Net Zero Technology Centre

Technology Driving Transition

Closing the Gap

A Global Perspective

November 2022

In Partnership with:

AIST

BUE

CSIRO Australia's National Science Agency

energy research & innovation

IDRIC

InnoTech Alberta
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NERA National Energy Resources Australia

NREL Transforming ENERGY

Research Centre for Greenhouse Gas Innovation

SCCS

TNO innovation for life

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In Partnership with:

Executive Summary

This report identifies *Global Priorities* to effect rapid deployment of net zero technologies, and *Proposed Actions for International Collaboration* to address them.

Global Priorities

Analysis conducted in 2022 by twelve research and technology organisations (RTOs) across eight countries, based on their perspective of their country's *National Net Zero Strategies*, identified *Technology Innovation Challenges.*

Challenges were identified in the reduction of emissions associated with hydrocarbon production, and across renewables, low-carbon hydrogen and carbon capture, utilisation and storage (CCUS) technologies, underpinned by digital transformation technologies. Investigating and comparing the challenges led to the agreement of *Global Priorities* to drive scalable innovation of net zero technologies.

Infrastructure development
Construction of assets and services. This includes electrical, transport and storage infrastructure. This applies to offshore wind, hydrogen and CCUS.

Novel materials
Development of materials with improved properties for specific applications. This applies to hydrogen and CCUS.

Energy efficiency
Improved energy efficiency and lower processing cost. This includes heat management. This applies to solar, hydrogen and CCUS.

Standardisation
Design of processes that are faster, affordable and replicable. Creation of specifications and supportive regulation. This applies to offshore wind, hydrogen and CCUS.

Venting, flaring and fugitive emissions
Eliminate the need for venting and flaring and reduce the amount of fugitive emissions. This applies to emissions reduction associated with hydrocarbon production.

Decarbonisation of power
Use of low-carbon sources, energy storage or electrification initiatives to reduce the amount of emissions from power generation onshore and offshore. This applies to emissions reduction associated with hydrocarbon production and CCUS.

Testing and demonstration facilities
Onshore and offshore facilities for testing and trialling under realistic conditions, to overcome innovation barriers and accelerate deployment. This applies to offshore wind, hydrogen and CCUS.

Use of data and sensors
Improvement of capture, management and use of data for the purpose of technology development and monitoring. Retrofittable sensors suitable for harsh environments, and to progress prediction and automation. This applies to all analysed technologies.

Proposed Actions for International Collaboration

This collaboration have agreed on five *Proposed Actions for International Collaboration* to address the *Global Priorities*, and will continue to work together in 2023 to develop a roadmap of proposed projects and present these at COP28. Each action is given alongside the *Global Priority* it addresses, the targeted countries, and the proposed action's intention.

1. **Establishment of collaborative 'Hydrogen Hub' demonstration facilities.**
   Intention: reduce low-carbon hydrogen production cost to US$2/kg by 2030.

2. **Establishment of a collaborative CCUS demonstration facility.**
   Intention: reduce costs of CO_2 capture for power generation and reformed hydrogen production to below $50 per tCO_2.

3. **Establishment of a joint Open Innovation Competition to fund disruptive floating offshore wind substructure demonstrations, to achieve at-scale deployment and reduced levelised cost of electricity (LCOE).**
   Intention: reduce floating offshore wind cost to US$90/MWh by 2030.

4. **Aligned planning for international 'Super Grids' of electrical infrastructure.**
   Intention: enabler of optimised electricity transport routes.

5. **Establishment of an international collaborative working group to drive implementation of shared data trusts for technology development purposes.**
   Intention: enabler of advanced data sharing to drive efficiency improvements.

Introduction

COP26 in Glasgow, Scotland united the world in its mission to do more to tackle climate change and ensure the world keeps a 1.5°C global temperature rise within its grasp. Against the backdrop of negotiations in Glasgow, a group of internationally recognised research and technology organisations from Australia, Brazil, Canada, Egypt, Japan, the Netherlands, the United Kingdom (UK) and the United States of America (USA) launched a collaboration.

The countries represented by research and technology organisations in this collaboration represent 20.2% of Scope 1 and 2 global energy-related emissions[1]. In 2022, this group worked together to identify the international technology priorities for the decarbonisation of fossil fuel regions, and propose actions to accelerate the transformation to net zero, to present these at COP27 in Sharm El Sheikh, Egypt.

The outcomes of this study evidence the opportunities available to players across the entire energy ecosystem. Governments and funders will be able to spread costs and investment risk; energy companies will develop a greater understanding of the global transition and possible opportunities to develop pilot projects worldwide; and there will be greater incentives to the supply chain once they are aware of the global applicability of certain technologies and technology solutions.

It is this group's intention to continue to pool our capabilities, insight and resources to design a roadmap of proposed projects that span international borders. These projects will target the technology priorities identified in this study, and be presented to investors and commercial partners at COP28 in the United Arab Emirates in 2023.

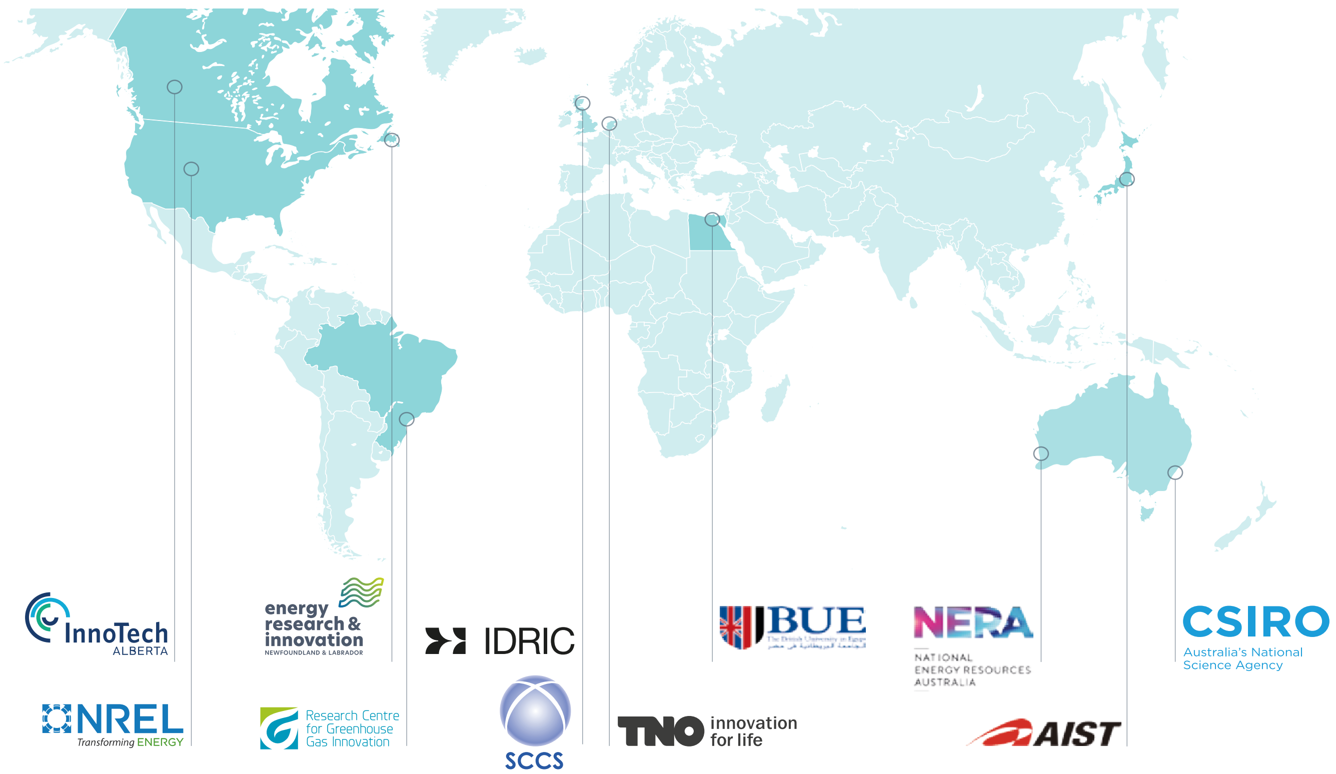


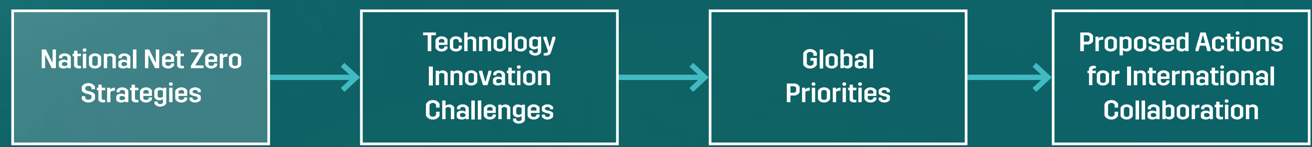
Figure 1: Partners Map

Net Zero Technology Centre
Technology Driving Transition

Closing the Gap

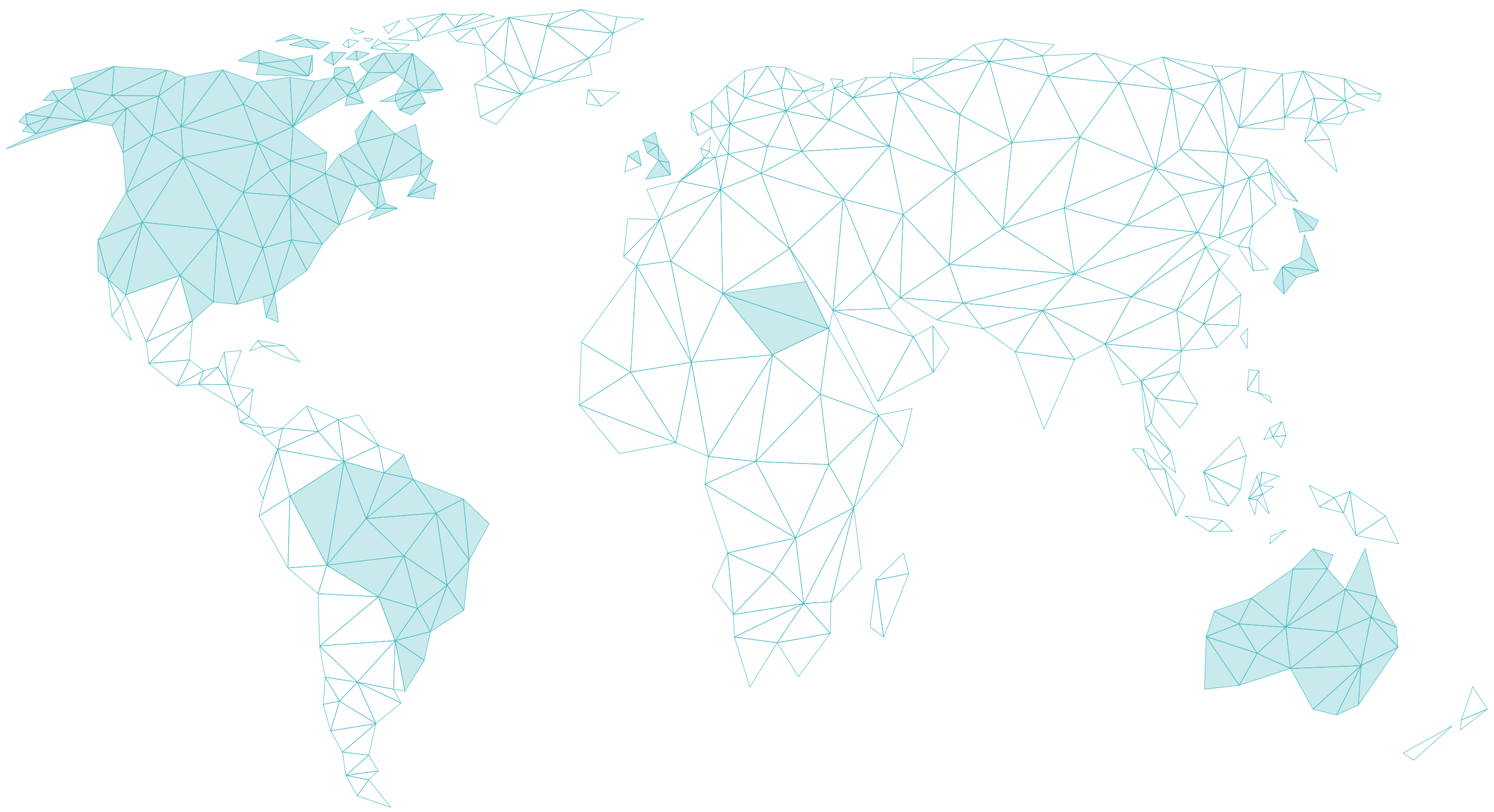
Analysis of the *National Net Zero Strategies* included in this collaboration (explored in Appendix B of this report) enabled the identification of common *Technology Innovation Challenges* that apply across these regions.

Investigating and comparing the challenges led to the agreement of *Global Priorities* to drive scalable innovation. A set of *Proposed Actions for International Collaboration* are then recommended to address these priorities and accelerate the global energy transition.



National Net Zero Strategies

The regions represented in this study are generally transitioning from oil and gas (O&G) producing regions to net zero integrated energy systems. National strategies have variations, but ultimately nations around the world are targeting the reduction of emissions associated with hydrocarbon production, while also targeting a mixture of onshore and offshore wind, solar, low-carbon hydrogen and carbon capture, utilisation and storage (CCUS), underpinned by digital transformation technologies. These national strategies are presented by the research and technology organisation (RTO) representing that nation in Appendix B of this study.



KEY:

- Low-carbon hydrogen
- CCUS
- Solar
- Onshore wind
- Offshore wind
- Hydrocarbon emissions reduction

AUSTRALIA

- A leader in low-carbon hydrogen production and exports
- Tremendous CCUS potential and extensive storage capacity
- Diverse natural resources in solar, onshore and offshore wind, and hydropower

JAPAN

- Lack of natural resources established Japan as an energy import country
- Published world's first national hydrogen strategy
- Ambitions to ramp up solar, onshore and offshore wind capacity by 2030

BRAZIL

- 46% of today's energy mix come from renewables
- Extensive storage capacity in sedimentary basins
- Diverse natural resources in solar, onshore and offshore wind and hydropower

THE NETHERLANDS

- European hub for global energy trade
- Ambition to become electrolytic hydrogen producer and hydrogen import hub for north-west Europe
- A world leader in offshore wind deployment

CANADA

- Carbon tax of CAD$50/tonne; CAD$170/tonne by 2030
- A leader in CCUS technologies and enhanced oil recovery
- Diverse natural resources in solar, onshore and offshore wind and hydropower, and evaluating responsible and feasible nuclear energy applications

UNITED KINGDOM

- Ambition to become European leader in low-carbon hydrogen production and exports
- Target of 4 low-carbon industrial clusters by 2030
- A world leader in offshore wind deployment

EGYPT

- Series of international MoUs signed to develop low-carbon hydrogen and CCUS capabilities
- Ambition to become global low-carbon hydrogen exporter
- Diverse natural resources in solar, wind and hydropower energy

UNITED STATES OF AMERICA

- Diverse natural resources in solar, onshore and offshore wind and hydropower
- 100% green electricity target by 2035
- Targeting low-carbon hydrogen production at under US$1/kg by 2030

In Numbers

Upon analysis of each country's national energy sectors, their respective focus areas and targets have been compiled below.

Australia

DIVERSE NATURAL RESOURCES IN SOLAR, ONSHORE WIND AND GEOTHERMAL ENERGY.

Renewables targets for 2050:

- 143 GW SOLAR
- 70 GW ONSHORE WIND

A world leader in green hydrogen production & exports

CLEAN HYDROGEN PRODUCTION AT UNDER **AU$2/KG** BY 2030

43% EMISSIONS REDUCTION BY **2030**

NET ZERO BY **2050**

Extensive CCUS potential & extensive storage capacity

Canada

DIVERSE NATURAL RESOURCES IN SOLAR, WIND AND BIOMASS ENERGY; AMBITION TO BE A WORLD LEADER IN CLEAN HYDROGEN PRODUCTION AND EXPORTS.

Renewables targets for 2050:

- 47 GW ONSHORE WIND
- 109 GW SOLAR BY 2050

CCUS STRATEGY SETS GOAL OF USING CCUS TO REDUCE NATIONAL EMISSIONS BY **15 $MtCO_2$** ANNUALLY

40% EMISSIONS REDUCTION BY **2030**

NET ZERO BY **2050**

CARBON TAX OF **CAD$50/T**

RISING TO **CAD$170/T** BY 2030

Brazil

46% OF TODAY'S CURRENT ENERGY MIX COMES FROM RENEWABLES; INCREASED FOSSIL FUEL PRODUCTION AND EXPORTS EXPECTED IN NEXT 10 YEARS.

Renewables targets for 2050:

- 27-91 GW SOLAR
- 110-194 GW ONSHORE WIND
- 16 GW OFFSHORE WIND

GREEN HYDROGEN PRODUCTION AT UNDER **US$2/kg** BY 2030

50% EMISSIONS REDUCTION BY **2030**

NET ZERO BY **2050**

Tremendous CCUS potential

INCLUDING EXTENSIVE STORAGE CAPACITY IN SEDIMENTARY BASINS

Egypt

DIVERSE NATURAL RESOURCES IN SOLAR, ONSHORE AND OFFSHORE WIND, AND HYDROPOWER ENERGY.

Renewables targets for 2035:

- 21 GW ONSHORE & OFFSHORE WIND COMBINED
- 40 GW SOLAR (32 GW PV & 8 GW CONCENTRATED)

Ambition to become a world leader in clean hydrogen production and exports

Increased fossil fuel production & EXPORTS EXPECTED IN NEXT 10 YEARS

OIL MINISTRY SIGNED **11 MoUs** WITH INTERNATIONAL FIRMS TO DEVELOP CCUS CAPABILITIES

SERIES OF **MoUs** SIGNED WITH OTHER NATIONS TO DEVELOP CLEAN HYDROGEN PRODUCTION CAPABILITIES

In Numbers

Japan

LACK OF NATURAL RESOURCES ESTABLISHED JAPAN AS AN ENERGY IMPORT COUNTRY, MOSTLY FOSSIL FUELS.

Renewables targets for 2030:

- **103.5-117.6 GW** SOLAR
- **17.9 GW** ONSHORE WIND
- **5.7-10 GW** OFFSHORE WIND

PRIORITISING HYDROGEN COST REDUCTIONS TO COMPETE WITH CONVENTIONAL GAS & LNG

46% EMISSIONS REDUCTION BY **2030**

NET ZERO BY **2050**

PROJECTS ONGOING WITH OTHER NATIONS TO DEVELOP GREEN AMMONIA PRODUCTION

Published world's first national hydrogen strategy

The Netherlands

ESTABLISHED AS A EUROPEAN HUB FOR GLOBAL ENERGY TRADE, MOSTLY IN FOSSIL FUELS.

Renewables targets for 2030:

- **27 GW** SOLAR (55-132 GW BY 2050)
- **21 GW** OFFSHORE WIND (70 GW by 2050)
- **3-4 GW** GREEN HYDROGEN ELECTROLYSER

Ambition to become European leader in green hydrogen production and exports

55% EMISSIONS REDUCTION BY **2030**

95% BY **2050**

Offshore Wind Energy Roadmap driving significant offshore wind deployment

UK

AMBITION TO BECOME EUROPEAN LEADER IN CLEAN HYDROGEN PRODUCTION AND EXPORTS.

Renewables targets:

- **70 GW** SOLAR (2035)
- **50 GW** OFFSHORE WIND (2030)
- **10 GW** LOW-CARBON HYDROGEN CAPACITY (2030)

TARGET OF 4 LOW-CARBON INDUSTRIAL CLUSTERS BY 2030, AND A NET ZERO INDUSTRIAL CLUSTER BY 2040

Emissions reduction targets from O&G production:

- **10%** BY **2025**
- **25%** BY **2027**
- **50%** BY **2030**
- **NET ZERO** BY **2050**

68% EMISSIONS REDUCTION GOAL BY 2030, AND NET ZERO BY 2050

USA

DIVERSE NATURAL RESOURCES IN SOLAR, ONSHORE AND OFFSHORE WIND, AND GEOTHERMAL ENERGY.

Renewables targets and forecasts:

- **760-1000 GW** SOLAR (2035)
- **202 GW** ONSHORE WIND (2030 - 318 GW BY 2050)
- **30 GW** OFFSHORE WIND (2030 - 86 GW BY 2050)

Recently overtook Russia as the world's greatest LNG exporter

52% EMISSIONS REDUCTION BY **2030**

NET ZERO BY **2050**

100% GREEN ELECTRICITY TARGET BY **2035**

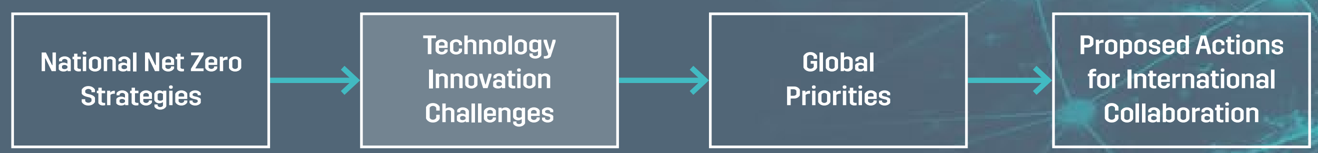
HYDROGEN PRODUCTION AT UNDER US$2/KG BY 2025: **US$1/KG** BY 2030

Technology Innovation Challenges

Analysis conducted by this collaboration identified five common focus technologies:

- **Renewables**
- **Low-carbon hydrogen**
- **Carbon capture, utilisation and storage (CCUS)**
- **Hydrocarbon emissions reduction technologies**
- **Digital transformation technologies**

For each of these five technologies, a series of *Technology Innovation Challenges* have been identified. Innovation efforts and funding mechanisms should be focused on addressing these challenges urgently, to effect rapid deployment of net zero technologies and facilitate a faster transition to net zero integrated energy regions.



Technology One: Renewables

The graphs below show the scale of the renewables ramp-up required between now and 2050 in offshore wind, onshore wind and solar capacity. This highlights the global opportunities available to the supply chain and technology innovators, to develop the technologies required to achieve this.

