Net Zero Technology Centre
Technology Driving Transition

Emission Reduction Technology Roadmap

In Partnership with North Sea Transition Authority

netzerotc.com

Executive Summary

The upstream oil and gas industry is focused on lowering its Greenhouse Gas (GHG) production emissions and has made impressive progress in recent years, delivering a 28% reduction between 2018 and 2023. However, further action is needed to ensure industry meets key targets agreed with the UK government, including a 50% reduction by 2030 and 90% by 2040, on the pathway to net zero by 2050.

There has been a strong focus on driving down production emissions from the upstream sector, with the majority of reductions made through operational improvements, energy efficiency, process optimisation and the decommissioning of older assets. Since the launch of its revised Strategy in 2021, the NSTA has worked closely with industry on measures which have prevented 3.7 million tonnes of lifetime CO_2e emissions.

This Emissions Reduction Technology Roadmap, developed by the Net Zero Technology Centre (NZTC) in partnership with the North Sea Transition Authority (NSTA) for the Technology Leadership Board (TLB) serves as an industry resource to raise awareness of deployable technology which can reduce the emissions from the most common sources in the upstream UK oil and gas sector. It also contains emission reduction technologies which are under development and information on their current Technology Readiness Level (TRL).

Addressing emissions from power generation offers the biggest potential for reducing emissions in the UKCS. The Original Equipment Manufacturers (OEMs) and service companies are working closely with industry to develop solutions for existing equipment that reduces demand through improved efficiencies or provides modifications for power generation units. Electrification, including power from shore, and alternative fuels, offer real opportunities but require a number of challenges to be addressed before these are realistic, implementable options.

It is clear that a range of technologies, combined with changes to operating practices, will be required to continue the drive to reduce emissions and meet the goals of the North Sea Transition Deal (NSTD), including Zero Routine Venting and Flaring by 2030.

A key conclusion from this Roadmap is that collaboration is essential. The supply chain, operators, regulators, technology developers and all the supporting organisations must work together more effectively to address and overcome the identified challenges and gaps.

Contents

This Roadmap, commissioned by the NSTA on behalf of the North Sea Transition workstream of the TLB, builds on the NZTC/NSTA Emissions Measuring and Monitoring Technology Roadmap, issued in April 2024, that identifies technologies for the measurement and monitoring of GHG emissions. It also draws on the TLB's Emissions Reduction Technology Showcase event held in May 2024, organised by its Accelerate Deployment workstream and hosted by NZTC. Industry input has been contributed by members of the Asset Stewardship Task Force and Offshore Energy UK's (OEUK's) Decarbonisation Forum and Atmospherics Group. The UK Energy Technology Platform has also supported the identification of relevant emission reduction technologies currently listed on its site, TechnologyCatalogue.com.

OEUK reports a UK upstream domestic production emissions reduction of 28% in 2023 to 13.5 mtCO_2e, representing roughly 3.5% of total UK territorial emissions and surpassing the 2027 target of 25% reduction from 2018 baseline levels. The progress of methane emissions reduction has been particularly significant, exceeding the 50% reduction by 2030 target with 53% reduction achieved by 2023.

The industry is demonstrating its ability to progress but needs to display continued advancement towards key emissions reduction targets and beyond to achieve net zero emissions.

As part of the NSTA's OGA Plan, published in March 2024, every Operator should develop, implement and maintain individual asset and/or infrastructure's GHG Emissions Reduction Action Plans (ERAP).

As stated in the OEUK's ERAP Guideline, issued in July 2024, the diverse nature of the UKCS assets, including wide variations in geography, geology, age and processing plant complexity, means there is no one size fits all approach to emissions reduction.

As part of the process of compiling the Roadmap, NZTC has engaged with industry through several workshops, collating information provided by Operators on current emission reduction measures and plans for further technology adoption. In the process, feedback on what is currently working, the challenges the Operators have encountered and what might be implemented in the future have also been established and are presented here. This has also identified the technology gaps where further work is required.

This Roadmap covers technologies that address emission reduction from the three main sources; power generation, flaring & venting and fugitive emissions. These emissions are primarily carbon dioxide (CO_2) and methane (CH_4) but can contain smaller quantities of other components such as nitrous oxide (N_2O), and are collectively known as Greenhouse Gases (GHGs).

Reducing emissions from the oil and gas sector is a global challenge, with many other countries and regions setting targets or aspirations. An example is the UN's Oil & Gas Methane Partnership 2.0 (OGMP 2.0) to monitor, report and reduce methane emissions, to which many companies in the UK and elsewhere have committed. NZTC collaborates widely with energy companies and regulators around the world to help achieve GHG emission reduction goals and relevant learnings from these interactions have been included in the roadmap where appropriate.

This Roadmap raises awareness of available and under development technology solutions and alternative approaches that can potentially be applied to oil & gas assets to reduce emissions and support the achievement of key targets and beyond.

Appendix A provides a list of TRL 9 (ready to deploy) technologies and Appendix B technologies and projects in the pipeline at lower TRL's. It should be noted that this is a non-exhaustive list. It is not possible to list the vast array of technologies in-use or available from all companies and developers. However, it is intended to give an indication of the variety of technologies across each of the three main emissions sources.

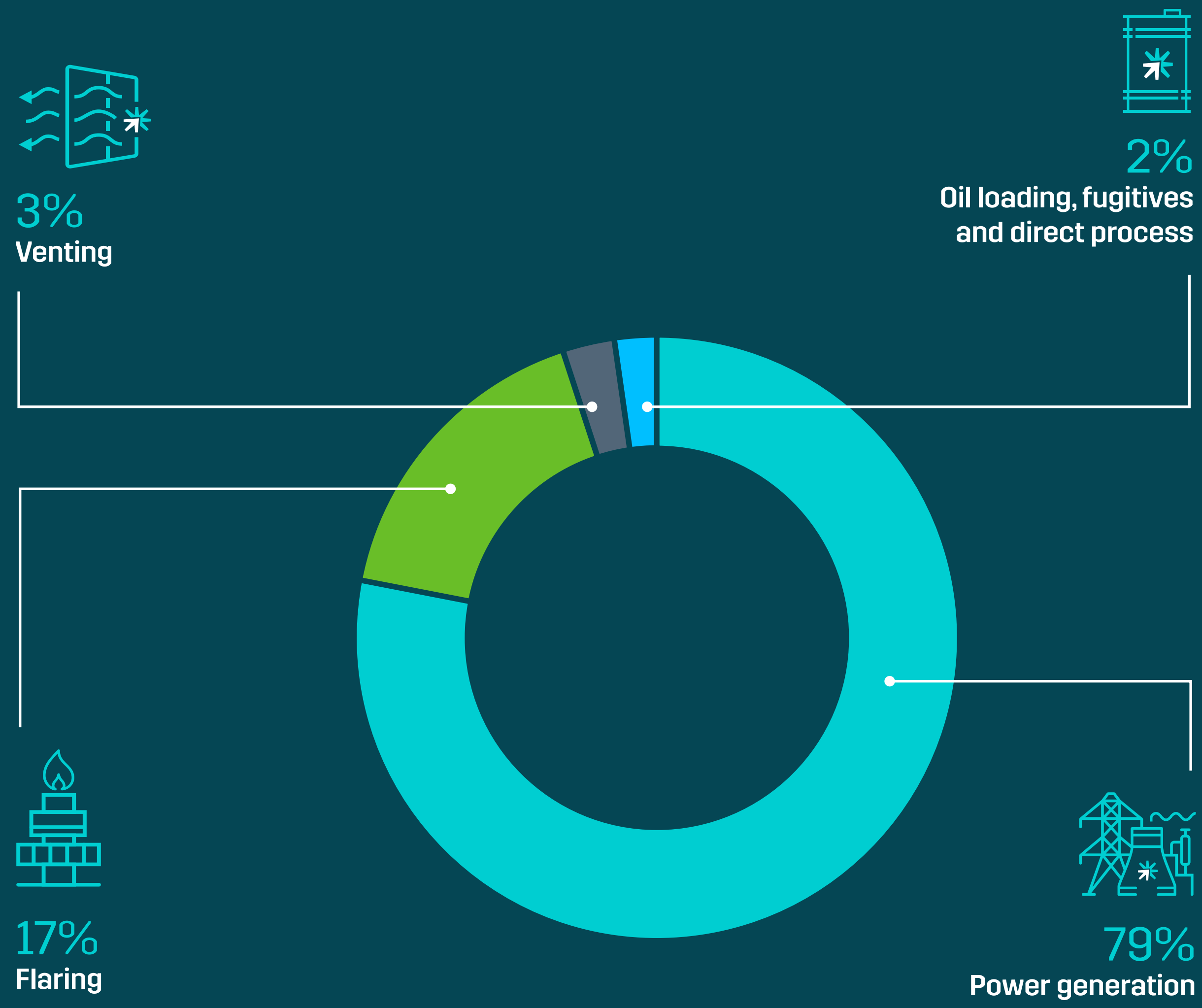


Figure 1: 2023 offshore field emissions by source (Source: NSTA Emissions Monitoring Report 2024)

The breakdown of emissions sources of the UKCS oil and gas sector, as reported to the Environmental and Emissions Monitoring System (EEMS) in 2023, is shown in the following figure and clearly shows the main areas the industry needs to focus emissions reduction technologies toward.

The main areas of focus for each emissions source are discussed in this document. As well as technology solutions, those that involve modifications to equipment and processes or changes in operating procedures have also been included as they are a key part of the ERAP process and deliver some of the reductions needed.

1. Power Generation Emissions

The combustion of natural gas or diesel for power generation on an asset is the largest contributor to emissions from UKCS oil and gas production, making up 79% of emissions in 2023.

The following table shows the focus areas for reducing emissions for Power Generation. All are discussed further with examples of projects and technologies that support these challenges.

Power Generation

Energy Efficiency	Reducing Demand – right-sizing, modifications and system upgrades
	Waste Heat Recovery
	Power Generation Equipment
	Power Management
Low Carbon Power	Alternative Fuels
	Full or Partial Electrification
	Small Scale Renewables
	Electrification of Equipment & Systems

Reducing the amount of fossil fuel burned is key to significantly reducing the emissions from an asset. The emissions result mainly as by-products from the power plant itself, i.e. from the gas turbines or diesel generators in providing electrical and mechanical power plus waste heat for use in process heating. Making changes to these large power generation equipment items will have a significant impact.

The power requirements are based on the asset demand and the need for a steady power supply. Over the years, the demand may naturally have reduced allowing for a reduction in the power generation needed. However, by targeting reduction in the demand from the users of the power, it may allow for the power generation equipment to be markedly downsized, reducing emissions.

Improving the energy efficiency of the asset is an important step to achieving emissions reductions. Energy efficiency improvements cover a range of opportunities that apply to the power generation equipment itself as well as identifying modifications that reduce the demand from processing, compression, pumping, heating and utilities on the asset.

Improving efficiencies of existing equipment; re-sizing (right-sizing), upgrades, repair and even replacement are all areas to consider. Changes to set-ups or operating methodologies for equipment, systems or packages will also have an impact.

Power management systems and other digital solutions are part of the energy efficiency options and can provide the integrated balance of power delivery against demand across the asset.

Many of these efficiency improvements are already being implemented or being considered by the industry and form part of submitted ERAPs. These are discussed in more detail in the following sections.

Replacing the fossil fuel, either partially or fully, with a low carbon alternative power solution can provide a big impact but these options can be complex, expensive and take much longer to implement. Another opportunity is the use of alternative low-carbon fuels.

Low carbon power solutions include full or partial electrification, with power from shore or offshore wind or use of renewable energy solutions, either small or large scale. Electrification has the potential to play a significant role in achieving emissions reduction targets, but there are challenges associated with its adoption.

Both energy efficiency and low carbon power solutions form part of the NSTA's published OGA plan, which sets out principles for Investment & Efficiency, Platform Electrification and Low Carbon Power.

As previously noted, there is no one size fits all and solutions are dependent on specific asset requirements, locations and processing facilities.

