# WP3 Scale and Cost Reduction

A NECCUS / OGTC report for the
Scottish Net Zero Roadmap

# WP3: Scale and Cost Reduction

## Table of Contents

# Background

The OGTC Net Zero Solution Centre aims to support the oil and gas industry as well as supporting trades to develop and deploy technologies to decarbonise operations and diversify its activities to position for a long-term sustainable future as the world's first net-zero hydrocarbon basin. The Centre focuses on two clear programmes;

1. **A Cleaner Industry:** Focused on the development of a cleaner oil and gas industry that contributes to emission reductions. Driving technology that delivers energy efficiency improvements, whilst lowering the sector's carbon footprint by reducing unnecessary activity, methane gas leaks, waste and operational emissions from flaring and gas turbines, ultimately decarbonising daily operations.

2. **Net Zero UKCS Basin:** Where we will develop, de-risk and deploy technologies that can be coupled with other offshore sectors, or industrial activities (renewables, hydrogen production, carbon capture usage and storage and others) to increase the flexibility of the North Sea infrastructure system. The re-use and re-purposing of existing infrastructure and systems will play a key role in delivery of a net zero basin which addresses not only the industry's 14.63 million tonnes (or) 3% emissions footprint, but also provides a service to other industrial clusters, thus contributing to the bigger net zero UK and Scotland goals.

The objective of this report is to review potential scale and cost reduction opportunities of key net zero technologies. Technologies existing at scale have been reviewed to demonstrate where there can be expected to be similar cost reduction pathways when scaling Net Zero technologies from First of a Kind (FOAK) to Nth of Kind (NOAK).

The key questions that we are trying to answer by identifying these pathways are:

- How much are costs expected to reduce by as technology is scaled up?
- How long will scale-up take, and what can be done to accelerate this?

# First of a Kind to Nth of a Kind- Net Zero Technologies

## Learning Rates

When assessing likely cost reduction through scale-up, the concept of a 'learning rate' is often applied.

The learning rate is a percentage reduction in cost per unit (e.g. cost per MWh) for every doubling of installed capacity (e.g. total number of units or total GW capacity).

A high learning rate means achieving a high rate of cost reduction as installed capacity increases. A low learning rate means a slower rate of cost reduction, which usually also means a longer time for a technology to reach a fully commercial level.

These learning rates can be used to assess whether technology costs are likely to have reduced to a point where they are commercially competitive without significant support, at a time they are seen as being an important part of the future energy mix. i.e. to assess what likely costs reductions are expected for net-zero technologies for a given capacity scale-up.

To do this successfully, a representative learning rate needs to be applied. Figure 1 below [Ref. 1] shows learning rates for a range of establish technologies. It can be seen that there is a wide range of gradients, and that in two of these cases (solar water heaters and nuclear) these gradients actually slope upwards – i.e. costs have increased as installed capacity has increased.

It is therefore important to understand what drives these learning rates, and to use learning rates from the most appropriate and analogous established technologies.