Figure 2: Offshore wind targets & forecasts (GW)

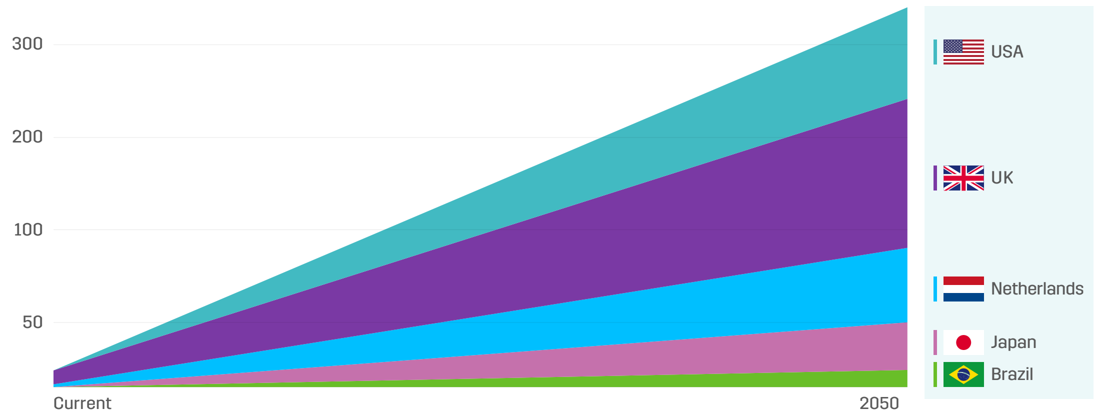


Figure 3: Onshore wind targets & forecasts (GW)

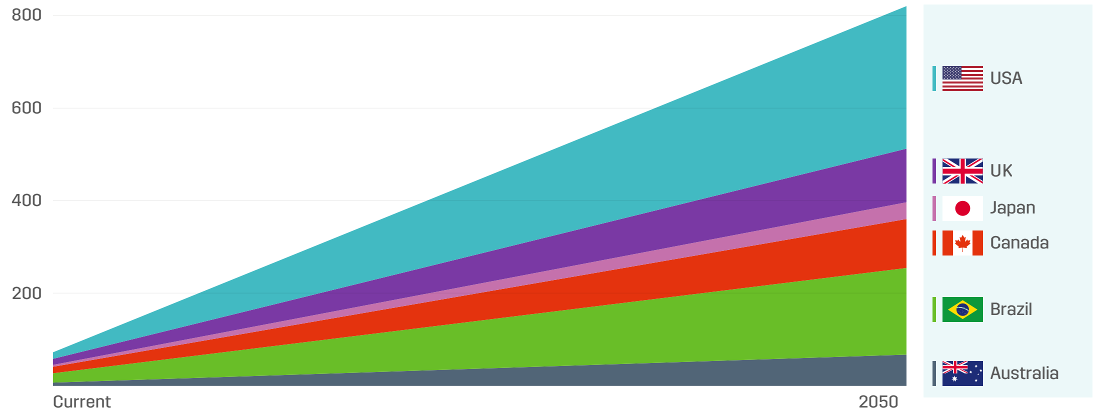
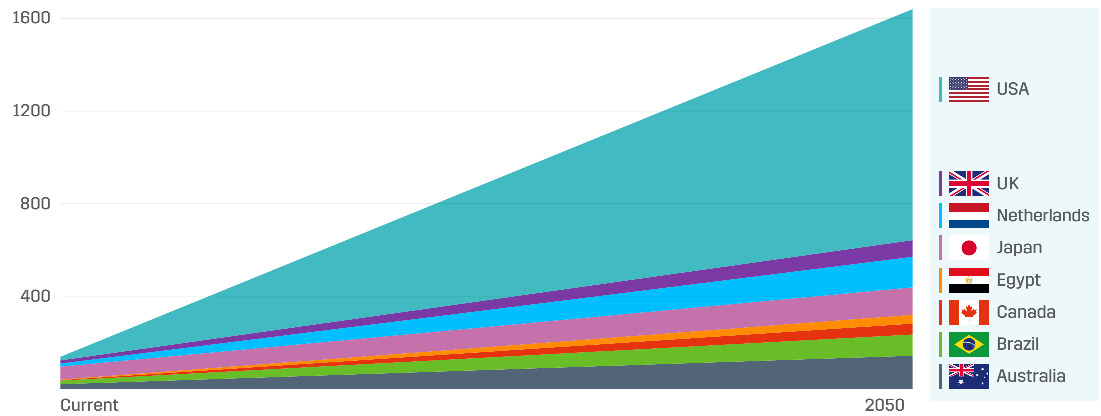


Figure 4: Solar targets & forecasts (GW)



Renewables Challenge **ONE:**

Optimisation of electrical infrastructure, highlighting synergies and maximising benefit from emerging technology deployment.

Countries targeting:

The decarbonisation of future energy systems with increasing shares of renewable power depends on a stable and efficient distribution of power. Electrical infrastructure and networks must be resilient to supply load fluctuations, providing avenues for the cost-efficient decentralised renewable energy generation. Taking a cohesive, integrated approach to grid infrastructure improvements, such as array cabling, transmission and integration options, can identify efficiency optimisation opportunities, while reducing impact on the environment and local communities.

Renewables Challenge **TWO:**

Optimisation of services associated with the operation, condition monitoring and maintenance of wind turbines across the asset lifecycle.

Countries targeting:

Operations and maintenance (O&M) are essential elements in the development of wind farms, affecting efficiency, safety and environmental impact. Maintenance strategies, which are strongly dependent on marine logistics between the wind farm and shore, have a considerable effect on the levelised cost of energy.
Because O&M can constitute up to one-third of the cost of energy for offshore wind power, improved solutions for the reliability and maintainability of components can have a significant impact in making this a more cost-effective source. Other areas for improvement include ageing prevention and downtime reductions.

As the scale of wind deployment is expected to rise quickly and steadily, end-of-life options such as repowering, life extension and decommissioning will become an increasingly important consideration for operators. Appropriate disposal mechanisms for common materials (metal, concrete, cabling) are available and may generate value while reducing environmental impact, but blade recycling is still a challenge area. Complex materials and critical minerals can also present challenges and require more careful management.

Renewables Challenge **THREE:**	Standardisation of designs for floating substructures that improve performance.
Countries targeting:	Australia, Brazil, Canada, UK, USA (flags)

Offshore structures are regularly exposed to severe environmental loads, which must be taken into consideration in the design of novel components. Suitable floating wind infrastructure is crucial for the development of offshore wind power in challenging environments, such as deep water, where environmental loads tend to be higher and wind resources are stronger and more abundant. Designs, therefore, need to be stable enough to withstand strong environmental loads and increasingly large turbine sizes.

Floating wind could make up one-third of offshore wind capacity by 2050 in Europe[2], and will be a significant contributor in other regions. The standardisation of designs for floating substructures is an important enabler to increase production volumes and develop the supply chain. This will be key to delivering the economies of scale required to achieve capacity levels that align with national targets.

Renewables Challenge **FOUR:**	Improved autonomous systems (air, land & sea).
Countries targeting:	Australia, Brazil, Netherlands (flags)

The use of digital technology, robotics and autonomous systems will optimise and future-proof service to offshore wind farms, from site development to O&M and decommissioning. The use of components that enable reliable communication across assets on condition monitoring and structural health can support the provision of fast, cost effective and safe servicing options while increasing awareness on asset performance levels.

Renewables Challenge **FIVE:**	Effective management of heat to maximise conversion efficiency of solar power technologies.
Countries targeting:	Australia, Brazil, Egypt, Japan, USA (flags)

Gradual improvements in conversion efficiency have been crucial in decreasing the cost of solar photovoltaic (PV) technology over the last few decades, but technology innovations such as heat management and the use of cost-effective materials can help drive further cost reductions. As the demand for solar power continues to grow, more opportunities in process automation and economies of scale are expected.

RENEWABLES CHALLENGE THREE: CASE STUDY

Axis Energy Projects – UKCS TLB Evaluation Study

As a relatively new industry, Floating Offshore Wind (FOW) has a large number of substructure designs in active development. This study investigates the applicability of a Tension Leg Buoy (TLB) technology for increased turbine stability across the UKCS. The TLB is a robust, proven substructure and mooring system that provides controlled stability, roll and pitch, keeping the turbine vertical even in the most extreme conditions.

Key info/numbers:

DETAILED	SMALL	30%	SIMPLE
MARKET AND TECHNOLOGY APPRAISAL	SEABED FOOTPRINT	LESS LCOE THAN OTHER FOW DESIGNS	DECOMMISSIONING PROCESS

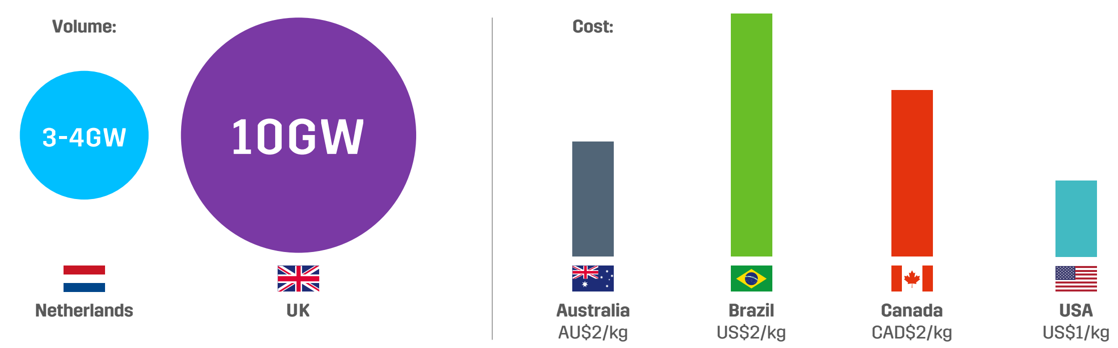
Partners: NZTC

Other noteworthy projects: Floating Solar Field Lab (Netherlands), Floating Wind Foundation Portfolio (UK)

Technology Two: Low-carbon Hydrogen

The approach to developing low-carbon hydrogen production capabilities differs from country to country. Some are targeting specific deployed capacity targets and sufficient quantities of hydrogen generation (largely driven by domestic consumption expectations), while others are targeting cheapened production and transportation (largely to drive exports). There are *Technology Innovation Challenges* that apply to both.

Figure 5: Low-carbon hydrogen targets (2030)



Hydrogen Challenge **ONE:**

Facilities and services for process demonstration to drive scale up and cost reduction at pace.

Countries targeting:

The rising demand for low-carbon hydrogen creates an opportunity for open innovation that can drive the establishment of a hydrogen economy. Evidence for this is provided by a steady increase in demonstration projects and collaborative initiatives, focused both on demonstrating enabling technologies and on building up necessary value chains for hydrogen production and distribution. Broad collaborations are key to the success of technology solutions and can help realise economies of scale, making investment in hydrogen technologies increasingly attractive. In addition to access to equipment and infrastructure for the validation of solutions, demonstration facilities provide developers with access to networks of researchers, industry partners, policymakers and other stakeholders driving the development of local hydrogen supply chains.

HYDROGEN CHALLENGE ONE: CASE STUDY

Asian Renewable Energy Hub (AREH)

AREH is a large-scale wind and solar renewable energy facility proposed for the production of electrolytic hydrogen and green ammonia for domestic and export use, as well as supplying generation capacity for local energy users such as mines and mineral processing. The site occupies 6,500 square km situated inland from Port Hedland in north-western Australia, and is expected to host 16 GW wind and 10 GW solar installed generation capacity. The first 15 GW stage of the project has received environmental approval from the Western Australian government.

www.bp.com/en/global/corporate/what-we-do/gas-and-low-carbon-energy

Key info/numbers:

26 GW RENEWABLE ENERGY

UP TO **23 GW** CLEAN H2 & AMMONIA PRODUCTION

US$36B INVESTMENT

50+ YEAR DESIGN LIFE

Partners: BP, InterContinental Energy, CWP Global, Vestas, Pathway Investments (Macquarie Group)

Other noteworthy projects: Technological Development Hub in Caucaia (Brazil), European Hydrogen Backbone (UK)

Hydrogen Challenge **TWO:**

Improve electrolysis processes leveraging novel materials to address cost, efficiency and durability challenges.

Countries targeting:

Electrolysis provides a clean and safe avenue for hydrogen production, but currently presents high capital costs.

The identification of new and more durable materials for electrolysis can support the design of more cost-efficient, stable and durable electrolyser technologies.

HYDROGEN CHALLENGE TWO: CASE STUDY

Supercritical Hydrogen

Supercritical is developing the world's first high pressure, ultra-efficient electrolyser for the production of hydrogen and oxygen from water with zero emissions. By using heat and pressure, the proprietary design exploits the benefits of supercritical water to deliver gases at over 200 bar of pressure, without the expense or challenges of hydrogen compressors. The water electrolyser will operate in a currently untapped temperature range of 375 to 400˚C, reducing electrical energy consumption using heat sourced from waste or low carbon sources.

www.supercritical.solutions

Key info/numbers:

20% LESS ENERGY THAN EXISTING ELECTROLYSERS

17% MORE EFFICIENT

WILL CUT COST OF CLEAN HYDROGEN PRODUCTION BY **>30%**

30% MORE EFFICIENT WHEN WASTE HEAT IS USED

Partners: NZTC, National Physical Laboratory (NPL), University of St Andrews, The Welding Institute (TWI), Department for Business, Energy & Industrial Strategy (BEIS)

Other noteworthy projects: Hydrogen from H2S (Canada), Waterwhelm Forward Osmosis Desalination (UK)

Hydrogen Challenge **THREE:**	High-efficiency production technology of green ammonia.
Countries targeting:	

Hydrogen's low volumetric energy density makes transport and storage a challenging aspect in most applications. Technology for the clean production of ammonia is being prioritised in several regions due to its potential for application as zero-carbon fuel, hydrogen carrier or as an energy storage solution. A wider application of green ammonia as an energy vector and carrier can help decrease reliance on fossil fuel sources and on energy imports, thereby increasing the resilience of energy systems. Distribution options need to be streamlined to allow significant supply chain development.

HYDROGEN CHALLENGE THREE: CASE STUDY

'Energy Carriers' (Production & Utilizations of Low-Carbon Ammonia)

Using a liquid hydrogen energy carrier is one of the methods to store and transport hydrogen efficiently, which is in gaseous form in its normal stage and difficult to handle. The Energy Carriers project, conducted as part of the Cross-Ministerial Strategic Innovation Promotion Program (SIP) and spear-headed by the Japanese Council for Science Technology and Innovation, established a hydrogen value chain by focusing on technology development for low-carbon hydrogen production, its conversion to liquid energy carriers (ammonia), storage, transportation, and utilisation. It utilises a high-temperature solar thermal energy supply to produce hydrogen using a steam electrolysis system, to develop a more efficient, low-temperature green ammonia synthesis process.

www.jst.go.jp/sip

Key info/numbers:

DEVELOPED FROM STUDY THROUGH TO DEMONSTRATION	COMMENCED	CONCLUDED MARCH	
	2014	**2021**	**JP¥16.6B** (US$113M)

Partners: Japanese Government, AIST

Other noteworthy projects: NOV Subsea Storage (USA), Project Lynx (Canada)

Technology Three: Carbon Capture, Utilisation and Storage (CCUS) Technologies

As hydrocarbon producing regions, depleted reservoirs and basins offer opportunities for large-scale CO_2 storage, but technology innovation is required at pace.

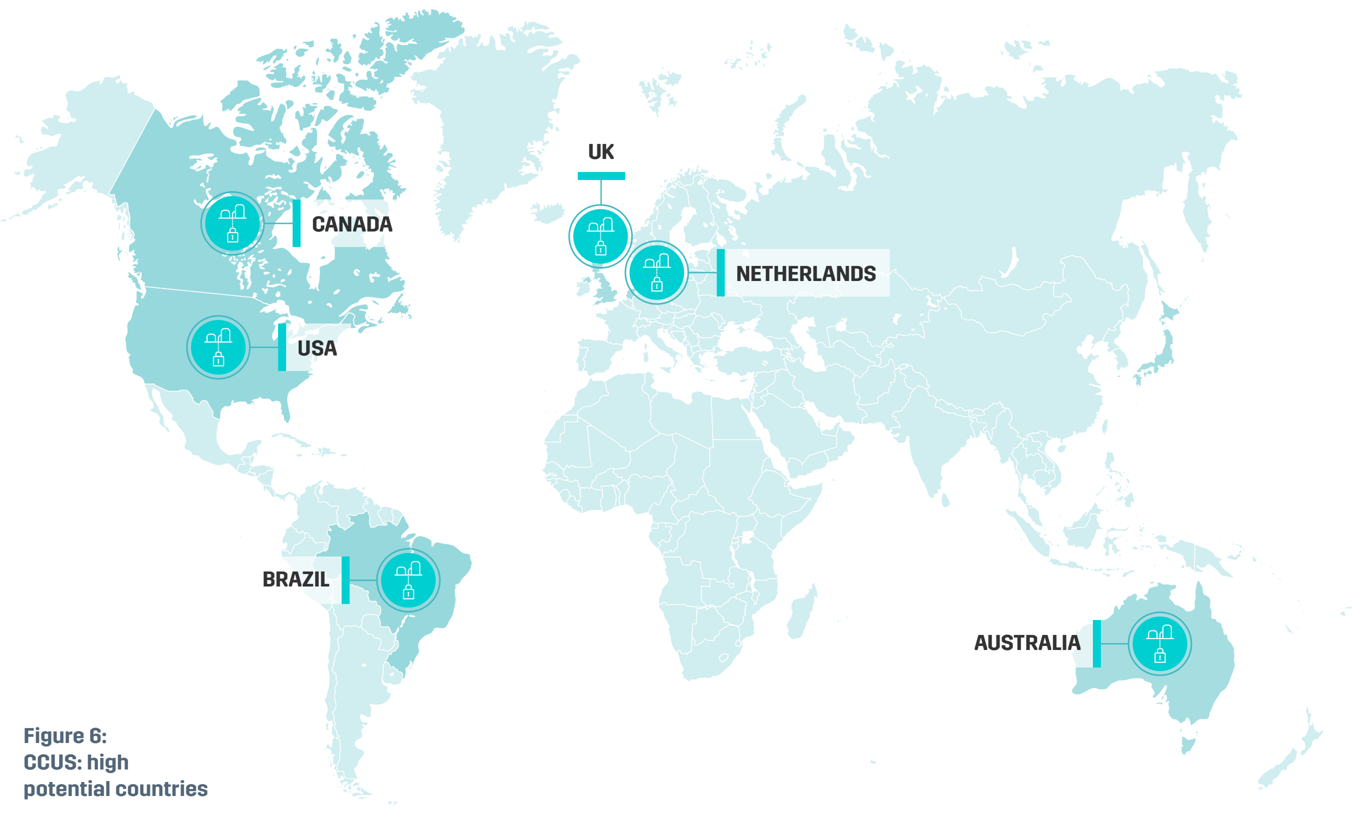


Figure 6: CCUS: high potential countries

CCUS Challenge **ONE:**	Novel capture materials to drive down the cost of CO_2 capture and increase deployment of CCUS technology.
Countries targeting:	

CCUS is a crucial element of climate change mitigation and a practical option for the decarbonisation of intensive industries. Nevertheless, current carbon capture methods are energy intensive and costly, representing up to two-thirds of the total cost of CCUS, limiting deployment and scalability.

Technology innovation, relating to cheaper material alternatives, is considered a key driver for the reduction of cost in carbon capture and to open up new deployment opportunities.

In NZTC's *Technology Driving Green Energy Growth* report, published in September 2022, the cost of carbon capture is identified as the main cost element currently involved in carbon capture and storage in the UK, and there is a huge opportunity for technology innovation to enable significant cost reductions.

CCUS Challenge **TWO:**

Advanced digital technologies to drive efficient geological behaviour prediction and modelling.

Countries targeting: Brazil, Canada, Netherlands, UK

A crucial part of storage site identification is ascertaining the certainty of permanent storage over long periods of time, but limitations in the understanding of geological behaviour pose a significant challenge.

Fully coupled models are needed, taking into account fluid flow in the wellbore and reservoir that consider geomechanical, geochemical and transient flow.

This can greatly improve the evaluation and prediction of caprock behaviour and effects of long-term CO_2 storage, greatly reducing geomechanical risk and helping reduce the risk of unintentional leakage.

CCUS CHALLENGE TWO: CASE STUDY

Salt cavern carbon capture, utilisation & storage feasibility studies

A methodology has been developed for the construction of salt caverns based on salt dissolution in order to capture, store and separate CO_2, CH_4 and other gases under high pressure. The project delivered studies and simulations for the construction, monitoring, risk management and CO_2/CH_4 separation during the entire lifespan.

Logistic and environmental studies were also considered to develop the best strategy for cavern cluster management and the design of a floating platform customized for the proposed mission, in order to handle the associated gas generated on the topside of floating production storage and offloading (FPSO) units.

Key info/numbers:

CO_2 STORAGE IN CONSTRUCTED SALT CAVERNS	PILOT CAVERN ESTIMATED TO COST ABOUT US$50M	COMMENCED SEPTEMBER 2017	CONCLUDED AUGUST 2021

Partners: University of São Paulo / FAPESP (Research Funding Agency of the State of São Paulo), Shell Brazil

CCUS Challenge **THREE:**

Improved modelling strategies to support storage capacity appraisals and safe injection site mapping.

Countries targeting: Australia, Canada, Netherlands, UK, USA

A better understanding of existing storage resources, through improved storage capacity appraisals, emerged as a key challenge across most participating regions. The global availability of storage resources is expected to be sufficient to support emission reduction targets. Nevertheless, in order for CCUS to be deployed at a global scale, countries need to know where storage resources are located and how much capacity is available.

Improved appraisal of accessible and viable storage sites that are ready to host CCUS facilities is required, as it can help bring prospective sites to a commercial level rapidly and drive down storage cost. This is closely linked to subsurface modelling to predict the behaviour of injected CO_2 and its impact on the surrounding geology, as well as monitoring, measurement and verification (MMV) approaches.

CCUS CHALLENGE THREE: CASE STUDY

Quest Carbon Capture and Storage

The Quest Carbon Capture Facility captures CO_2 from the process stream by using an amine solvent. The CO_2 is separated from the solvent by applying heat. The captured CO_2 is then dehydrated and compressed into liquid before being transported by a 60 km underground pipeline to a storage site in another province. The liquid CO_2 is injected into porous rock for permanent storage 2 km below ground.

www.shell.ca/en_ca/about-us/projects-and-sites/quest-carbon-capture-and-storage-project

Key info/numbers:

6.8 MT CO_2 INJECTED BY END 2021	COMMENCED NOVEMBER 2021	YEARLY, WILL CAPTURE AND STORE UP TO 1.2 MT CO_2

Partners: Shell, Canadian Natural Upgrading Ltd, Chevron Canada Limited, Athabasca Oil Sands Project, InnoTech Alberta, Alberta Government, Canadian Government

Other noteworthy projects: Acorn CCS (UK), Gorgon CCS (Australia), Salt Cavern Feasibility Studies in the Pre-Salt Layer (Brazil)

Technology Four: Hydrocarbon Emissions Reduction

Technology innovation is required to reduce emissions associated with hydrocarbon production.

***Technology Innovation Challenges* exist in:**

- **Decarbonisation of power**
- **Fugitive Emissions**
- **Venting and flaring**
- **Field development**

Emissions Reduction Challenge **ONE:**	Alternative solutions for electricity storage (on and offshore).
Countries targeting:	

Microgrids or battery storage systems could provide suitable electricity storage solutions, while enabling fuel savings and increased penetration of wind power.

For example, in the offshore environment, the integration of power from offshore wind farms into O&G platforms will drive cleaner platform operations if the variable nature of renewable power can be overcome.

Emissions Reduction Challenge **TWO:**	Flare and vent gas recovery & storage options.
Countries targeting:	

Systems for gas recovery can reduce the flaring and venting of gases, with clean environmental benefits, but implementation in legacy infrastructure can be challenging.

Novel technologies for the conversion of recovered gas to electricity or hydrogen can prevent harmful GHG emissions and generate commercial value from what would otherwise be waste streams.

EMISSIONS REDUCTION CHALLENGE THREE: CASE STUDY

Measuring Methane Emissions from Offshore O&G Platforms

This project involved collecting aircraft-based measurements of methane around oil production facilities offshore Newfoundland and Labrador to quantify and verify methane emission levels. Results were compared to measured values of other offshore platforms in the North Sea and Gulf of Mexico, and to Canadian onshore environments which are thought to have higher methane intensity. The study provided comparisons between offshore operations, and suggestions for government regulations and policy regarding greenhouse gas (GHG) emissions. Measurements also validated previously reported emissions and confirmed Canada's offshore production is among the least methane-intensive in North America.

www.energyresearchinnovation.ca/wp-portfolio

Key info/numbers:

COMMENCED APRIL	CONCLUDED MAY	
2021	**2022**	**CAD$613K** (US$445,112) COST

Partners: St. Francis Xavier University Fluxlab Research Group (lead), Energy Research and Innovation Newfoundland and Labrador (ERI NL), Provincial Airlines (PAL) Aerospace, Memorial University of Newfoundland and Labrador (MUN), Royal Holloway University of London, Dalhousie University, National Resources Canada (NRCan)

Other noteworthy projects: Flylogix Remote Methane Detection (UK)

Emissions Reduction Challenge **THREE:**	Accurate detection & quantification of methane emissions.
Countries targeting:	

Methane emissions can originate in a number of sources, from flares to pneumatics, pipework, valves and seals.

Often of unintentional nature, methane emissions can be difficult to identify, accurately measure and control. Several regions are looking for better ways to detect and quantify methane emissions, in order to better understand their origin, impact and to develop strategies for prevention.

