which ESB is a member. Additionally, ESB has been undertaking a storage technology ranking study in collaboration with the Electric Power Research Institute (EPRI) to evaluate a variety of long duration technologies including thermal energy storage. The aim is to identify the technology suppliers with the greatest potential based on the quality of their technology.

Leading OEMS

A variety of TES OEMs have been evaluated as part of the LDES Technology ranking study with several having demonstrated integration into electricity grids across the world such as Kyoto Group's HeatCube, Brenmiller Energy and Rondo.

Summary

TES systems have potential as a versatile solution for the electricity grid, particularly in the context of long-duration energy storage.. Previously, the focus has been on utilizing TES for direct heat applications. The challenge lies in demonstrating the AC-AC conversion capabilities of TES, which would broaden its applicability and enhance its role in the transition towards a more sustainable and flexible electricity grid.

2. Storage (continued)

TRL
7

Iron-Air Batteries

Iron-Air batteries are energy storage systems that use reversible rusting (oxidisation) of iron to store and release electricity. The leading company is US based Form Energy, who aim to achieve 100 hours of electrical storage using Iron-Air batteries. Eirgrid, in a document entitled 'A Call for Evidence on the Market Procurement Options for Long Duration Energy Storage' defined Form Energy technology as TRL 7.

Graphic of Form Energy Iron-Air battery. Credit: Form Energy

Sample projects
Great River Energy is an electric cooperative based in Minnesota. Together with Form Energy, they are developing a proof of concept 1.5 MW / 150 MWh project in Cambridge.

FuturEnergy Ireland (ESB, Coillte joint venture) has also announced their intention to develop a storage project, using Form Energy batteries, near Buncrana, Co. Donegal.

Cost
There are currently no commercial demonstration projects available yet to validate the costs. However Form Energy are targeting costs of $20/kWh which they hope will be achieved when the batteries reach commercial scale. However, this target is an in-house projection and has not been validated independently.

Timelines
The Cambridge project referenced above is due to come online in early 2025. Larger commercial scale projects ranging from 5 MW/500 MWh to 15 MW/1500 MWh are expected in the 2025-2027 timeframe. Form Energy is building out a commercial-scale factory in West Virginia to start mass-producing Form Energy batteries by the end of 2024.

Potential to scale
If Form Energy achieves the technological progress and price points that they have planned, then the potential to scale is very large, of the order of GWs.

ESB Activity
ESB Innovation have signed a Memorandum of Understanding (MOU) with Form Energy in Q1 2024, to explore how the technology may help ESB to achieve its Net Zero targets.

Leading OEMS
Form Energy.

Summary
Iron-Air battery, is a rapidly developing promising technology, which potentially offers the possibility of achieving 100 hour storage with low costs. One key strength of the technology is that the primary materials (particularly iron) are easily sourced and in plentiful supply.

TRL 1-2 Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 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

TRL 9

Hydrogen Storage (Large Scale)

There are many ways of storing hydrogen both at the small and large scale. At the small scale, pressurised tanks (TRL 9) are a long-established method. At the large scale (TWh), research is ongoing into compressed hydrogen storage in underground caverns (aquifers, salt caverns, depleted gas fields, lined caverns, lined shafts). Salt caverns are currently considered the most mature for static storage (TRL 9).

Sample projects
Four hydrogen salt caverns sites are currently operational in the world, however these are not yet coupled with a renewable hydrogen production facility. Instead, they are used as static storage for the chemical industry rather than cycling storage for the power industry. Spindletop, in Texas, is the world's largest hydrogen storage facility (>120 GWh).

The world's first hydrogen storage facility in a depleted gas field was opened in 2023 in Austria and has successfully injected and withdrawn hydrogen on a small scale. Then next phase is a seasonal storage pilot as part of a €20m EU funded programme.

The HyPSTER pilot 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).

Infographic of planned hydrogen Storage in Cork

Sample projects (continued)
Renewable hydrogen will be produced from local renewable energies (photovoltaic, hydroelectric) and a 1 MW electrolyzer. The plan is that the salt cavern will ultimately store 50 tonnes (1.65 GWhr) of renewable hydrogen.

Cost
In an Irish context the cost of storing hydrogen underground is unknown, but it is expected that depleted gas fields will be the cheapest option available. The IEA Hydrogen TCP-TASK 42 Underground Hydrogen Storage report of 2023 indicates that new salt caverns will cost $0.51 per kWh of hydrogen stored, and underground storage in porous media (i.e. depleted gas fields) $0.2 per kWh of hydrogen stored.

Timelines
In Ireland, the development of large-scale caverns for storing renewable hydrogen will probably be in the post 2035 timescale. Ireland has no proven existing salt cavern storage sites, research suggests some potential in the Irish sea but costs would be much higher than onshore development.

Potential to scale
There is the potential for hydrogen storage to achieve TWh scale in Ireland.

ESB Activity
ESB formed a joint venture company Kestrel DAC with dCarbonX, a geological company which develops subsurface assets for hydrogen and carbon storage and BGE as subsidiary of Centrica who are developing Rough gas field for hydrogen storage. Kestrel DAC is proposing to redevelop the decommissioned gas reservoirs in the offshore Kinsale area gas fields for large-scale energy storage of renewable gas and renewable hydrogen The consenting process for hydrogen storage at the retired Kinsale natural gas field has commenced. The plan is to have initial storage of natural gas in the early 2030's and transitioning to hydrogen storage when sufficient volumes become available, potentially by mid 2030's.