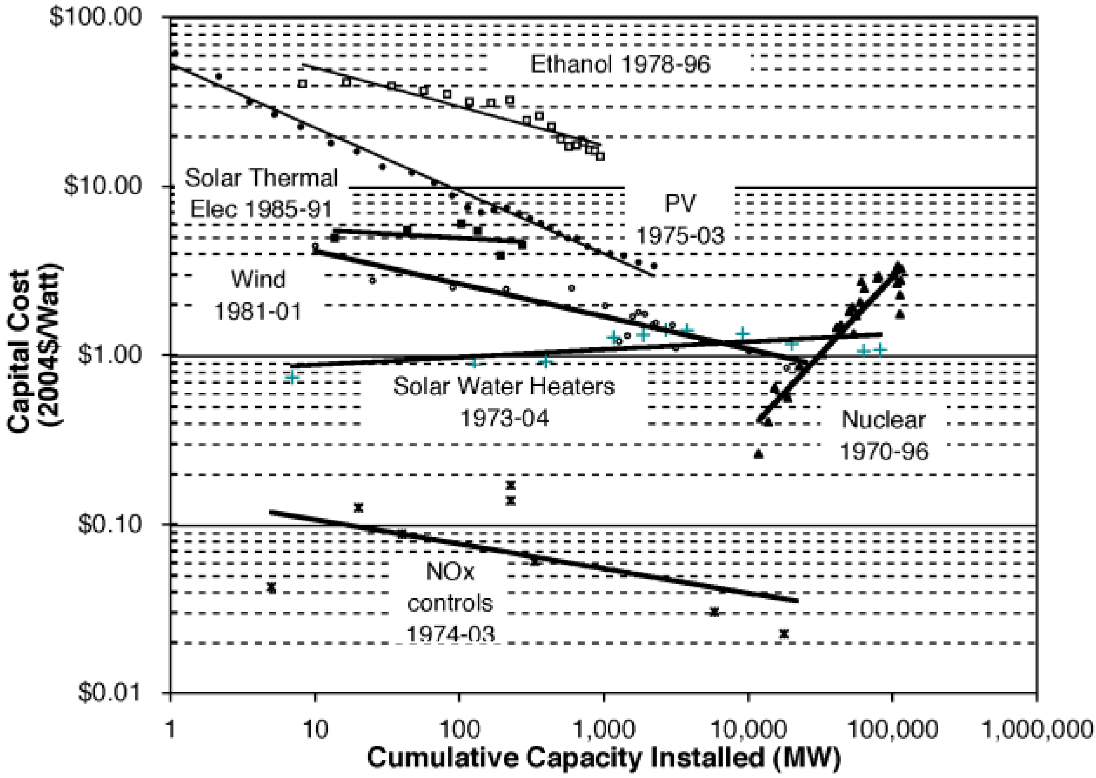


*Figure 1 – Cost Reduction Trends [Ref.1]*

The learning rates (% cost reduction for each doubling in installed capacity, log scale) is presented in Table 1.1.

*Table 1.1 – Historic Learning Rates*

| **Technology** | **Learning Rate** | **Grouping** |
|---|---|---|
| Solar PV | 23% | 20% |
| Ethanol | 15% | 15% |
| Wind | 13% | |
| NOx Controls | 9.7% | 10% |
| Solar Therma Elec | 2.9% | Neutral |
| Solar Water Heaters | -3.2% | |
| Nuclear | -89% | Steeply negative |

It can be observed that there is one example with a learning rate greater than 20%, two at approximately 15%, and one at 10%. There are two which are approximately neutral (slightly negative or slightly positive) and one (nuclear) which is strongly negative.

Learning rates are also reported in Ref. 3 and shown in Figure 2 below. These show similar figures / groupings. Only Solar PV achieves greater than 20% learning rate and there is a cluster between 10 and 15%. Indicative figures for CCS technologies as reported by Global CCS Institute show an average learning rate of 12%. One point to note is the number of studies and spread around each mean.


[7] Assumes 8% cost reduction for every doubling of installed capacity, and a 100-fold increase in installed capacity.
[8] Increase in installed capacity from 1Mtpa to 2.4Mtpa. Capital cost per Mtpa $CO_2$ capture capacity of Boundary Dam was approximately AU$750 million. Capital cost per Mtpa $CO_2$ capture capacity of Petra Nova was approximately AU$593 million.
[9] Source: Based on (Rubin,et al, 2015; EPRI, 2013)

*Figure 2 – Learning Rates for Electricity Generation Technologies [Ref. 3]*

## Commercial Readiness vs Technology Readiness

Technology development advances technology through the familiar technology readiness level (TRL) scale, to the point where a 'first of a kind' (FOAK) technology is available to the market. Further advancement to a commercially attractive offering typically comes as the technology is applied at a larger scale.

Scaling of technologies from single technical demonstrations, through small scale commercial trials, and eventually through large scale, multiple commercial applications and beyond is associated with cost reduction. As technology becomes mature, competition arises, and costs are further driven down through market forces and through maturation and competition through the whole supply chain.

Reviewing analogous technologies, the pathways they have taken and the magnitude of cost savings that are associated with scale up allows predictions to be made for new technologies. It also allows key enabling steps or activities to allow the technologies for be fully commercialised to be identified.

It is clear that learning rates of 10% and higher are possible and have been achieved in technologies that are similar to or have been developed to in response to similar pressures (fuel gas desulphurisation technology and NOx reducing technologies for example). It is also clear that there is potential for the learning rate to be much lower than this, a few percent or neutral, and even to be negative. Examples where a negative learning rate could be seen (perhaps for only part of the scale-up process) for low carbon technologies would be where scaling up in size introduces additional complexity, risk, and cost. This could possibly be seen, for example, as offshore wind advances further afield and needs larger equipment to install larger turbines in deeper water and harsher environments. This is not what is currently expected to happen, partly due to the economies of scale due to larger individual units (higher power output per unit) and partly due to learning from expertise in the oil & gas industry. However, it illustrates the type of scenario in which increasing scale & size can introduce additional complexity. Another example would be the nuclear sector where increasing safety & regulatory mechanisms have led to developing complex designs and thereby related costs.