EMISSIONS REDUCTION CHALLENGE FOUR: CASE STUDY

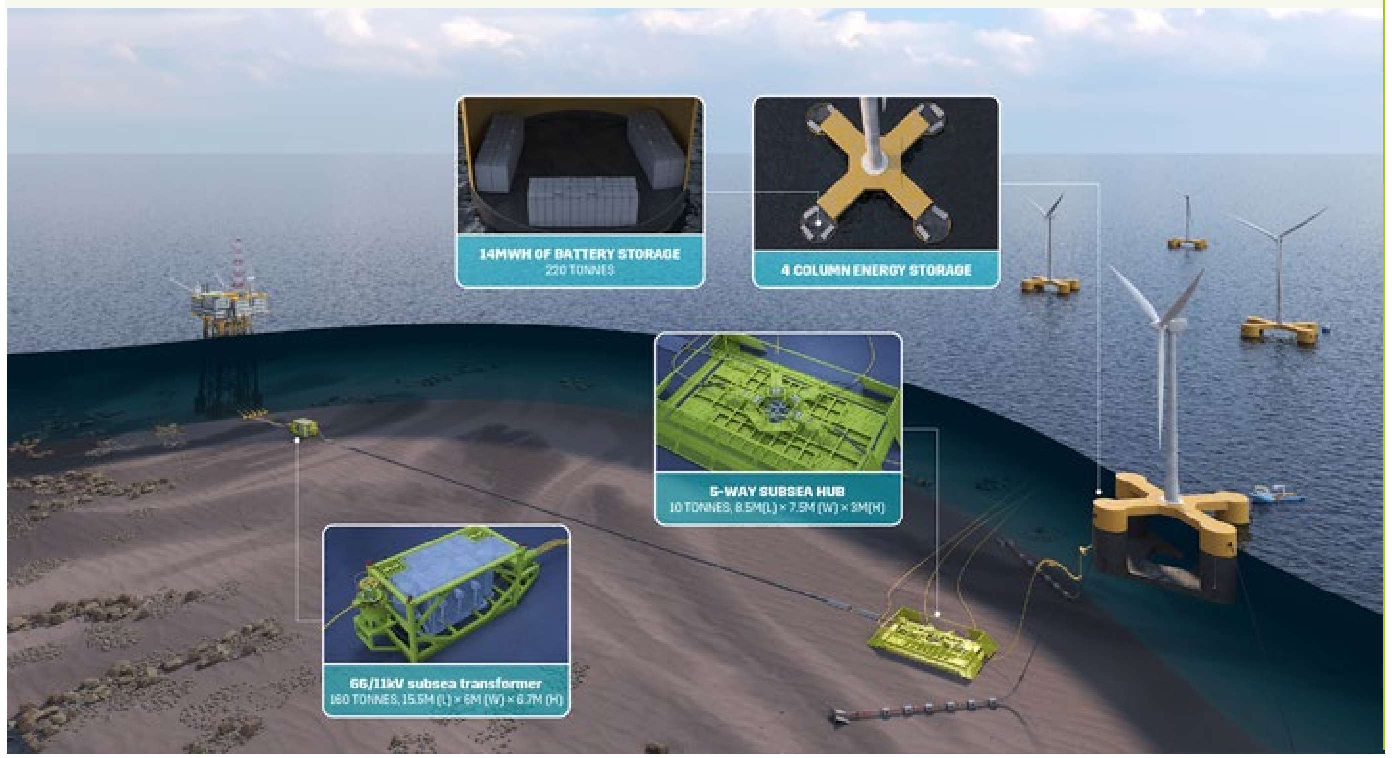
WINTOG Launch Project

Part of the Energy Transition Alliance (ETA) programme, this project is a feasibility study to evaluate and analyse the potential of a floating wind turbine generator (WTG) connected to an Oil and Gas platform for a first-time deployment in the United Kingdom Continental Shelf (UKCS). It will deliver a concept for a prototype demonstrator project(s) and it will explore the market opportunity for this 'Partial Electrification and Clean Fuel' opportunity across the Central North Sea (CNS) and Northern North Sea (NNS). The design will be modular and it will objectively consider opportunities for technology development across the system. The design also aims to minimise topside modifications by utilising subsea technology.

Key info/numbers:

OFFSHORE **O&G** PLATFORM ELECTRIFICATION	COMMENCED MARCH **2022**	CONCLUDED SEPTEMBER **2022**	**£250,000** (US$277,000) TOTAL FUNDING

Partners: NZTC, Offshore Renewable Energy Catapult (OREC), Siemens Energy, Subsea 7, Xodus Group



Emissions Reduction Challenge FOUR: Electrification and alternative energy sources for offshore assets.

Countries targeting: Australia, Netherlands, United Kingdom

O&G production will continue to serve society, but decarbonising energy consumption on offshore platforms represents a key step towards the decarbonisation of O&G production.

Electrification will play a key role, often via offshore wind and solar power, but other decarbonisation means exist to power offshore assets, including battery storage.

Technology Five: Digital Transformation

Digital transformation technologies will be key enablers for renewables and low-carbon hydrogen to be integrated with next-generation energy systems, and will allow the hydrocarbon industry to further decarbonise and electrify.

Technology Innovation Challenges **exist in:**

- Data
- Sensors
- Remote & autonomous operations
- Advanced process control

Digital Transformation Challenge **ONE:**

Shared data trusts to enhance analytics capability and support decision making.

Countries targeting:

Data has a progressively important role in process optimisation and operational efficiency increase, but applications are often restricted by quality or inaccuracy issues. Wider and secure data sharing will provide a foundation for artificial intelligence/machine learning (AI/ML) applications, for the development of improved algorithms and for improved prediction and automation approaches. The development of data trusts and repositories for both industry and ecosystem data will provide robust platforms for data sharing and lead to the establishment of verified datasets, deployable in a range of processes and technology development applications.

DIGITAL TRANSFORMATION CHALLENGE ONE: CASE STUDY

Offshore Energy Digital Architecture (OEDA)

This collaborative, enabling project brings together operators, the supply chain, and advisory organisations to initiate the development of an OEDA. The architecture will support the integration of data and digital infrastructure required to deliver the future offshore energy system and demonstrate that critical industry data be secured, captured and made available in an open and collaborative way. This will provide an opportunity to develop people and protect future jobs. By facilitating the access to, and use of key industry data sets that support the development of a digital and technology ecosystem related to energy, centred in Scotland, the project allows for the initial development of the world's first Smart Energy Basin.

Key info/numbers:

WORLD'S FIRST **SMART** ENERGY BASIN	**£425,000** (US$471,000) COST	COMMENCED SEPTEMBER **2022**	TO BE CONCLUDED APRIL **2024**

Partners: NZTC, Scottish Government, Open Data Institute (ODI), Baringa, Industrial Data Hub (InDHu), Offshore Renewable Energy Catapult. Energy Systems Catapult, Palantir

Other noteworthy projects: Fiivesense AI (UK), Smart Chips Solution (Canada)

Digital Transformation Challenge **TWO:**

Intuitive human-machine interfaces to improve trust and risk awareness among users.

Countries targeting:

A key aspect in successful deployment of digital technologies is related to dissemination and trust among users. The development of intuitive and straightforward interfaces is an important element in bridging this gap, but can also support diagnostics and production monitoring, leading to efficiency improvements.

Safety considerations must be taken into account, to prevent incidents caused by poor design of interfaces or malfunctions in the interaction between humans and machines.

DIGITAL TRANSFORMATION CHALLENGE TWO: CASE STUDY

Technologically Enabled Frontline Workforce Assistance

A project building mixed reality tools to assist the Centrica Storage Easington Gas Terminal frontline workforce to improve efficiency and effectiveness in routine maintenance and operational tasks via a holographic headset (Microsoft HoloLens 2). The project sought to explore the potential of mixed reality in four areas: to enhance worker navigation across large complex sites; to eliminate paper-based information processing; to present live data and information to operators in context of machinery; and to enable offsite experts to provide remote support to frontline workers.

Key info/numbers:

MIXED **REALITY** TECHNOLOGY	**12** MONTH PROJECT	**REMOTE** SUPPORT TO FRONTLINE WORKERS

Partners: NZTC, Centrica, Microsoft

Other noteworthy projects: Development of Numerical Techniques and Software for Inversion Problems in Seismic Processing (Brazil)

Digital Transformation Challenge **THREE:**	Low cost, light touch and low maintenance sensors for harsh environments.
Countries targeting:	

The use of sensors for component monitoring and data gathering is an important element of understanding and optimising performance, which can pave the way for predictive maintenance capability development. Sensors can be deployed within a wide range of applications, but they must be robust and retrofittable for widespread application in legacy infrastructure.

As sensors become equipped with smart capabilities, they can become the foundation for data-driven functionality and efficiency improvements.

DIGITAL TRANSFORMATION CHALLENGE THREE: CASE STUDY

Oil Sands Extraction Analyzer ML Predictive Maintenance

This project brings remote connectivity, data collection and advanced data analytics to existing oil sands extraction process field analysers to help monitor sensor conditions and alert operators to instrument issues or risks to instrument health. Field instrument data will be analysed to predict impending equipment issues, detect deteriorating instrument condition, and monitor faults.

This project is centered around InnoTech's Near Infrared Ore Grade Analyzer but once proven, will be applied to several other InnoTech field analyzers. It will use advanced data analysis to validate the health of the sensor and the quality of the process measurements.

Key info/numbers:

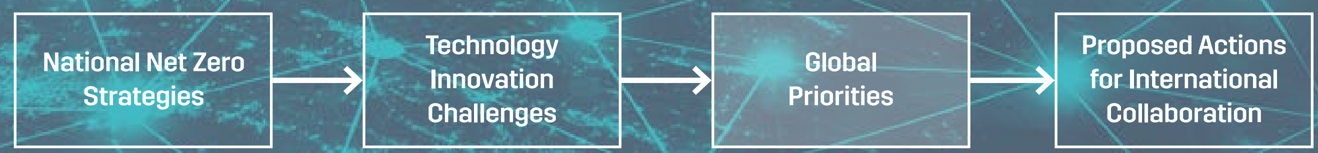
ADVANCED DATA ANALYSIS	CAD$135K (US$104,000) COST	COMMENCED JANUARY 2021	TO BE CONCLUDED MARCH 2023

Partners: InnoTech Alberta, Syncrude

Other noteworthy projects: Sensor Remote Connection/Predictive Maintenance (Canada)

Global Priorities

Analysis of the *Technology Innovation Challenges* led to the agreement of common *Global Priorities* that will drive scalable innovation of net zero technologies.

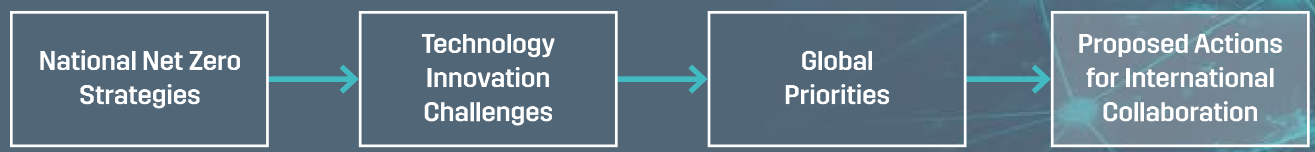


The table below shows *Global Priorities* that apply across the five selected technologies, and flags *Technology Innovation Challenge* examples for each priority.

Global priority	Challenge examples	Technology	Description
Infrastructure development	• Optimisation of electrical infrastructure, highlighting synergies and maximising benefit from emerging technology deployment • Solutions for energy storage offshore	• Offshore wind • Hydrogen • CCUS • Hydrocarbon emissions reduction	• Construction of assets and services. This includes electrical, transport and storage infrastructure.
Novel materials	• Materials to improve electrolysis processes, addressing cost, efficiency and durability • Materials to drive down the cost of CO_2 capture and increase technology deployment	• Hydrogen • CCUS	• Development of materials with improved properties for specific applications.
Energy efficiency	• Effective management of heat to maximise conversion efficiency and drive the commerciality of solar power technologies • High efficiency production technology of green ammonia	• Solar • Hydrogen • CCUS	• Improved energy efficiency and lower processing cost. This includes heat management.
Standardisation	• Standardisation of floating substructure designs • Improved modelling strategies to support storage capacity appraisals and safe injection site mapping • Advanced digital technologies to drive efficient geological behaviour prediction and modelling	• Offshore wind • Hydrogen • CCUS	• Design of processes that are faster, affordable and replicable. Creation of specifications and supportive regulation.
Venting, flaring & fugitive emissions	• Accurate detection and quantification of fugitive emissions • Enhanced gas recovery and storage options	• Hydrocarbon emissions reduction	• Eliminate the need for venting and flaring and reduce the amount of fugitive emissions.
Decarbonisation of power	• Electrification and alternative energy sources for onshore and offshore assets	• Hydrocarbon emissions reduction • CCUS	• Use of low-carbon sources, energy storage or electrification initiatives to reduce the amount of emissions from power generation onshore and offshore.
Testing & demonstration facilities	• Facilities and services for process demonstration to drive scale-up and cost reduction at pace	• Offshore wind • Hydrogen • CCUS	• Onshore and offshore facilities for testing and trialling under realistic conditions, to overcome innovation barriers and accelerate deployment.
Use of data & sensors	• Optimisation of services associated with the operation, condition monitoring and maintenance of wind turbines across the asset lifecycle • Shared data trusts to enhance analytics capability and support decision making • Intuitive human-machine interfaces to improve trust and risk awareness among users • Low-cost, light-touch and low-maintenance sensors for harsh environments	• All	• Improvement of capture, management and use of data for the purpose of technology development and monitoring. Retrofittable sensors suitable for harsh environments, and to progress prediction and automation.

Proposed Actions for International Collaboration

Having identified *National Net Zero Strategies*, *Technology Innovation Challenges* and *Global Priorities*, this study proposes a number of actions that will accelerate technology innovation and deployment to achieve net zero as quickly, efficiently and affordably as possible.



Proposed Action ONE: Establishment of collaborative 'Hydrogen Hub' demonstration facilities.

Intention: reduce low-carbon hydrogen production cost to US$2/kg by 2030
***Global Priorities* tackled:** Novel materials | Energy efficiency | Testing and demonstration facilities

Targeted countries:

Low-carbon hydrogen will form a key component of the future energy mix and the approach to developing production capabilities differs between countries. Some are targeting deployed capacity and sufficient quantities of hydrogen generation (largely driven by domestic consumption expectations), while others are targeting cheapened production and transportation (largely to drive exports).

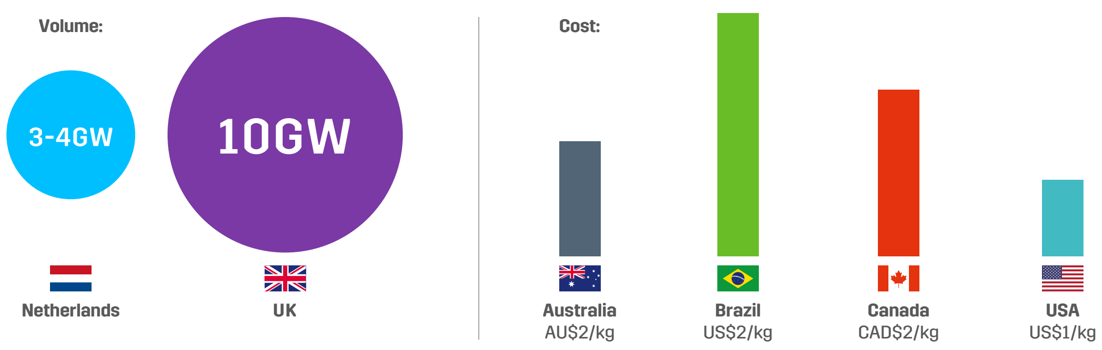
Despite differing approaches, numerous technology centres expressed a lack of accessible facilities and services was a major barrier that is currently preventing trialling and demonstration to drive production cost reductions and increased capacity. Technology deployment must be a test bed to accelerate technology innovation and crucial field trials and reduce production costs, producing supply chains capable of delivering domestic and export requirements.

Specialised Hydrogen Hub demonstration facilities will enable several key technology innovation priorities to be tackled, including increased process efficiencies in electrolysis and reforming, novel materials for catalysts and membranes, and other next-generation process solutions. Mapping analysis of specialised hydrogen testing facilities, including best practices and lessons learned, will provide direction on possible locations for Hydrogen Hubs. These may need to be constructed near renewable energy sources, to enable the production of electrolytic hydrogen, where appropriate.

Following this assessment, the study recommends Hydrogen Hubs be developed by hydrogen-focused nations such as Australia, Canada, the Netherlands, UK and the USA, that are open to international collaboration and knowledge sharing. High-priority, mid-TRL technologies currently working with this group will be fast-tracked within these 'living labs' to accelerate concurrent and parallel technology development and enable crucial field trials. These facilities will enable hydrogen upskilling and job creation, improved safety and developed regulations.

The scale of the energy transition, coupled with growing global power consumption and a need for diverse energy sources, means countries should not consider the development of low-carbon hydrogen technologies as a competitive field, but as a collaborative playground. Pooling approaches and resources internationally will enable greater cost reductions and more scalable innovation than working in isolation. This collaboration is aiming to reduce the cost of low-carbon hydrogen to US$2/kg by 2030, in line with the Mission Innovation Initiative's Clean Hydrogen Mission.

Figure 7: Low-carbon hydrogen targets (2030)



Proposed Action TWO: Establishment of a collaborative CCUS demonstration facility.

Intention: reduce costs of CO_2 capture for power generation and reformed hydrogen production to < $50 per tCO_2
***Global Priorities* tackled:** Novel materials | Energy efficiency | Testing and demonstration facilities

Targeted countries:

CCUS technologies are expected to have a strategic value in tackling climate change and transitioning to a net zero economy, but deployment has been slow. Significant support and collaboration will be required to bring technology development to the pace required to meet climate targets.

As projects and initiatives come online, there is a need for alignment, laying the foundation for CCUS clusters to be established. The establishment of CCUS demonstration facilities, acting as 'living labs', can provide a platform for technology innovation to help overcome key CCUS barriers identified in this study. This will include efficiency improvements and more efficient and durable capture materials.

As a key enabler to the wider deployment of CCUS technologies, the improvement of capture processes could contribute to generate significant economic value and the creation of new jobs, while developing avenues for business to decarbonise their operations and reach their emissions reduction targets. Large-scale projects will also contribute to the development of supportive commercial models.

The facility may be located near to energy-intensive industries to enable a cluster approach. Industrial clusters (also referred to as 'industrial hubs' in some geographies) are geographic areas where related, hard-to-decarbonise industries – such as chemicals, glass, oil refining, iron and steel – are co-located. The proximity of multiple industrial energy consumers creates opportunities to scale low-carbon technologies by aggregating demand and scaling infrastructure around a guaranteed future market.

Adopting a cluster approach for this facility may allow the deployment and utilisation of shared infrastructure, enabling industry to reduce the unit cost for each tonne of carbon abated. This will enable the development of technologies across the full value chain, from capture, through utilisation, transport, processing and storage. The ability to share risk and resources among multiple partners allows for the creation of integrated, clean and reliable systems, while de-risking the uncertainty in nascent technologies and building a strong foundation for private investors' security .

Mapping analysis shall be conducted to identify a suitable location for a collaborative CCUS facility, which may be also close to an onshore or offshore storage facility. This location will be in one of the collaborating countries and will be supported by all centres, to enable opportunities for scalable innovation, access to tested technologies, and international knowledge exchange. It will provide a platform for the mid-TRL technologies within the portfolios of this collaboration of centres, to accelerate deployment and immediate emissions reduction.

Given Canada's expertise in CCUS technologies and Alberta's active technological ecosystem supporting the development of geological carbon storage, the country has the knowledge and geological resources to be an effective partner in the development of a collaborative CCUS demonstration facility.

Based on current costs of CO_2 capture being between US$50-$100 per tCO_2 for power generation and reformed hydrogen production, this collaboration is aiming to reduce this cost to below $50 per tCO_2.

www.iea.org/data-and-statistics/charts/levelised-cost-of-co2-capture-by-sector-and-initial-co2-concentration-2019

Proposed Action **THREE:**

Establishment of a joint Open Innovation Competition to fund disruptive floating offshore wind substructure demonstrations, to achieve at-scale deployment and reduced levelized cost of electricity (LCOE).

Intention: reduce floating offshore wind cost to US$90/MWh by 2030
***Global Priorities* tackled:** Infrastructure development | Standardisation
Targeted countries:

Floating wind is expected to make up a third of global offshore wind capacity by 2050, as power production capabilities in challenging environments with strong resources increase. Brazil, Canada and the UK generally possess great offshore water depths, inviting opportunities in floating offshore wind.

Offshore structures are regularly exposed to considerable environmental loads, often in deep waters and locations with stronger and more abundant wind resources. Removing depth constraints allows for the selection of sites with best availability of resources, which offer better capacity factors but may impose restraints on the design of novel components.

The standardisation of designs and centralisation of production for floating substructures could be important enablers for the increase of production volumes, supply chain development and cost reductions. Designs need to be robust enough to withstand environmental loads and increasingly large turbines.

Around the world, efforts are ongoing to develop innovative substructure designs that are able to cope with increasingly large turbine sizes, as well as harsh environments. As more designs come onto the market, it is important to compare functionalities and understand which features are real differentiators for developers and the supply chain, and that can help the technology reach global markets at the pace required.

A joint substructure design assessment is initially proposed, comparing the features of existing floating substructure designs across the participating regions. This will support a better understanding of the fundamental elements of widely deployable, robust designs. Considerations such as modularity, suitable depth range, ease of production, transport and assembly, and reusability and recyclability will be taken into account.

The UK and the Netherlands are world-leading in floating offshore wind technologies, and it is consequently recommended that this design assessment exercise is led by these countries, to share best practices with Australia, Canada, Brazil and the USA, reflecting the floating offshore wind potential in these countries.

Following the design assessment, an Open Innovation Competition will be developed and coordinated by the UK, the Netherlands, Australia, Brazil, Canada, and the USA. Funding will be secured and high-TRL, disruptive substructure technologies with international application will be identified, to enable crucial demonstrations.

This collaboration aims to reduce the LCOE of floating offshore wind to US$90/MWh by 2030, which would indicate that floating offshore wind is on course to achieve cost parity with fixed bottom offshore wind by 2050.

Proposed Action **FOUR:**

Aligned planning for international 'Super Grids' of electrical infrastructure.

Intention: enabler of optimised electricity transport routes
***Global Priorities* tackled:** Infrastructure development | Standardisation | Decarbonisation of power
Targeted countries:

The development of electrical infrastructure (including array cabling, transmission and grid integration) was identified as a key technology innovation priority in Australia, Brazil, Canada, Egypt, the Netherlands, UK and USA, and therefore represents a major global priority.

The development of aligned electrical infrastructure will be pivotal to stabilise global supply as the energy mix becomes increasingly diverse. International electricity transport systems can only be achieved through internationally aligned planning.

The study believes greater international alignment and collaboration is required to construct optimised electricity transport routes to enable seamless import and exports, minimising infrastructure duplication, standardising where possible and increasing system security with whole system planning.

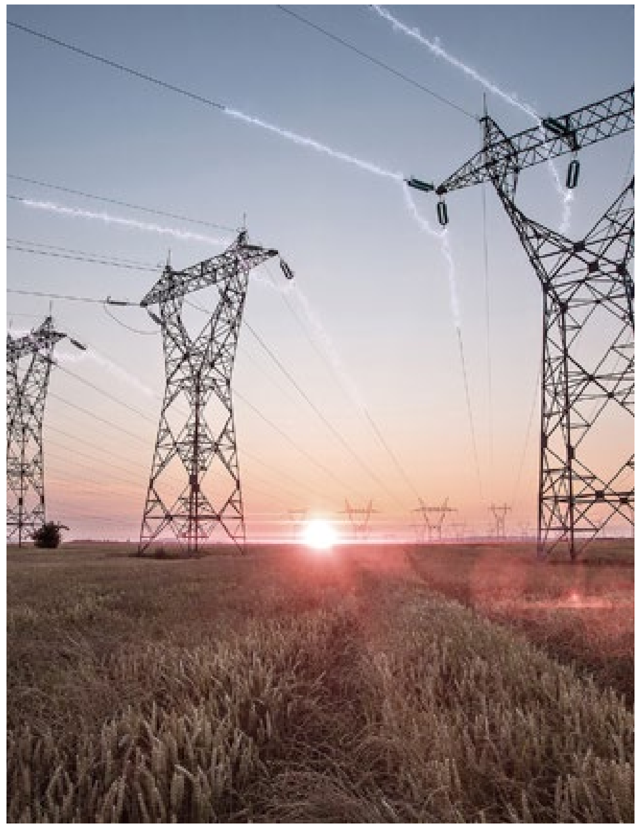
A coordinated and integrated approach to infrastructure development, providing greater connections between existing grids, can accelerate the deployment of innovative technologies, helping reduce complexity and risk.