Identifying solutions that are feasible and add value in the short to medium term is the key to industry adoption and making a significant impression on power emissions.

1.1 Energy Efficiency Improvements

Improving energy efficiency of an asset is often the first step to reduce the amount of power required and, therefore, the amount of fuel needed to be combusted to provide that power.

The equipment and systems currently installed on assets were often specified and selected based on the initial projected requirements and conditions of that facility. Over time, production will have typically decreased, compositions changed, and operating parameters altered, moving the expected use cases away from original expectations. Combined with ageing facilities and equipment, decreased performance is to be expected with equipment operating at sub-optimal efficiency.

Sub-optimal equipment performance due to wear and tear, and equipment not operating at or near its best efficiency point increases emissions and hence offer two routes to potential reductions.

Current ERAP submissions present energy efficiency improvements as the most common way in which Operators plan to reduce emissions from power generation.

Identifying modifications or upgrades of existing equipment or changes to operating methodologies can often offer the chance to reduce emissions and improve operational efficiency with the least disruption to the asset or continued operations.

There are many ways of achieving energy efficiency improvements. Right-sizing, upgrading, recalibration or modification of the equipment or auxiliary systems can result in wholesale improvements or may bring incremental change across some or all of the asset. Ensuring inspection, maintenance and repair is performed consistently and in a timely manner can keep equipment operating as intended. Reinstatement of equipment previously withdrawn from operation can improve efficiencies and forms part of some of the current ERAP submissions. Finally, replacement of outdated and inefficient equipment with new, more efficient models, can be considered. This last option presents a more invasive solution and may have a larger impact on ongoing operations and, therefore, has to be considered in relation to the expected remaining life of the asset.

Adoption of digital solutions particularly for rotating equipment can provide automated condition monitoring, vibration analysis, predictive maintenance and surge or recycle management, all of which can impact efficiency. An integrated power management solution that balances power with demand across an asset can provide valuable improvements in operational efficiency.

1.1.1 Reducing Demand - Right Sizing, Modifications & System Upgrades

Reassessing the asset for current operational conditions and requirements often leads to resizing or right-sizing opportunities. Right-sizing will often result in a need to change not just the main equipment but the associated systems as well.

This is applicable across the assets starting with the demand for power from separation, compression and pumping equipment to the resulting impact on flaring and venting systems and utilities and then ultimately to the power generation equipment itself.

Regular planned maintenance and inspection can optimise costs versus benefit and extend the life of equipment, whilst also reducing emissions associated with poor operational efficiency. High quality maintenance can also contribute to higher availability confidence and may lead to avoidance of spinning reserve hence delivering emission reduction from having fewer machines online.

A review of performance across each asset, modifying the arrangement or operating set-up and potentially reducing the number of units in service could enable the units that are in use to be operating closer to their best efficiency points.

Re-assessment, even on one area, often leads to multiple, interlinked modifications that can bring significant improvements to efficiencies, reducing the power demands through reducing fuel consumption and thereby reducing emissions.

Changing operational methodologies or set-ups can also be a way to improve overall efficiency. Improvements to existing equipment are generally lower cost than replacement, however, new, more efficient models correctly sized for current requirements may offer better results overall.

The next sections discuss the opportunities for equipment items that create the biggest loads on the power demand and the main power generation plant items. There are examples of ongoing or planned work and some of the companies and technologies that offer solutions in each section.

Compression on an asset will usually be the biggest user of power and be the main contributor to the amount of power generation needed. Ensuring that gas compression is right sized for current and expected future conditions can have the most significant reduction on power demand and could enable downsizing of power generation equipment. Compression is often across multiple stages with side streams between stages based on the pressure needed. Each stage of compression has different power demands and therefore assessing all compression against requirements is essential.

In later life on an asset, where production rates have dropped, suction pressures have fallen and/or gas compositions changed, compressors typically operate far from their original design points, often with substantial recycle streams to avoid machine damage. Resizing, reconfiguring or upgrading compression trains presents an opportunity to right-size, raise efficiency and reduce power demand.

Serica Energy
Bruce Platform

Serica Energy identified opportunities for improvement on the Bruce platform by revamping medium pressure and export compression. They worked with the Original Equipment Manufacturer (OEM), Siemens Energy, to revamp the drivers to suit the changes to operating conditions. Re-wheeling the primary compression stage has also been undertaken. This has resulted in an efficiency improvement of 10-20%, reducing fuel gas usage and significantly reducing emissions.

Status: Implemented
TRL: 9
Website: Click here

Revamping or modifying the drivers, re-wheeling the compressors, optimising recycles, surge mapping and anti-surge measures are all areas that can be considered along with repair or replacement of some of the associated equipment such as filters and seals.

Variable Speed Drives (VSDs) and/or variable frequency drives are an option that can be retrofitted on both compressors and pumps. These can match the compressor or pump output to the capacity required by changing the speed and/or frequency of the drive, reducing the overall power consumption.

VSDs allow more precise control of the speed and therefore make the compressors more energy efficient, saving energy and reducing emissions compared to a fixed speed compressor.

Another opportunity is to change out compressors from gas turbine driven to electric motor driven. Electric drivers are more efficient and reduce the overall demand on the system. It also opens an opportunity to switch to renewable energy sources to provide the required electrical power.

Associated equipment and systems that have an impact on compressor efficiency include the filters and seals. These require appropriate maintenance to keep them working properly. Replacement of filters, and predominantly high efficiency particulate air filters (HEPA filters), is a common theme in many Operator's submitted ERAPs.

Dry gas seals provide an alternative to oil seals and their associated ancillaries. These can lower leakage risks and raise overall compressor performance.

Full change out of the compressors for more efficient and correctly sized models is likely to be an expensive, complex and longer duration modification but is something that should be kept in mind if the balance of emissions reduction, remaining life of the field and cost is achievable. Support for right sizing equipment can be obtained from OEMs or non-OEMs depending on the risk appetite of the Operator.

There are numerous pump packages on an asset with varying demands on the power systems depending on the type of services. Main oil-line (MOL) pumps, booster pumps, seawater lift pumps and water injection pumps are the largest users but other pumps for process, chemical injection, firewater or general service all add to the demand.

As with the compressors, many of the pumps are operating outwith their original design envelopes so reassessment of current operational requirements and resizing, restaging, revamping and replacement can all be considered. In some instances, reinstatement has been undertaken to allow for changes in asset requirements, particularly export.

Many platforms operate with multiple pumps for a given service, sea water lift pumps are a good example, which are now no longer all required given the platform is operating at a lower capacity than originally designed for. The configuration of these pumps could be revisited to assess if all are required or if the number in operation could be reduced. This would allow those still in operation to run at a higher efficiency, perhaps with less recycle flow, rather than being run for a lower volume of liquid.

If an asset has water injection requirements, then it is likely that water injection pumps and the associated seawater lift pumps will be large power consumers. Some Operators are considering whether continuous water injection can be replaced with batch injection. This reduces the continuous power demand when not injecting, which has the potential to reduce emissions

Similar to compressors, improvements to auxiliary and supporting equipment and systems may lead to improved efficiencies.

Process operations and their configuration, such as oil and gas separation, heating or cooling requirements and water handling needs, impact equipment requirements, power consumption and emissions.

As with everything, there is a need to ensure that processing facilities are right-sized for the current requirements, with flexibility for expected future needs in order to minimise power consumption.

Review of operating pressures through separation and compression can lead to an opportunity to remove or relocate some key equipment. This could include removal/bypass of a separator or relocation of compression stages to onshore or subsea. However, although displacing the emissions to subsea or onshore equipment may not necessarily reduce emissions overall it might offer an opportunity for a more efficient or alternative source of power that does reduce emissions.

Later life operations often mean that water treatment packages are operating at capacity, limiting production throughput. Debottlenecking the process, eg by installing additional dewatering equipment can relieve this. It can take the form of new, more compact separators or potentially subsea separation to remove the bulk of the water ahead of first stage separation.

BSC Separation
Moseley Separator

BSC Separation has developed a compact, multi-phase separator which can be retrofitted to the internals of existing vessels. These can allow for the processing of 4 times more water, at a lower differential pressure. These vessels have a much lower space footprint (10% of conventional separators) making them highly suitable for environments with limited space.

Status: Field trials planned for 2025
TRL: 6
Website: Click here

All the energy efficiency measures considered above should be a reduce the power demand allowing for potential to address power generation equipment resizing. There is also the potential that operational and processing efficiencies are also improved which can have a knock-on effect on flaring and venting, often for the better.

1.1.2 Waste heat recovery

Waste heat recovery solutions capture the heat from the hot exhaust gases exiting turbines and engines on an asset. The captured heat is then be used for process heating or power generation, optimising the energy usage in delivering the overall load by the asset's heating/cooling systems.

There are many platforms in the UKCS that utilise waste heat recovery. For example, bp's Clair Ridge platform was installed with dual-fuel gas turbines with a waste heat recovery unit and TotalEnergies Elgin-Franklin platform has a combined heat and power system, which generates electricity and useful heat from the same energy source. Utilising the heat from these high temperature sources for process heat, reduces the requirement to generate the heat through other means, such electrical heating. Removing this requirement reduces the demand and therefore reduces emissions.

Modifications to the gas turbines so they operate more efficiently may change the temperature or amount of exhaust gases which will impact the waste heat recovery available and, therefore, needs to be assessed.

Opportunities for adding or improving waste heat recovery can be through the use of new turbines such as combined cycle or organic Rankine cycle turbines. These types of turbines are regularly used onshore in power plants and are starting to be considered more for oil and gas offshore applications.

Combined cycle gas turbines utilise the exhaust heat from the gas turbine to create steam with a heat recovery steam generator. The steam is then fed to a turbine to produce additional power output. This increases the thermal efficiency of the turbines as well as reducing the requirement for other sources of heat and power and thereby reduces emissions. Their installation would typically require additional weight and space provision. Combined cycle gas turbines are used onshore but are being considered for offshore use on greenfield sites by Siemens and other OEMs.

Siemens Energy
Ultra Light Combined Cycle

Siemens have been developing ultra-light combined cycles which can be retrofitted on existing oil and gas platforms or integrated into greenfield sites. These have a smaller footprint than traditional combined cycle plants.

Status: In development
TRL: 5
Website: Click here

Another promising option for use offshore is organic Rankine cycle (ORC) turbines. ORCs convert low-temperature waste heat from gas turbines using an organic fluid as the medium for heat recovery. They have been installed and proven at onshore terminals but need to be proven offshore and can present a weight issue.

ElectraTherm
Power+ Generator

ElectraTherm's Power+ Generator produces low emissions electrical power from waste heat using the organic Rankine cycle (ORC). This can increase the efficiency of the process and reduce the need for flaring.

Status: Deployed onshore
TRL: 9
Website: Click here

Provision of process heat has been identified as one of the key challenges with electrification. Removing the source of the heat through removal of the power generation turbines and replacing with renewable electricity solutions means additional equipment is required to provide the necessary heat for normal operation of the asset.

Challenges and Gaps

Space and weight restrictions are significant when considering equipment for offshore installation. This can limit the application of the combined cycle equipment and may mean that they are more suitable for onshore facilities.

Organic Rankine Cycles have been implemented for onshore facilities to use the waste process heat to generate power. It has been studied by a number of operators for use offshore but to date it has not been taken further.

1.1.3 Power Generation Equipment

Gas turbines are typically the most energy intensive pieces of equipment installed on an asset. In most instances, they provide most of the power required for the asset and will have the largest associated emissions.

Gas turbines and diesel generators, present a significant opportunity reduce the emissions from an asset.

In general, reduced throughputs and changing conditions on the asset over time result in the power generation requirement naturally declining, offering an opportunity to downsize the power equipment.

Combined with the measures being undertaken to improve energy efficiencies and reduce the demand across the asset from the main users of the power, there is the potential that the power generation equipment itself can significantly modified.

Most gas turbines are dual fuel which does give an increased degree of flexibility, by allowing the capability to switch from one fuel to another. This means that the turbine can continue to operate on back-up fuel, usually diesel, when there is no fuel gas available such as on process restarts. These dual-fuel turbines offer an opportunity to switch to a lower carbon fuel during these back up operations rather than use diesel.