Leading OEMS
SNAM (Europe's largest gas storage provider).

Summary
Hydrogen, and derivatives such as ammonia, are considered the leading options for seasonal storage of electrical energy at TWh scale, dCarbonX is 50% owned by SNAM.

2. Storage (continued)

TRL
6-9

Bio-derived Renewable Diesel

Renewable diesel can be used as a direct substitute for fossil diesel offering the potential to decarbonise a wide range of end uses including transport, heating and electricity generation. Currently most renewable diesel is produced by hydrotreating waste vegetable oils and animal fats through an established and mature process (TRL 9) called 'HEFA' (Hydroprocessed Esters and Fatty Acids). This renewable diesel is generally known as 'HVO' (Hydrotreated Vegetable Oils). There is however a limited availability of sustainably sourced, waste animal fats and vegetable oils in the world. To enabling the scaling up of the production of renewable diesel requires the development of alternative production pathways. These emerging technologies include the 'Gasification with Fischer Tropsch' of woody biomass and Municipal Solid Waste (MSW) (TRL 6) and the 'Alcohol to Jet' processes which converts grain and waste derived ethanol to Jet fuel (TRL 7-8).

HVO at a Circle K refulling station, Dublin Port

Sample projects

Circle K and Certas have been expanding the availability of HVO across their network of forecourts in Ireland, offering a sustainable alternative to their customers for diesel vehicles. The FLITE project (Fuel via a Low Carbon Integrated Technology from Ethanol) which is supported by the Horizon 2020 program is building Europe's first of a kind Alcohol to Jet facilities in the Netherlands converting waste derived ethanol to over 30,000 tons of sustainable aviation fuel per year.

Cost

The cost of producing renewable diesel is very dependent on the production process and the feedstock used. Renewable HVO produced through the HEFA process costs between €1 – €1.50/litre whereas renewable diesel produced using the Gasification & Fischer Tropsch and the Alcohol to Jet processes are 2-5 times more expensive.

Potential to scale

HEFA produced renewable diesel has a relatively low ability to scale due to the limited volumes of sustainable recycled vegetable oil that are available to be recovered. Both the 'Gasification & Fischer Tropsch' as well as the 'Alcohol to Jet' pathways offer a much higher potential to scale to provide significant volumes (MT/annum) of renewable diesel given the much larger volumes of available feedstocks that these processes can manage.

ESB Activity

ESB is actively tracking the market and is exploring ways it could sustainably incorporate HVO into its dispatchable thermal generation fleet.

Leading OEMS

'HEFA based' includes NESTE, ENI, Total. 'Alcohol to Jet' includes Lanzajet, SkyNRG.

Summary

Renewable diesel (HVO) is a flexible, versatile drop-in replacement for fossil diesel which offers an attractive decarbonisation option for existing asset owners. The HEFA production process is developed and mature however the supply of sustainable feedstock for this production process is limited. Renewable diesel generated through the developing Gasification and Fischer Tropsch process has a much higher potential to scale but is more expensive. The Alcohol to Jet process is also developing and has the potential to significantly scale up to help meet the ambitious EU sustainable aviation fuel targets.

TRL 1-2 Concept phase / research	TRL 3-5 Small scale prototype deployed in lab / controlled environment	TRL 6-7 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

TRL 6-9

E-Diesel

E-Diesel is a type of electrofuel (e-fuel) that is chemically identical to fossil-based diesel (petrodiesel). An e-fuel is produced synthetically from renewable power and renewable resources like water and biogenic carbon dioxide (CO_2). There are different ways of producing e-diesel using water and carbon dioxide, however the most established begins by producing hydrogen, from water electrolysis, and combining this with biogenic CO_2 using a reaction called Reverse Water Gas Shift (RWGS). This reaction transforms the mixture of hydrogen and CO_2 into a synthesis gas (syngas) that undergoes a secondary reaction process to form long-chain hydrocarbons like e-diesel. This secondary reaction process is known as Fischer-Tropsch synthesis.

The Fischer-Tropsch synthesis is at a very mature state (TRL 9), however RWGS reaction is currently at a lower state of development (TRL 6). An alternative method to synthetically produce e-diesel is to initially produce methanol. Through a similar series of reaction pathways, methanol can subsequentially be processed into longer-chain hydrocarbons to form e-diesel. This method of e-diesel synthesis is currently at TRL7.

'HIF' e-diesel pilot plant, Magallanes, Chile. Credit: HIF

Sample projects

Although Sasol has been producing synthetic diesel since the 1950's from non-renewable sources, some companies have started to produce e-diesel using renewable feedstocks. One example is Infinium, a US-based company that has a Fischer-Tropsch-based plant in Texas. According to Bloomberg, they produce roughly 8,300 litres per day of fuels that include e-diesel, E-Jet and naphtha. Another example of e-fuel production is the HIF plant in Chile. In 2023, they started a first-of-a-kind pilot plant using the methanol to e-diesel process, producing up to 130,000 litres per year of e-Gasoline. The plant produced hydrogen by using an on-site wind turbine and reacting it with biogenic CO_2 to produce methanol and gasoline. This fuel has been exported to Porsche in the UK in shipments of 24,600 litres.