As an initial focus, it is recommended that infrastructure planning related to a Super Grid specific to the North Sea is conducted by the UK and the Netherlands, with further invites issued to potential partners in Norway, Denmark and Germany.

The One North Sea (ONS) database, already under way between NZTC and TNO, will provide an introductory dataset.

Mapping of existing electrical infrastructure will be conducted, to identify the shared challenges associated with existing systems. This will allow the identification of specific technology requirements required to unlock international Super Grids to enable seamless cross-border electricity transportation, access to diversified power sources and improved regional energy security.

Findings and lessons learned from the North Sea can then be shared with the USA, Australia and Egypt and countries in other regions including the Gulf of Mexico, Asia, and the Middle East and North Africa, to highlight the value of cross border energy master-planning and cooperation.



Proposed Action **FIVE:**

Establishment of an international collaborative working group to drive implementation of shared data trusts for technology development purposes.

Intention: enabler of advanced data sharing to drive efficiency improvements
***Global Priorities* tackled:** Venting, flaring and fugitive emissions | Use of data and sensors

Targeted countries:

The development of data trusts and repositories for both industry and ecosystem data has become a shared global priority.

As data becomes an increasingly valuable asset, joint data trusts are being developed to improve secure access to relevant data. The aim is to establish verified datasets that could be deployed in a range of processes and technology development applications. Several initiatives are already under way to support the development of digital infrastructure and improve the use of data.

The study proposes the establishment of knowledge sharing forums, made up of key stakeholders from different regions including Australia, Brazil, Canada and the UK, focused on the identification of measures to help make data accessible to relevant stakeholders, as well as innovative uses for data and sharing of best practices.

This will be beneficial for the automation of a number of different energy sources, providing cross-sector benefits and contributing to efficiency improvements.

As an introductory exercise, a shared data trust shall be established by this collaboration of centres, to share the data and technology innovation relating to venting, flaring and fugitive emissions.

Next Steps

These proposed actions will be taken forward by this group in 2023, and may include further collaboration from additional centres, governments and industry stakeholders, to develop a clear roadmap.

At COP28 in the United Arab Emirates, this roadmap will be presented with the aim of creating consortia to fund and deliver them. Organisations and technology centres willing to join this collaborative effort are encouraged to contact the NZTC by email at **info@netzerotc.com**

Net Zero Technology Centre
Technology Driving Transition

Appendix A:
Methodology & Findings

A breakdown of the technologies included in this study's analysis is hereby provided. The full list of *Technology Innovation Challenges*, alongside the countries where they apply, is also given.

Included Technologies

A number of technology groups have been analysed on a national and international basis. Each of these are considered to be directly contributing to the decarbonisation of global O&G production, and therefore '*closing the gap*' to net zero integrated energy systems.

The identified technologiesemerged during collaborative workshops between centre experts and are considered of greatest relevance to decarbonising traditionally O&G-producing basins. Each centre participated in the analysis of the technology groups most relevant to its own and its country's focus areas.

	AIST	BUE	CSIRO	ERI NL	IDRIC	InnoTech	NERA	NREL	NZTC	RCGI	SCCS	TNO
Renewables	•	•	•	•			•	•	•	•		•
Hydrogen	•	•	•	•	•	•	•	•	•	•	•	•
CCUS			•	•	•	•	•	•	•	•	•	•
Hydrocarbon Emissions Reduction			•	•	•	•	•	•	•	•		
Digital				•		•	•		•	•		

Renewables

Analysis of renewable electricity included offshore wind, onshore wind, solar and geothermal power. Tidal, wave and nuclear technologies were considered and are important in specific locations, but they are less common focus areas of the centres contributing to this study.

Global renewable energy capacity increased by 9.1% in 2021, rising from 2.8 to 3.1 TW, despite the impact of Covid-19[165]. However, it's estimated that 27.5 TW renewable power generation capacity is required to achieve net zero by 2050, meaning annual growth of 0.84 TW every year, roughly a 2.5-fold increase on last year[155].

Low-carbon Hydrogen

Analysis of low-carbon hydrogen included electrolytic hydrogen generated from renewable sources, hydrogen generated from natural gas (such as reforming) with associated CCS, hydrogen generated from methane pyrolysis, and ammonia. The International Renewable Energy Agency (IRENA) sees hydrogen meeting 12% of global energy demand and cutting 10% of all current carbon emissions by 2050. 5 TW of electrolyser capacity alone will be required in 2050 to reach net zero and supply global 2050 demand of 614 Mt/year[166].

Carbon Capture, Utilisation and Storage (CCUS) Technologies

Analysis of CCUS technologies included CCS, CCU, bioenergy with CCS (BECCS) and direct air capture (DAC). The Energy Transitions Commission estimates that by 2050, the world will likely need to capture and either use or store 7 to 10 Gt per year of CO_2 – up from today's 40 Mt per year[167].

Hydrocarbon Emissions Reduction

Analysis of hydrocarbon emissions reduction technologies included decarbonisation of power, methane leaks removal, flaring/venting elimination and oil sands pollution prevention. Though coal production remains prevalent in some of the regions analysed, the majority of analysis in this section relates to O&G production. In the Net Zero Emissions Scenario outlined in the IEA's *Net Zero by 2050*, fossil fuel production and use "*does not fall to zero in 2050 – significant amounts are still used in producing non-energy goods, in plants with CCUS, and in sectors…such as heavy industry and long-distance transport.*[168]"

Future National Renewable Targets and Forecasts

	Onshore Wind	Offshore Wind	Solar
	• 32 GW by 2030 • 70 GW by 2050	•	• 48 GW by 2030 • 143 GW by 2050
	• 33 GW by 2026 • 110 to 194 GW by 2050	• 16 GW by 2050	• 27 to 91 GW by 2050
	• 109 GW by 2050	•	• 47 GW by 2050
	• 21 GW (total wind) by 2035	•	• 40 GW by 2035
	• 17.9 GW by 2030 • 38 GW by 2050	• 5.7 to 10 GW by 2030 • 30 to 45 GW by 2050	• 103.5 to 117.6 GW by 2030
	•	• 21 GW by 2030 • 50 GW by 2040 • 70 GW by 2050	• 27 GW by 2030 • 55-132 GW by 2050
	• 70 GW by 2035 • 80-120 GW by 2050	• 50 GW by 2030 (including 5 GW floating) • 95-140 GW by 2050	• 70 GW by 2035
	• 202 GW by 2030 • 318 GW by 2050	• 30 GW by 2030 • 86 GW by 2050	• 760-1000 GW by 2035

Future Low-carbon Hydrogen Targets & Forecasts		
	Cost	**Capacity**
🇦🇺	• A$2 kg by 2030	•
🇧🇷	• US$2 kg by 2030	•
🇨🇦	• CAN$2 kg by 2030	•
🇪🇬	•	•
🇯🇵	•	•
🇳🇱	•	• 3 to 4 GW electrolyser capac-ity by 2030
🇬🇧	•	• 10 GW by 2030 (minimum • 5 GW electrolytic)
🇺🇸	• US$2 kg by 2025 and US$1 kg by 2030	

Future CCS Targets & Forecasts	
🇦🇺	•
🇧🇷	•
🇨🇦	•
🇪🇬	•
🇯🇵	•
🇳🇱	•
🇬🇧	• 20 to 30 $MtCO_2$/year by 2030
🇺🇸	• 212-252 $MtCO_2$/year by 2025

Future O&G Emissions Reduction Targets & Forecasts	
🇦🇺	•
🇧🇷	•
🇨🇦	• 31% by 2030 (from 2018 levels)
🇪🇬	•
🇯🇵	•
🇳🇱	•
🇬🇧	• 10% by 2025, 25% by 2027, 50% by 2030 and net zero by 2050 (from 2005 levels)
🇺🇸	•

Digital Transformation

Analysis of digital transformation technologies included sensors, robotics, artificial intelligence (AI) and digital twins. These are considered enabling technologies that will help develop remotely controlled operations across a number of energy sources.

Not in Scope

Technologies that contributed to the general reduction of national emissions (outside the decarbonisation of O&G production) were considered out of scope and not included.

Efforts in sectors such as agriculture, reforestation and demand-side measures (such as efforts to reduce consumption of energy across the economy) were considered out of scope.

Full Technology Innovation Challenge List

The following pages provides a breakdown of the key innovation challenges in each technology group, for each country represented in the study. It should be noted that these are the top challenges in each region and do not provide a comprehensive overview of the region's portfolio.

Technology	Challenge	🇦🇺	🇧🇷	🇨🇦	🇪🇬	🇯🇵	🇳🇱	🇬🇧	🇺🇸
Offshore wind	Advanced simulation, testing and validation (related to wind condition analysis and prediction)			•		•			
	Optimisation of electrical infrastructure, highlighting synergies and maximising benefit from emerging technology deployment	•	•	•	•	•	•	•	•
	Improved autonomous systems (air, land and sea)	•	•				•		
	Optimisation of services associated with the operation, condition monitoring and maintenance of wind turbines across the asset lifecycle		•				•	•	•
	Standardisation of designs for floating substructures that improve performance		•	•				•	•
Solar	Effective heat management to maximise conversion efficiency of solar power technologies	•	•		•	•			•

Technology	Challenge	Australia	Brazil	Canada	Egypt	Japan	Netherlands	UK	USA
Hydrogen production	Facilities and services for process demonstration to drive scale-up and cost reduction at pace	•	•	•	•	•	•	•	•
	Seawater electrolysis to enable offshore hydrogen production			•				•	
	Biomass gasification technologies for hydrogen production		•				•		
	High-efficiency production technology of green ammonia	•		•	•	•	•		
	Development of methane pyrolysis process to commercial readiness (plasma-based, catalytic cracking, thermal) and high-temperature operation			•					
	Improve electrolysis processes leveraging novel materials to address cost, efficiency and durability challenges	•		•			•	•	•
Hydrogen transportation and storage	High-efficiency and low-cost production technology of LOHCs	•	•		•	•			
	Large-scale storage of hydrogen in depleted reservoirs (onshore and offshore)						•	•	
	Materials compatible with hydrogen at high pressures/low temperatures								•
	Substantial efficiency improvements in liquefaction technology	•				•			
CCUS (general)	Timely, accelerated cluster delivery to achieve large-scale full-chain projects						•		•
	Develop regulatory frameworks and commercial incentive mechanisms to increase demand	•	•						
CCUS (capture)	Novel capture materials to drive down the cost of CO_2 capture and increase deployment of CCS technology	•		•				•	•
CCUS (transport)	Mature CO_2 transportation networks to drive a circular carbon economy			•			•	•	
	Design of CO_2 specifications for full CCS chain							•	

Technology	Challenge	Australia	Brazil	Canada	Egypt	Japan	Netherlands	UK	USA
CCUS (storage)	Advanced digital technology to drive efficient geological behaviour prediction and modelling		•	•			•	•	
	Long-term liability and transfer of assets			•			•		
	Improved modelling strategies to support storage capacity appraisals and safe injection site mapping	•	•	•			•		•
De-carbonisation of power	Electrification and alternative energy sources for offshore assets	•					•	•	
	Alternative solutions for electricity storage (on and offshore)	•	•	•				•	
Field development	Low emissions drilling								•
Production	Accurate detection and quantification of fugitive emissions	•	•	•			•		•
Venting and flaring	Efficient brownfield retrofit solutions for closed flare systems			•				•	•
	Enhanced gas recovery and storage options		•	•			•	•	
Sensors	Low cost, light touch and low maintenance sensors for harsh environments		•	•				•	
	Smart sensor applications using AI/ML for data interrogation		•						
Remote and autonomous operations	Advanced remote and autonomous operations infrastructure and technologies			•					
	Intuitive human-machine interfaces to improve trust and risk awareness among users		•					•	
Advanced process control	Shared data trusts to enhance analytics capability and support decision making	•	•	•				•	
	AI/ML applications for large data volumes			•				•	

Appendix B:
National Snapshots

Each research and technology organisation has put forward their snapshot of the net zero status and strategy of their country, with all information accurate in October 2022. This includes analysis of the key technologies identified – namely renewables, low-carbon hydrogen, CCUS, emissions reduction associated with hydrocarbon production, and digital transformation. Key *Technology Innovation Challenges* have also been identified for each nation through input from each organisation's subject matter experts.

The technology groups analysed for each country reflect the activity of their representative research and technology organisation, and also generally reflect the technology focus of that country. For example, emissions reduction associated with hydrocarbon production is not a focus area in Japan due to its status as a fossil fuel importer, and consequently the National Institute of Advanced Industrial Science and Technology (AIST) did not provide analysis on this technology area for Japan.

The impact of the energy transition in each country is analysed in relation to national economics (job creation, industry creation, investment, economic/gross domestic product (GDP) impact), exports (current and future) and skills (how each country is planning to upskill an O&G workforce to create a diversified energy workforce with a transferable skillset).

Finally, ongoing evidence of the energy transition from each nation's fossil fuel industry is identified.

Partners:

CSIRO Australia's National Science Agency

NERA National Energy Resources Australia

AUSTRALIA: Context & Energy History

For decades, the Australian resources and energy sector has successfully powered Australia's economic performance and helped power its neighbours in the Indo-Pacific region. Oil, natural gas and coal have dominated Australia's primary energy consumption and the design of its energy networks and systems. Fossil fuels account for around a quarter of the country's annual export income, and the country is a leading exporter of liquefied natural gas (LNG), coal and uranium.

The Australian Government (elected in May 2022) is setting a new vision for *Powering Australia* that aims to ensure Australia has access to secure, reliable and affordable energy and reduces emissions by boosting investment and growth in clean energy technologies. Australia has world-leading R&D and technologies that can be deployed at home and globally and is striving to be a leading global source of low emissions energy, technology and capability.

Australia is endowed with diverse natural resources, a highly-skilled workforce, a world-class research sector and established trading relationships. The experience and expertise of Australia's LNG industry will be critical in helping Australia develop an export-oriented hydrogen industry. Australia also plans to utilise its strong capability in offshore oil and gas to rapidly develop an offshore wind industry, given the considerable skills overlap between the two sectors.

As Australia and global economies now move to invest trillions of dollars in renewable energy technologies, the country can build on decades of complex project experience, investment and innovation to power a decarbonised economy. It can play a significant role in helping trading partners and the region meet their energy, decarbonisation and technology ambitions.

Australia faces some unique challenges as the economy and energy sector transition to net zero emissions, including the country's geographical size, remoteness, and dispersed population.

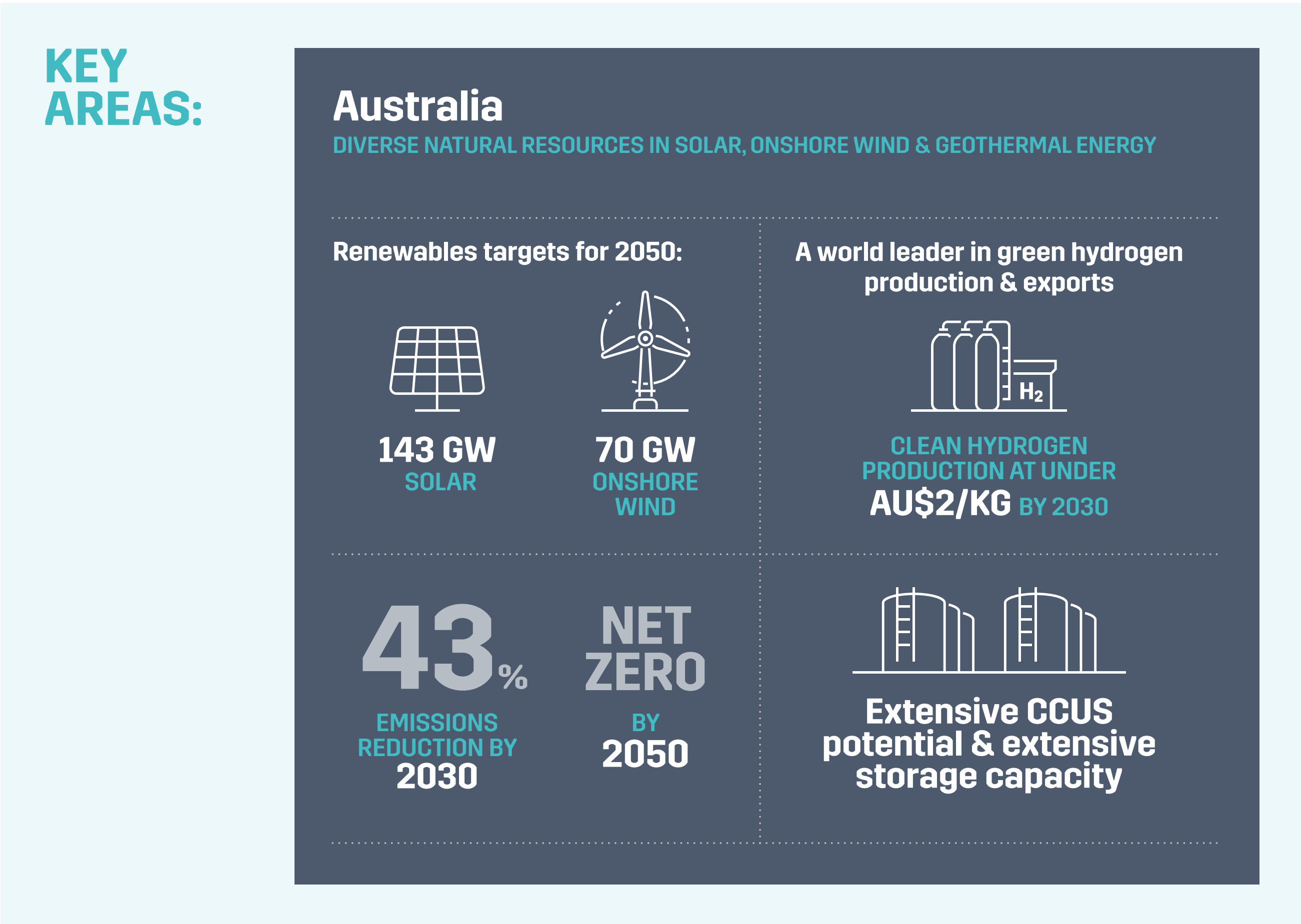
However, Australia also has the world's highest penetration of rooftop solar, and significant resources of critical minerals and rare earth elements needed to support renewable energy technologies, offering a huge opportunity to be a global leader in renewable energy.

In addition, Australia is focused on the decarbonisation of heavy and heat process industries, value-adding to its resources and supporting the large-scale deployment of technologies in industrial regions where critical mass can be achieved.

A surge of new investment and activity in low emissions technologies is driving a significant transition in Australia's energy mix. Coal power stations in Australia are getting older and less reliable and increasing competition from renewables is making them less profitable and harder to operate. The *Australian Energy Market Operator's Integrated System Plan* suggests that up to 60% (14 GW) of Australia's coal capacity could exit the system by 2030[4]. The federal, state and territory governments are working together to manage this transformation of the electricity system.

The future of the energy system across the country will include a mix of solar, wind, existing flexible gas generation, biomass, hydrogen, pumped hydro, critical minerals, batteries and CCS, all supported by investment in transmission to decarbonise Australia's energy system and industries.

In June 2022, the Government updated Australia's Nationally Determined Contribution (NDC) under the Paris Agreement, formalising Australia's pledge to reduce GHG emissions by 43% below 2005 levels by 2030 (2005 baseline year), and putting Australia on track to achieve net zero by 2050 – while also creating new jobs[5].



Innovation Challenges by Technology

Renewables

Offshore Wind

Area	Challenge
Electrical Infrastructure	• Optimisation of electrical infrastructure, highlighting synergies and maximising benefit from emerging technology deployment
O&M and Lifecycle	• Improved autonomous systems (air, land and sea)

Increased renewable capacity is required in Australia, both to meet domestic demand and to enable its transformation into a producer and global exporter of electrolytic hydrogen. Rapid onshore wind and solar deployment is the immediate focus of the Australian Government, which is targeting an increase in the share of renewables in the national market to 82% by 2030[6].

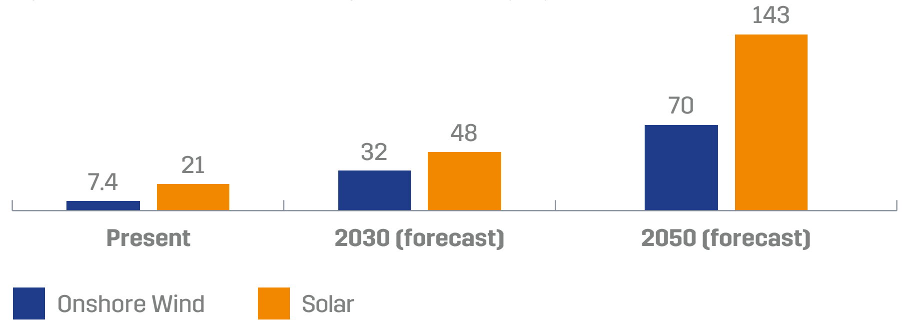
Australia's onshore wind capacity currently sits at 7.4 GW, but the Australian Government's *Integrated System Plan* forecasts this to quadruple to 32 GW by 2030, and ultimately to rise to 70 GW by 2050.

Solar

Area	Challenge
Heat management	• Effective management of heat to maximise conversion efficiency and drive the commerciality of solar power technologies

With some of the best solar resource in the world, Australia is targeting a massive scale-up in solar capacity – from the current installed solar capacity of 21 GW, the country is forecasting this will progress towards 48 GW by 2030, and 143 GW by 2050, representing a near seven-fold increase.

Figure 8: Renewable Production Targets in Australia (GW)



Despite existing infrastructure still being at a formative stage, Australia possesses significant offshore wind resources, with the potential to install over 2,000 GW of offshore wind turbines within 100 km of current electricity substations, and 19 proposed offshore wind farms[7]. The *Offshore Electricity Infrastructure Bill*, endorsed by the Australian Government in 2021, aims to facilitate and regulate the development of offshore renewable energy and electricity transmission infrastructure.

Australia is in the preliminary stages of developing an offshore wind industry. The state of Victoria has committed to a 4 GW offshore wind target by 2035 and a 9 GW target by 2040[8]. Still, Australia as a nation has not yet defined any total capacity targets.

Australia's renewable targets demand rapid deployment of renewable electricity technologies. Greater investment in transmission and storage is required to help address the challenges of intermittency, grid instability and end-of-grid remoteness, which currently impact energy networks with high shares of renewable power.

Low-carbon Hydrogen

Area	Challenge
Production	• High-efficiency production technology of green ammonia • Improve electrolysis processes leveraging novel materials to address cost, efficiency and durability challenges • Facilities and services for process demonstration to drive scale up and cost reduction at pace
Transport & Storage	• Substantial efficiency improvements in liquefaction technology • High efficiency and low-cost production technology of liquid organic hydrogen carriers (LOHCs)

Hydrogen is expected to play an important role in Australia's future energy mix, with heavy transport in haulage trucks and road trains likely to be early-use markets. Australia also plans to establish itself as a global exporter of low-carbon hydrogen by leveraging its comparative advantages including abundant renewable energy and CCS potential, established trade relationships, export infrastructure and proximity to major energy markets in Asia, and is targeting clean hydrogen production at less than AU$2/kg (US$1.25) by 2030[9]. In addition, 69 GW of hydrogen electrolyser capacity has also been proposed in planned projects[10].

To drive private investment in hydrogen technologies, the Australian Government is supporting the development of Hydrogen Hubs across the country. Hubs will bring hydrogen producers, users and exporters together to accelerate industry growth by lowering the cost of production, encouraging innovation and enhancing skills and training efforts[11].

With an eye on its ambition to become a global exporter of hydrogen and hydrogen technologies, Australia has formed partnerships with Japan, South Korea, Singapore and others to build supply chains. The HySupply partnership between Australia and Germany, also involves transferring knowledge on electrolysis and other renewable hydrogen production technologies.