All the major power equipment OEMs, including Siemens Energy, GE and Wartsila, are working on turbine efficiencies and upgrades and have been in consultation with the operators to provide solutions that ensure less emissions from the installed equipment per unit of power generated.

Existing turbines could benefit from upgrading their rotors. These changes can increase the efficiency and lifespan of a turbine and reduce its emissions.

Installation of enhanced turbine controls can increase operating efficiency including through better management of the turbine's air compressor section.

Both OEMs and non-OEM service companies can provide servicing and upgrades to existing equipment to improve efficiency and reduce emissions.

Ethos Energy
ECOMAX

Ethos Energy offers several different solutions to increase efficiency, improve performance and extend the life of existing gas turbines and other rotating equipment. For example, ECOMAX provides a customisable tuning platform, which uses live data to calculate optimum operating conditions. This increases power output and efficiency, whilst maintaining emissions compliance.

Status: Commercially Available & Deployed
TRL: 9
Website: Click here

Most gas turbines are open-cycle but expanding or modifying them to become combined-cycle turbines can deliver up to 3.5 MW of additional power per machine, potentially enabling single turbine operation, if the capacity is sufficient. Reducing the number of turbines substantially reduces the associated GHG emissions.

Power generation must be based on the revised power demand and the requirement for steady power. There are opportunities to consider new, more efficient replacements or modifications to adopt alternative fuel solutions for existing equipment. Other solutions may be to install energy storage that can provide for intermittent power requirements rather than keeping an additional turbine running continuously.

With reduced demand optimisation of the number of turbines in operation is possible, for example, running 3 out of 4 turbines rather than running all 4 at a lower capacity and lower efficiency would reduce the fuel gas requirement and thereby reduce emissions.

Replacing a turbine with a more efficient model will involve capex and brown field modifications potentially impacting ongoing operations, but this could significantly reduce emissions.

Diesel generators can be used to provide the full or partial power needs of an asset or as a back-up should gas turbines be out of operation. As for turbines, these are likely to have been sized on initial requirements and the capacity is now more than necessary, meaning they are operating sub-optimally.

Generators could be resized to ensure that efficiency is improved and in turn emissions are reduced. Removing and replacing or modifying in situ would involve significant work, cost and possible production continuity impact, so would have to be balanced against expected emission reduction gains.

There is potential to use alternative sources of power generation in place of diesel generators, depending on the power requirements. Small scale renewables are of particular interest along with the potential to switch to alternative fuels are discussed later. For onshore terminals using small scale renewables is a real opportunity to replace diesel generators.

Revterra
Kinetic Stabilizer

Revterra have developed a flywheel energy storage system, known as the Kinetic Stabilizer where electrical energy is converted into kinetic energy and can be drawn down when required. These industrial scale units can provide up to 2 MW of power and can store up to 100 kWh of energy each.

Status:
TRL: 7
Website: Click here

Challenges and Gaps

One of the biggest challenges associated with any modifications to the power system is ensuring there is always sufficient power and back-up on the asset to maintain the power requirements under all scenarios. This is from the standpoint of both ensuring minimal impact on normal operations, as well as under non-routine or emergency operations. Energy storage systems may provide an opportunity to provide some back-up power but these need to be developed further and be proven in an offshore environment.

Modifications and particularly change out of equipment always presents challenges in terms of cost and time to implement, and potential impact on ongoing production. Although there may be a high initial outlay, emissions and operating costs have the potential to be reduced significantly.

With ageing equipment, upgrades can be challenging, however it is possible to reverse engineer solutions for obsolete equipment. An economic analysis, including emissions analysis, will help decide between renovation or replacement.

1.1.4 Power Management

Balancing power availability with demand can offer emission reduction potential. Power management systems can be developed, or are available off the shelf from vendors, that can provide a full or partial digital solution that will address this issue.

Software and AI-enabled digital solutions now provide a more comprehensive understanding of the data with real-time monitoring allowing for understanding of the energy consumption on an asset and identifying the right optimisation measures to balance the plant operation.

Some operators are already using integrated live emissions data with live operational data to identify where equipment can be shutdown or started up to provide the best balance of power.

Surge management and prevention of unwanted load shedding are all part of such power management systems.

There are a several service companies that provide these power and energy management systems that provide this type of capability, such as ABB, Kongsberg and others.

ABB
Power & Energy Management System (PEMS™)

ABB offer a Power and Energy Management System (PEMS™) to ensure optimal operating performance. The system is integrated with the facilities electrical system and uses high speed digital communication with ABB's switchboards, protection devices and controllers. This ensures power resources are used in a safe and environmentally friendly manner.

Status: Commercially Available & Deployed
TRL: 9
Website: Click here

The progress of these digital tools offer a means to collect and analyse the data supporting economic analysis for emissions reduction modification projects.

Challenges and Gaps

Through engagement with industry, it was clear that more work is required before such power management software is widely adopted. A trusted certification process could be developed to increase confidence in its use

As always, an economic assessment is required to evaluate the fuel and emission benefits versus the expected costs.

1.2 Low Carbon Power Solutions

Replacing or displacing fossil fuels used in power generation equipment with alternative low-carbon power solutions, will significantly reduce power emissions.

There are several low carbon power solutions available but the cost, time required and complexity to install and implement them can be prohibitive, especially for remote assets or those with early cessation of production dates.

Electrification, either full or partial, with power provided from shore and/or from offshore wind or other renewables sources would significantly reduce offshore emissions.

Use of smaller scale renewable energy solutions could provide clean energy that will supplement or partially replace power generation requirements. This technology area is continually being developed and many of the solutions provide a combination of technologies such as wave and battery. The energy storage aspect of these solutions is key to ensure uninterrupted power supply to oil & gas assets.

A promising solution is to replace fuel gas or diesel with an alternative low carbon fuel. Other associated industries are also considering such a switch, including the shipping industry which is looking at green methanol as an alternative for marine engines.

These alternative solutions for fuels or power sources are discussed in the sections below.

1.2.1 Alternative fuels

The technology issues associated with alternative fuels are discussed below, but in parallel to raising the TRL for their deployment, an appropriate mechanism to recognise their GHG emission reduction capacity is required. At present this mechanism does not exist and GHG emissions are counted in the same way as for diesel. It is likely an appropriate mechanism will be required to sufficiently incentivise their uptake.

In recent years there have been numerous advances in the development of low carbon alternatives to traditional fuels such as fuel gas or diesel. There are many different solutions in this area. Some solutions can be retrofitted to existing equipment with small or larger modifications, but others can be used as direct replacements.

Many of the OEMs are currently working on retrofittable solutions which accommodate alternative fuels for existing equipment.

Biofuels and e-fuels, including e-methane, bio-diesel, and bio or e-methanol are being considered in the near term, with ammonia and hydrogen longer term prospects.

In addition to technology readiness concerns, supply chain reliability remains uncertain. While manufacturing in Europe is increasing rapidly for some alternative fuels, there is still insufficient availability for industry to go for a wholesale switch. Reliability of supply and cost are the key issues. A potential opportunity exists to create a domestic UK alternative fuel production capacity to match expected demand.

Along with the supply of the fuel, transport and storage are also a consideration. Some alternative fuels require higher volumes to produce the same levels of power which requires larger or alternative storage solutions.

Alternative fuels can also offer lower NOx and SOx emissions and in some instances, these can even be eliminated.

Switching to alternative fuels for back-up or auxiliary power may be a more realistic solution in the shorter term and this would be a good stepping stone to more widespread adoption. Alternative fuels present an option where electrification is not feasible.

NZTC currently has a number of industry projects under the Net Zero Technology Transition Programme (NZTTP) investigating the use of different alternative fuels and their application to the sector.

Alternative diesels like hydrotreated vegetable oil (HVO), fatty acid methyl ester (FAME), biodiesel and e-diesel can be used in diesel engines and generators to produce lower GHG emissions than standard diesel.

Due to the similarities with diesel properties, early trials have shown that this could be possible with minimal equipment modifications, however, this must be assessed on a case-by-case basis to ensure there are no harmful effects on performance or equipment life.

As both biodiesel and HVO properties are comparable to diesel, similar volumes of the fuel are required to generate the same quantities of energy. This means current storage facility capacities can be easily repurposed.

As part of the NZTTP Alternative Fuel Gas Turbines (AFGT) project there has been a focus on the use of alternative fuels for EnQuest's Kraken platform, in particular the use of bio-diesel and HVO.

03
Emissions Reduction Technologies

EnQuest
Kraken HVO Study

A number of studies have been completed on behalf of EnQuest and their Kraken FPSO to assess the suitability of HVO as an alternative fuel. This has considered all aspects of its use such as technical, economics and operations. It was determined that all equipment was compatible with the use of HVO and a demonstration trial was scheduled for late 2024, with result still to be published.

Status: Demonstrator in progress
TRL: 7
Website: Click here

However, HVO is not currently recognised from a carbon credits point of view. Without this, switching to HVO from diesel will not deliver significant emissions reduction and the higher cost of the HVO and the risk of the supply chain associated with the switch makes it unattractive.

Green methanol (bio-methanol or e-methanol) can be used in power generation equipment in pure or blended form. Methanol produces lower emissions of greenhouse gases compared to conventional fuels and, when produced from renewable sources, can be carbon neutral.

E-methanol refers to methanol which has been produced using hydrogen from the electrolysis of water which has been powered by renewable energy, reducing its associated emissions.

Methanol is already used in oil and gas production, typically for hydrate control in production operations, so there is already experience in the transportation and logistical practices of handling methanol offshore. A key difference for e-methanol as a fuel would be the very much larger quantities required to be transported and stored, both of which present some challenges for offshore use.

Methanol as an alternative fuel can provide a significant near-term transition in terms of technology availability. Many OEMs are offering methanol compatible engines and turbines, i.e. existing equipment designs that require minimal modifications to switch fuels. This is coupled with a significant growth in renewable methanol production plants, particularly in Europe and Asia.

Wartsila have developed a methanol-fuelled engine that has powered a passenger ferry since 2015. The conversion of 4 of the ferry's engines to run with methanol as the primary fuel has resulted in a 25% reduction in CO_2, a 60% reduction in nitrogen oxide emissions and a 99% reduction in sulphur oxide emissions.

Siemens Energy, provider of a large percentage of the world's gas turbines, believe that methanol is the "most likely transition fuel" for gas turbines because it can provide a power generation decarbonisation solution much sooner than hydrogen, ammonia or electrification schemes. The source of carbon in any methanol is important in determining its green credentials.

As part of the NZTTP, Siemens Energy haven investigated the potential to retrofit existing turbines with the ability to switch to green methanol. The project has successfully demonstrated the feasibility to do this initially on the smaller SGT-A20 and, more recently, the much larger SGT-A35 units.

NZTC & Siemens Energy

AFGT

As part of the Alternative Fuel Gas Turbine project NZTC has worked in collaboration with government and industry to accelerate development and deployment of gas turbines capable of running on clean fuels. During the project Siemens Energy tested the suitability of e-methanol as a fuel for their existing turbines. The trial involved the operation of the SGT-A20, which successfully demonstrated that e-methanol could be used safely in the turbine. The lower flame temperature also has the potential to extend the life of turbine components. It is possible that the power output of the turbine could be increased by up to 10% compared to Kerosene, however further investigation is required for this.

Status: Study complete
TRL: 6/7
Website: Click here

Using e-methanol in existing turbines with minimal modifications to the turbine package itself presents a significant opportunity to the industry to reduce emissions from power generation.

Another alternative fuel to be considered is ammonia. It can be classified as a carbon zero fuel when produced using electricity from renewable sources, as there is no CO_2 produced during combustion.

However, there are challenges associated with using ammonia in existing equipment, mostly that it has a high ignition energy.

Although zero carbon ammonia has been developed, the equipment required to utilise it needs to be developed further. Ensuring that turbines are compatible has been a focus area for the leading turbine manufacturers. Several studies and field trials are underway, with positive results being achieved. Mitsubishi Power is developing a 40MW ammonia fired gas turbine system that is still in the development and demonstration phase.