This leaves the question of how to estimate, or even roughly categorise, cost reductions due to scale up of new technologies. This needs an understanding of the 'levers' that would drive cost reduction, which are available / present for the new technology, and which historic analogues are most similar.

## Cost Reduction and Commercialisation Levers

The commercial readiness indicators proposed by ARENA [Ref. 2] are a useful representation of the ways in which scaling up costs can be reduced. This approach scores 8 commercial readiness indicators on a scale from 1 (hypothetical commercial proposition) to 6 ('bankable' grade asset class).

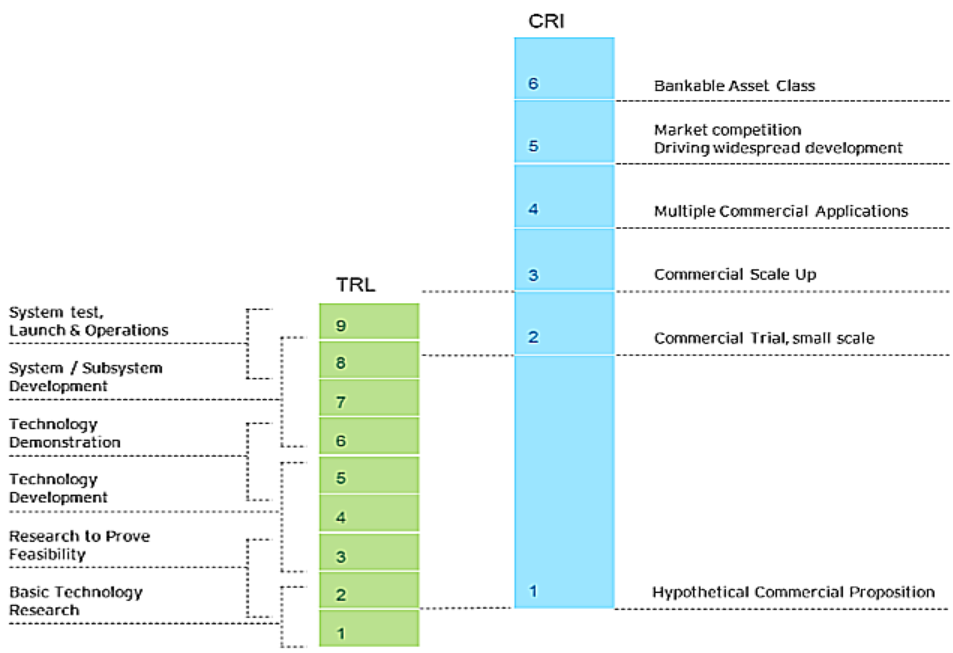


*Figure 3 – Technology Readiness vs Commercial Readiness [Ref. 2]*

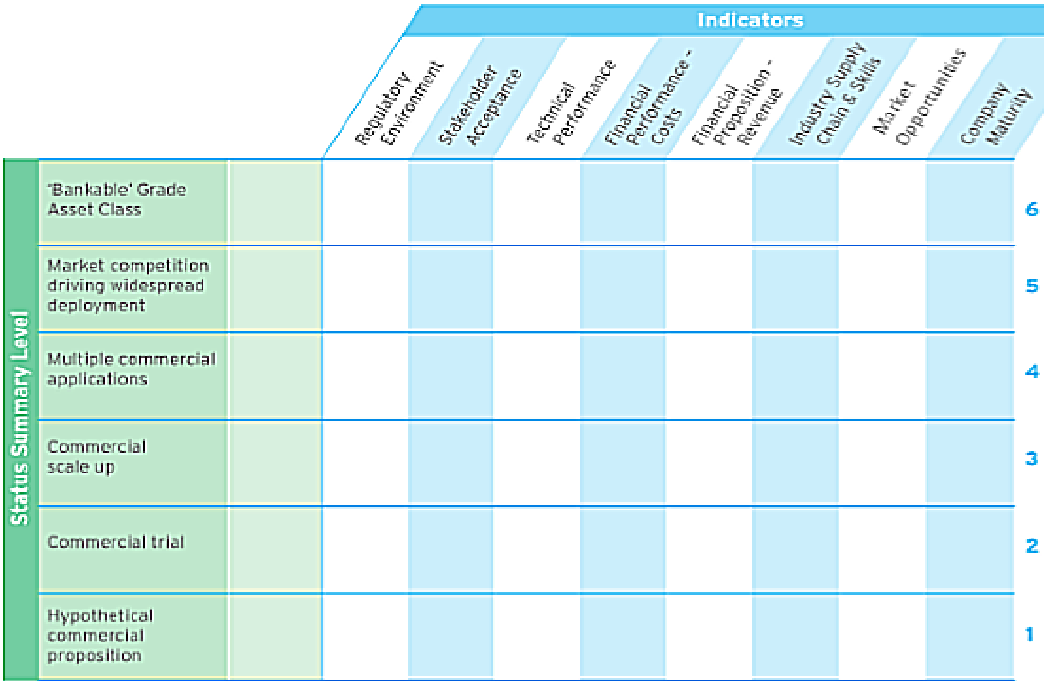


*Figure 4 –Commercial Readiness Indicators [Ref. 2]*

These eight categories are:

- Regulatory Environment
- Stakeholder Acceptance
- Technical Performance
- Financial Performance – Costs
- Financial Proposition – Revenue
- Industry Supply Chan & Skills
- Market Opportunities
- Company Maturity

Details of how these are scored against the commercial readiness levels can be found in Ref. 2. Each of these is discussed below with relevant examples.

## Regulatory Environment

High maturity within the regulatory environment is represented by well-defined regulations and planning and permit processes. Distinct investment by governments into these technology areas through incentives and subsidies, or penalties for competing technologies, will support the development of low TRL technologies and reduce some commercial barriers.

For example, BEIS have recently called for responses regarding the creation of a Third Pot to be introduced into future CfD Allocation Rounds. A third funding pot specifically focused on floating offshore wind will help to accelerate investment into floating technologies, reducing the length of time it takes for cost reduction to succeed, therefore allowing it to compete with rival, more commercially ready, technologies.

Another example is carbon trading (or) taxing mechanisms. The EU Emissions Trading Scheme is an example of a regulatory mechanism that introduces incentives, including financial incentive, for reducing carbon emissions, encouraging new technologies that enable this to be adopted.

### Stakeholder Acceptance

A barrier to the successful introduction of any significant nascent technology to an industry is stakeholder acceptance. This may include local communities located close to testing (or) deployment sites, local supply chains and ports, (or) competing industries such as fisheries. For example, the Port of Nigg in the Cromarty Firth supports the Moray East wind farm as a staging port for 103 foundation jacket structures. Ideally located, had the Port of Nigg as a key stakeholder not supported this project, there would have been increased costs in transporting these foundations from a port further afield. Being able to source local content often introduces significant cost savings from technology developers but this often requires investment to be made by the supply chain.