Shipping and aviation are strong focus areas for the application of hydrogen in Australia, where renewable and low emissions ammonia and liquefied hydrogen supply chain projects are being developed. Yara Pilbara and ENGIE are collaborating on a plant for renewable ammonia production. The Hydrogen Energy Supply Chain (HESC) project aims to deliver liquefied hydrogen from Victoria's Latrobe Valley to Japan, with the world's first liquefied hydrogen cargo dispatched in January 2022.

Partners involved in this study, Commonwealth Scientific and Industrial Research Organisation (CSIRO) and National Energy Resources Australia (NERA), have collaborated with the Australian Hydrogen Council and Future Fuels Cooperative Research Centre to develop the HyResource website, which summarises more than 100 industrial-scale hydrogen projects progressing in Australia. This is a collaborative online knowledge-sharing resource supporting the development of Australia's hydrogen industry[12].

CASE STUDY:

Hydrogen Energy Supply Chain (HESC)

An integrated hydrogen production, storage and transportation supply chain intended to deliver liquefied hydrogen produced in Australia to Japan. The pilot demonstrated production of hydrogen from coal and biomass, liquefaction of hydrogen gas and trans-ocean shipment of hydrogen, with activities now being undertaken towards building a commercial-scale project.

www.hydrogenenergysupplychain.com

Key info/numbers:

PILOT COMMENCED
2018

FIRST SHIPMENT ARRIVED FEB
2022

AU$500M
INVESTMENT (PILOT PHASE)

COMMERCIAL SCALE GREEN H2 PRODUCTION
225,000
TONNES LIQUID H2/YR

Partners: Kawasaki Heavy Industries, J-Power, AGL, Shell, Iwatani Corporation, Marubeni Corporation

CCUS

Area	Challenge
General	• Develop regulatory frameworks and commercial incentive mechanisms to increase demand
Capture	• Novel capture materials to drive down the cost of CO2 capture and increase deployment of CCUS technology
Storage	• Improved modelling strategies to support storage capacity appraisals and safe injection site mapping

Australia has tremendous CCS potential, and decarbonising heavy industrial areas is an early priority to accelerate CCS deployment at scale, enhance cost competitiveness and unlock hydrogen opportunities.

Australia's competitive advantage in CCS comes from its geological storage basins, many of which are close to industries that emit highly concentrated streams of CO_2. While Australia's CCS capacity is modest (3.4 to 4 million tCO2 per annum), it plans a significant scale-up by 2030. The Gippsland, Surat, and Cooper Basins, together with the Petrel and Barrow sub-basins, host carbon storage sites at an advanced stage of development, and each has genuine industry interest and support. The combined storage capacity of these four locations alone is over 20 billion tCO_2[13].

To take advantage of Australia's geological CCS advantages, the Australian Government pledged AU$250 million (US$ 156.6 million) over 10 years for CCUS hub developments across the country, and recently implemented the first financial incentive scheme in the Asia Pacific region for CCS-specific CO_2 abatement.

The Government has reframed its support for CCUS activities to align and contribute to the Powering Australia agenda, which seeks to drive innovation to achieve climate targets at the lowest cost. The Government will play a role to support ongoing CCUS deployment through robust regulatory frameworks and policy settings, and working with like-minded countries to support knowledge and technical exchanges.

Hydrocarbon Emissions Reduction

Area	Challenge
Decarbonisation of Power	• Electrification and alternative energy sources for offshore assets • Alternative solutions for electricity storage (on and offshore)
Production	• Accurate detection and quantification of fugitive emissions

Emissions associated with fossil fuel production in Australia are forecast to increase by 2030, in the absence of official government targets or regulations. However, the Australian Government is implementing policy reform measures to ensure that the nation's largest emitters – including O&G producers – cut emissions or purchase carbon offsets to help reach Australia's legislated 43% emissions reduction target by 2030 and net zero by 2050.

Though CCS is analysed as a separate technology group in this study, it will be a core enabler of low emissions hydrocarbons, and will dictate the success of Australia's natural gas industry and its exports. Australia is one of the world's largest LNG exporters and has the potential to leverage its significant CCS ability to enable low-emissions hydrocarbons, both for domestic and overseas use. CCS (along with electrification) could also play an important role in decarbonising liquefaction, an energy-intensive process and significant source of emissions in the LNG supply chain.

Each of Australia's eight state and territory governments has its own transition strategies and emissions reduction plans. CSIRO and NERA assist governments of all levels in collaborating with industry and researchers, to enable strategic and aligned action to reduce hydrocarbon emissions at the pace required to achieve net zero by 2050.

Digital Transformation

Area	Challenge
Advanced process control	• Shared data trusts to enhance analytics capability and support decision making

Impact of the Transition

Economics

An Australian hydrogen industry could be worth between AU$72 billion (US$45.1 billion) and AU$130 billion (US$81.4 billion) in 2050[14], while expanding production and processing of metals like lithium, nickel, copper and uranium could be worth around AU$122 billion (US$76.4 billion) in exports in 2050[14]. Australia is well-positioned to sustainably supply and process these minerals, which could employ between 4,000 and 6,000 people[15].

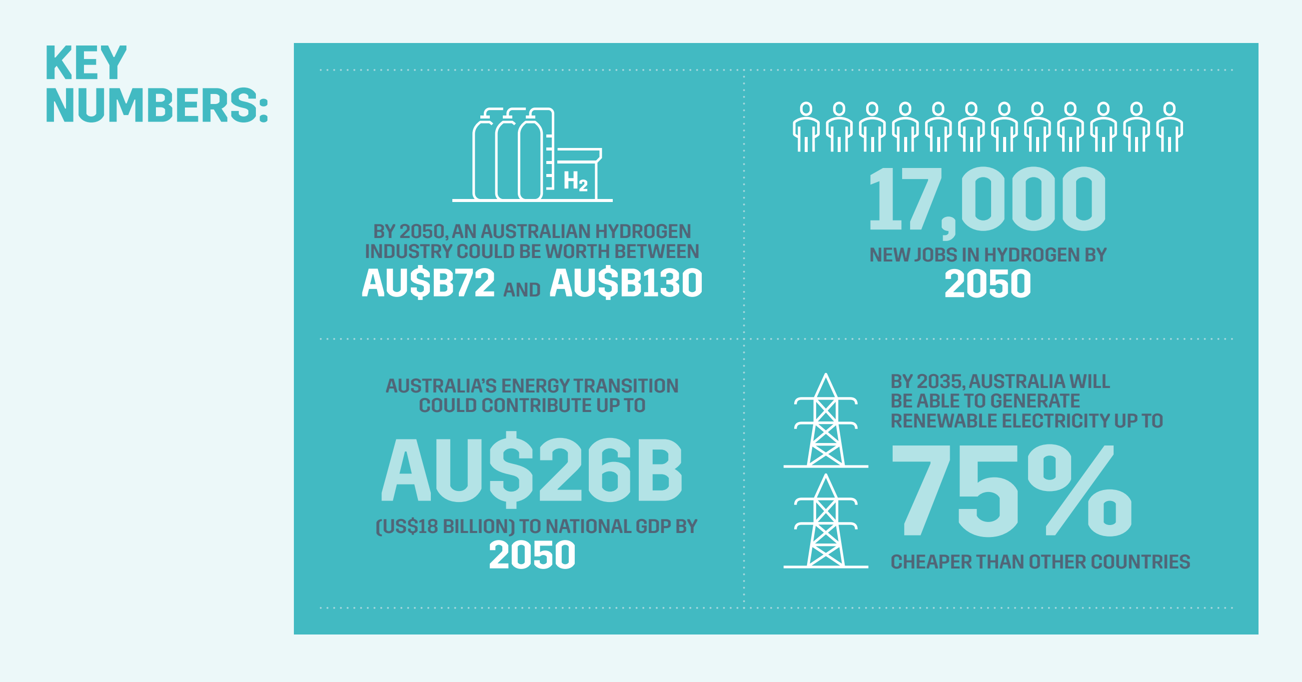
Australia's *National Hydrogen Strategy* estimates that 17,000 jobs could be created over the next three decades in hydrogen alone[16].

Due to geographical constraints in East Asian countries such as Japan and South Korea, Australia has an opportunity to utilise established connections from existing natural gas and coal trades, to supply 20% of the green energy demand in these countries. This would generate AU$90 to $100 billion (US$56.4 to $62.6 billion) in capital investment, and create approximately 20,000 infrastructure jobs and 30,000 ongoing operational jobs over the next 15 years[12].

By 2035, Australia should be able to generate renewable energy at approximately AU$17 (US$10.6) per megawatt hour (MWh) – up to 75% cheaper than other countries, placing it at the forefront of renewable electricity and low-carbon hydrogen production[13].

The impact of the transition on the country's GDP will be significant, with a high-demand scenario contributing over AU$26 billion (US$16.3 billion) a year by 2050[14]. In addition, the overall impact of reduced fossil fuel exports on Australian GDP is expected to be relatively small and gradual. In a net zero scenario, fossil fuel contribution to annual GDP growth would only fall by 0.1% relative to today[17].

Exports



Over 80% of total energy produced in Australia is for overseas consumption, evidencing its role as a major global energy exporter[18]. Australia currently exports vast amounts of coal and natural gas to Asia (mainly China, India, Japan, South Korea and Taiwan), but the energy export picture will be very different by 2050. Gradually, Australia is expected to reduce its natural gas and coal exports.

Australia's economy is expected to become increasingly reliant on renewables-based hydrogen exports, mainly through existing trade relationships with Asian countries like Japan, China and South Korea, and in new growth markets such as Singapore and Germany. Australia's *National Hydrogen Strategy* expresses an aspirational goal to be among the top three exporters to Asian markets by 2030.

Figure 9: 2050 Export Expectations

Skills

Industry skills development is largely coordinated within Australian states and territories. In Western Australia for example, O&G majors work collaboratively with the State Government, universities and vocational education and training centres, through the LNG Jobs Taskforce, to identify training needs and standardise skills training across the industry. In addition, several Australian states have established renewable energy 'hub' initiatives to bring together the necessary infrastructure, services, training and support industries to facilitate the development of new industries and supply chains.

The skills and expertise already available in Australia's O&G sector will be a crucial enabler for offshore renewable deployment and CCS project execution. Consequently, industry must work with government, educators and training providers to identify future skills requirements and develop the capability needed to diversify skillsets and underpin emerging low emissions industries.

Evidence of the Transition

Australian-based operators have repositioned over the past two years from 'coal, oil and gas' to 'energy', investing heavily in renewables, hydrogen, biofuels, CCS and digital technology projects to decarbonise operations, enhance efficiency and deliver low-carbon energy alternatives.

In June 2022, bp purchased a 40.5% stake in the Asian Renewable Energy Hub (AREH) in Pilbara, Western Australia, billed as having the potential to become one of the biggest suppliers of electrolytic hydrogen in the world. AREH is projected to generate up to 26 GW of wind and solar energy (a third of Australia's current electricity generation capacity) and produce around 1.8 million tonnes (Mt) of hydrogen and up to 10 Mt of green ammonia per year. As well as providing electricity for the Australian domestic market, AREH will also export to Japan and South Korea, and will be operational in 2027[19].

Elsewhere in Australia, Woodside Energy plans to invest AU$5 billion (US$3.1 billion) in new energy products and lower-carbon services by 2030 and has announced two major hydrogen projects in Perth (Western Australia) and Bell Bay (Tasmania). Woodside is also progressing the Woodside Solar Project, which could supply 100 MW of solar energy to Pluto LNG and other customers located near Karratha in Western Australia, with a potential expansion up to 500 MW[20].

In late 2021, Santos and Beach Energy also announced a final investment decision to proceed with the AU$220 million (US$137.7 million) Moomba CCS project in South Australia[21]. The project is expected to commence in 2024 and will leverage CCS as a pathway to generate clean fuels, including blue hydrogen. Shell also recently acquired a near half share of wind farm developer, Westwind, which has permitted 2 GW of Australian wind projects and aims to progress a further 3 GW of renewable capacity in coming years[22].

In addition to project investments, most major operators in Australia have also officially released self-imposed emissions mandates and net zero operations targets, driven by Environmental, Social, and Governance (ESG) investing principles, cost reduction, and public perception benefits, but generally these apply only to scope 1 and 2 emissions.

Santos has a goal to achieve net zero emissions for scope 1 and 2 operations by 2040, while Woodside, Chevron Australia, Shell Australia, INPEX and Origin Energy aim to reach this target by 2050. In the nearer term, Shell Australia aims to reduce scope 1 and 2 emissions by 50% by 2030, while Santos, Woodside and INPEX are targeting a 30% reduction.

Utilising existing Australian coal, oil and gas infrastructure offers a considerable challenge to the industry but will be a key enabler for next-generation technologies. Established refuelling and logistics networks, for example, will be needed in CCS project execution and scaling blue hydrogen production, along with its access to methane.

In 2021, the Centre of Decommissioning Australia (CODA), was established by NERA to connect O&G majors and leading service and research organisations to address the challenges and opportunities of decommissioning ageing O&G infrastructure. Optimising the reuse, repurposing and recycling of infrastructure is among CODA's key strategic objectives.

BRAZIL: Context & Energy History

Large offshore O&G discoveries, the majority in pre-salt, deep-water basins, have established Brazil as one of the world's foremost O&G provinces. Brazil has little exporting facilities for natural gas currently, but is prioritising becoming the world's premier offshore gas producer, rivalling the likes of the USA and Qatar, following the sanctions on Russian natural gas.

However, to allow continued O&G production (to meet domestic demand and for exports) and still adhere to the country's net zero target, Brazil is decarbonising its energy industry through the development of green technologies, while also drawing on its vast renewable energy resources.

Brazil's energy mix today consists of 48% renewables, with hydropower and wind energy the two most important sources for electricity generation, making its energy system one of the least carbon intensive in the world[23].

Onshore wind is the fastest-growing energy generation business in the country, and Brazil now boasts 21.5 GW onshore wind capacity. Only China and the USA installed more wind power plants than Brazil in 2021[24].

Brazil also has excellent offshore wind resources, although no offshore wind farm has yet been built in the country. In January 2022, the Brazilian Government issued a decree to regulate the use of physical space on the territorial waters of the country for power generation, with the vision that floating offshore wind power can decrease the carbon footprint of the O&G industry if turbines are employed to supply power to production and exploration units.

Brazil is also in the process of developing a hydrogen economy, to take advantage of its natural resources for generating green electricity. A national hydrogen strategy is currently being developed, which is expected to unveil plans to equip Brazil to become a mass exporter of hydrogen.

At COP26, Brazil announced its revised emissions reduction goals, targeting a 50% reduction by 2030, and to be net zero by 2050 (2005 baseline year)[25].

KEY AREAS:

Brazil

46% OF TODAY'S CURRENT ENERGY MIX COMES FROM RENEWABLES; INCREASED FOSSIL FUEL PRODUCTION & EXPORTS EXPECTED IN NEXT 10 YEARS

Renewables targets for 2050:

- **27-91 GW** SOLAR
- **110-194 GW** ONSHORE WIND
- **16 GW** OFFSHORE WIND

GREEN HYDROGEN PRODUCTION AT UNDER **US$2/kg** BY 2030

50% EMISSIONS REDUCTION BY **2030**

NET ZERO BY **2050**

Tremendous CCUS potential
INCLUDING EXTENSIVE STORAGE CAPACITY IN SEDIMENTARY BASINS

Innovation Challenges by Technology

Renewables

Offshore wind

Area	Challenge
Electrical Infrastructure	• Optimisation of electrical infrastructure, highlighting synergies and maximising benefit from emerging technology deployment
O&M and Lifecycle	• Optimisation of services associated with the operation, condition monitoring and maintenance of wind turbines across the asset lifecycle • Standardisation of designs for floating substructures that improve performance

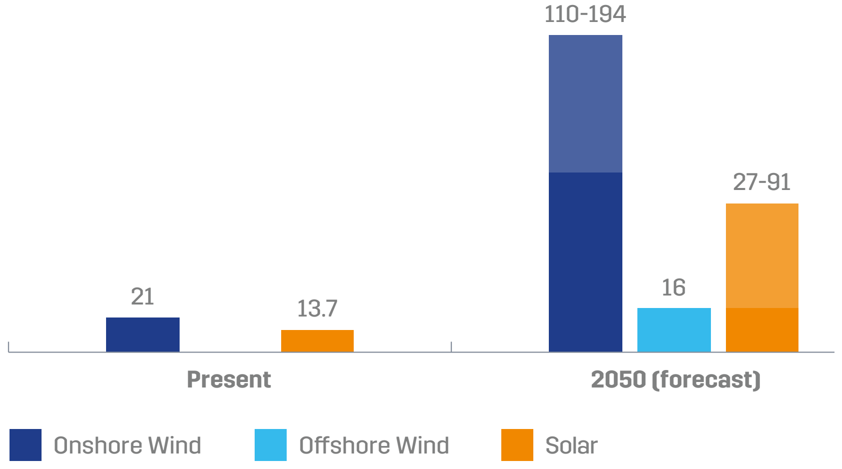
Brazil has a considerable renewables industry, accounting for nearly 85% of the country's electricity supply, with plans to expand[21]. Its current onshore wind capacity sits at 21 GW, and the country expects to have 33 GW by 2026 based on the current pipeline[26], before a significant increase to between 110 and 194 GW by 2050[25]. Despite no offshore wind farm yet being built, Brazil possesses significant offshore wind resources, and is working to develop offshore capabilities. There are currently 66 offshore wind farm projects whose environmental licence request is being analysed, totalling 11,571 wind turbines and 169 GW of potential power[27], which exceeds the nation's offshore wind forecast of 16 GW by 2050[25].

Solar

Area	Challenge
Heat Management	• Effective management of heat to maximise conversion efficiency and drive the commerciality of solar power technologies

Solar capacity targets are also ambitious. Despite a current solar capacity of 5 GW centralised and 8.7 GW decentralised, Brazil is forecasting a total of between 27 and 91 GW by 2050[28].

Figure 10: Brazil Renewables Targets/Forecasts



Low-carbon Hydrogen

Area	Challenge
Production	• Facilities and services for process demonstration to drive scale-up and cost reduction at pace • Biomass gasification technologies for hydrogen production
Transport & Storage	• High-efficiency and low-cost production technology of LOHCs

Boasting abundant wind and solar potential, a low-carbon power grid and a geographical location that allows export to Europe and the east coast of North America, Brazil has the opportunity to become a world leader in electrolytic hydrogen production.

Regarding domestic use, the chemical industry will be the priority for the initial deployment of green hydrogen technologies in Brazil, but blue hydrogen or hydrogen produced in sugarcane mills offer a necessary transition, according to the Brazilian Energy Research Office. It's estimated sugarcane-based hydrogen could deliver up to 57% of total transport sector energy demand.

To take advantage of a fast-moving global picture, and to achieve a cost under US$2/kg for green hydrogen by 2030, the Brazilian Government will soon present its strategy for developing a national hydrogen economy capable of significant export.

CASE STUDY

Açu Harbour Green Hydrogen Plant

A pilot plant, expected to be ready in 2025, which will undertake water electrolysis, using electricity from the national grid, for the production of green hydrogen. The plant will have an initial capacity of 10 MW and may expand to 100 MW. Part of the generated hydrogen will be destined for storage and subsequent shipment to potential consumers, while the remaining hydrogen is destined for a renewable ammonia generation plant. This pilot will promote the entire development of the value chain of renewable hydrogen generation, from the technology suppliers, through the domain of plant operation to the training of specialised labour, and represents the first steps to building a green hydrogen economy in Brazil.

Key info/numbers:

WATER ELECTROLYSIS FOR THE PRODUCTION OF **CLEAN** HYDROGEN

10MW PRODUCTION CAPACITY IN 2025, 100 MW IN FUTURE

KICKED OFF IN **2022**

OPERATIONAL BY **2025**

Partners: Shell, Açu Harbour

CCUS

Area	Challenge
Transport	• Develop regulatory frameworks and commercial incentive mechanisms to increase demand
Storage	• Improved modelling strategies to support storage capacity appraisals and safe injection site mapping • Advanced digital technology to drive efficient geological behaviour prediction and modelling

Brazil has extensive sedimentary basins and other geological formations, making up an estimated 17.51 GtCO_2 storage capacity. Petrobras is currently undertaking research into the prospective construction of giant salt caverns in the salt layers of offshore sedimentary basins. However, Brazil does not yet have any specific policies or legislation to encourage the deployment of CCS technologies.

Despite the lack of policy focus, O&G majors and ethanol producers expect to have bioenergy with carbon capture and storage (BECCS) pilot projects under way by 2026, with CO_2 captured from bioenergy production and injection into geological reservoirs in onshore areas. In offshore 'pre-salt' basins, carbon sequestration is being conducted on a large-scale associated with enhanced oil recovery (EOR) by Petrobras and partners. Petrobras aims to reach an accumulated volume of 40 $MtCO_2$ reinjected by 2025[29].

There are also plans to store the CO_2 captured from burning coal in power plants in the southern states. It is expected that by 2030 all of Brazil's coal power plants will capture and store around 80% of CO_2 emissions. Programmes are under way, focused on the synthesis of sorbents for CO_2 capture from coal ashes (zeolites) and solid amine sorbents. A pilot plant (of 2.5 tons of CO_2/day) is expected to be operational by 2023 and a commercial unit is expected by 2030. Brazil's coal power plants currently work with the most favourable scenario of capturing and storing 80% of its total CO_2 emissions beyond 2030.

Hydrocarbon Emissions Reduction

Area	Challenge
Decarbonisation of power	• Alternative solutions for electricity storage (onshore and offshore)
Production	• Accurate detection and quantification of fugitive emissions
Venting and flaring	• Enhanced gas recovery and storage options

The Brazilian Government has announced forecasts to increase oil production from 2.9 million barrels per day (mB/D) in 2020 to 5.2 mB/D by 2031[30], and its gross natural gas production by more than 100%, reaching 1.6 million barrels of oil equivalent per day (BOE/d), to consolidate its position as a major fossil fuel exporter.

Petrobras's *Strategic Plan*[31], however, does include R$9.1 billion (US$1.7 billion) investment in projects related to the decarbonisation of operations (specifically scopes 1 and 2), with emphasis on CO_2 separation, methane detection systems, and commissioning of closed flaring. This should lead to reduced national production emissions, given Petrobras's key role in the Brazilian O&G industry.