Significant changes to the entire power plant are required to use ammonia as an alternative fuel. It is expected that ammonia-fuelled turbines are still 5 years from being proven and therefore it is unlikely to be a solution for power generation for offshore oil and gas.

Ammonia, produced through the Haber-Bosch process, is a gas at ambient conditions and would require refrigeration and/or pressurisation to remain in a liquid state. This raises the energy required for transportation and presents challenges for storage. Ammonia also produces significantly higher levels of NOX, and SOX during its lifecycle in comparison with other alternative fuels. Hydrogen is very likely to be part of the future energy landscape and power generation equipment fuelled by hydrogen is in development by the main equipment providers.

GE Vernova have developed gas turbines that will be able to run on up to 100% hydrogen and have demonstration projects ongoing in the US, Australia and China. Currently the turbines are running on a 50/50 hydrogen/natural gas blend. These are all operating onshore at power plants. There are several challenges around hydrogen as an alternative fuel for power generation.

It is not considered a 'drop-in' solution and it is expected to be approximately 10 years before some of the challenges for offshore application can be resolved and is therefore a longer term solution.

Projects such as NZTC's Hydrogen Offshore Production project (HOP2) which is demonstrating the feasibility of offshore green hydrogen production at scale through repurposing of offshore oil and gas assets may be one solution if hydrogen as an alternative fuel for gas turbines becomes a potential solution.

Alternative Fuels Challenges and Gaps

As part of the EnQuest Kraken alternative fuel studies, some of the gaps associated with using alternative fuels for emissions reduction in power generation were identified that apply across most of the solutions. The initial challenge is with compatibility which is particularly relevant for methanol, ammonia and hydrogen. Ideally, retrofitting existing equipment would be the most straightforward solution with minimal modifications but this is not always achievable.

One of the main challenges for all alternative fuels is the supply of the fuel with manufacturing of the fuels still developing and global demand increasing. For example, with the ongoing switch by the marine shipping industry to utilise green methanol there is and will continue to be an increase in the manufacturing across the globe but this will also be met with an increase in the demand, which may in turn increase the cost.

At present, most of the manufacturing plants are located in Europe which presents further challenges to secure supply and ensure alternative fuel supply logistics can be established.

There are initiatives to investigate opportunities to manufacture alternative fuels in the UK. The partners in the HyLion network recently announced a plan to produce CO_2-reduced hydrogen from renewable energies and then convert is to e-methanol. The plant would be located in Scotland.

The HyLion network partners include ARUP, McPhy Energy S.A.S, Bosch Manufacturing Solutions GmbH, E.ON Energy Infrastructure Solutions, CO_2 Recovery Ltd & The Carbon Removers, Mareneco Ltd, Cadeler A/S, and P1 Fuels.

Establishing manufacturing capacity for alternative fuels in the UK is certainly a clear opportunity alongside the development of hydrogen production and carbon capture projects. It would create an opportunity for a supply chain for the fuels that are required for decarbonisation of industry, not just oil and gas, but also shipping, aviation and transport.

Once the supplier of the fuel is found, transportation, bunkering and storage capacity are all potential challenges, particularly if the fuels require specific conditions.

When comparing with traditional fuels, such as diesel, the volume of e-methanol and ammonia required to produce the same quantity of energy is almost double. This poses challenges in the capacity of alternative fuel storage. Alternative methods of storage may be required as the footprint of an asset is unlikely to accommodate this. A potential solution could be the implementation of subsea storage, such as NOV's Subsea Storage System.

NOV

Subsea Energy Storage System

NOV have developed a membrane-based subsea storage solution which can be used for a range of oils, chemical and now clean liquid energy sources such as ammonia or e-methanol. These are situated on the seafloor, and provide safe, subsea storage at ambient pressures and temperatures.

Status: Final stages before commercialisation

TRL: 8

Website: Click here

Another key challenge identified is around evolving regulations both from the safety perspective and the emissions, including the lack of credits for using some alternative fuels.

These gaps and challenges need to be addressed by industry and regulators to ensure that alternative fuels are a feasible and affordable alternative for power generation. At present turbine manufacturers have shifted most of their focus towards other alternative fuels rather than HVO/biodiesels. Currently, Operators interested in exploring the use of HVO have to provide full funding for any trials, resulting in slow uptake. This could present an opportunity for a collaborative industry project to trial the use of HVO in turbines onshore prior to deploying on offshore oil and gas facilities.

The Energy Hubs project as part of the NZTC's NZTTP programme is looking at creating multiple energy hubs in strategic locations around the UK to provide an integrated approach. The hubs will utilise renewable energy sources such as wind and tidal with the production of green hydrogen and alternative fuels at scale. The project will address some of these highlighted challenges.

1.2.2 Full or Partial Electrification

Electrification has the potential to play a significant role in achieving emissions reduction targets, but there are challenges associated with its adoption.

The OGA Plan, which places electrification and low carbon power at the heart of emissions reduction, states that any asset due for first oil after 2030 should be fully electrified or run on an alternative low carbon power source, and those whose first oil will be prior to 2030 should be electrification ready.

Electrification of offshore assets is a complex challenge and several alternatives for full or partial electrification are being considered including; power from shore, power from windfarms, offshore microgrids or standalone solutions such as a wind turbine providing power direct to a single platform.

At the 2024 UK-Norway Offshore Decarbonisation Workshops held jointly by the NSTA and the Norwegian Energy Partners, electrification was one of the main areas discussed and it offered a vehicle to learn more from Norway's electrification schemes. The workshops brought together operators and the supply chain from the UK and Norway to discuss some of the challenges and opportunities associated with this option.

These included high capital cost, regulations and pathways to grid connections, availability of the technologies themselves, the scale of the brownfield modifications required and the capacity of the supply chain to deliver equipment and services.

Power from shore is an option which has been long discussed involves the provision of electricity from the onshore UK national grid asset(s) offshore. This is something that has been implemented successfully in other countries, such as Norway, where power from shore has been adopted across a large number of assets.

Some oil and gas assets under development are making provisions during construction so that the asset can be 'plugged-in' as and when electrification becomes reality.

Equinor

Rosebank

Equinor's Rosebank facility, West of Shetland, is intended to be one of the first to be powered from shore. A redeployed FPSO, it will be electrification-ready when it arrives in-field. A hub power solution for the area nearby Rosebank is currently being assessed.

Status: In development

TRL: 7

Website: Click here

Alternative electrification solutions are being investigated including the potential to connect offshore hubs to onshore power and supply other installations in the vicinity. This would reduce the need for multiple connections to shore.

Offshore windfarms provide a potential opportunity to connect and provide electrical power to offshore oil & gas assets. The windfarm's onshore grid connection would offer the ability to reverse flow power when there is insufficient wind, maintaining continuity of supply to the oil & gas facility. This would reduce the distance of cabling to connect the installation to onshore power. Onshore power is planned to be largely decarbonised by 2030 resulting in low carbon solutions for offshore installations tied in after this time.

Integrating offshore wind energy with oil and gas platforms can provide a reliable and renewable power source, reducing the carbon footprint of offshore operations and creating hybrid systems that can provide stable and sustainable energy for offshore operations. Hybrid Energy Systems (HES): combining offshore wind farms with oil and gas platforms to provide renewable electricity for platform operations reducing the carbon footprint of offshore operations and enhancing energy security.

Emerging technologies include the development of advanced wind turbine technologies which are larger and more efficient with higher capacity factors. Innovations include modular blades, advanced materials, and improved aerodynamics.

Offshore energy storage is an emerging area with the development of large-scale energy storage systems, such as batteries and compressed air energy storage, to balance supply and demand and integrate intermittent renewable energy sources. Some form of mitigation of the inherent intermittency of wind power is essential to maintain ongoing oil and gas production operations given its requirement for uninterrupted power.

Subsea 7 & FLASC

PowerBundle

The PowerBundle concept combines FLASC's Hydro-Pneumatic Energy Storage and Subsea 7's pipeline bundle technology for a scaleable energy storage system. The long duration offshore storage bundle uses pressurised seawater and compressed air to store energy.

Status: Development
TRL: 4
Website: Click here

The advance of floating wind solutions extends the opportunity to deeper waters than previously achievable through fixed offshore wind assets.

Equinor

Hywind Tampen

Hywind Tampen is the first floating wind farm built specifically to power offshore oil and gas installations and is now supplying electricity to Equinor's Snorre and Gulfaks fields in the Norwegian North Sea. The system has a capacity of 88 MW and consists of 11 wind turbines. The wind farm is estimated to meet about 35% of the annual electricity power demand of the 5 platforms.

Status: Operational
TRL: 8
Website: Click here

Floating offshore wind is considered a real opportunity for the UK, providing significant power for the grid but also offering opportunities for locating wind close to existing oil and gas infrastructure, reducing the distance for tie-in. There is considerable work ongoing in the technologies behind floating offshore wind. Areas of particular focus are substructure design and manufacturing, port usage, platform design, and suppliers for moorings, anchors, and array cables, some of which are already strongly linked to oil and gas expertise.

Electrification in the UKCS is often considered on a platform-by-platform basis. This approach means that due to the scale and the associated space and weight of the modifications required electrification can be regarded as infeasible. Microgrids or offshore distribution networks provide an area wide solution, minimising the costs of platform modifications by locating the main electrification equipment items on a nearby hub.

As part of the NSTD the NSTA ran an Electrification Competition to identify innovative solutions for electrification that supported oil and gas operations. The three selected winners were studies focused on solutions that did not require power from shore.

Orcadian

CNS Microgrid Solution

A consortium led by Orcadian Energy, sets out a design for a viable, off-grid option for powering UKCS platforms in the Central North Sea taking power from local wind farms. The intermittent electrical power goes to distribution hubs with gas fuelled reciprocating engines and battery back-up power to create a number of microgrids supplying nearby platforms.

Status: Study
TRL: 2
Website: Click here

Katoni

An offshore 'island' grid without the requirement for connection to shore. The basis is that with a reliable electrical power source any platform could be electrified. A modular design that can be scaled up or down to suit local infrastructure, providing a 'plug-in' solution that means there are minimal modifications required on the existing asset. The solution is based on a hub and spoke concept with a Main Hub and Sub Hub.

Status: Study
TRL: 4
Website: Click here

Orsted, Neptune & Goal7
Project Neos

Investigation of the technical and commercial aspects of an electrical connection between an Offshore Wind Farm and an offshore Oil and Gas installation without connection from shore. Two technical concepts were investigated, using subsea cables and considering concept feasibility in terms of power availability and reliability.

The study demonstrated the levels of technical feasibility and which drivers can make projects more cost effective, such as maximum CAPEX related to infrastructure upgrades, and minimum remaining field life. Sensitivities to gas, electricity and carbon prices were also investigated.

Status: Study
TRL: 4
Website: Click here

Standalone solutions, such as independent wind turbines could provide an alternative power source for offshore assets. The Innovation and Targeted Oil and Gas (INTOG) leasing round encouraged developers to apply for seabed rights to deploy offshore wind projects that could directly reduce emissions from oil and gas production. This involves locating floating structures in the vicinity of oil & gas assets and connecting with a power cable. INTOG is designed both to use floating offshore wind to directly reduce emissions from oil and gas production (TOG) and to develop a series of agreements for commercial pilot scale innovation projects (IN).

NZTC and the Offshore Renewable Energy Catapult (OREC) jointly run the INTOG Innovation Network programme that focuses on maximising the impact of commercial, pilot scale, innovative, floating wind projects through the INTOG leasing process.

TotalEnergies
Floating wind demonstrator

TotalEnergies are planning a demonstrator project to show how an existing oil & gas asset can be partially electrified using a floating wind turbine. This allows them to test the multiple technology elements necessary for a floating offshore wind unit. The wind turbine generator will be 3 MW and will be supported by a semi-submersible light floating hull. The demonstrator is located at the Culzean Field and is planned to be in operation towards the end of 2025.