A high level of maturity within Stakeholder acceptance is characterised through clear processes which are used to engage stakeholders' groups, and which have resulted in the gained stakeholder acceptance. It is crucial for new technology developers to undertake in-depth stakeholder analysis to create visibility of support (or) opposition and create a response plan.

### Technical Performance

During the early stages of technology development, it can be difficult to accurately predict the real-life technical performance of a fully deployed technology within the correct operating environment. As a result, there is increased risk when investing and calculating ROI. A high maturity in technical performance is present when there are several full-scale commercial projects in secondary markets where externally verified performance data can be drawn upon. A lower maturity within this area will be present if predictions are based on simulations (or) extrapolated from pilot tests. To secure investment and ensure bankability, site-specific data is required, project performance warranties need to be defined, and evidence of output, reliability and operating costs proven, ideally based on similar projects. This can be difficult for nascent technologies but creating a defined roadmap towards enhancing investor confidence is key.

Typically, where there are large numbers of deployed and standardised units, greater costs saving is achievable through standardisation of design (both of individual components, but also modularisation and standardisation of complete systems), learnings in manufacturing and installation. Similarly, scaling up in size tends to bring improved performance on a cost / unit output basis (if this is not outweighed by increased complexity). These technical aspects are a key cost reduction driver with respect to the learning rate.

## Financial Proposition – Cost and Revenue

Regarding cost, to progress towards maturity, technology costs must be fully understood. Costs must evolve from projections and forecasts with little data to substantiate them, through to projections and historic cost data based on actual project performance.

Similarly, to cost, revenue must mature from unsubstantiated forecasts through to revenue projections based on proven forecasts and commercial data. As a result, transparency regarding industry benchmarking will be evident and lenders will be willing to support continued development even at merchant risk.