Cost

E-Diesel production is an energy-intensive process, and therefore production costs are strongly influenced by the renewable electricity prices. The World Economic Forum estimates a cost for e-Jet Fuel (similar to e-diesel) of $2400-3000 per tonne by 2025, with steep decreases in production costs expected. This equates to circa 4-5 times the price of fossil jet fuel.

Timeline

E-Diesel is currently being produced in a couple of relatively small plants in the world, with an expected exponential growth in the next decade driven by the aviation sector and due to the UK and EU mandates for e-Jet fuel.

Potential to scale

Large potential to scale (expected market size of $50 billion by 2030). Demand for e-Jet fuel is mandated by the UK and EU from 2030 onwards.

ESB Activity

Currently ESB is developing a pilot project that is expected to produce around 400 litres/day of e-fuels, including e-diesel.

Leading OEMS

Sasol, Infinium, HIF, Topsoe, UOP Honeywell, Zero Petroleum, Johnson Matthey, Arcadia, Norsk-E.

Summary

E-Diesel is a drop-in alternative for fossil-based diesel that can be produced with 100% renewable resources. The core technology is very mature but challenges in renewable feedstocks are being faced. Several companies are developing projects to fulfil mandated demands in the aviation sector. E-Diesel is substantially more expensive than fossil-based diesel.

3. EMPOWERED CUSTOMER

3. Empowered Customer (continued)

TRL
7-9

Industrial Heat Pumps

Industrial Heat Pumps (IHP) are heat pumps used in an industrial setting that actively recover waste heat and which can provide temperatures up to 200°C. The TRL of IHPs varies according to the temperature output. According to the IEA's Technology Collaboration Program (TCP) on High Temperature Heat Pump (HTHP), IHP achieving 120°C are at TRL9 while IHP achieving 160°C are at TRL7.

Green houses in East Anglia heated by heat pumps

Sample project
The Irish company, Astatine, has successfully installed a 1 MW IHP, supplying temperatures of 120°C, at the Ahascragh distillery, Galway.

Cost
With higher Capital Expenditure (Capex) and Operational Expenditure (Opex), the economics of IHP can be challenging when compared to a gas equivalent. However, the costs are dependent on each application and the availability of waste heat sources.

Timelines
The roll out of IHP is gaining momentum and the 2024 Climate Action Plan includes an action to deliver a roadmap to phase out fossil fuel for all heat usages under 140°C.

Potential to scale
With time, IHP have the potential to substitute all fossil fuel heating solutions under 200°C. Currently the higher cost of electricity and high Capex relative to gas installations are a barrier to the roll out of IHP and requiring grant support for adoption. In Ireland, the principal support system for IHP is the Support Scheme for Renewable Heat which offers Capex grants of up to 40% or €1m depending on the temperature output and the systems coefficient of performance.

ESB Activity
ESB signed a contract with one of Europe's leading food processors, ABP Food Group. As part of this contract, ESB delivered an 870kW ammonia heat pump with 65°C water output and is currently working on installing a second project. ESB has deployed heat pumps in the UK in two large greenhouses in East Anglia. The total thermal output is 72 MW and the total area of the greenhouses is 29 hectares.

Leading OEMS
ECOP, SPH and Fuji are offering heat pumps solutions delivering water and steam temperatures greater than 160°C, with future plans for temperatures greater than 200°C.

Summary
The outlook for IHPs 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 and the temperature output by IHP. Financial supports are currently required to overcome high upfront costs and the relatively low cost of gas solutions.

TRL 1-2 Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 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

TRL 9

Vehicle to Everything Charging

Vehicle to Everything charging (V2X) is a term used to describe bi-directional power flow from an Electric Vehicle (EV) to other non - transport applications, such as to a home (V2H), to the grid (V2G) or to external loads (V2L). The technology to enable this is relatively mature (TRL 9) however the markets to monetise this service are emerging. Using V2X technologies, an EV can act as a battery storage system and participate in grid service activities such as demand time shifting, arbitrage or backup power, given suitable infrastructure and permissions are in place.

Sample project

There are an increasing number of large-scale pilots testing V2X technology and commercialisation across Europe and around the world. The Ford F150 Lightening can become a mobile generator providing V2L and V2H services. The EV manufacturer Polestar plan to trial V2G for a large fleet of Polestar 3 cars in Sweden and California, starting in 2024. The pilot aims to study commercialisation and trial real world, scalable use cases for V2G adoption.

EV Charging

Cost

The charging hardware to provide V2X services are significantly more expensive than standard unidirectional chargers. In Ireland there is no export tariff yet to sell stored energy in an EV through use of V2X chargers. Demand response and optimised charging / discharging schedules based on market conditions are the source of revenue potential for V2X. In the UK, Octopus offers free EV charging when users sign up to their V2G Powerloop trial.