Status: Trial 2025
TRL: 6/7
Website: Click here

For all the floating offshore wind electrification options, the cables are a critical requirement, both from a technology readiness point of view but also from a supply chain angle.

The dynamic nature of the cables presents more engineering challenge than the static cables used in fixed bottom wind applications, which have already seen failures due to design, manufacture and installation problems.

There are concerns on the size, weight, reliability and capacity of the cables with some windfarms experiencing downtime due to difficulties with connecting cables. There are cable manufacturers in the UK developing next generation cables including using different materials for the core conductors.

It is essential that learnings from Norway's electrification of oil and gas assets is understood and taken into account when assessing electrification as an option. ORE Catapult holds the data on the cables used in Norway.

03
Emissions Reduction Technologies

Enertechnos
CTS

Enertechnos' Capacitive Transfer System (CTS) is an innovative concept for power cables design, introducing a "linear capacitor" through the cable length leading to lower losses and allowing delivery of more power than equivalent legacy cable systems. Originally developed for electricity distribution networks, Enertechnos has refined CTS to be applicable in a wider area of applications, in offshore grids, wireless EV charging, aviation and other sectors. To minimise the risk of adoption CTS solutions are being optimised to be manufactured on conventional cable-making equipment using; developed jointing methods with a designed-in cable protection system.

Status: In development – working towards field trials
TRL: 6/7
Website: Click here

Some manufacturers are stating that slots will be available from 2026 onwards, but these will be booked up quickly. This means that decisions and commitment from the operators need to be swift to ensure delivery but, given the complexity of electrification for offshore, this is not straightforward.

Transformer lead times range from 18 months for small units up to 50 months for a large ATEX-rated unit.

Replacement for the waste heat currently taken from the gas turbines for process heating needs to be found if the gas turbines are removed. Industrial heat pumps, currently used onshore, are a potential solution for offshore if adapted for harsh service and correctly sized.

Challenges and Gaps

Despite electrification being an effective and proven onshore method of reducing emissions, the main barrier to full electrification for offshore operators are high capital expenditure costs, impact of brownfield modifications, availability of onshore grid connections and dependable power, and acceptable costs.

The remote location of many offshore assets means very long cables are required to connect them to the onshore power grid. This can be avoided or reduced with local offshore power hubs. Both require access to green power at reasonable cost.

The OGA Plan requires operators to develop and implement their plans to achieve electrification by 2030 in order to support the achievement of emission reduction milestones set out in the North Sea Transition Deal.

Floating offshore wind structures are required due to the water depth around most oil & gas assets. More consistent and higher energy wind is available in these locations, compared to near shore or onshore, but the environmental conditions are also more challenging. Suitable designs for the structure, mooring, anchoring, electrical offtake and other ancillary components require to be developed and tested in order to demonstrate their suitability for the expected service conditions.

Many oil & gas assets have been in production for a long period of time and have ageing equipment and infrastructure. Retrofit of equipment to enable power import on such brownfield facilities will prove very challenging and any impact on ongoing production operations will have to be carefully managed.

The electrification of existing FPSOs may require upgrading of their power import route through the vessel's swivel. Retrofitting such upgrades offshore is very challenging, and rare, and may enforce taking off station for completion in calmer waters or in port. New build FPSOs or retrofits prior to installation have the option to resolve this issue prior to deployment.

1.2.3 Small Scale Renewables

Some renewable solutions can provide small scale power in place of conventional sources. This is most likely for remote operations or subsea equipment.

This area of renewables is constantly seeing new technologies and research. The NZTC's TechX programme has seen a significant rise in the companies with wave, solar, battery and other energy storage technology solutions coming through the programme, some of which may form part of the long term solution.

Wave, tidal and solar are all good sources of renewable power offshore but all require energy storage solutions, such as batteries, to balance the intermittency of renewable energy and ensure more consistent power supply is achieved.

Batteries already play a pivotal role in oil and gas, both topsides and subsea, acting as the main or back-up power source for a wide range of equipment. Some uses currently include subsea gauges, drilling tools, smart buoys and underwater vehicles. This means that designs already encompass some of the harsh conditions associated with offshore operation.

Utilising battery technology on a wider and potentially larger scale to store energy to counteract the intermittency of renewable energy sources is a real opportunity. Battery and energy storage technologies are advancing at a pace, addressing the challenges of safety, reliability, efficiency and the availability of precious metals in manufacture.

Combined systems that encompass the means to harness the renewable energy with energy storage and provide a complete solution for uninterrupted power are being developed and trialled by the industry.

Industry supported field trials have been carried out separately by Ocean Power Technology and by Mocean as part of their NZTC supported Renewables for Subsea Power project. Both incorporate wave power combined with batteries for energy storage.

Mocean Energy & Verlume

Renewables for Subsea Power (RSP)

Mocean Energy and Verlume have developed a combined energy generation and storage solution. It incorporates the Blue X wave energy converter by Mocean Energy with the Halo underwater battery storage system built by Verlume. The technology has been designed for harsh environments and tackles one of the key challenges of energy storage. This has been part of an industry partnership to drive towards deployment and has been proven in a relevant environment. Although the system may be a few years away from commercialisation it has the potential to positively impact emissions reduction.

Status: Field demonstration

TRL: 7

Website: Mocean Energy
Verlume Halo
Verlume

- The European Marine Energy Centre (EMEC) in Orkney provide the location and facilities for testing technologies in a marine environment. However, long term testing in the harsh offshore locations needs to be undertaken to reduce risk and gain confidence in the technologies.

Challenges and Gaps

The use of renewable energy such as wind, wave or solar cannot guarantee a constant supply due to their intermittency. A mechanism to deal with this such as combustible fuel generators or energy storage will be required to smooth out power generation.

The power generated from these technologies is not sufficient to replace existing power generation equipment on an asset but can supplement it and reduce demand. It will also ensure power is provided to remotely located equipment that has smaller power requirements, such as subsea wells.

1.2.4 Electrification of Equipment and Systems

Traditional mechanical and hydraulic systems can be replaced with electric systems, although this requires brownfield modifications offshore with a potential impact on ongoing production operations.

Electrical systems are often more efficient than mechanical or hydraulic ones which can lead to reduced overall energy consumption and lower operating costs. These may also have the option for increased control which again can lead to an improved performance and productivity.

Electric systems can be integrated with digital and electronic systems which can offer greater flexibility and scalability.

The primary reason for such a change however is to enable the change from fossil fuel driven equipment to a renewable electricity driven approach.

Challenges and gaps

Although there are many challenges in retrofitting the equipment and systems required to enable electrification, being able to demonstrate the economic benefits of such a change is one of the biggest challenges.

Many assets have been in operation for a number of years and have ageing power generation equipment. Installing new electrically powered equipment could also increase the electrical power demand of the installation, e.g. if gas turbine drivers were replaced by electric motor drives. This could mean that existing power generation would need to be replaced or upgraded to meet the demand with associated cost impacts.

2. Flaring and Venting

Currently, 20% of UKCS GHG emissions from oil & gas activities are attributable to flaring and venting, including 71% of total methane emissions in 2022.

The North Sea Transition Deal has set a target of zero routine flaring and venting by 2030, along with an overall emissions reduction target of 50% from 2018 levels. Although routine flare and venting operations will cease, emergency and non-routine emissions will still be required. These emissions have the potential to be reduced through deployment of new technologies.

The OGA Plan has Flaring and Venting as one of the four areas supporting the strategy for GHG emissions reduction. As part of this, the NSTA intend to publish a list of assets which flare routinely.

Flaring and venting can be split into three categories. A good illustration of types of flaring and venting, along with rates during different operating phases of an asset, are shown in Figure 2.1.

Routine (Category A)
the regular controlled burning or release of excess gas during normal oil & gas operations for safe disposal;

Non-routine (Category B)
intermittent and of short duration and occurs during maintenance or unplanned events, and;

Emergency (Category C)
occurs when disposal is necessary for the operation of safety critical equipment and elements.

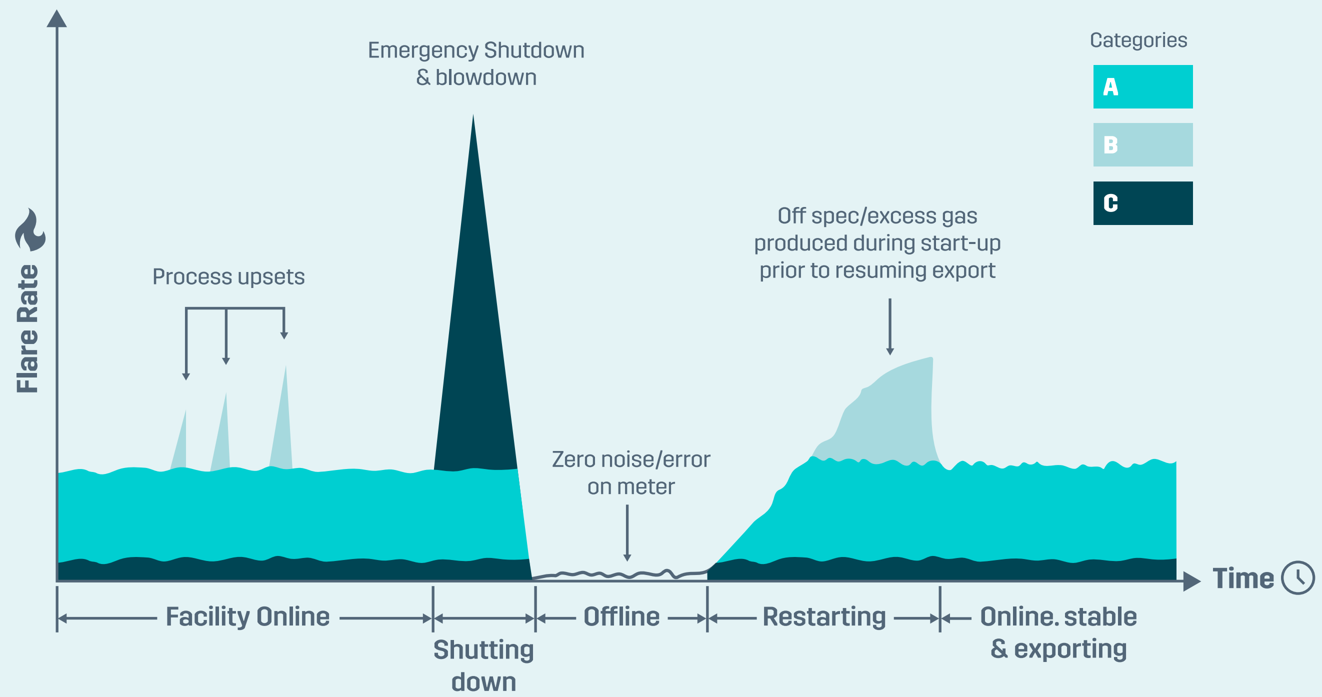


Figure 2.1: Illustrative flaring and venting profile with gas stream category allocations (not to scale) (Source: NSTA Flaring and Venting Guidance).

Flaring and venting consents are issued by the NSTA, which places limits on the amount of gas operators can release year on year. Producers are required to measure the resultant amount of CO_2 released by flares within certain accuracies, and report this according to the UK ETS before the carbon credits deadline. It is therefore important that routine, non-routine and emergency flaring and venting is minimised by all operators.

The following table shows the focus areas for reducing Flaring and Venting emissions. All are discussed further with examples of projects and technologies that address these challenges.

Flaring & Venting	Process Optimisation
	Flare Gas Recovery
	Vapour Recovery Units
	Alternative Routing or Utilisation of Gas
	Flare Optimisation
	Vent Optimisation

Most flaring and venting occurs during the changing of operating processes. "Smoothing" those peaks and troughs through optimisation has always been a target on assets but becomes even more so to eliminate and reduce all flaring, routine or non-routine.

Venting, which contributes 3% vs 17% from flaring, presents a monitoring and measurement challenge. Re-routing cold vents to flare systems allows for control and burns the methane, reducing the GHG impact from the emissions.