Fixed offshore wind is at the crux of this point with some project developers and lenders now beginning to consider progressing projects at merchant risk.

## Industry Supply Chain and Skills

As touched on briefly within Stakeholder Acceptance, the supply chain must first be willing to participate and then they must be capable to deliver it. A low maturity in this indicator would represent a supply chain that perhaps is unaware of the need to participate. Subsequently, they may either support the project (or) actively participate in the procurement processes; however, they may resist change. As the supply chain maturity increases, buy-in will increase and experience on similar projects will drive supply chain efficiencies and build confidence.

## Market Opportunities

Market opportunity matures from an individual (or) business that has a promising technology and a peer reviewed business case, through to market pull where the market is clearly understood. During this process, commercial trails will take place proving the technology can produce the desired technical and commercial outcomes and market research has taken place to identify the size of potential market. Once this has been proven, focus will move towards the commercials - optimising cost and performance to reduce costs in alignment with the expectations of the market.

## Company Maturity

A nascent market will have zero, or very few, companies competing. However, as the market and industry mature and develops, industry bodies and key players begin to emerge as a new 'sector' emerges. The balance sheets of key players are healthy and allow for reinvestment which continues growth and technology development. At full maturity, leading companies are public with large balance sheets.

# Case Studies

## Case Study – Solar PV

The development of Solar Photovoltaic panels in Germany is reviewed and discussed in the context of the ARENA commercial readiness indicators in Ref. 6. Over the period review, total installed Solar PV capacity increase from approximately 10MW to 4000MW. Critical policy interventions that increased the Commercial Readiness Index (CRI) across multiple factors – directly and indirectly – were key to this success. Here the policy enables the scale up and the scale up then delivers the economy of scale cost savings.