Digital Transformation

Area	Challenge
Sensors	• Low cost, light touch and low maintenance sensors for harsh environments • Smart sensor applications using AI/ML for data interrogation
Remote and autonomous operations	• Intuitive human-machine interfaces to improve trust and risk awareness among users
Advanced process control	• Shared data trusts to enhance analytics capability and support decision making

Impact of the Transition

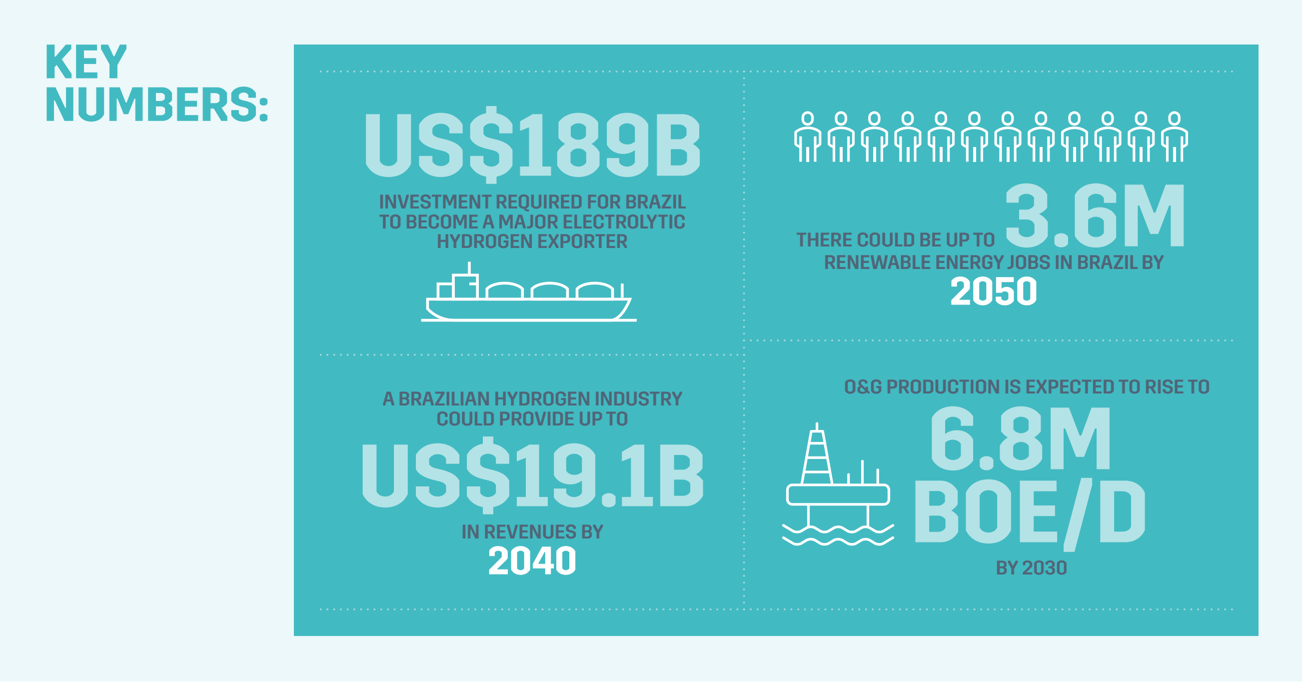
Economics

Brazil has the potential to become a world leader in low-carbon hydrogen production, and a Brazilian hydrogen economy could amount to up to R$76 to 101 billion (US$14.4 to 19.1 billion) in revenues by 2040. R$51 to 61 billion (US$9.6 to 11.5 billion) will come from serving the domestic market (especially trucking, steel production and other energy-intensive industries). Another R$20 to 30 billion (US$3.8 to 5.7 billion) could come from exports of electrolytic hydrogen-derivatives to the USA and Europe[32].

For Brazil to realise its full potential to develop and export electrolytic hydrogen, R$1 trillion (US$189 billion) investment is required, largely to develop 180 GW in additional power capacity from renewable sources[33].

Some 1.2 million jobs have already been created in renewable energy in Brazil, the majority of these in liquid biofuels, followed by hydropower, solar PV, solar heating and cooling, and wind power. With strong expansion of these sectors forecast in the coming years, total jobs in renewables in Brazil is expected to double or even triple by 2050.

The O&G industry in Brazil currently employs about 110,000 people, and this number will also rise as Brazil's O&G production is expected to significantly increase. Brazil's O&G industry currently produces 3.5 million BOE/d. By 2030, however, this is expected to rise to 6.8 million BOE/d, and the subsequent role of Brazil's O&G industry in the nation's economy will become ever more pivotal[34].



Exports

Brazil currently exports significant amounts of oil to the USA, China and India, and this is expected to continue in 2050.

Brazil also sees huge opportunities in the emergence of a European hydrogen economy and is expecting to export vast quantities of hydrogen to Belgium, France, Germany and the Netherlands.

Brazil's tremendous CCS potential also means there may be an opportunity to sell carbon sequestration to European countries.

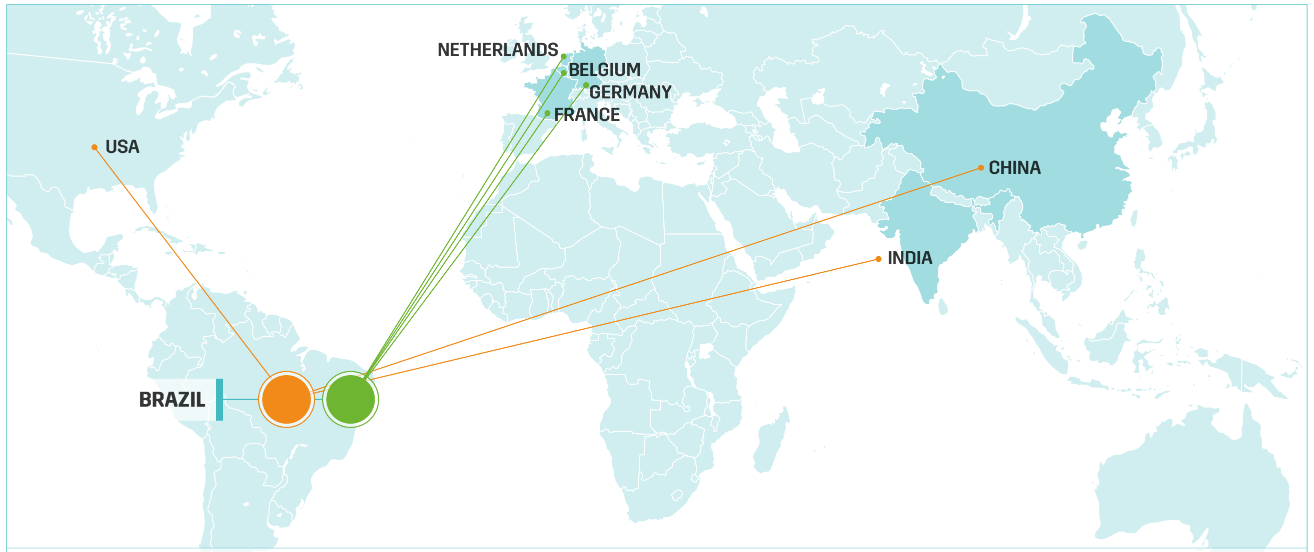


Figure 11: 2050 Export Expectations

Skills

The Brazilian Government has established the EnergIF Program, in partnership with all the institutions of the Federal Network, promoting a list of 15 priority actions. Based on dialogue with leading companies working in the renewables and energy efficiency sectors, as well as with ministries, research institutions and government agencies, priority occupations have been mapped. This has led to the publication of 10 training itineraries for the implementation of courses to upskill relevant workers[35].

The latest phase of the *Human Resources Training Program* for the Oil, Natural Gas and Biofuels Sector (PRH-ANP) granted scholarships to specialised undergraduate and graduate personnel in Brazil to build expertise in a number of low-carbon technologies including CCS, nature-based solutions (NBS) and biofuels.

Evidence of the Transition

The revamp of the Brazilian early O&G offshore infrastructure (mostly located in shallow waters in the Campos and Santos basins) may be vital enablers of CCS in Brazil's most industrialised states. In addition, the Brazilian infrastructure associated with nationwide bioethanol distribution can be leveraged to allow electrolytic hydrogen production and transportation from ethanol reforming.

Petrobras is not following the trend of other majors in transitioning to a more general 'energy' focus. After discovering additional ultra-deep O&G pre-salt resources, Petrobras reduced its transitioning efforts to retain its focus as a self-proclaimed 'oil and gas company'.

However, Petrobras has reduced emissions by more than 20% and the company has set emissions reduction targets for 2025 and 2030 to continue on that path. In addition, by reinjecting 6.7 $MtCO_2$ back into the producing fields in pre-salt basins between January and September 2021, Petrobras does claim to have developed the world's largest offshore CCUS programme, becoming a world-class pioneer in operating such large-scale offshore CCUS facilities[36].

Shell has partnered with COSAN (Brazil's private energy group) to form Raízen (Brazil's largest ethanol producer and distributor), which is expected to boost BECCS as well as other pathways to net zero from its sugarcane biorefineries.

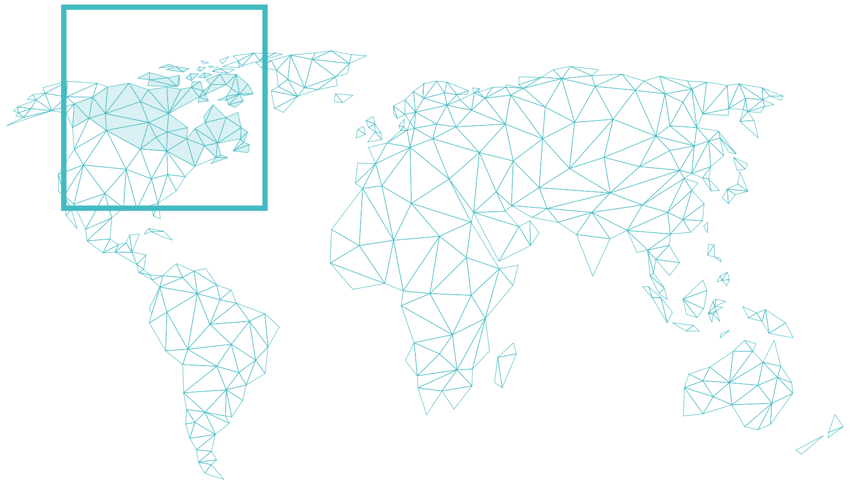
Shell Brasil and the Port of Açu recently announced plans to develop a 10 MW electrolytic hydrogen plant in Rio de Janeiro by 2025, with plans to expand to 100 MW[37]. The project will function as a research laboratory to develop learning, conduct decarbonisation tests and boost Brazil's hydrogen industry.

But these project investments are considered the exceptions. Only a small number of O&G companies in Brazil are acting in favour of the transition, and committing investment to hydrogen, CCS and renewable technologies.

Petrobras, Brazil's largest O&G company, has pledged to reach net zero across scope 1 and 2 operations in a "*timeframe compatible with the Paris Agreement*", and has set up important challenges to promote more sustainability and social acceptance in its current O&G activities. A 'shadow' carbon price, which will help better understand the emissions reduction potential of new technologies and help dictate Petrobras's investments, is also on the horizon.

However, these commitments only extend to scope 1 and 2 emissions, which is a pattern amongst Brazilian O&G companies, and only a small number of O&G producers in Brazil have made emissions reduction commitments across their entire value chain.

Partners:



CANADA: Context & Energy History

Canada has a long-standing history of driving its economy through natural resources. Energy makes up 10% of Canadian GDP, with O&G production the key economic driver[38]. Canada has the world's third-largest oil reserves and is the world's fifth-largest producer of natural gas.

However, Canada is also rich in renewable energy resources and capacity that it plans to leverage to place itself at the forefront of the clean energy transition. Canada's electricity supply has one of the world's lowest carbon intensities, largely due to its hydroelectric generation and nuclear capacity. World-class CO_2 storage geology, potential for incremental growth in variable renewables with substantial solar and wind resources, large-scale biomass supply, and freshwater resources will also be key enablers of the transition in Canada.

An ambitious carbon tax of CA$50/tonne (US$36.3/tonne) is in place today, and this will rise by CA$15/tonne (US$10.9/tonne) annually, reaching CA$170/tonne (US$123.3/tonne) by 203035. This has sent a clear message to the Canadian market to prioritise the innovation and development of clean energy technologies.

The hydrogen heartland in the state of Alberta has answered the clean technology, decarbonisation and emissions reduction challenge call, by retrofitting and updating technologies for hydrogen production that are GHG emission neutral (using CCUS solutions), helping Canada become one of the top hydrogen producers in the world. Other industries with the potential to contribute significantly to the energy transition are critical minerals mining to enable transport electrification, next generation biofuels, CO_2 enhanced farming practices, small modular reactors (SMRs) and geothermal energy.

CCUS is considered to be a key pathway for the Canadian Government and industry to reach their net zero ambitions. Experience from pioneer technologies and infrastructure like CO_2 geological storage, where R&D and deployment started as early as 2000, will enable significant cost reductions for similar projects in the future. The implementation of technologies for CO_2 capture and enhanced oil production have also been done successfully, namely EOR (enhanced oil recovery) projects.

Alongside the government of the state of British Columbia and the Canadian division of Royal Dutch Shell, the federal government granted CA$35 million (US$25.4 million) in 2021 to benefit the Centre for Innovation and Clean Energy[39]. The Centre will undertake R&D projects in various clean technologies.

Canada is also looking to further exploit non-emissive uses of hydrocarbons, to increase the potential diversion from fossil fuels to possible alternatives. For example, Bitumen Beyond Combustion (BBC), including carbon fibre, asphalt binder and activated carbon among others.

Furthermore, the use of Small Modular Nuclear Reactors (SMNRs) as a supportive technology is being considered by the Canadian Government (based on over 70 years of experience being a world leader in nuclear energy) as it has the potential to provide economically-feasible, environmentally conscious and reliable energy for on-grid power, heavy industry and the O&G sector (especially in remote locations) in order to meet Canada's emission reduction plan[40].

Canada's 2030 *Emission Reduction Plan*[41], released this year, commits the country to emissions reduction of 40% by 2030, to put Canada on track to achieve net zero by 2050 (2005 baseline year).

KEY AREAS:

Canada

DIVERSE NATURAL RESOURCES IN SOLAR, WIND & BIOMASS ENERGY; AMBITION TO BE A WORLD LEADER IN CLEAN HYDROGEN PRODUCTION & EXPORTS

Renewables targets for 2050:

47 GW ONSHORE WIND

109 GW SOLAR BY 2050

CCUS STRATEGY SETS GOAL OF USING CCUS TO REDUCE NATIONAL EMISSIONS BY **15 $MtCO_2$** ANNUALLY

40% EMISSIONS REDUCTION BY **2030**

NET ZERO BY **2050**

CARBON TAX OF **CAD$50/T** RISING TO **CAD$170/T** BY 2030

Innovation Challenges by Technology

This study has received analysis from InnoTech Alberta, and Energy Research and Innovation Newfoundland and Labrador (ERI NL) – two research and technology organisations generally representing onshore and offshore regions in Canada, respectively. For the challenges included under the following technology groups, those identified represent a combination of both the onshore and offshore perspectives.

Renewables

Offshore wind

Area	Challenge
O&M and Lifecycle	• Advanced simulation testing and validation (related to wind condition analysis and prediction)
Electrical Infrastructure	• Optimisation of electrical infrastructure, highlighting synergies and maximising benefit from emerging technology deployment
Substructures	• Standardisation of designs for floating substructures that improve performance

The Canadian Renewable Energy Association (CanREA) estimates that to achieve net zero by 2050, wind and solar energy must increase from 6% of Canada's energy generation to at least 33%, prompting a greater focus on increasing renewables capacity[42].

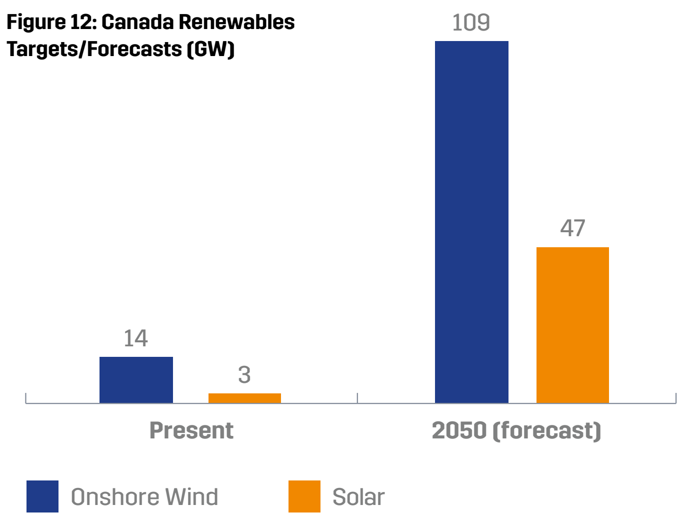
CanREA estimates that Canada's currently modest solar capacity of 3 GW must increase to 47 GW by 2050, in order to achieve net zero[39]. The Canadian Government is understood to be taking this into account, though it has not yet released an official target. Some 109 GW wind capacity will be required in 2050, almost a tenfold increase on today's 14 GW installed capacity[39].

Canada is closely monitoring the development of fixed and floating offshore wind technologies in more established basins, such as the North Sea, to help inform the development of offshore wind projects on the Canadian east coast.

Canada's strategies for offshore fixed and offshore floating wind energy) are at the preliminary stages of study and the regulatory process for offshore wind projects is currently being explored for future development. The State Government of Newfoundland and Labrador lifted its moratorium on wind development in April 2022.

Electricity storage is also a keen focus area in Canada. The E*lectricity Statutes (Modernizing Alberta's Electricity Grid) Amendment Act 2022* provides a clear definition guideline for energy storage in Alberta's legislative and regulatory framework, leveraging industry investment to enable a low-carbon future.

Figure 12: Canada Renewables Targets/Forecasts (GW)



Low-carbon Hydrogen

Area	Challenge
Production	• Facilities and services for process demonstration to drive scale-up and cost reduction at pace • Development of methane pyrolysis process to commercial readiness (plasma-based, catalytic cracking, thermal) and high-temperature solutions • Improve electrolysis processes leveraging novel materials to address cost, efficiency and durability challenges • Seawater electrolysis to enable offshore hydrogen production • High efficiency production of green ammonia

Canada is rich in the feedstocks to produce low-carbon hydrogen, which alongside well established international collaborations and an existing strong energy sector, making the country well-placed to becoming a global hydrogen exporter.

The *Hydrogen Strategy for Canada*, published by Natural Resources Canada, lays out an ambitious framework to cement Canada as a global, industrial leader of clean renewable fuels. It encourages the Canadian Government to establish early deployment hubs in mature applications, and to employ regulations to drive near-term investments.

One such example is Alberta's Hydrogen Centre of Excellence, which was launched with an initial investment of CA$50 million (US$36.3 million). The Hydrogen Centre of Excellence was created and conceived by Alberta Innovates to deliver the research and innovation aspects needed to create a hydrogen economy in Alberta. The Centre will support technology, innovation, and demonstration projects across the hydrogen value chain (production, distribution, storage, and market/end use) to validate hydrogen safety, build public awareness and confidence in hydrogen, and advance technologies across Alberta's economy and across the hydrogen supply chain.

The governments of Canada and Germany recently signed a Declaration of Intent to establish a Canada-Germany Hydrogen Alliance between their respective governments. The purpose is to promote opportunities for a bilateral trade relationship pertaining to hydrogen and its derivatives, as well as hydrogen-related technologies, and to accelerate the expansion of the hydrogen industry and the improvement of infrastructure and supply chains. The signing of the Declaration in Newfoundland and Labrador highlights the significant potential of Newfoundland and Labrador's renewable energy resources, in particular its wind resources, and the opportunity to bring them to the global marketplace.

Switching from conventional gasoline, diesel and natural gas to zero-emissions fuel sources, and embracing new technologies will be key to give Canadians more choice of zero-emission alternatives, for which hydrogen will be pivotal. The Hydrogen Council's *Path to Hydrogen Competitiveness* outlines applications for hydrogen that, with enough investment, policy change and demand, will become increasingly competitive starting as early as 2030.

CCUS

Area	Challenge

Capture	• Novel capture materials to drive down the cost of CO_2 capture and increase deployment of CCUS technology
Storage	• Improved modelling strategies to support storage capacity appraisals and safe injection site mapping • Long-term liability and transfer of assets • Advanced digital technology to drive efficient geological behaviour prediction and modelling
Transport	• Mature CO_2 transportation networks to drive a circular carbon economy

CCUS will be key to low-emissions hydrogen production (SMR coupled with CCUS) and to decarbonise oil production and refining, cement, fertiliser and other large industrial emitters[43], and Canada is undertaking a series of large-scale CCUS development projects. These include:

- The implementation of technologies to both capture CO_2 and aid in oil production – namely EOR projects – which include the Enhance Clive Project (connected to Alberta Carbon Trunk Line (ACTL) as detailed below) and Weyburn CO_2 Miscible-Flood project, which have the capacity to use 1.7 million and 1 million tCO_2 annually, respectively[44].
- The Alberta Carbon Trunk Line (ACTL) which involves capture from operations in Alberta's industrial heartland, transportation in large-capacity CO_2-dedicated pipelines globally, and sequestration in central Alberta mature hydrocarbon reservoirs in CO_2-EOR sites[45]. Canada also sees opportunities in providing CCUS as a service to the petroleum and industrial sectors, both nationally and internationally.
- The Alberta Carbon Conversion Technology Centre (ACCTC) (managed by InnoTech Alberta), which offers an essential testing facility in carbon capture and utilisation technology development and is one of only a few such facilities globally.
- The Geological Survey of Canada and an Eastern Canadian Carbon Storage Atlas, which are being developed by other stakeholders, will provide a deeper understanding of the storage potential, both on and offshore.
- Natural Resources Canada (NRCan) initiated a call for proposals in July 2022 on CO_2 capture and for CCUS technology research, development and demonstration (RD&D), and is investing CA$319 million (US$231.3 million) over seven years to advance the commercial viability of CCUS technologies.

Canada's *Carbon Capture Industrial Strategy* introduced a 50% investment tax credit for capital invested in CCUS projects, with the goal to reduce emissions by at least 15 $MtCO_2$ annually. It also committed to investing CA$194 million (US$140.7 million) to expand the Industrial Energy Management System to support ISO 50001 certification, energy managers, cohort-based training, audits, and energy efficiency-focused retrofits for key small-to-moderate projects.

CASE STUDY:

Alberta Carbon Conversion Technology Centre (ACCTC)

Owned and operated by InnoTech Alberta, the ACCTC is a unique facility built to demonstrate and re-risk CO_2 capture and utilisation technologies. The site is fully equipped for the provision of required utilities and has experienced operational staff to ensure steady services for technology innovators. The ACCTC is located next to the Shepard Energy Centre, an 860 MW natural gas-fuelled power generation facility jointly owned by ENMAX and Capital Power. Innovators have the opportunity to evaluate new carbon capture and utilisation technologies at demonstration scale using flue gas from Shepard or concentrated CO_2 from the capture unit, which is also available for R&D.

www.innotechalberta.ca/facilities/alberta-carbon-conversion-technology-centre

Key info/numbers:

DEMONSTRATION FACILITY FOR **CCUS**	TO BE OPERATIONAL FROM 2016 TO **2027**	**CAD$24M** INVESTMENT (US$17.4 MILLION)	**9 KT** CO_2/Y AT FULL CAPACITY

Partners: InnoTech Alberta, Canadian Oil Sands Innovation Alliance (COSIA), Government of Alberta, Government of Canada

With regards to cost reductions associated with the cost of capture materials, the development of second-generation technologies such as molten carbonate fuel cells (MCFCs), sold sorbent and facilitated transport membranes[41].

Hydrocarbon Emissions Reduction

Area	Challenge

Decarbonisation of power	• Alternative solutions for electricity storage (onshore and offshore)
Venting and flaring	• Enhanced gas recovery and storage options • Efficient brownfield retrofit solutions for closed flare systems
Production	• Accurate detection and quantification of fugitive emissions

Drawing on Canadian Emissions Reduction Plan (ERP) modelling, the 2030 ERP identifies a projected contribution from the O&G sector of reducing emissions by 31% from 2005 levels to reach 110 Mt in 2030 (equivalent to a 42% reduction from 2019 levels)[46].

A discussion paper released by the Government in July 2022, outlined proposed next steps to develop an O&G emissions cap for the Canadian O&G industry. A series of consultation sessions across Canada are planned[47].

At COP26, the Canadian Government announced its commitment to establish further 2030 and 2035 emissions reduction targets for the O&G sector based on international benchmarks, and to being a founding member of the Climate and Clean Air Coalition, in partnership with the International Energy Agency (IEA)[48]. The coalition is targeting methane emissions reductions associated with O&G production of 45% by 2025 (which the country is on track to achieve), and 60 to 75% by 2030, with further consultations taking place with the O&G industry, provincial governments and the public to determine additional reduction targets for 2035 and 2040.

The Canadian Emissions Reduction Innovation Network (CERIN), a collaborative programme between Alberta Innovates and NRCan will support targeted infrastructure investments at existing facilities or sites within Canada and the creation of consortia capable of connecting national expertise and facilities to an integrated network.

Alberta Innovates published the *Bitumen Beyond Combustion (BBC) Strategy* which provides a vision for oil to thrive in a net zero economy and a pathway to get there. The strategy calls for a greater portion of heavy oil/bitumen production to be diverted away from fuel production and dedicated to the manufacture of high-value products and materials. Some key BBC products include carbon fibre, asphalt binder, and high-value carbon materials such as activated carbon, graphene, carbon nanotubes, metal carbides and synthetic graphene.

ERI NL also partnered with NRCan on delivery of the Offshore Research, Development and Demonstration Emissions Reduction Fund in late 2020. A broad portfolio of projects were selected through a defined process, spanning process and power optimisation, flare reduction, digitalisation, vessel electrification, CCUS, power-from-shore, renewables including offshore wind, and hydrogen as mechanisms to reduce emissions.