Timelines

EVs that use the Japanese charging standard CHAdeMo are already capable of availing of V2X services. An example of this is the Nissan Leaf. The EV industry in Europe is moving toward the CCS charging standard, with plans for CCS2 to become V2X capable in 2025. Outside Ireland, service providers such as The Mobility House and Octopus are already offering demand response V2G charging solutions. In Ireland, Grid Beyond recently launched demand response EV charging solutions.

Potential to scale

With the governments CAP24 target of 845,000 passenger EVs and 95,000 commercial EVs to be on Irish roads by 2030, the potential to scale is significant but questions around battery degradation and the limited number of compatible EVs need to be overcome to enable wide adoption of the solution.

ESB Activity

ESB Networks installed 5 domestic WallBox V2G chargers as part of the Dingle Project in 2021 and 1 V2G charger in Leopardstown as part of the RESERVE Project in 2019. Both projects trialled and tested the operability of V2G chargers and their effect on the local grid.

Leading OEMS

Most EV OEMs have V2X capabilities or plan to have them in the near term. The are a number of OEMs which already offer V2X chargers, such as WallBox and Nuvve. Grid Beyond, The Mobility House and Octopus are leading the integration of chargers onto demand response and wholesale energy markets.

Summary

As the global mass adoption of EVs continues, flexible EV charging and V2X will become an integral part of future demand side grid flexibility services. Deployment is currently uneven around the world, V2X commercial offers are available in countries like the US, UK and France, but not available yet in Ireland. Despite issues around public acceptability, technology availability and policy, the future for V2X in Ireland looks positive.

3. Empowered Customer (continued)

TRL
8-9

District Heating (4th and 5th Generation)

District Heating (DH) is a centralised heating system which uses one or more energy centres to generate and distribute heat to buildings, industrial or commercial premises via a network of insulated pipes. Fourth-generation district heating (4GDH, TRL 9) uses low-temperature water and integrates renewable energy sources, while fifth-generation (5GDH, TRL 8) systems use ambient temperature networks with decentralized heart sources.

A wide range of heat sources are available, including waste heat recovery, solar thermal, geothermal and heat pumps. These DH schemes will also include thermal storage to allow for peak shaving and demand response.

District Heating Pipes

Sample project

The Tallaght DH Scheme is a 4GDH network capable of providing up to 3MW of heat to several public buildings and the TU Dublin – Tallaght campus. The energy centre uses low grade waste heat from a nearby Amazon data centre and upgrades the heat using two heat pumps. It is owned by South Dublin County Council and was co-developed by Codema. Fortum designed, built, and now operate and maintain the network. An expansion of the network is planned from 2024 to 2025 and is due to connect residential buildings.

Cost

DH costs vary substantially and become more commercially competitive in areas with a higher density of heat demand. A recent report by the Irish District Energy Association (IrDEA) published in May 2024 estimated that the Levelized Cost of Heat (LCOH) coming from a DH scheme supplied by heat recovered from a data centre and in a high heat density area is €93/MWh, which is competitive with an individual heat pump.

Timelines

The 2024 Climate Action Plan sets out a target of up to 2.7 TWh of DH to be delivered by 2030, with up to 0.8 TWh by 2025. Dublin City Council is preparing a joint venture procurement for the delivery and operation of the Dublin District Heating System. The project is included in Dublin City's Capital Programme 2024-2025.

Potential to scale

There is very little DH in Ireland today, however in other jurisdictions (notably the Nordic countries and Eastern European countries), DH has reached penetration levels of 50 – 90%. The National Heat Study (NHS) found that up to 54% of residential and SME heat demand in Ireland could be met through DH. The density of heat demand is one of the deciding factors when it comes to scaling of DH networks. A spatial analysis from SEAI prioritizing the highest heat density area found that of the 2.7 TWh target set out in current Climate Action Plan, 50% can be delivered in Dublin and Cork city alone.

ESB Activity

ESB is actively monitoring the development of DH in Ireland.

Leading OEMS

DH are large energy projects often run by utilities or energy services companies. Leading developers and operators in Europe with operations in Ireland are Veolia and Fortum.

Summary

DH currently provides less than 1% of Irelands heating demand, putting Ireland in the bottom five of EU countries. Successive Climate Action Plans recognise the role DH can play in decarbonising heat in Ireland, setting ambitious targets. Policy and financial support are critical to deliver this ambition.

TRL 1-2 Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 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

TRL 9

Anaerobic Digestion & Biomethane

Anaerobic Digestion (AD) is a mature technology which processes organic waste and agricultural feedstock (e.g. silage) and converts them into usable products contributing to the circular economy. The two main products are digestate which can be used as agricultural fertiliser and biogas which is comprised of c. 60% methane & 40% biogenic CO_2. The biogas may be further 'upgraded' to produce biomethane (>97% methane) and once it meets the gas grid standards can be compressed and injected directly into the gas grid. AD has been successfully deployed in many countries around the world and is a mature technology (TRL9)Compared to other EU countries Ireland has a strong potential opportunity to deploy further AD to support the National Climate Action Plan. The National Biomethane Strategy for Ireland which was published in May 2024 lays out a plan for the industry's ambitious growth by 2030 to realise this potential opportunity.