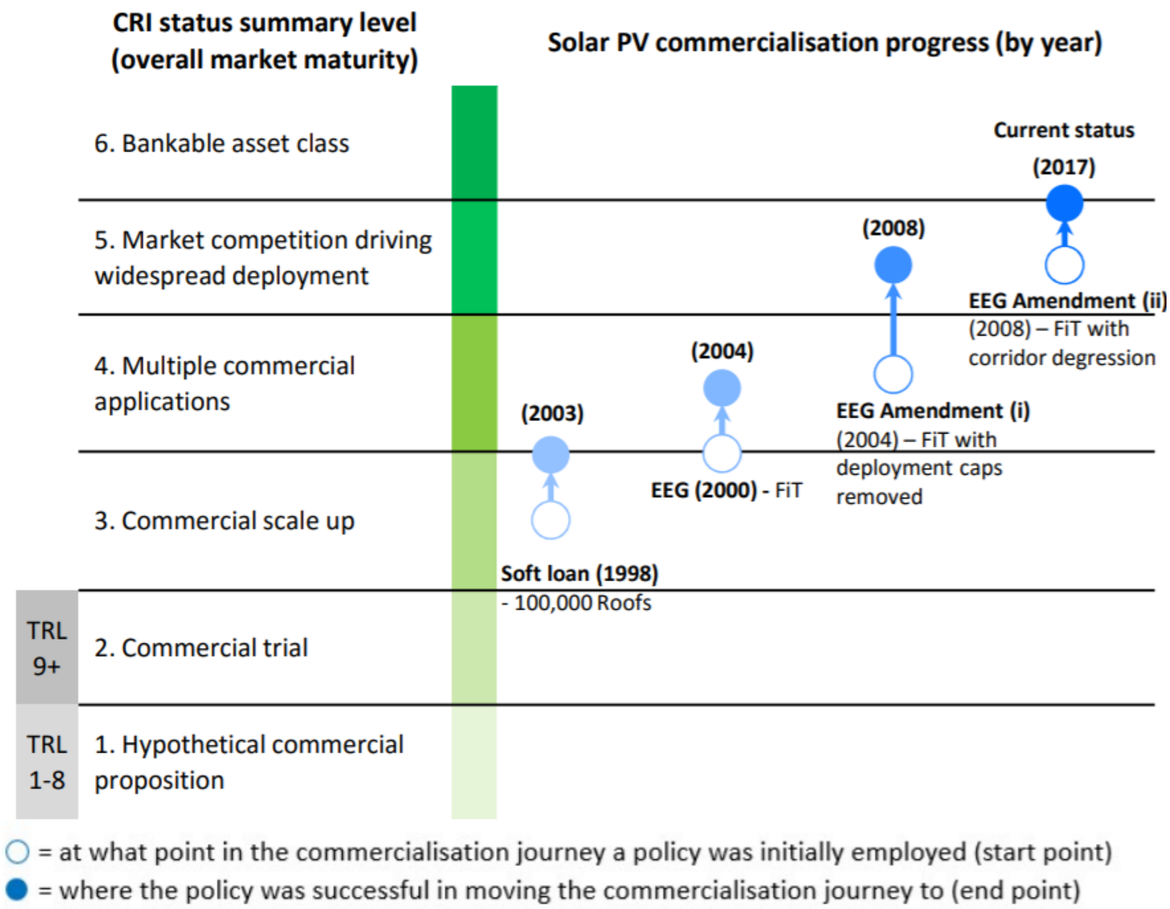


*Figure 5 – Solar PV Germany, Commercial Readiness Journey*

## Case Study – Offshore Wind

Ref. 6 also describes the commercialisation journey of Offshore wind in the UK. Here policies delivered long-term revenue and financial performance, which allowed capacity to be scaled up. Market competition has also been established, which has also had a significant effect on driving down costs.

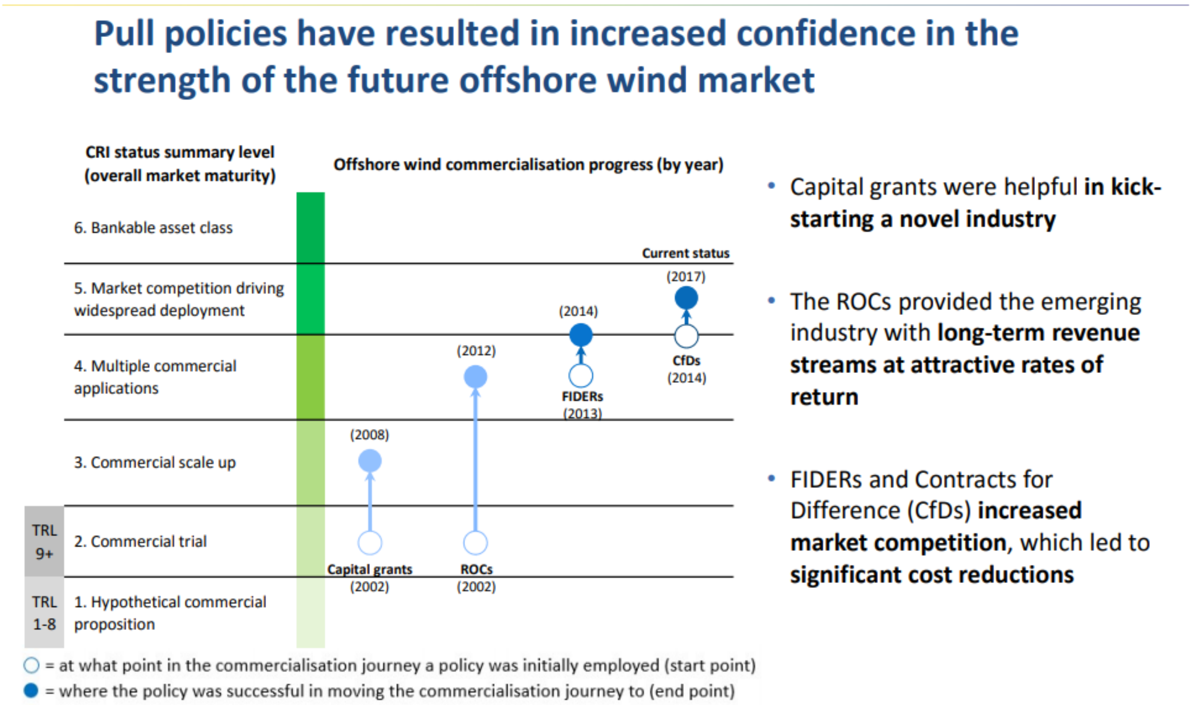


*Figure 6 – Offshore Wind UK, Commercial Readiness Journey*

## Case Study – CCS

Learning rates for CCS are reported and analysed in many sources. It can be seen from Figure 2 that, while an average learning rate of 12% is reported by the Global CCS Institute, there is a wide spread of learning rates across the studies considered in coming up with those averages. Figure 7 shows the levelized cost of $CO_2$ capture over time, for historic, operating, and planned facilities. It can be clearly seen that, if the period up to 2016 (Boundary Dam) is considered, the learning rate would be negative. It is assumed for planned facilities that learning from these high cost projects has been captured and that the types of development are not adding similar complexity, and cost of scaling issues.