For some assets the excess gas can be recovered and re-routed for processing, to be added to the export gas or injected subsurface for pressure support or enhanced oil recovery. This gas may also be used as fuel gas for power generation. Some assets will recover more gas than is needed and will have no obvious route for the excess, leaving flaring as the only alternative unless new utilisation technologies are found.

An alternative route or use for gas routed to flare or vent is required.

If there is no alternative but to flare the excess gas then ensuring the flare is at optimum efficiency is essential. Maximising the combustion of the gas will reduce the methane released, maintaining and modifying the flare tips, ensuring the flare is lit or installing automatic ignition systems and monitoring of the flare are all essential.

The main considerations when reducing or eliminating flaring and venting are process optimisation, flare gas recovery, vapour recovery units, alternative routing and uses, and flare optimisation. These themes are explored in more detail in the following section.

2.1 Process Optimisation

To reduce the quantities of gas being vented or flared, the first step should be to assess the efficiency of all operating processes and identify potential for improvements.

With the target of zero routine flaring and venting by 2030, implementing technology which reduces the requirement to flare should be the first priority.

Monitoring, modelling and predictive tools for process and production optimisation can help regulate operations, utilities and predict potential operational upsets that can then be resolved through changes to operating parameters. This results in smoother and more efficient operations, reducing process upsets and trips and can minimise or reduce the time of shutdowns. Venting and flaring across all categories can be reduced or minimised through implementation of these tools either on a system or asset-wide level.

There are three main areas of operations to be considered for optimisation:

- Routine (normal) operations
- Non-routine operations
- Emergency shutdowns

The use of dynamic process simulation software tools allows for the option to model all these modes of operations, predict any issues, troubleshoot performance and adapt operating parameters and procedures to reduce the impact of any operational changes. The aim is to keep production flowing as smoothly as possible by monitoring and predicting operations from reservoir, through subsea and topsides and onwards to export.

Many of the software packages are already used by Operators and engineering houses for the initial design of systems and assets and can be applied to either a part of the system or as a more integrated model.

Using the tools for remodelling the systems based on revised conditions such as throughputs, compositions, temperatures and pressures can go a long way to reassessing for resizing or modifying operations to improve efficiencies and reduce power demands as well as reducing flaring and venting occurrences.

Many of the packages also offer a real-time solution that can use installed sensors and measurements to manage and predict operational scenarios. These can in turn be incorporated into wider digital solutions that monitor and manage the emissions on the asset

By optimising the process using these tools, all operations can be investigated, reducing requirements for interventions, reducing both process and systems shutdowns, and, if these do occur find an operational procedure that will minimise flaring and venting during these non-routine and emergency operations.

In addition, it helps reduce the need for additional chemicals, leading to less pumping, providing an overall improvement in system efficiency.

There are several process optimisation and simulation software tools on the market which can provide quick wins when used for day-to-day production management.

SLB

Symmetry Process Simulation Software
Production ExPRESS

slb offers a portfolio of digital solutions for modelling, prediction and monitoring.

Symmetry process software models process, pipeline and flaring operations and the associated workflows in a single environment. This predicts the levels of emissions throughout and optimises plans to allow for the reduction or elimination of routine flaring.

'Production ExPRESS', helps quickly bring production forward and avoid shutdowns, thereby minimising venting. The technology covers early production facilities (EPFs), surface pressure boosting, fluid preconditioning, debottlenecking, and pipeline or facility maintenance. SLB's express EPF enables operators to start up production faster than a conventional EPF and can be deployed while a dedicated facility is being built for early cash flow.

Status: Commercially available
TRL: 9
Website:
Symmetry process simulation software
Production ExPRESS Solutions

Wood

Virtuoso

Virtuoso provides a solution to address complex single and multiphase gathering, production, transportation and process modelling. It can provide performance management, virtual flow metering and flow assurance solutions during design, training or integrated asset simulation.

Status: Commercially available
TRL: 9
Website: Click here

2.2 Flare Gas Recovery

Flare gas recovery systems (FGRS) aim to reduce the level of flaring by capturing the flare gases with the intention to export or utilise the byproduct.

Gas that would be routinely vented or flared is redirected from the flare header to the FGRS, where it is compressed and fed back into the process, recovering any liquids en route, for export or use as fuel.

Mechanisms for gas compression are typically either a mechanical compressor or an ejector or eductor.

Ejectors and eductors can efficiently handle and compress gases, recovering low-pressure gases that would otherwise be flared. They typically are static, pipework based with no moving parts, making them reliable and ow maintenance. They use a high pressure motive stream, which can be fuel gas or existing waste gas or liquid streams. The source of their motive fluid will impact the overall efficiency and GHG emissions footprint, but it is typically lower than for mechanical compressors.

They can be used efficiently in FGRSs and VRUs to create vacuums for processes that require low-pressure environments.

Utilising the water injection system to drive eductors is a potential solution that is being investigated.

Transvac
Flare Gas Recovery Ejectors

Transvac's unique Flare Gas Recovery Ejectors, are proven to reduce emissions associated with routine flaring. Can be configured in three ways, with each having their own individual benefits; gas motivated ejectors, liquid motivated ejector recirculation systems or liquid motivated ejectors using existing pumps and/or separators.

Status: Commercially available
TRL: 9
Website: Click here

GBA
Flare Gas Recovery Unit (FGRU)

FGRUs are traditionally based upon liquid ring compressor technology and are designed and supplied by GBA complying with industry specifications. Liquid ring compressors comply with API 681 standard, with mechanical seals per API 682, and can be customised as necessary.

Liquid ring compressors are connected to the flare header in a position between the knock-out drum and the liquid seal drum. As the flare header pressure reaches the pressure set point, the liquid ring compressor starts and begins the compression of the flare gas. Designed as skid-packaged units.

Status: Commercially available
TRL: 9
Website: Click here

Zeeco
Flare Gas Recovery Unit

Zeeco's flare gas recovery system recovers waste gases to be processed, compressed and reused as fuel or for export rather than being flared. This helps to reduce routine flaring. The system can be designed for specific process conditions to maximise efficiency.

Status: Commercially available
TRL: 9
Website: Click here

2.3 Vapour Recovery Units

Vapour recovery units (VRUs) collect vapours that would otherwise be vented, for utilisation elsewhere in the process. Additional benefits include the reduction of fire hazards as the combustible vapours are removed from local release. Many assets already have vapour recovery units in operation, and these may benefit from performance assessment, with or without modification, resulting in higher efficiency and/or reduced emissions.

Similar to flare gas recovery systems, eductors and ejectors or compressors can be used to boost the pressure before the gas is treated and rerouted back to the process for utilisation.

Shell Penguin has installed a VRU to recycle waste streams which would otherwise have been routed to flare. The VRU compresses fuel gas which has been used for purging the vapour space in the oil cargo tanks and as stripping gas in the TEG regeneration unit and feeds it into the gas compression train.

2.4 Alternative Routing or Utilisation of Gas

In 2022, the volume of offshore flaring decreased to 22 billion cubic feet of gas, a decrease of 50% since 2018. Operators must find alternative routes or uses for excess gas to achieve zero routine flaring and venting. The gas can be repurposed for power, fuels, specialty products, and/or specialty chemicals.

Gas is often used for reservoir pressure management through the gas lift system to maintain pressure, increase production or manage some of the flow assurance challenges. In reality, the injected gas is just added to the produced gas and comes back to surface so still needs an alternate route.

Gas can also be reinjected into underground storage facilities for future use, helping to manage supply and demand fluctuations. A suitable formation, and regulatory approval would be required, plus the necessary well(s) and compression equipment.

If the gas is not routed to the flare or vents, then it needs to be routed or utilised elsewhere on the asset. This can be an opportunity if the gas can be recovered and rerouted for export or conversion to another commercial commodity. This becomes a particular issue for assets without gas export facilities.

The other opportunity is the Gas-to-X solutions, which are solutions that take the gas and turn it into other commodities that can either be utilised on the platform or sold. Technologies that are addressing this are growing but often present an issue with being in early stages of development or need large deck space and have weight constraints. For offshore implementation these may not be near term but onshore is much more feasible. Any solution that produces a by-product that is not utilised on the asset will still need an export route.

Small, modular gas-to-liquid (GTL) plants could be deployed to convert recovered gas into valuable liquid fuels and chemicals such as methanol, ethanol, liquified natural gas, and/or diesel oxygenated fuel-blends. These plants can be more flexible and cost-effective than large-scale GTL facilities and reduce GHGs. The size and cost of these plants are typically large but for modest gas quantities they may offer an economic solution to help unlock a field development.

M2X

Gas to Methanol system

M2X's technology is a modular unit which converts methane into green methanol for use as a low-carbon fuel for the marine sector, as a hydrogen carrier or as a chemical feedstock. The units are quick to install and utilise a non-catalytic, partial oxidation reformer to harness the feedstocks and convert into methanol.

Status: Demonstrated in field, working towards commercialisation (2-3 years)

TRL: 7

Website: Click here

Challenges and gaps

The best solution is to find a route for the excess gas to be exported but this is not always possible.

None of the options described above are very attractive in dealing with gas utilisation or disposal offshore. However specific applications are worth considering as they may offer the potential for deployment as part of a larger project.

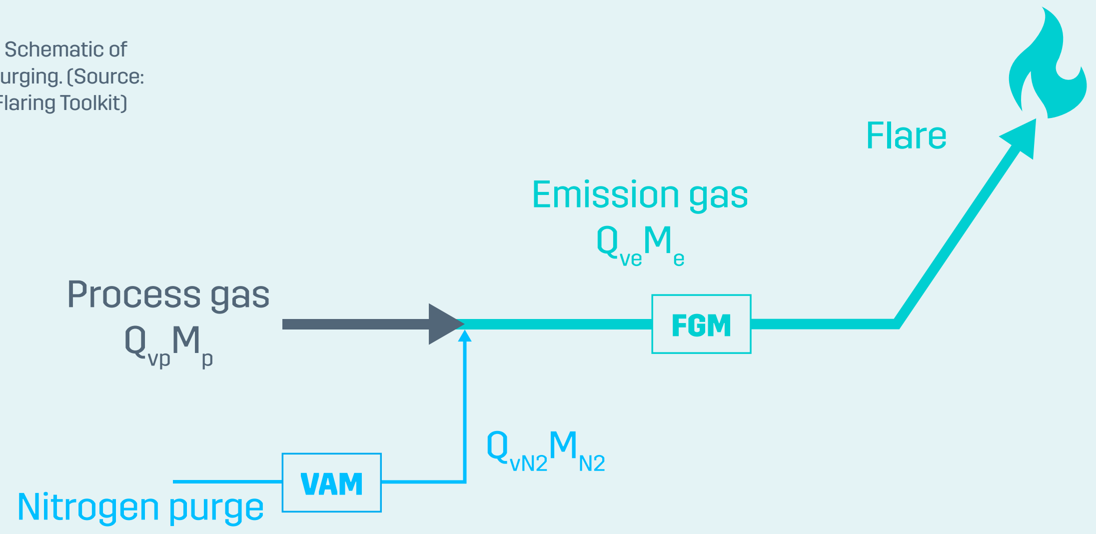
The safety function of offshore flares is expected to remain, and efforts will continue to minimise the demand on such systems, however recovering gas routed to flare during emergency conditions is unlikely to be practicable.

2.5 Flare Optimisation

Flaring operations emit CO_2 from combustion, and unburned methane which occurs from incomplete combustion. CO_2 emissions post combustion can be addressed through carbon capture technologies, whilst flaring operations must be optimised to reduce the volume of unburnt gas (incomplete combustion).

Monitoring and predictive modelling tools for flare gas systems aim to reduce the amount of gas combusted by identifying and addressing the causes of flaring. Technologies that improve and regulate the combustion process are also available and discussed in this section.

Figure 2.2: Schematic of nitrogen purging. (Source: Methane Flaring Toolkit)



Flare tip modification involves upgrading or changing the design of the flare tip to improve its performance. Air-assisted or steam-assisted tips give additional air or steam to improve combustion efficiency and reduce smoke and Coanda effect tips enhance the mixing of air and gas, leading to more complete combustion and lower emissions.