Anaerobic digestion plant in Timoleague

Sample project

Green Generation's 'Cush' plant is a 1.5 MW project producing 25 GWh of biomethane per annum. The site is co-located with a piggery and 5 km from Ireland's only biomethane injection point in Co. Kildare. It features two stage digestion and gas cleaning and upgrade equipment. The feedstock is primarily based on Tesco's food waste and the plant was commissioned in 2020.

Cost

The estimated cost to produce biomethane reported in the National Biomethane Strategy is between €120-150/MWh for a 50 GWh plant.

Timelines

In Ireland, AD deployment is expected to significantly ramp up in the period 2025 - 2030 enabled by the expected introduction of capital grants and the Renewable Heat Obligation in 2024-25. The national target is to deliver 5.7 TWh of indigenous biomethane in 2030 as outlined in the Climate Action Plan.

Potential to scale

AD has good potential to scale in Ireland. The target of 5.7 TWh of biomethane would cover 10% of Ireland's current overall gas demand. To take an example from a market leader, in Denmark where AD has been deployed at scale it is currently covering more than 40% of Denmark's Natural Gas demand.

ESB Activity

ESB is actively reviewing developments in the anaerobic digestion industry in Ireland

Leading OEMS

The largest developers in Ireland include Nephin Renewable Gas, Bia Energy, Bord Gais.

Summary

AD has a positive outlook for growth in Ireland with a national target to create 5.7 TWh of indigenous biomethane per annum by 2030. To enable this the National Biomethane Strategy for Ireland was published in May 2024 and the Renewable Heat Obligation is due to be published in Q4 2024.

4. CARBON CAPTURE UTILISATION AND STORAGE (CCUS)

4. Carbon Capture Utilisation and Storage (CCUS) (continued)

TRL
9

Biochar

Biochar is a porous material comprising of >90% carbon which has a high stability and permanence. Biochar is produced through the process of pyrolysis. Pyrolysis is a thermal decomposition process that occurs in an oxygen-deficient thermal environment. In the pyrogenic process shredded feedstock materials are heated to temperatures of between 300 and 900°C and are converted into relative amounts of solid, liquid and gas components (char, bio-oil, and syngas), depending upon the specific pyrolysis technology employed

End use applications of biochar include use as a soil amendment (fertiliser supplement), animal feed, carbon sequestration or concrete aggregate. TRL is defined as 9 as there are 100+ full scale sites worldwide.

Biochar. Source: Biogreen Energy, 2024

Sample project

Novocarbo's Baltic Sea site was commissioned in 2023 and uses sawmill waste as the feedstock. The project has deployed two PX1500 machines from Pyreg and has a capacity to produce 1,400+ tonnes of Biochar per annum. It features feedstock drying, biochar packaging, and waste heat utilisation in the nearby district heating system.

Cost

The cost of carbon removal using biochar is €100 – €200 per tonne of CO_2 which compares favourably with other carbon removal technologies.

Timelines

In Ireland, the biochar market is nascent and requires Irish based research to confirm findings from European projects particularly around the permanence of the carbon sequestration. The EU Carbon Removal Certificate Framework (CRCF) has included Biochar, allowing standardised trading of Carbon Removal Certificates (CORC).

Potential to scale

Biochar has potential to scale in line with availability of feedstock and demand for the biochar.

ESB Activity

ESB is investigating a small-scale pilot project in partnership with Coillte and Enterprise Ireland.

Leading OEMS

Pyrolyser manufacturers include Pyreg, Biomechon, Carboforce.

Summary

Biochar in Ireland has a potential to scale in the long term as the price of carbon increases. Its main benefit over other forms of carbon sequestration is the fact that the storage medium is soil rather than requiring storage in a geological formation.

Globally, as new methodologies and standards for carbon removal are developed and refined, the role of biochar and similar technologies will likely become increasingly integral to global carbon management strategies.

TRL 1-2	Concept phase / research
TRL 3-5	Small scale prototype deployed in lab / controlled environment
TRL 6-7	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

TRL 6-9

Point Source Carbon Capture

Point Source Carbon Capture (PSC) involves the capture and processing of flue gas from a refinery, gas turbine, or other source to separate the CO_2 for storage. This allows the process to be close to Net Zero. Flue gas ranges in carbon content from 5-90% depending on the process requiring different types of technologies for carbon capture from point sources. These are mostly divided into pre-combustion, oxy-combustion and post-combustion. Here the focus is on post-combustion, since it is the only alternative that does not require upstream modifications to the emitting process. Among post-combustion carbon capture technologies are chemical absorption (mostly with amine-based solvents, TRL 9), physical separation (TRL 8), membrane separation (TRL 6), calcium looping (TRL 7) and enzymes-based capture (TRL 7). TRL levels above are according to the IEA. The technology selected for each case depends on the point source CO_2 partial pressure, flow, contaminants, and other gas characteristics.

Amager Bakke waste-to-energy plant in Copenhagen includes carbon capture.

Sample project

The EU research project REALISE CCUS implemented a demonstration site in Irving Oil in Cork. The flue gas is approximately 10% CO_2. The technology was tested on 5 different stacks and proved CO_2 can be captured at a rate of >95%. The project proved the effectiveness of the solvent HS-3, which requires less material changeover than the traditional amine solvent.