While there are technical improvements – particularly design, manufacturing and efficiency – that are likely to be seen with scale up, what has historically been missing is the financial performance lever, a means by which projects can be approved with a reasonable expectation of revenue. A slow rate of scale-up means a slow rate of cost reduction. This is discussed in Ref. 7, along with other concerns around high assumed learning rates for CCS. In summary:

- Learning rates based on application of CCS on coal power plants are increasing, but demand for coal is reducing. In those countries where demand is increasing, China and India particularly, a very high investment in CCS would be needed.
- Competing energy sources - rapid reduction in costs of renewables are out competing CCS in most cases.

- NOAK / Learning rate predictions – concerns that some of these predictions are unrealistic.

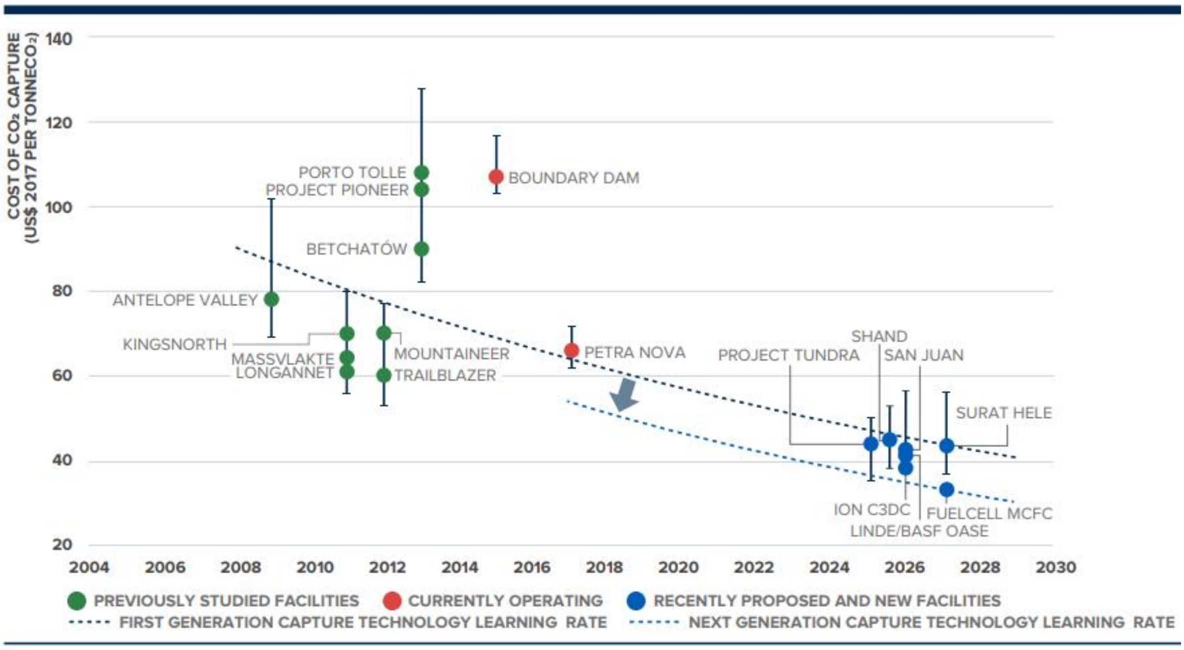


**FIGURE 8** LEVELISED COST OF $CO_2$ CAPTURE FOR LARGE SCALE POST-COMBUSTION FACILITES AT COAL FIRED POWER PLANTS, INCLUDING PREVIOUSLY STUDIED FACILITIES[vii]

*Figure 7 – CCS, Cost Reduction Journey*

## Application to Net-Zero Technologies

A separate technology scanning report [Ref. 5], has identified current 'Net Zero' technologies in ongoing deployment projects and how these could be more widely used.

Developed through a comprehensive technology scan, cross industry knowledge and technology development projects, coupled with publicly available information and vendor engagement, this has defined a list of available technology as well as foreseen gaps.

The below Table 2 lists all the net-zero technologies that have been discussed within our technology scanning report [Ref. 5], and the TRL ratings reported. The third column describes what are the potential quick wins to influence the learning rate. Each of these principal levers is linked to the most appropriate commercial readiness indicators described in Figure 4.