When the flare gas has a lower heating value, combustion efficiency can be improved by adding extra fuel or air to maintain a stable flame. Operating the burner at a higher velocity or with swirl velocity for cleaner combustion and reduced levels of CO and NO emissions. Sonic tips are designed to discharge the flare gas at sonic velocities, usually in a multi-arm design, with fixed or variable exit areas to allow greater flexibility in velocity and therefore mixing with air for low emission combustion which can enable efficiency of 98% or greater.

The use of an efficient ignition system can ensure complete combustion with advanced systems capable of detecting and reigniting unlit flares quickly, minimising the release of unburnt hydrocarbons in the atmosphere.

Modern ignition systems can include autonomous monitoring and control tools that can adjust the flare operation based on gas flow and composition data to ensure optimal operation.

There are various software tools available to improve emissions reduction from flaring. Sensors and analytics can provide real-time monitoring and data analysis of flare performance including measurement of gas flow rates, gas composition, and combustion efficiency. Flare management platforms provide an automated control system that can adjust the flow of assist gases (air or steam) for immediate adjustments to be made to maintain optimal combustion efficiency.

Condition monitoring offers predictive maintenance to avoid unexpected failure events that lead to non-routine flaring upon start-up.

Accord

Combustor

The Accord combustor provides a process simulation model, known as CHARM, which allows operators to calculate an accurate combustion efficiency to monitor and improve their flaring operations, leading to a reduction in their overall CO_2e emissions. This can be configured to give a minute-by-minute view of the methane, CO_2 and CO_2e emissions. CHARM's calculations are transparent and referenced in the OGMP2.0 and OGUK Methane Action Plan. These can be integrated into an existing monitoring and control system to improve on the data quality without the need for onsite physical installation or additional metering.

Status: Commercially available
TRL: 9
Website: Click here

Panametrics

Flare.iQ

Panametrics (a Baker Hughes company) has developed a full-stream flare solution which includes three elements which can be operated independently or in any combination. These include: an interactive flare system to optimise the combustion at the flare tip by providing operators with critical information about the flare system; a real-time combustion efficiency (CE), destruction removal efficiency (DRE) and predictive emissions modelling system (PEMS), to allow for the reporting of emissions based on real-time data; and a digital verification which allows operators to verify flare meters remotely, reducing HSE risk of erecting scaffolding and resources to manually verify flares meters.

Status: Commercially available
TRL: 9
Website: Click here

The NZTC's Methane JIP is bringing industry together to identify campaigns that will standardise methane measurement and monitoring. The JIP has recently supported a trial that combines the technologies from Flylogix and Accord to support this calibration campaign.

From a CO_2 perspective, carbon capture, utilisation and storage is seen as a key part of the decarbonisation strategy for the UK and much focus is ongoing regarding gathering from onshore emitters for storage in the subsurface offshore.

Carbon capture and storage for CO_2 emitted on offshore installations, from power generation equipment or extracted from reservoir fluids, is a potential technology that has undergone some field trialling. Due to the very low pressure of power generation exhaust streams, this CO_2 equipment tends to be large and takes up a lot of space and weight allowance. Use of amine systems can recover native CO_2 in the process fluids, but this again is large and costly. Once recovered, any CO_2 requires a disposal route, either via dedicated pipeline, ship or to a CO_2 store. All three of these present significant challenges.

Amplus Energy & Carbon Circle

Amplus Energy and Carbon Circle have partnered to complete a pre-FEED study on the design of an FPSO process & utility design to include post-combustion carbon capture, CO_2 conditioning and reinjection. This would be the first full-scale post combustion CCS system on an FPSO.

Status: pre-FEED Study Completed
TRL: 2/3
Website: Click here

Challenges and gaps

The optimisation of flaring for routine emissions will also help to reduce the environmental impact of any emergency disposals, but as these are very infrequent this aspect will have only a minimal contribution to 2030 and beyond emission reduction targets.

The main challenge operators have with optimising flaring operations is achieving accurate and reliable emissions measurements to monitor progress. Having accurate data allows for targeted and impactful interventions. Measurements must be consistent and reliable with both top-down and bottom-up methods to ensure repeatability, minimise uncertainty, and establish minimum standards and guidance for measurement methods. Flare systems operate under constantly changing conditions, including fluctuating flow rates, varying gas compositions, and are strongly influenced by environmental factors like wind speed and direction.

The use of nitrogen as an alternative to fuel gas for flare line purging to maintain safe operation by preventing air ingress can reduce local GHG emissions. However, additional equipment to make the required nitrogen offshore, or the supply chain to secure it from onshore will both have a GHG footprint. Lack of continuity of nitrogen supply may impact flare system availability.

Carbon capture for reinjection offshore is a challenge due to the size and weight of the equipment required and the relatively early stages of development. Lessons should be learned from other industries who have already looked at this as an option.

2.6 Vent Optimisation

Venting accounted for 3% of offshore GHG emissions in 2023. In a similar way to flaring, optimisation of venting operation can reduce the overall emissions.

Venting facilities may be required to allow for the repair and maintenance of equipment such as valves. There are solutions available to reduce the need for this such as double block and bleed valves:

STATS Group

Remote Tecno Plug & BISEP

STATS Remote Tecno Plug & BISEP technologies provides temporary isolation tool to significantly reduce fugitive emissions. These valves reduce the need for venting or flaring when undertaking maintenance and repair processes, as they provide double block and bleed isolation avoiding the need for the pipeline to be partially of fully depressurised.

Status: Commercially available
TRL: 9
Website: Click here

IK Group

AOGV

AOGV mechanical isolation provides a barrier between flange pair whilst in continuous operation. This reduces the size of the work area, reduces the maintenance time and removes the need to vent, therefore reducing associated emissions.

Status: Commercially available
TRL: 9
Website: Click here

Technip FMC

HISEP

HISEP by TechnipFMC separates CO_2 rich gas on the seabed for re-injection into the reservoir. This reduces GHG intensity and boosts production capacity on the topside. Reduced system CO_2 emissions intensity during production at Mero 3 by up to 30%.

Status: In development
TRL: 4-5
Website: Click here

HISEP by TechnipFMC separates CO_2-rich dense gas on the seabed, eliminating the need to bring this gas to the surface. The separated CO_2 gas is reinjected back into the reservoir which helps maintain reservoir pressure and enhances oil recovery. With the separation happening subsea, the topside facilities on the FPSOs are less burdened with gas processing tasks which leads to lower GHG emissions topside. However additional equipment is required on the seabed which is generally higher cost than equivalent processing on a topsides.

Challenges and gaps

To optimise existing venting operations, plant modifications are often required. These require downtime and can prove costly. An impact assessment can identify the emission savings as well as associated costs.

3. Fugitive Emissions

Fugitive emissions are defined as the unintentional release of gases or vapour from pressurised equipment due to leaks or seeps and other irregular releases. The NSTA's 2024 Emissions Monitoring Report shows that fugitive emissions accounted for 2% of the total offshore field emissions in 2023.

Although a small percentage of the overall emissions, the impact and occurrence of fugitive emissions can be mitigated and controlled through regular maintenance, equipment upgrades, or optimised operations.

Fugitive emissions are difficult to measure, so although they are estimated to make only a small contribution, better measurement is required to be more certain on their quantity. As they generally comprise of methane, the impact on the environment is magnified due to their much higher GHG emission factor than CO_2.

03
Emissions Reduction Technologies

3.1 Equipment and Fitting Sources

Leaks from equipment and pipe fittings can significantly contribute to fugitive emissions. Leaks often occur in malfunctioning or worn-out valves, poorly designed seals or vents in storage tanks, and high-pressure conditions in connectors, flanges and pipelines. Proper maintenance and replacement of worn-out items are required to address fugitive emissions.

Where practical replacement with new, more efficient equipment such as stemless valves may offer improved sealing performance. These omit the traditional valve stem, removing the need for stem packing, which is often a source of leaks. They have fewer moving parts, reducing the potential for wear and tear, and the advanced sealing technologies used minimise fugitive emissions. Several such products are already available on the market or are in development.

Oxford Flow
ES Stemless Axial Flow Valve

Oxford Flow's ES axial flow stemless valve offers high performance and reliability for a wide range of applications in oil and gas, petrochemical and process industries. The valve is electro- hydraulically actuated which reduces the size and weight by 50%. The valve is claimed to be leakproof and is available in a variety of materials, sizes and pressure ratings.

Status: In development
TRL: 7
Website: Click here

Actuation Lab
Dragonfly Valve

The Dragonfly Valve is claimed to be a leak-free solution suitable for variety of applications including cryogenic temperatures. The body is fully sealed, preventing contained gases from reaching the atmosphere. The use of magnetic couplings and small electric actuators means minimum force is required to open and close the valve. Valves are in use for ammonia and hydrogen applications, with natural gas projects scheduled for 2025.

Status: Pre-commercialisation
TRL: 7
Website: Click here

Challenges and gaps

When calculating the fugitive emissions from equipment such as valves, the model or make of valve (and their leakage performance) as well as the number of valves should be taken into account.

3.2 Integrity Management

Without regular inspection and maintenance, equipment such as valves, seals, and pipelines are more likely to develop leaks, leading to prolonged periods of unmitigated emissions. Good asset integrity management has an important role to play in preventing unintended emissions. This could include smart repairs and maintenance, equipment monitoring such as infrared Leak Detection and Repair (LDAR) technology, or the use of data analytics and machine learning for predictive maintenance.

Smart repairs and maintenance refers to the use of technology to optimise the repair and maintenance of equipment, structures, or other assets. It involves the collection of data from sensors and other sources to monitor the condition of the asset and identify problems before they occur. This allows for predictive maintenance, which can be scheduled in advance to minimise downtime and prolong the life of the asset.

Corrosion under insulation (CUI) is a leading contributor to equipment degradation, consuming 40 to 60% of maintenance budgets. CUI can be responsible for forced shutdowns, lost production, early repair and replacement, and safety and environmental consequences.

Copsys
Intelligent Digital Skin

Copsys Intelligent Digital Skin (CIDS) offers an alternative to conventional CUI management and involves close visual inspection of process piping and equipment. CIDS replaces costly manual inspection with a continuous digital presence and live status updates for active protection. It is the first paint with feelings – able to remotely detect and accurately locate coating barrier failure in real time before corrosion can occur, with advanced coating-integrated cathodic protection to stop corrosion before it can occur.

Status: In development
TRL: 7
Website: Click here

Technologies like infrared cameras, ultrasonic detectors, and portable gas analysers can be used to monitor equipment integrity. LDAR programmes involve periodic inspection of equipment to detect leaks and can be carried out with technologies such as infrared cameras and ultrasonic detectors to identify leaks quickly and accurately, allowing for timely repairs. By identifying and repairing leaks promptly, LDAR programmes significantly reduce the quantity of fugitive emissions released into the atmosphere.

Integrity management can also come from accurate and up-to-date inventory management. Envio's Intelligent Equipment Containers were originally intended to track the geographical location of expensive equipment but have been developed to transmit sensor data on the handling and temperature exposure of sensitive equipment. This technology, alongside data analytics and machine learning, can allow operators to anticipate failures and leaks before they occur.

Implementing continuous integrity monitoring systems can provide real-time data on emissions, allowing operators to utilise data management systems to track the condition of equipment and schedule timely maintenance. This allows for proactive management and reduction strategies.

03
Emissions Reduction Technologies

Asset 55 & Score Group
Emissions Elimination Program

Asset 55 and Score Group have formed a partnership to create a new solution to manage emissions. The Emissions Elimination Program aims to reduce an operator's footprint and achieve emissions targets. The Program builds out an asset's inventory and communicates with CMMS systems to track maintenance activities and accurately report methane emissions.

Status: Commercially available
TRL: 9
Website: Click here

Imrandd
ALERT

Imrandd offer a range of technologies which allow for the monitoring of an asset. The ALERT programme monitors in real-time for integrity threats, meaning that operators can act before any damage occurs. This can be used for scenario modelling to investigate the impact of new processes or changes in variables on asset integrity.