Cost

According to the IEA and McKinsey, the estimated cost to capture flue gas CO_2 varies according to sources and partial pressures. For high partial pressure streams like bioethanol or ammonia production, costs are as low as $25-35/tonne, while for lower partial pressure flue gases like cement, power generation or iron and steel manufacturing the costs are estimated to go from $40/tonne to €120/tonne.

Timelines

There are 68 CCUS projects currently operating (most of them PSC) and more than 550 projects announced by 2030. The McKinsey Global Energy Perspective 2023 report forecasts that CCUS plants deployment will grow 100 times reaching 4-6 gigatonnes of CO_2 capture capacity by 2050, from which more than 85% is from point source emissions.

Potential to scale

Large potential to scale for some of the CCUS technologies available (e.g. chemical absorption, calcium looping, enzymes-based, and physical separation).

ESB Activity

ESB worked with an EU consortium of research bodies including Trondheim, University College Cork, University of Delft, Bord Gais, and Ervia to deliver the REALISE CCUS project.

Leading OEMS

Occidental Petroleum, Equinor, Shell, Total, Saipem, ExxonMobil and BP.

Summary

PSC comprises of a variety of technologies that aim to decrease the direct release of CO_2 into the atmosphere from industrial gases. The technology based on solvent absorption has reached technical and commercial maturity and is TRL 5-9. The cost of capturing CO_2 from point sources depends strongly on the CO_2 partial pressure in the flue gas, being cheaper for those with higher shares of CO_2. As a technology that enables carbon-negative and carbon-neutral emissions, it is expected to be deployed widely in the next decades. ESB has done some R&D work in this field by supporting the REALISE CCUS project.

4. Carbon Capture Utilisation and Storage (CCUS) (continued)

TRL
5-8

Direct Air Capture

Direct Air Carbon capture (DAC) is a type of technology that captures CO_2 from the ambient air. Ambient air has between 0.03%-0.04% CO_2 so when capturing such diluted quantities of carbon, a lot of energy is required. Two types of technologies are available, liquid DAC (TRL 5-6) and solid DAC (TRL 7-8). Both technologies use cycles of absorption and release of CO_2. Liquid DAC requires higher temperatures to release the absorbed CO_2 than solid DAC. The IEA estimates that the global DAC capacity is 0.01 Mtonne CO_2/year, but that it is growing fast.

Carbfix project in Iceland

Sample project

Climeworks is currently developing the largest DAC plant in the world with a total capacity of 36 ktonne of CO_2/year in Iceland, following their previous 4 ktonne of CO_2/year plant installed in 2021. The plant will take CO_2 from the air and then dissolve it into water, which will be pumped underground reacting with subterranean basaltic rock to turn the CO_2 permanently into stone. The plant will run with 100% renewable electricity generated from a local geothermal plant.

Cost

The world economic forum reports solid DAC prices of USD 600-1250 per tonne of CO_2 captured. These are expected to decrease over time.

Timelines

The IEA is expecting to see an increase in DAC deployment within the next years if the right policy and incentives are developed.

Potential to scale

DAC has a large potential to scale however one important bottleneck of DAC is the energy requirements, which needs to come from a renewable source to produce negative emissions.

ESB Activity

ESB does not have any active projects regarding DAC but is keeping a watching brief on this topic.

Leading Organisations

Climeworks, Global Thermostat, 1PointFive/ Carbon Engineering, CarbonCapture.

Summary

DAC is a technology that could potentially provide negative emissions or a pathway to zero carbon for hard-to-abate sectors. However, several challenges regarding scale, costs and energy usage need to be addressed before becomes a large-scale deployed technology.

TRL 1-2 Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 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

TRL 9

Nature Based Solutions

In Ireland, Nature Based Solutions (NBS) for CCUS include appropriately sited reforestation/afforestation, peatland restoration, and soil carbon sequestration. These approaches allow ecosystems to better sequester carbon, contributing to climate mitigation and ecological integrity. NBS are an important tool in achieving Net Zero and can be considered the most established of the CCUS approaches.

The UK Woodland Carbon Code indicates that the average rate of carbon sequestered will be 647 tonnes of CO_2 per hectare over 100 years. While NBS are effective at carbon sequestration, they tend to bring multiple other socio-environmental benefits, including biodiversity uplift, social amenity value, and water management. Often, carbon sequestration represents just a small amount of the overall benefit to society.

Forestry – a nature based carbon capture solution

Sample project

As part of the Peatlands Climate Action Scheme (PCAS), Bord na Móna (BNM) has committed to peatland decommissioning, rehabilitation, and restoration measures, targeting circa 33,000 hectares in over 80 former Bord na Móna peat harvesting bogs.

Timelines

Various nature restoration projects are ongoing in Ireland and will continue over several decades.

Potential to scale

The potential to scale is very large. For example, the PCAS project above is targeting 33000 hectares of nature restoration. In addition, Nature Trust (Ireland) has an ambition of afforesting 1% (70,000ha) of Ireland with new native woodland.

ESB Activity

ESB does not have any active projects related to NBS for CCUS but is keeping a watching brief on this topic.