*Table 2 – Net Zero Technologies Identified During Roadmap development*

| Technology | TRL rating | Observation – quick wins to influence learning rate |
|---|---|---|
| **Modular CCUS** | Med-High | Standardisation of component parts, modularisation, and standardisation of these into functional systems. This allows cost reduction and easier (faster) adoption by customers. *[Technical Performance] [Regulatory Environment]* |
| **Direct Air Capture** | Med | Larger scale adoption is needed to drive down cost. This technology is particularly suited to standardised design with large numbers of identical units, and as such as healthy learning rate you be achievable. It is coming from behind when compared with CCS (in terms of cost / tonne). To support this adoption, means of incentivising adoption and means of easing site planning (large site areas are needed) could deliver quick results. Another potential quick win is to assess the market for carbon capture as a service – where DAC can be used to offset emissions from sites where modifications to capture carbon are either not possible or are prohibitively expensive. *[Regulatory Environment] [Stakeholder Acceptance] [Market Opportunities]* |
| **$CO_2$ Transport** | High | Development of standards for design & operation of $CO_2$ pipeline systems to remove any 'roadblocks'. A very clear stakeholder engagement process, particularly for onshore systems, to avoid delays in planning etc. *[Stakeholder Engagement] [Regulatory framework]* |

| Technology | TRL rating | Observation – quick wins to influence learning rate |
|---|---|---|
| $CO_2$ Utilisation | Low-Med | Establishment of the size of the market for $CO_2$ (and products). Without a strong market pull, scale-up will be difficult and therefore cost reduction will not happen. Increasing efficiency / reducing costs through technical advancement *[Market Opportunities]* *[Financial Proposition and Revenue]* *[Technical Performance]* |
| $CO_2$ Sequestration | High | Development of standards for assessment, selection & long-term monitoring operation of $CO_2$ sequestration system to remove any ‘roadblocks’. A very clear stakeholder engagement process, to avoid delays in planning etc. *[Stakeholder Engagement]* *[Regulatory framework]* |
| Electrification | High | This is an existing technology, and it is not expected that significant cost reduction is likely. The main lever to encourage further uptake is cost – therefore there needs to be a cost associated with operations ‘as is’ that can be saved. Carbon pricing, tax credits, and/or regulation are therefore the only realistic levers available. *[Regulatory environment]* |
| Renewable Integration | Med-High | This is an application for renewable power generation, which could itself be an enabler for electrification of assets. |
| Battery Storage | Low-High | This technology is particularly suited to standardised design with large numbers of identical units, and as such, a healthy learning rate should be achievable (the learning rate for batteries in the last decade has been particularly high). Battery storage is really a component part of an energy production system that has a high proportion of ‘non-steady-state’ generation source. Therefore, it is likely to progress in parallel with scale up of renewable energy generation. *[Technical Performance]* |
| Efficiency Optimisation | Med-High | This is an existing technology, and it is not expected that significant cost reduction is likely. The main lever to encourage further uptake is cost – therefore there needs to be a cost associated with operations ‘as is’ that can be saved. Carbon pricing, tax credits, and/or regulation are therefore the only realistic levers available. *[Regulatory environment]* |

| Technology | TRL rating | Observation – quick wins to influence learning rate |
| --- | --- | --- |
| **Hydrogen Generation (SMR)** | High | An inherent part of pre-combustion CCS, which several studies predict learning rates of the order of 5-10%. Scale-up potential is large, noted as a key enabler to achieve net zero for many countries, particularly for domestic heating. However, progress in terms of build has been slow. Carbon pricing, tax credits, and/or regulation are therefore the short term 'quick wins' available. *[Regulatory environment]* |
| **Green Hydrogen** | Med-High | Support to scale up and enable technical improvements (efficiency) and manufacturing costs to reduce are an immediately quick win. *[Technical Performance] [Financial Performance – Costs]* |
| **Alternative Fuel Power Gen** | Low-Med | The main barriers to scale-up are not the power generation equipment, but the means of storing / transporting the alternative fuel to where it is needed. Therefore, establishing networks or hubs that allow scale up in clusters is a scale up acceleration option *[Stakeholder Engagement]* |
| **Hydrogen Fuel Cells** | Med-High | Support to scale up and enable technical improvements (efficiency) and manufacturing costs to reduce are an immediately quick win. *[Technical Performance] [Financial Performance – Costs]* |
| **Hydrogen Storage** | Low | Hydrogen storage is really a component part of an energy production system that has a high proportion of 'non-steady-state' generation source. Therefore, it is likely to progress in parallel with scale up of renewable energy generation/green hydrogen. *[Technical Performance]* |

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