Digital Transformation

Area	Challenge
Sensors	• Low cost, light touch and low maintenance sensors for harsh environments • Smart sensor applications using AI/ML for data interrogation
Remote and autonomous operations	• Intuitive human-machine interfaces to improve trust and risk awareness among users
Advanced process control	• Shared data trusts to enhance analytics capability and support decision making

Impact of the Transition

Economics

The Government of Canada's investments in clean technology have totalled more than CA$3 billion (US$2.2 billion) since 2016[49]. By 2025, clean technology's contribution to national GDP is expected to grow to CA$80 billion (US$58 billion), rising from CA$26 billion (US$18.9 billion) in 2016[50]. The national clean energy sector's GDP is also estimated to grow – by up to 58% by 2030. This is significantly more than fossil fuels, which will grow by only 9%[51].

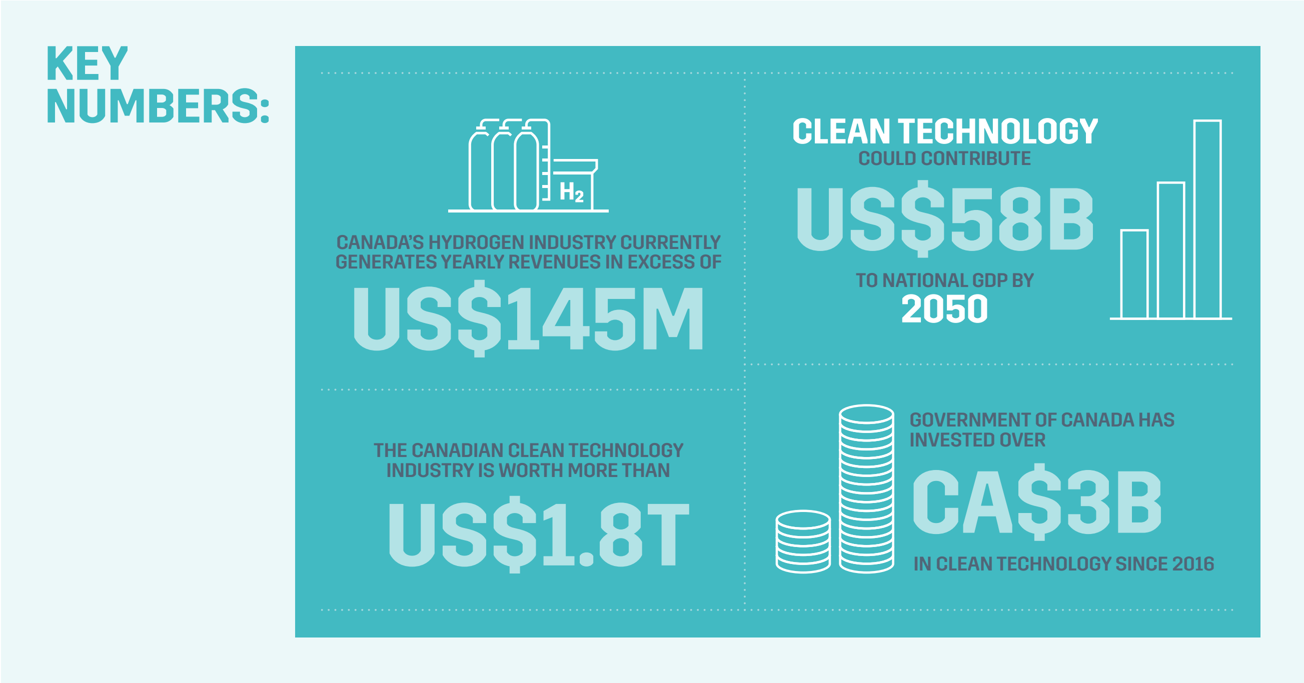
In 2018, approximately 195,000 Canadians were employed in clean technology, which contributed CA$2.6 billion (US$1.9 billion) to the Canadian economy. The clean technology market is expected to exceed CA$2.5 trillion (US$1.8 trillion) globally by 2022, and Canada is recognised internationally for its leadership, with 12 Canadian companies identified on the 2020 Global Cleantech 100 list[52].

Canada is already seeing the benefits of an emerging hydrogen industry. As of 2017, there were over 100 established companies working in hydrogen and fuel cell technology in Canada, generating revenues in excess of CA$200 million (US$145 million)[53]. 2,100 people are currently employed in the hydrogen industry in Canada, and this figure is expected to rise to 350,000 by 2050.

Rural communities that host large-scale wind and solar energy projects have the opportunity to experience huge economic benefit. These communities often rely heavily on variable sources of income, including agriculture and fishing, and the revenue from renewable energy projects will allow for increased economic stability.

Alberta Innovates has indicated that, with the industry's *Oil Sands Pathways to Net Zero Alliance* initiative as a strong foundation, BBC has the potential to create significant economic opportunities, including the creation of thousands of jobs in Alberta while also helping Canada to realise its net zero ambitions[54].

Exports



Canada currently exports natural gas and significant quantities of oil to the USA and China, and this is expected to continue to 2050, as well as the addition of Mexico and Indonesia and major export partners.

With regards to hydrogen exports, Canada is casting its net wide in terms of possible export locations. It sees opportunities in Asian markets such as Japan and South Korea, via its North American counterparts in the USA, and to European markets in Germany and the UK.

Canada also sees opportunities to sell carbon sequestration to the USA, and Asian countries such as Japan and South Korea.

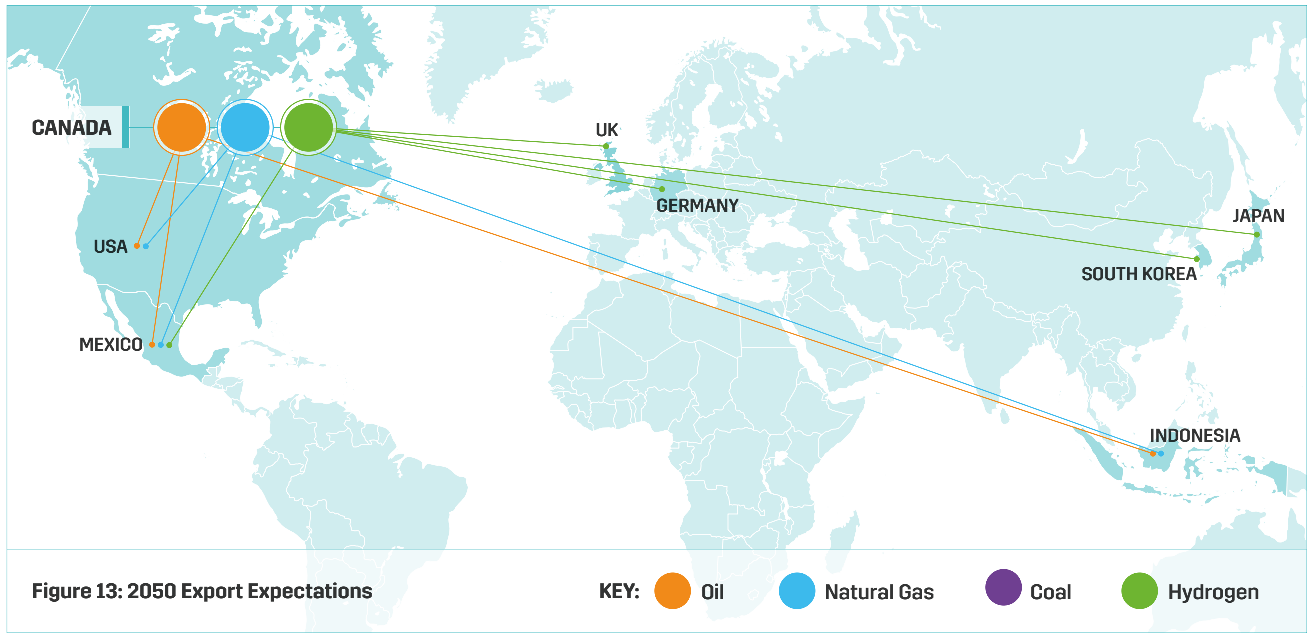


Figure 13: 2050 Export Expectations

Skills

Canada's *Regional Energy and Resource Strategy* recognises that a clear path is required to ensure that the right skills training is available for the in-demand jobs necessary to build a net zero energy system, but it is clear Canada has some work to do, given the expected growth in clean technology industries. The country must also ensure a just transition that is population-centred in its values and puts all-skill workers and communities at the centre of the Government's decision-making processes on emission reduction actions.

By 2025, the country is estimated to be unable to fill 27,000 environmental and net zero jobs based on a shortage of skills. By 2050, up to 400,000 new and high-skilled job descriptions will be changing due to the net zero transition[55]. A clear plan is needed to ensure that training in the right skill-sets is available via efficient pathways, to provide the skills needed for the in-demand jobs necessary to reach a net zero economy. This need has been recognised in the *Regional Energy and Resources Strategy*.

Upskilling will also be vital in enabling a series of new carbon transport and sequestration initiatives, that promise to decarbonise large amounts of oil sands extraction and processing, generation and other heavy industries. This is being spurred both by industry and government, to create a system of carbon sequestration hubs throughout the province.

Evidence of the Transition

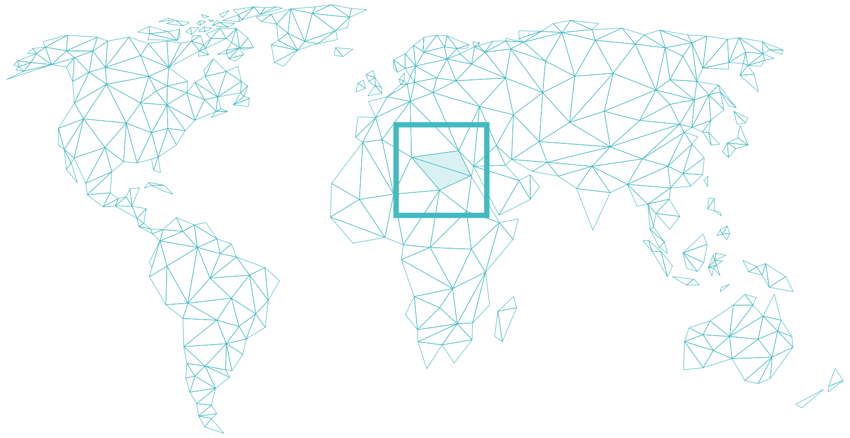
Preliminary R&D has begun in Canada to explore the potential for re-purposing O&G assets, and is seen as a viable tool to aid hydrogen production, CCUS, fuel switching, renewable energy and critical minerals extraction.

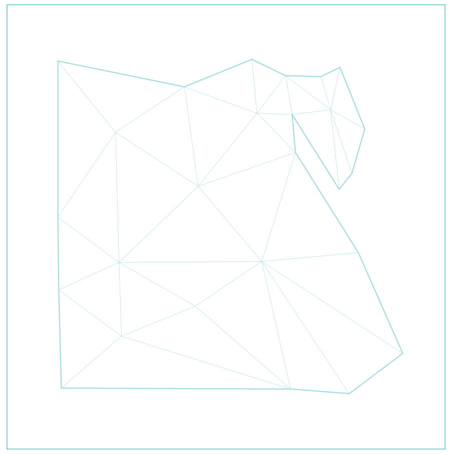
Early research points to opportunities for reusing pipeline assets for hydrogen transportation, repurposing O&G sites with existing electrical infrastructure as a base for renewables deployments, potentially exploiting depleted O&G reservoirs for in-situ hydrogen production, and there could be some potential in the future for offshore repurposing.

The Canadian O&G industry is also pledging substantial investments in innovation and implementation of new technologies to improve efficiency and reduce environmental impacts. In 2021, the major oil sands operators (accounting for 95% of Canada's oil sands production) proposed the 'Pathways Alliance'[56], building on a decade of work by COSIA, wherein intellectual property was shared among oil sands producers to reduce GHG emissions by implementing emissions reduction technologies.

Experience from the Shell Quest project will enable significant cost reductions for CCUS projects in the future, including capture from the process streams that contain the highest CO_2 concentrations and partial pressures. Newly announced low-carbon hydrogen production and net zero ethylene production projects will also benefit from the Shell Quest project, including the Air Products Low-carbon Hydrogen Production Hub and the Suncor/ATCO (ATR) Hydrogen Facility.

Major operators in Canada are based or represented in other countries as well, and generally have some form of emission reduction strategies and targets in line with Canadian Government targets. Industry players have responded by creating alliances to achieve the Government's emission reduction targets, and by also imposing targets of their own.





EGYPT: Context & Energy History

Population growth and increased industrial demand have led fossil fuel demand and consumption continue to increase in Egypt, with 57% of the country's primary energy consumption coming from natural gas, 36% from oil and 1% from coal – with 6% from renewables[57].

Exceeded domestic production expectations, supplemented by interconnection networks between countries, have meant that Egypt has also vastly developed its fossil fuel export capabilities. However, Egypt is now looking to capitalise on its wind and solar resource to build capability in renewable electricity and reduce reliance on fossil fuels. Renewable electricity production increases each year, currently sitting at around 6 GW installed capacity and accounting for 20% of the country's current electricity capacity, with the goal to reach 42% by 2035[58].

Egypt's focus on a diversified energy mix was exemplified by its *National Climate Change Strategy* [59], which prioritises R&D in green energy technologies and identifies programme costs for mitigation and adaptation at EGP6.2 trillion (US$315 billion).

The establishment of a number of government-led bodies and organisations, to pool ingenuity and expertise in green energy technologies, such as the *Supreme Council of Energy* and the *New and Renewable Energy Authority* will also accelerate the transition.

Egypt has a clear plan to increase the production of renewable energies from wind, solar and hydroelectric energy in both the Gulf of Suez and the Nile River. Egypt is planning to use renewable energies in desalination plants to generate renewable electricity for villages and tourist centres away from the grid.

Harnessing this renewable resource also opens up opportunities for producing and exporting electrolytic hydrogen and ammonia, an opportunity Egypt is keenly exploring. In 2022, Egypt signed a EGP95.8 billion (US$4.9 billion) Memorandum of Understanding (MoU) with Norwegian renewable energy company Scatec, to develop a plant in the Suez Canal area for producing green ammonia from electrolytic hydrogen[60].

Egypt does not yet have a confirmed target year to achieve net zero.

The decision to award the COP27 presidency to Egypt was taken to shine a spotlight on all of Africa and encourage the deployment of climate investment in developing nations, to allow them to develop and deploy clean energy technologies while also ensuring energy access for all.

KEY AREAS:

Egypt

DIVERSE NATURAL RESOURCES IN SOLAR, ONSHORE & OFFSHORE WIND, & HYDROPOWER ENERGY

Renewables targets for 2035:

21 GW ONSHORE & OFFSHORE WIND COMBINED

40 GW SOLAR (32 GW PV & 8 GW CONCENTRATED)

Ambition to become a world leader in clean hydrogen production and exports

Increased fossil fuel production & EXPORTS EXPECTED IN NEXT 10 YEARS

OIL MINISTRY SIGNED **11 MoUs** WITH INTERNATIONAL FIRMS TO DEVELOP **CCUS** CAPABILITIES

SERIES OF **MoUs** SIGNED WITH OTHER NATIONS TO DEVELOP **CLEAN HYDROGEN** PRODUCTION CAPABILITIES

Innovation Challenges by Technology

Renewables

Egypt is blessed with varied natural resources that could be key to decarbonisation, namely in strong sunlight and wind in many regions of the country. Some 20% of the country's electricity currently comes from renewable sources[61].

Offshore wind

Area	Challenge
Electrical Infrastructure	• Optimisation of electrical infrastructure, highlighting synergies and maximising benefit from emerging technology deployment

Solar

Area	Challenge
Heat Management	• Effective management of heat to maximise conversion efficiency and drive the commerciality of solar power technologies

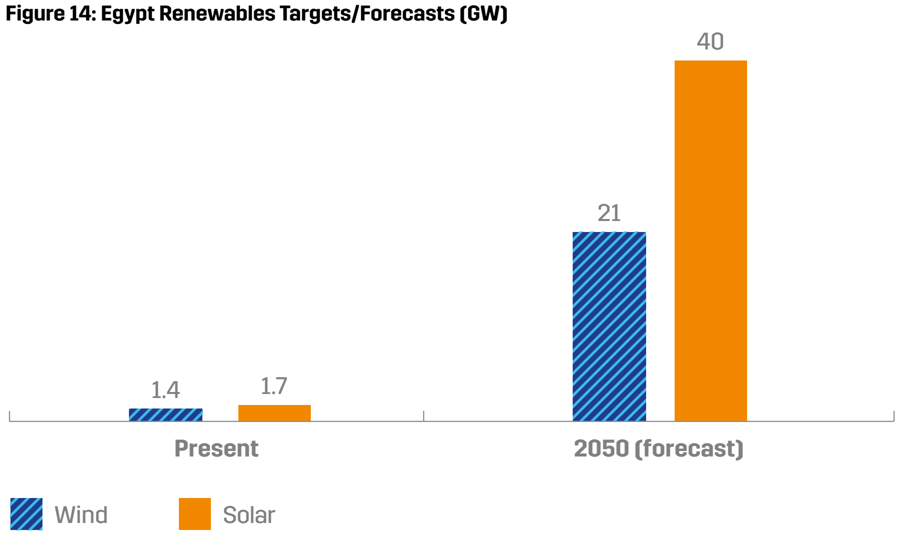
Egypt's *2035 Integrated Sustainable Energy Strategy*[62] sets medium-term targets to boost power production from renewable sources to 42% of the country's installed capacity by 2035, representing 63 GW. Current renewables capacity include 1.4 GW of wind power[63] and 1.7 GW solar[64].

The strategy does not differentiate between onshore and offshore wind in its targets, but its forecast for 2035 predicts 21 GW of total wind energy capacity, 32 GW from PV solar power and 8 GW from concentrated solar power, with a further 3 GW from hydro[59]. A key barrier in Egypt is the accumulation of dust on solar panels, which limits efficiency.

The Egyptian Government has introduced a number of laws and incentives to encourage the development of renewable energy sources. The *Egyptian Solar Plan*[65], which targets 3.5 GW of solar power by 2027, came with an investment scheme which was further developed by adding bids, feed-in tariffs and third-party access schemes. This largely boosted the creation of solar and wind energy sites in Egypt.

Renewable energy investments were helped further by the *Decree No. 17/2015*, which regulates renewable energy tax incentives. This means sale taxes were cut from 10 to 5% and custom duties on production equipment are set to 2%[66].

Figure 14: Egypt Renewables Targets/Forecasts (GW)



CASE STUDY:

Benban Solar Park

Benban Solar Park is a power complex of 41 solar power plants across 36 km2 and is the biggest solar project in Africa. The site was divided into 41 plots by the Egyptian Government, which were then assigned to 30 developers through financial incentives called 'feed in tariffs', where the Government promised the developers a fixed price for generated power for 25 years. The entire project is being overseen by the state-owned New and Renewable Energy Authority (NREA). The 1.8 GW installation represents the first utility-scale photovoltaic plant in Egypt. The potential annual energy production will be slightly more than 4 TWh/yr, with a capacity factor of approximately 26%.

www.woodplc.com/solutions/expertise/case-studies/infinity-50-benban-solar-park

Key info/numbers:

EGP40B
(US$2 BILLION) INVESTMENT

CONSTRUCTION FEBRUARY 2018 TO NOVEMBER
2019

ENOUGH ELECTRICITY TO POWER ALMOST
69,000
HOMES

1.8
GW INSTALLATION

Partners: New and Renewable Energy Authority (NREA), Egyptian Government, Wood plc

Low-carbon Hydrogen

Area	Challenge
Production	• High-efficiency production technology of green ammonia • Facilities and services for process demonstration to drive scale-up and cost reduction at pace
Transport and storage	• High-efficiency and low-cost production technology LOHCs

There has been a flurry of activities relating to hydrogen production development in Egypt, following the announcement that Egypt would be hosting COP27. The European Bank for Reconstruction and Development (EBRD) signed an MoU with Egypt to provide guidelines for the development of a low-carbon hydrogen strategy.

This follows an MoU signed between the Egyptian Government and the Belgian conglomerate DEME in March 2021 to conduct feasibility studies for the production and export of electrolytic hydrogen, and to determine optimal locations for hydrogen production hubs.

The Egyptian Government has also announced construction of a 100 MW electrolytic hydrogen production facility in an industrial site located in the Red Sea port of Ain Sokhna.

In July 2022, the governments of Egypt and India signed an MoU to develop an electrolytic hydrogen plant, with investments of US$8 billion, and a potential capacity of 220,000 tonnes annually, in the Suez Canal Economic Zone[67].

The Middle East and North Africa (MENA) region has ambitions to be the centre of the hydrogen economy by 2040, with Saudi Arabia and the United Arab Emirates (UAE) signing agreements in 2021 with future export partners Germany and Japan, respectively.

Egypt is also interested in green ammonia production as a means of storing and shipping green hydrogen. Egypt is the world's seventh largest ammonia producer, and consequently ammonia will be a key component in the country's awaited low-carbon hydrogen strategy.

CCUS

In the MENA region, CCS technologies offer an attractive means of decarbonisation, as they promise CO_2 emissions reduction within current operations without compromising energy security or economic strength. The core vision of the region is to keep hydrocarbon technologies as a central part of the energy mix, reducing emissions rather than fossil fuel production.

In preparation for hosting COP27 (where CCS is expected to be a key theme), Egypt has been engaging in a series of international partnerships, with the view to establishing carbon capture projects in the country.

Egypt's Oil Ministry signed 11 MoUs with international firms on CCUS projects at the Egypt Petroleum Show in February 2022. Egypt has also announced its first carbon capture initiative – a 479 million (US$25 million) project to store 25,000 to 30,000 tCO_2 each year, in collaboration with Eni[68]. The project is expected to test the feasibility of the technology in Egypt and, if successful, similar projects will be rolled out in other areas of the country.

Hydrocarbon Emissions Reduction

Egypt's *National Climate Change Strategy* identifies the reduction of emissions associated with hydrocarbon production and use as a key objective.

It also pledges to phase out coal and switch to low-carbon fuels (such as biofuels) as an alternative. The Egypt Oil Ministry has announced an EGP11.5 billion (US$584 million) biofuel production plant, which is expected to produce 350,000 tonnes of biofuels from algae oil each year and reduce CO_2 emissions by up to 1.2 million tonnes annually[63].

Energy efficiency is identified as a key focus area both in Egypt's *National Climate Change Strategy* and the *Integrated Sustainable Energy Strategy*. O&G companies are identified as requiring energy efficiency measures to ensure projects are emitting as little as possible, though no official emissions reduction targets have been set.

The continued production of natural gas is expected to be a major talking point at COP27. As host, Egypt is expected to represent the voice of a number of African nations that want to continue using natural gas as a transition fuel for the development of their economies.