Leading Organisations

BNM and Coillte, as Irelands largest landowners, are leading NBS providers in Ireland. Numerous private non-profit companies are also in operation.

Summary

Nature Based Solutions represent a proven methodology to sequester carbon, as well as providing may other co-benefits, including biodiversity uplift, social amenity value, and water management. The scale of projects is potentially very large. Care must be taken that activities are undertaken in harmony with all stakeholders, specifically with the farming community.

5. GRID TECHNOLOGIES

5. Grid Technologies (continued)

TRL
7-9

High Voltage Direct Current Transmission

High Voltage Direct Current (HVDC) is an electric power transmission system that uses Direct Current (DC) instead of the more common Alternating Current (AC) for transmitting electricity. It is a relatively mature technology although it is continuing to evolve (TRL 7-9) and it has several advantages over AC systems including:

Lower power loss over longer distances relative to equivalent AC lines

- It allows for independent control of power flows making it useful for stabilising networks.
- It enables the bulk transfer of low-cost forms of renewable electricity over long distances.
- It enables subsea interconnection between countries.
- It is the cost-effective transmission solution for integrating offshore wind in deep water (c. >60km offshore) with the onshore electricity grid.

North Sea Offshore HVDC Substation

Sample projects

China's 1,100 kV HVDC link which was completed in 2019 is a 3,300 km HVDC link that has a 12 GW rating. The Rio Madeira link in Brazil connects the new hydro power plants in Porto Velho to Sao Paulo over 2,375 km and has a 6.2 GW rating. The 'Sun Cable' that is in development between Darwin and Singapore is planned to include a 4,300km 2 GW subsea cable to supply up to 15% of Singapore's electricity needs.

Cost

The cost of HVDC connections depends on several factors such as power capacity, transmission medium and the converter technology. It does however offer cost advantages in specific scenarios such as long-distance transmission, in subsea connections, and in integrating offshore wind farms in deep water (> c. 60km offshore) with the onshore electricity grid.

Timelines

HVDC transmission lines are available to deploy, and the reducing costs of solar PV and storage are making these projects more economically viable. As offshore wind farms move further from the coast and into deeper waters (> c.60km) HVDC systems will become more prevalent as they are the cost-effective solution.

Potential to scale

HVDC transmission technology has the potential for significant growth, particularly as fixed and floating wind farms are developed further offshore and multi-terminal systems become prevalent across the energy system. Standardisation, scalability and strategic planning will all be required to enable its full potential, and these are significant areas of current research.

ESB Activity

ESB is keeping a watching brief on this topic. ESB sits on the Wind Energy Ireland 'Future Networks' working group, which covers HVDC technology.

Leading OEMS

Leading OEMs in this field include ABB, Siemens, GE, Hitachi and Mitsubishi Electric.

Summary

HVDC transmission technology will play a crucial role in efficient and reliable power transmission across long distances and in integrating offshore windfarms with the onshore electricity grid. The falling cost of PV and storage will enable further large projects that integrate areas with high natural resource potential with population centres. The significant planned growth in offshore wind will also drive the growth of HVDC transmission systems which will have a knock-on impact on the design of the wind turbine technology, transformer platforms etc.

TRL 1-2 Concept phase / research

TRL 3-5 Small scale prototype deployed in lab / controlled environment

TRL 6-7 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

TRL 8-9

Static Synchronous Compensator (STATCOM)

A Static Synchronous Compensator (STATCOM) system is designed to be integrated into the electricity grid to stabilise any fluctuations in the grid by absorbing or feeding in voltage supporting reactive power, depending on the requirements to maintain a stable system.

STATCOM systems are used to increase the reliability and capacity of the electricity network. This approach significantly improves grid stability and resilience as it reduces the risk of voltage drops and black outs that could be triggered from sudden events such as loss of wind generation or fault events occurring at peak times. The Irish electricity system is being rapidly decarbonised, driving the replacement of large fossil fuel power generation plants (which would have traditionally provided reactive power) with a wind and solar system which is intermittent, variable and widely distributed. To compensate for the increasing levels of variable fluctuating electricity on the grid systems, operators are using STATCOM system as a solution to help stabilise the grid. STATCOMS can also provide additional functionality to dampen harmonic distortion that is increasingly being imposed on the power system because of renewable generation sources such as solar and inverter fed wind generation. STATCOMS are increasingly being employed with off-shore wind to compensate harmonics and reactive distortion that can be a consequence of the long undersea cables required to connect to offshore wind. The core technology behind STATCOM are power devices derived from electronic transistors which revolutionised computing in recent decades.

STATCOMs at ESB site

IGBT(Insulated Gate Bipolar Transistors) are used to create large DC to AC converters that provide a fully controllable AC sinusoidal waveform that when injected into the grid can be used to compensate inductive and capacitive reactive power on the system and so control the voltage of the grid and maintain stability.

Sample projects

ESB Networks recently installed three STATCOMS in Ireland on the 110 kV transmission system - Ballynahulla +/- 100 MVAr, Ballyvouskill +/- 100 MVAr and Thurlas +/- 30 MVAr incorporating active harmonic filtering. A fourth +/- 200 MVAr system connected at 220 kV is currently being planned.