Status: Commercially Available & Deployed
TRL: 9
Website: Click here

Challenges and gaps

Many assets on the UKCS operate beyond their original design life, and a significant portion of pipe failures are attributed to CUI. Detecting and mitigating CUI is crucial for reducing fugitive emissions, but current technologies for detection and inspection are not always designed to work seamlessly with older infrastructure.

Fugitive emissions can come from numerous sources, such as valves, pipe connections, equipment seals and compressors. The very small and widespread nature of these emissions makes them difficult to detect and quantify with existing technologies.

4. Other Integrated Asset Solutions

Although a focussed effort on the largest emissions categories such as power generation, flaring and venting, and fugitive emissions is vital, there are other technologies which could be beneficial but don't necessarily fit into the above categories.

These technologies may directly or indirectly reduce emissions associated with offshore assets, and their lifecycle, or may be more future focussed with much more development required to reach maturity.

The following table shows the focus areas for reducing emissions through other integrated asset solutions. These are discussed further with examples of projects and technologies that address these challenges.

Integrated Asset Solutions	Digital Solutions
	Robotics and Autonomous Systems
	Decommissioning

4.1 Digital Solutions

Artificial Intelligence (AI) and machine learning technologies can support the development of a more efficient energy sector, predicting maintenance activities, optimising energy consumption, supply chains, and renewable energy integration.

A digital twin is a virtual model of a physical asset, created using real-time data and advanced analytics. It incorporates all key features and characteristics of the asset, including its design, operating parameters, and performance data, combined with 'what if' AI simulation capabilities. A digital twin can be used to optimise operations in real-time by analysing production data, simulating different operational scenarios and identifying areas where production rates could be adjusted to reduce venting and flaring.

ERM
emissions.AI

emissions.AI by ERM provides a solution for large industrial assets, to deliver savings and drive compliance in operations by giving insights into the drivers of excess energy usage and emissions hidden in plant and process configurations, operating procedures, plant start-ups and shut-downs, and other operational data. A digital twin is built directly from existing plant data with no new hardware required. This provides insights from the facility to equipment level, whilst AI suggests new ways to reduce emissions whilst maintaining production levels.

Status: Commercially Available & Deployed
TRL: 9
Website: Click here

Xodus
Xamin

Xodus' Xamin platform combines a suite of data management products, each designed for a different task. These include integrity management, environment management, permits and consents, vibration, emissions and production surveillance.

Status: Commercially available
TRL: 9
Website: Click here

Other digital solutions provide methods of optimising operations such as logistics. This provides an opportunity for the reduction in associated emissions such as transportation.

PlanSea
Marine Logistics Operation

PlanSea uses AI and digital technology to allow for emission and cost reduction by optimising marine logistics operations. This enhances operational visibility and allows for sector collaboration.

Status: Ready for deployment
TRL: 8
Website: Click here

4.2 Robotics and Autonomous Systems

Robotics and Autonomous Systems (RAS) include: underwater robotic vehicles - Autonomous Underwater Vehicles (AUVs) and Remote Operated Vehicles (ROVs); Unmanned Surface Vehicles (USVs); and Unmanned Aerial Systems (UASs) including unmanned aircraft and drones. RAS can offer continuous monitoring, higher quality data gathering and reduced human intervention. Often less transportation via helicopter or vessel is required.

Drones have the ability to cover large areas and can be quickly deployed to inspect hard to access or beyond line-of-sight areas on an offshore installation. The drones themselves can also be fitted with sensors to measure methane and CO_2 emissions. The data collected by drones on emissions and environmental conditions can improve data analysis leading to optimised operations and reduced emissions.

Flylogix
BvLOS Remote Methane Measurement

Remote Methane Measurement by Flylogix involves an unmanned aerial system (UAS) operating beyond visual line of sight, with a highly sensitive miniaturised sensor to collect data in the field. Detailed post-flight analytics provide insight into emission rates. This technology could support operators in the drive towards net zero and in meeting best practice principles for methane management such as those outlined in the Oil and Gas Methane Partnership 2.0 framework.

Status: Commercially Available
TRL: 9
Website: Click here

Other initiatives have been developed to explore options for remote operations and robotics systems.

03
Emissions Reduction Technologies

NZTTP
Advancing Remote Operations (ARO)

The advancing remote operations project was completed as part of the Net Zero Technology Transition Programme (NZTTP). The project equips the energy industry with the knowledge and technologies to accelerate the adoption of remote operations. The ARO playbook addresses key drivers for change as well as enabling technology solutions.

Status: Complete
TRL: 8
Website: Click here

NZTTP
Offshore Low Touch Energy Robotics & Autonomous Systems (OLTER)

The OLTER project consolidated RAS data and knowledge within the UK to showcase how offshore assets could use robotics to reduce human exposure and emissions. The project enabled field trials of technologies such as Skyports Drone Services.

Status: Complete
TRL: 8+
Website: Click here

Challenges and gaps

Robotics and Autonomous Systems show promise for the future and have developed significantly in recent years. There are a number of uses for technologies such as drones, however further work is required before these are more widely adopted for other use cases.

4.3 Decommissioning

Towards the end of an asset's life, consideration must be given to the potential emissions savings during its decommissioning.

Decommissioning is the fourth area that forms part of the OGA plan, referred to as 'Inventory'. Advances in robotics, automation, and remote monitoring have the potential to improve the efficiency and safety of decommissioning operations. Emphasis on repurposing, recycling and reusing materials to reduce waste and environmental impact is improving the circular economy. Increased collaboration between operators, regulators, and service providers is required to share best practices and reduce costs.

The repurposing of assets and infrastructure for CCUS or renewable projects will reduce the need for new construction. Using alternative energy generation and peak load management can reduce energy consumption and emissions during late life operations and into decommissioning.

Challenges and gaps

The main challenge faced in this area is to reduce the substantial costs of decommissioning and to identify technology which could assist in this objective. With well P&A expected to make up around half of the UKCS decommissioning cost, seeking and proving alternative barrier materials and methodologies is a priority.

NZTC
Wells Collaboration Group

The NZTC-led Wells Collaboration aims to address industry challenges and accelerate the pace at which well decommissioning technologies are progressed through to field trial, with operators benefiting from learnings along the way to commercialisation. The overall goal of the Wells Collaboration is to reach the industry target of 35% cost reduction and 50% emission reduction in well decommissioning by 2035 and is supported by the Technology Leadership Board, the NSTA and OEUK in its efforts.

Net Zero Technology Centre
Technology Driving Transition

Status: Field Trial
TRL: Various
Website: Click here

04
Acknowledgements

This Technology Roadmap would not have been possible without the collaboration of the Net Zero Technology Centre, The North Sea Transition Authority, the Asset Stewardship Task Force (ASTF) and the Technology Leadership Board.

A special mention to the ASTF ERAP subgroup, and OEUK's Decarbonisation Forum and Atmospherics group, whose general support and specific participation in industry engagement workshops provided valuable insight to current practices and challenges.

05
Supporting Materials

In addition to this Technology Roadmap, the following documents provide further resources to support the emissions reductions efforts of the operators:

NSTA OGA Plan (2024) - OGA Plan - Emissions Reduction

NSTA Emissions Monitoring Report (2024) - Emissions Monitoring Report 2024

OEUK Emissions Reduction Report - Emissions Reduction Report 2024 | Offshore Energies UK (OEUK)

North Sea Transition Deal (2021) - North Sea Transition Deal - GOV.UK

OEUK ERAPs guidelines - Emissions Reduction Action Plan (ERAP) | Offshore Energies UK (OEUK)

UK Clean Power Energy 2030 Action Plan (2024) - Clean Power 2030 Action Plan - GOV.UK

NSTA Technology Survey & Insights Report 2024 - NSTA Technology Survey & Insights 2024

Oil and Gas Methane Partnership 2.0 (2020) - OGMP_20_Reporting_Framework-1.pdf

Appendix A
Available Technologies

TRL 9 Technologies (ready to deploy)

Power Generation

- ABB - Power & Energy Management System (PEMS™)
- Amphibious Energy - EnergyPod
- AVT Reliability - Machine Sentry - Web Hosted Condition Monitoring
- Destinus - OP16 Gas Turbine
- ElectraTherm - Power+ Generator
- ERM Energy - Emissions.AI
- Ethos Energy - EcoMAX
- Hitachi - HVDC Light
- Kongsberg - K-Chief Power Management
- NOV - Subsea Oil Storage
- Siemens Energy - GT-400
- SLB - Intelligent Power Management
- Sudelac - Fuelox fuel treatment
- Technip - All Electric Subsea Solutions (eSolutions
- Verlume - Halo - Subsea battery solution
- Watsila - 32 Methanol Engine

Flaring and Venting

- Accord - Combustor
- AESSEAL - EcoGuard Dry Gas Seals
- Baker Hughes (Panametrics) - Flare.IQ
- Cimarron - Smart VRUs
- GBA - Flare Gas Recovery System
- Kongsberg - K-Spice dynamic simulator
- ik Group AOGV - Mechanical Isolation System
- MAN Energy Solutions - FG Recovery
- Primetech - E-2500 eductor
- SLB - Reda multiphase separator
- SLB - Production ExPRESS
- SLB - Symmetry Process Simulation Software
- Solar Injection Australia - HPVR
- STATS - BISEP Line Plugging
- STATS - Tecno InLine Isolation
- Transvac - Flare Gas Recovery Ejectors
- TUV NEL - Flare gas measurement
- ValveTight - DBB SAVER
- Wood - Virtuoso
- Zeeco - Flare Gas Recovery Unit

Fugitive Emissions and Other

- Asset 55 & Score Group - Emissions Elimination Program
- ERM Energy - emissions.Ai
- Flylogix - BvLOS Remote Methane Measurement
- Gdi - Vision
- Kinetics Controls & Innovations Ltd (KCI) - Mas-Pac & MS-Sealant
- IMRANDD - Asset Management - Alert
- slb - Delfi digital platform
- Strohm - TCP Flowlines
- Three60 - Poseidon
- TSC Subsea - Triton
- Xodus - Xamin

Appendix B
Technologies in development

Category	TRL 2/3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8
Power Generation	**Amplus Energy and Carbon Circle** - Pre-FEED study - FPSO - full scale post combustion CCS system **Subsea & FLASC** - PowerBundle longer duration energy storage (LODES)	**Carnot Energies** - Hydrogen Auxiliary Power Unit **TechnipFMC & Partners** - Deep Purple™ Pilot - zero emission offshore energy system **Glasgow Caledonian University & Verlume** - Subsea Microgrid	**REVOLUTION Turbine Technology (RTT)** - Micro-expansion turbine system (mETS) **HyLiion** - KARNO Generator Low temperature, flameless oxidation process to produce ultra low carbon energy **Siemens Energy** - Ultra Light Combined Cycle (ULCC) offshore power plant	**BSC Separation** - Compact Separator **TotalEnergies** - Floating demonstrator **SeaTwirl** - Unique floating wind turbine technology **Enertchnos** - Subsea Cables **Thomassen Energy** - Cutting-edge Gas Turbine Combustion Retrofits - enabling burning of versatile fuels inc. hydrogen & ROC	**Enquest** - Kraken HVO Study **Mocean & Verlume** - Renewables for Subsea Power	**Innovatium** - PRISMA Liquid Air battery
Flaring and Venting		**TechnipFMC** - HISEP **Moreld Minox & Parnters** - compact CO_2 Capture System		**HiiROC** - Thermal Plasma Electrolysis	**M2X Energy** - Gas to Methanol System	
Fugitive Emissions & Others			**Frontier Robotics** - AWARE Project - Sonar Autonomous Underwater Vehicle		**Copsys** - Intelligent Skin for CUI **Oxford Flow** - Stemless Valves **Mokveld** - Zero emissions control valve **Actuation Lab** - Dragonfly Valve	**Vysus Group** - Energy Transition Databox **Novatech** - NESSI **Fugro** - Uncrewed Surface Vessels **Plansea** - Marine Logistics Operation

N.B. All TRL levels have been designated according to publicility available information, or where not available author's judgement.

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