EWA (Electricity and Water Authority) in Bahrain recently integrated a +/- 200MVAr transformer unit into the EWA grid at the Manam 220kV substation. The STATCOM unit featured a voltage source converter architecture comprising air core reactors, filters and insulated gate bipolar transistors.

Timelines

STATCOMs are a developing technology which will scale up to provide grid stability in line with the energy transition to zero carbon electricity systems.

Potential to scale

STATCOMS have significant potential to scale to complement the growth of variable, intermittent renewable sources.

ESB Activity

ESB has recently commissioned three STATCOM systems in Ireland and was the lead consultant for a system with EWA (Electricity and Water Authority) in Bahrain.

Leading OEMS

Siemens, Hitachi, RXHK and GE Grid Solutions.

Summary

STATCOM systems provide a technical solution to maintain a stable and reliable electrical grid. These solutions will become increasingly important as the energy system transitions to one driven by variable, intermittent renewable energy technologies. STATCOMs provide a solution which allows network operators to improve voltage stability, enhance grid reliability, support renewable integration, and control reactive power flows in their networks and will play an increasingly important role over time.

5. Grid Technologies (continued)

TRL
5

High Temperature Superconductor Cables

A 'high temperature' superconducting cable (or tape) is made from a superconducting material which exhibits the phenomenon of superconductivity when cooled by liquid nitrogen to approx. –180°C. The term 'high temperature' is relative to other superconducting materials which operate at much lower temperatures. Superconducting transmission cables are nearly perfect electrical conductors and use the phenomenon of superconductivity to transmit large amounts of electricity over long distances with very low losses.

They have only been used in relatively short connections to date and a medium distance connection demonstration has yet to be developed so the technology has a TRL of 5. High temperature superconducting cables offer several advantages over building conventional power cables including:

- Providing near perfect conditions for transmitting large amounts of electricity over long distances.
- They allow for maximum power transmission in a limited space, one superconducting cable can transmit as much power as five conventional cables.
- They enable increased public acceptance due to their low visual impact and low costs to build compared to new transmission lines.
- They have shorter installation times compared to conventional cables.

Graphic of Super Conductor cable. Credit. SuperNode.

Sample projects

The Shingal project in South Korea connects the 154 kV substations of Shingal and Heugdeok which are 1 km apart, the system was built in 2019 and is operating as planned since commissioning and KEPCO (Korea Electric Power Corporation) are investigating further projects. The SCARLET project is a recently launched project with fifteen industry partners and which is being funded through the Horizon Europe scheme. The project aims to set common industry standards for high power superconducting cables and to demonstrate a full scale bipolar 1GW transfer.

Cost

The costs for high temperature superconductor cables are estimated by OEMs to be lower than for conventional systems however no large-scale demonstration system is available yet to validate the cost estimates.

Timelines

High temperature superconducting cables are expected to reach TRL 8 over the next ten years. A key focus area for their development will be the establishment of long-term ageing test facilities.

Potential to scale

High temperature super conducting cables have the potential for significant growth and to be an important enabler of high levels of interconnection and renewable electricity. Standardisation and scalability of the cryogenic systems will be required to enable its full potential.

ESB Activity

ESB does not currently have any active projects related to superconducting transmission lines but is keeping a watching brief on this topic including ongoing regular discussions with OEMS, other utilities and the Council on Large Electric Systems (CIGRE) experts. ESB's HV and MV network has been fully ducted since the early 2000s which means that existing design cables can be pulled out of the ducts and new superconducting cables can be installed without having to re-excavate the network at high financial and disruption cost. Hence, retrofitting superconducting cables in the future can be undertaken without massive disruption.

Leading OEMS

VEIRs, NKT, SuperNode, Fujikura Ltd, BASF, Nexans, Thevas GmbH.

Summary:

High temperature superconducting transmission cables offer minimal losses, smaller diameter, and the potential to transmit much larger amounts of electricity compared to conventional cables. As the technology develops and matures, they may play an important role in accelerating the integration of large amounts of renewable energy into the electricity grid and in sustaining grid reliance.

Glossary

AD	Anaerobic Digestion
AWED	Airborne Wind Energy Device
BESS	Battery Energy Storage System
CAP	Climate Action Plan
CAPEX	Capital Expenditure
CCUS	Carbon Capture Utilisation and Storage
DAC	Direct Air Capture
DH	District Heating
EPRI	Electric Power Research Institute
EV	Electric Vehicle
FLOW	Floating Offshore Wind
HVDC	High Voltage Direct Current
HVO	Hydrotreated Vegetable Oils
IHP	Industrial Heat Pumps
IRENA	International Renewable Energy Agency
LCOE	Levelised Cost of Energy
LCOS	Levelised Cost of Storage
LV	Low Voltage
MV	Medium Voltage
HV	High Voltage
NREL	National Renewable Energy Laboratory
NIB	Sodium-ion batteries
OEM	Original Equipment Manufacturer
PSC	Point Source Capture
SMR	Small Modular Reactors
TES	Thermal Energy Storage
TRL	Technology Readiness Level
VFB	Vanadium Flow Batteries
V2X	Vehicle to Everything
WEC	Wave Energy Converters

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