Impact of the Transition

Economics

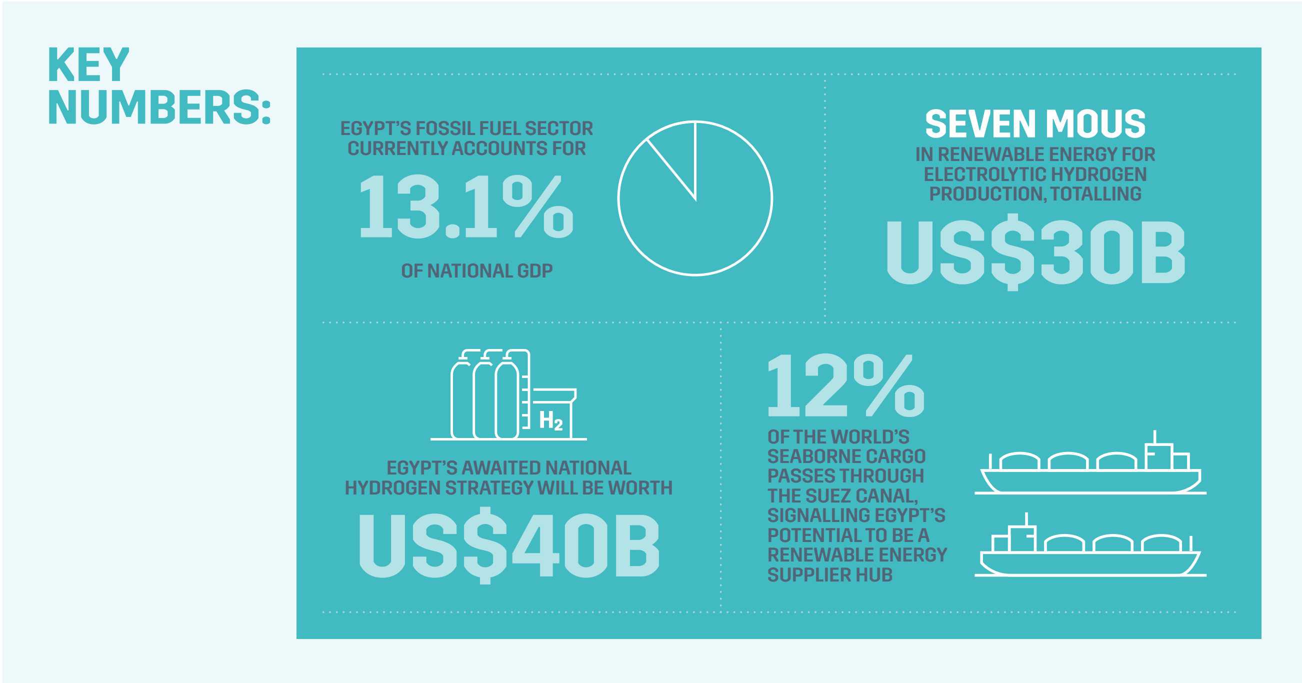
The (fossil fuel dominated) energy sector in Egypt accounts for 13.1% of the GDP59, therefore playing a vital role in the Egyptian economy. However, Egypt sees great economic opportunities in the development of clean energy technologies, including green technologies for EOR.

For example, Egypt has signed seven MoUs with foreign companies specialising in renewable energy production to establish industrial complexes for the production of electrolytic hydrogen in the Ain Sukhna industrial zone, with an expected volume of more than US$30 billion[69]. Egypt's awaited hydrogen strategy is expected to be worth US$40 billion[70].

Egypt has a number of novel energy technology projects scheduled to come online before 2035[71]. This comes from the Government's recognition of green hydrogen and ammonia in its economic development strategy, which qualifies these technologies for state support and tax incentives.

Egypt has unique potential to supply renewable energy in all directions due to its geographic position, with about 12% of the world's seaborne cargo passing through the Suez Canal[72]. The domestic market will also reap the rewards, as the agriculture industry adopts super-green fertiliser use.

Exports



Egypt currently exports oil and natural gas to predominantly Asian markets, including India, China and Pakistan[73].

In 2050, Egypt expects to export fossil fuels and hydrogen, with hydrogen markets seen in the UAE, and in Europe via Belgium, France and Germany.

Skills

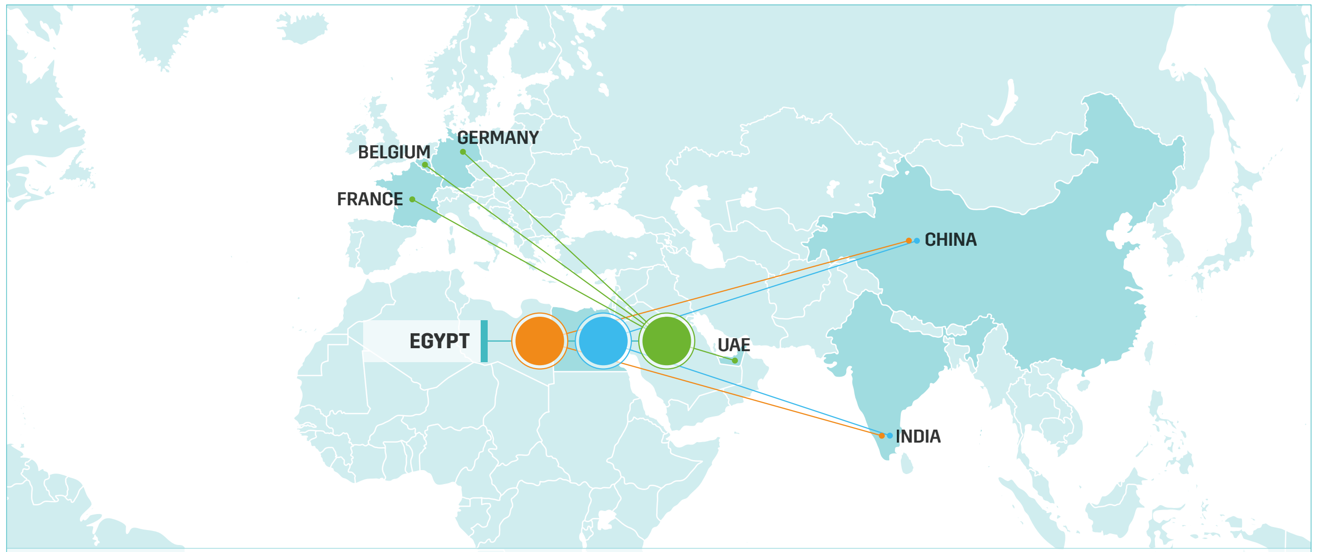


Figure 15: 2050 Export Expectations

KEY: Oil, Natural Gas, Coal, Hydrogen

A sustainable Egyptian O&G industry will continue to play an important role in the country's energy mix. O&G workers and workers in hydrogen, CCS and renewables will be required, to make up a diversified energy workforce with a transferable skillset.

Egypt's *National Climate Change Strategy*[56] expresses a focus on ensuring the equitable transformation of the current fossil fuel workforce. To transition from a hydrocarbon-dependent economy to one powered by electrolytic hydrogen and renewable energy, a huge upskilling effort across the current Egyptian workforce is required.

Due to the expected expansion of Egypt's solar and wind industries, the Egyptian Government has launched a renewable energy curriculum for students to train in next generation renewable energy. Developed in collaboration with the US Agency for International Development (USAID)[74], the curriculum was partially established to produce highly-skilled workers capable of working in the Benban Solar Park, an EGP79 billion (US$4 billion) project with a capacity of 1.8 GW[75].

Evidence of the Transition

In April 2022, Egypt's Hassan Allam Utilities and UAE major Masdar signed agreements with state-backed Egyptian organisations to develop large-scale electrolytic hydrogen projects in Egypt.

The two agreements related to facilities planned for the Mediterranean coast and Suez Canal Economic Zone (SCZONE) and are aiming for electrolyser capacity of 4 GW by 2030, and the annual production of up to 480,000 tonnes of electrolytic hydrogen[76].

A group of international project developers and private equity firms have pledged to invest US$32 billion into green hydrogen and ammonia projects in the SCZONE. In total, seven MoUs have been signed with Egyptian authorities to develop seven large-scale projects. If realised, this would deliver 3 Mt of green ammonia per year, and 2.4 Mt of green hydrogen[77].

With easy access to global markets and independent governance over its tariffs and taxes, SCZONE is positioning itself as a green ammonia export hub, and an ideal location for refuelling future vessels in a decarbonised shipping industry.

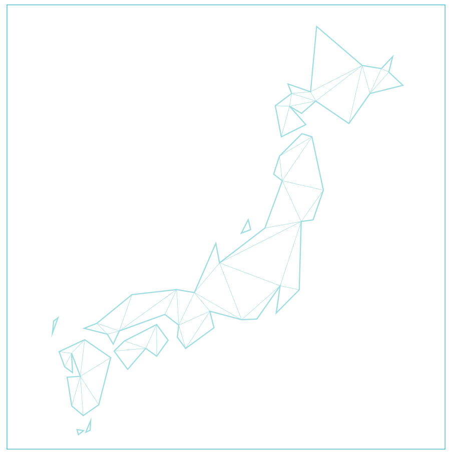
In September 2021, EGAS, an Egyptian petrochemicals holding company, signed an MoU with Japan's Toyota Tshusho, to develop low-carbon hydrogen projects using Japanese carbon capture technology, to test the feasibility of the technology in Egypt[63].

The European Bank for Reconstruction and Development (EBRD) has also pledged to finance the decommissioning of 5 GW of inefficient gas-fired power plants in Egypt from 2023 while pledging up to US$1 billion for renewables. It provides up to US$300 million in sovereign financing for projects to stabilise Egypt's grid, adding battery storage, developing the local supply chain for renewables and to retrain Egyptian workers.

A separate US$1 billion pledged for renewables would be about one-tenth of the private funding needed for 10 GW of mainly wind-powered projects planned by 2028.

Partners:

AIST



JAPAN: Context & Energy History

Establishing a stable energy supply has traditionally been a significant issue for Japan, given its lack of natural resources. Japan's rapid economic growth from the late 1950s until the early 1970s was supported by fossil fuels imported from the Middle East, which in 1973 accounted for 76% of the country's domestic supply of electricity[78].

Japan remains heavily reliant on the import of fossil fuels, which made up 84% of the country's domestic energy supply in 2019 (oil 37%, coal 25% and natural gas 22%), with the remaining 16% made up from hydro, nuclear and others[79].

However, in October 2020, the Japanese Government declared its aim to become carbon neutral by 2050, and is promoting energy conservation, diversification and decentralisation of its energy supply, to reduce its dependence on fossil fuels and increase capacity in alternative energy sources.

This process had already begun in December 2017, when Japan published the world's first national hydrogen strategy. The *Basic Hydrogen Strategy* sets out a future vision that Japan aims to achieve by 2050 and serves as an action plan to accomplish desired hydrogen technology development by 2030[80].

The strategy sets a goal for Japan to reduce hydrogen costs to the same level as conventional energy (e.g. gasoline and LNG), with integrated policies across ministries ranging from hydrogen production to utilisation.

By achieving a carbon-free society under the strategy, Japan will present hydrogen to the rest of the world as a new energy choice and will lead global efforts to establish a carbon-free society, taking advantage of Japan's strong points.

The *Green Growth Strategy Through Achieving Carbon Neutrality* in 2050 (*Green Growth Strategy*)[81] was then formulated in June 2021, which committed to making bold investments in a range of technology innovations to realise an overhaul of the existing energy system.

The *Green Growth Strategy* identifies 14 priority sectors in a range of different industries. Renewable energy (offshore wind, solar and geothermal power), hydrogen and ammonia, next-generation heat energy and nuclear power were all identified as promising sectors for the next generation of energy in Japan.

The JP¥2 trillion (US$13.7 billion) *Green Innovation Fund*[82] was established to support R&D, with each promising sector assigned an individual action plan to accelerate technology development. The action plan for the hydrogen industry, for example, lays out steps to bring hydrogen power generation turbines and fuel cell trucks into marketable products, and to strengthen supply through international hydrogen transportation and storage, to eventually reduce costs and expand capacity.

The *Green Growth Strategy* also places great focus on international collaboration, with Japanese companies encouraged to cooperate with overseas firms, and the Japanese Government signing framework agreements with the USA and the European Union (EU) to encourage such collaboration. Japan has also developed strong trade and innovation links with Australia, to accelerate the development of hydrogen and ammonia technologies.

The Japanese Energy Transition Initiative (JETI) has been established, to bring together stakeholders from finance, business, policy and civil society, to accelerate the energy transition in Japan. Its focus areas include energy policy engagement, offshore wind power, the automotive sector and the national climate investor agenda.

Japan's updated Paris Agreement target, announced at COP26, commits to reducing emissions by 46% by 2030, and a 2050 net zero target (2013 baseline year)[84].

KEY AREAS:

Japan

LACK OF NATURAL RESOURCES ESTABLISHED JAPAN AS AN ENERGY IMPORT COUNTRY, MOSTLY FOSSIL FUELS

Renewables targets for 2030:

103.5-117.6 GW SOLAR

17.9 GW ONSHORE WIND

5.7-10 GW OFFSHORE WIND

H_2

PRIORITISING HYDROGEN COST REDUCTIONS TO COMPETE WITH CONVENTIONAL GAS & LNG

46% EMISSIONS REDUCTION BY **2030**

NET ZERO BY **2050**

NH_3

PROJECTS ONGOING WITH OTHER NATIONS TO DEVELOP GREEN AMMONIA PRODUCTION

Published world's first national hydrogen strategy

Innovation Challenges by Technology

Renewables

In attempts to wean the country off imported fossil fuels, Japan has set a number of ambitious renewables forecasts for 2030 and 2050. According to the Japan Wind Power Association (JWPA), wind power could supply more than 20% of the domestic electricity demand in Japan by 2050.

Offshore wind

Area	Challenge
Electrical Infrastructure	• Optimisation of electrical infrastructure, highlighting synergies and maximising benefit from emerging technology deployment
O&M and Lifecycle	• Advanced simulation, testing and validation (related to wind condition analysis and prediction)

Japan is forecasting heavily increased onshore wind capacity by 2030, rising from 4.2 GW today to 17.9 GW[85]. The JWPA has said that as much as 38 GW will be required by 2050[86].

Japan is another country that possesses significant offshore wind resources, despite no current installed capacity. Japan is targeting between 5.7 and 10 GW offshore wind capacity by 2030, and between 30 and 45 GW by 2040[77]. Construction has begun on Japan's first commercial offshore wind farm in the coastal waters of Akita, costing a total of ¥100 billion (US$683 million).

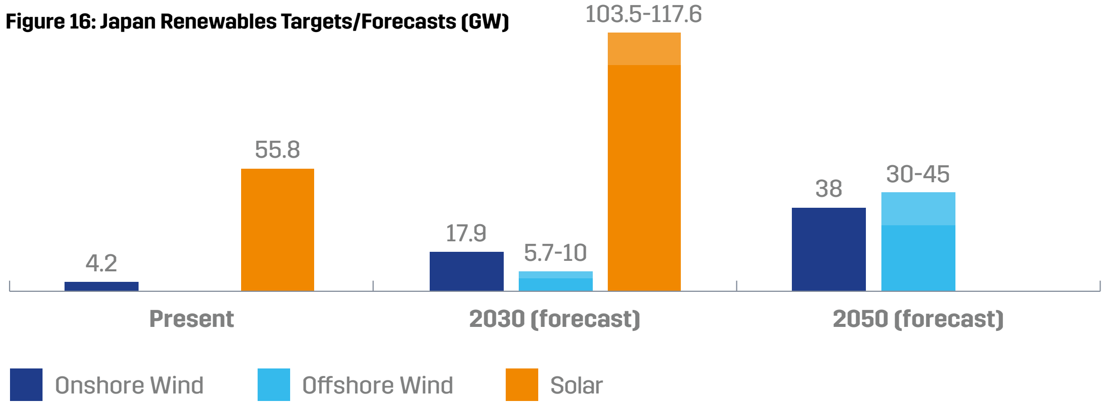
Japan possesses one of the world's largest residential solar markets[87]. The country's current solar capacity sits at 55.8 GW, with forecasts projecting this to increase to between 103.5 and 117.6 GW by 203078.

Solar

Area	Challenge
Heat Management	• Effective management of heat to maximise conversion efficiency and drive the commerciality of solar power technologies

Japan's rapid renewable expansion will increase the security of its national supply and allow the country to reduce its reliance on foreign imports.

Figure 16: Japan Renewables Targets/Forecasts (GW)



Low-carbon Hydrogen

Area	Challenge
Production	• Facilities and services for process demonstration to drive scale-up and cost reduction at pace • High-efficiency production technology of green ammonia
Transport and storage	• High-efficiency and low-cost production technology of LOHCs • Substantial efficiency improvements in liquefaction technology

Japan is prioritising hydrogen cost reductions rather than capacity targets. Released in December 2017, Japan's *Basic Hydrogen Strategy* was the world's first national strategy for hydrogen. It provided a strategy and action plans for both 2030 and 2050 which aim to ultimately reduce hydrogen production costs to the same level as conventional gasoline and LNG.

The strategy seeks to overcome technological challenges and secure economic efficiency in three steps: phase 1 refers to the dramatic expansion of hydrogen use from present, through expanding the use of fixed fuel cells and fuel cell vehicles (FCVs), which it hopes to become a world leader in; phase 2 is the full-fledged introduction of hydrogen power generation and establishment of a large-scale hydrogen supply system by the second half of the 2020s; and phase 3 is the establishment of a CO_2-free hydrogen supply system on a total basis by 2040.

Japan is also interested in green ammonia production as a means of storing and shipping electrolytic hydrogen, and is undertaking a variety of projects with Australian-based organisations to develop technology capabilities and build hydrogen economies in both countries. The two countries have also established a *Clean Hydrogen Trade Program* worth AUS$150 million (US$94 million), to accelerate the development of an Australian hydrogen export industry that could become the supplier of choice for Japan and the region.

AIST is involved in this collaboration and is also hosts of the RD20 collaboration which looks to prioritise R&D into clean energy technologies, where hydrogen is a key focus area. CSIRO, another member of this collaboration, offers an Australian perspective, with further centres representing Brazil, Canada, South Africa, Germany and France, among others.

In June 2021, the Keidanren (Japan's Business Federation) published its *Urgent Policy Proposal Toward Achieving Green Growth*[88], which provided innovative recommendations for the private sector to align with government targets regarding net zero by 2050. It strongly promotes developing visions for carbon neutrality by 2050 and recommends the development and deployment of innovative emissions reduction technologies. Hydrogen was flagged as a priority, ideally in partnership with international industry partners.

CASE STUDY:
Large-Scale Hydrogen Supply Chain Establishment

In addition to enlarging the transportation facilities, and other resources including hydrogen carriers, the project will implement demonstrations of hydrogen power generation at an actual power plant (co-combustion with other fuels and single-fuel combustion using hydrogen only). The aim is to establish technologies that will make reducing supply costs possible along with creating a large-scale demand for hydrogen, and to achieve a hydrogen supply cost competitive with fossil fuels by 2030. A target supply cost of JP¥30/Nm³ (US$2.30/kg) is set for 2030, and JP¥20/Nm³ (US$1.60/kg) or below by 2050. This project is funded by Japan's national Green Innovation Fund.

www.green-innovation.nedo.go.jp/en/project/hydrogen-supply-chain

Key info/numbers:

TARGETING SUPPLY COST COMPETITIVE WITH FOSSIL FUELS BY
2019

USING LIQUEFIED HYDROGEN AS A
CARRIER

FUNDED BY JAPAN'S NATIONAL
GREEN INNOVATION FUND

Partners: New Energy and Industrial Technology Development Organisation (NEDO), Japanese Ministry of Economy, Trade and Industry (METI)

CCUS

Japan's *Roadmap for Carbon Recycling Technologies* outlines how the country will look to capture and reuse CO_2 for concrete, chemicals and fuel production. It specifies goals, technological challenges and timeframes, and will accelerate innovation by sharing common goals among government officials, private companies, investors and researchers in Japan. It was revised in July 2021 to reflect accelerating R&D and commercialisation of capture technologies, and further accelerate efforts towards carbon recycling.

Japan's largest oil company, ENEOS, and utilities provider, J-Power, have jointly announced the launch of the country's first CCS project by 2030. As well as storing CO_2 emitted from coal-fired power plants, the project will also extract hydrogen from biomass, and capture and store the CO_2 by-product underground.

In 2022, Japan's Ministry of Economy, Trade and Industry announced plans to create a legal framework for CCS to enable companies to start storing CO_2 underground or under the seabed by 2030. The Ministry estimates that Japan will store between 120 and 240 $MtCO_2$ per year in 2050[89]. The framework will include a scheme to transport CO_2 emitted in Japan to other countries. A national, long-term CCS roadmap for Japan is also expected before the end of 2022.

Hydrocarbon Emissions Reduction

As an import country, Japan does not have a large-scale O&G industry, and consequently the reduction of emissions associated with hydrocarbon production is not a priority in Japan.

Impact of the Transition

Economics

Japan's *Green Growth Strategy* predicts the formation of an integrated net zero energy system will have an economic impact of approximately JP¥140 trillion (US$956 billion) in 2030 and JP¥290 trillion (US$2 trillion) in 2050. It's also expected to employ a total of approximately 8.7 million people in 2030, and 18 million in 2050[75]. A study assessing the potential economic employment impact from renewable energy found that total job creation in renewables-related construction and manufacturing would outweigh any loss in mining, construction of thermal power and thermal power generation employment. However, this job creation will spike in 2050, leading to the possibility of workforce shortages unless Japan invests in upskilling and producing a workforce capable of meeting demand[90].

Recent government predictions illustrate how more than JP¥150 trillion (US$1 trillion) of both public and private investment over the next 10 years will be crucial if Japan is to meet its net zero goals[91]. The Japanese Prime Minister has promised an investment roadmap, with an outlook of JP¥20 trillion (US$137 billion) in government support. The roadmap will also include incentives for private investors[92].

KEY NUMBERS:

A JAPANESE NET ZERO ENERGY SYSTEM WILL HAVE AN ECONOMIC IMPACT OF **US$956B** BY 2030, AND **US$2T** BY 2050

8.7M PEOPLE ARE EXPECTED TO BE EMPLOYED IN ENERGY IN JAPAN BY 2030, AND 18 MILLION BY2050

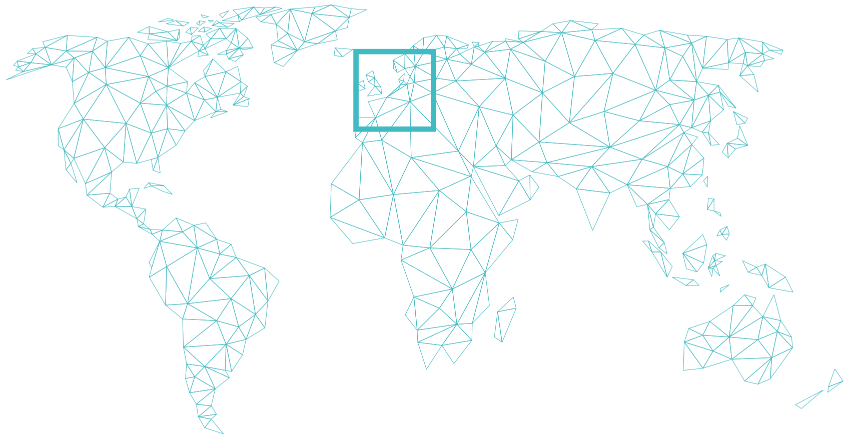
A NATIONAL SHORT-TERM INVESTMENT ROADMAP IS AWAITED, PREDICTED TO INCLUDE **US$137B** OF INITIAL GOVERNMENT SUPPORT

MORE THAN **US$1T** PUBLIC AND PRIVATE INVESTMENT IS REQUIRED TO MEET NET ZERO

Exports

As an energy import country, Japan does not export O&G and does not see any opportunities in the export of hydrogen, or in selling carbon sequestration to other countries.

Partners:



THE NETHERLANDS: Context & Energy History

The Netherlands has established itself as a European hub for global energy trade, mostly in fossil fuels, and the country's domestic energy consumption is also dominated by O&G. Rotterdam is the biggest port in Europe, and plays a key role in providing a reliable energy supply for North-West Europe, while the port of Amsterdam is the largest distributor of transportation fuels (including gasoline, petrol and aviation fuels) in the world. Decarbonisation represents a significant challenge, both to domestic supply and the Dutch economy as a whole.

Currently the country's domestic energy consumption is dominated by O&G, as well as petroleum being one of its largest import and export products. Since the 1960s, the Netherlands has been extracting gas onshore (from Europe's largest natural gas field in Groningen). Given its extensive national gas reserves it has developed an extensive gas grid, including temporary gas storage locations in underground salt caverns and depleted reservoirs.

The Netherlands is, therefore, strategically positioned to utilise these resources to transition to low-carbon gases. Given the current reliance on gas, including imports, decarbonisation represents a significant challenge.

The focus of Dutch energy policy is to transition to a low-carbon society, with government setting various ambitious targets to overhaul the energy system. A strong focus has been placed on offshore wind and hydrogen production.

Between 3 to 4 GW of hydrogen electrolyser capacity is targeted by 2030[93], which will be supplemented by significant offshore wind deployment, driven by the Offshore Wind Energy Roadmap. Targets have been set to increase offshore wind capacity from 2.5 GW today to 4.5 GW by 2023, and 21 GW by 2030, which would represent 75% of the country's current electricity consumption[94].

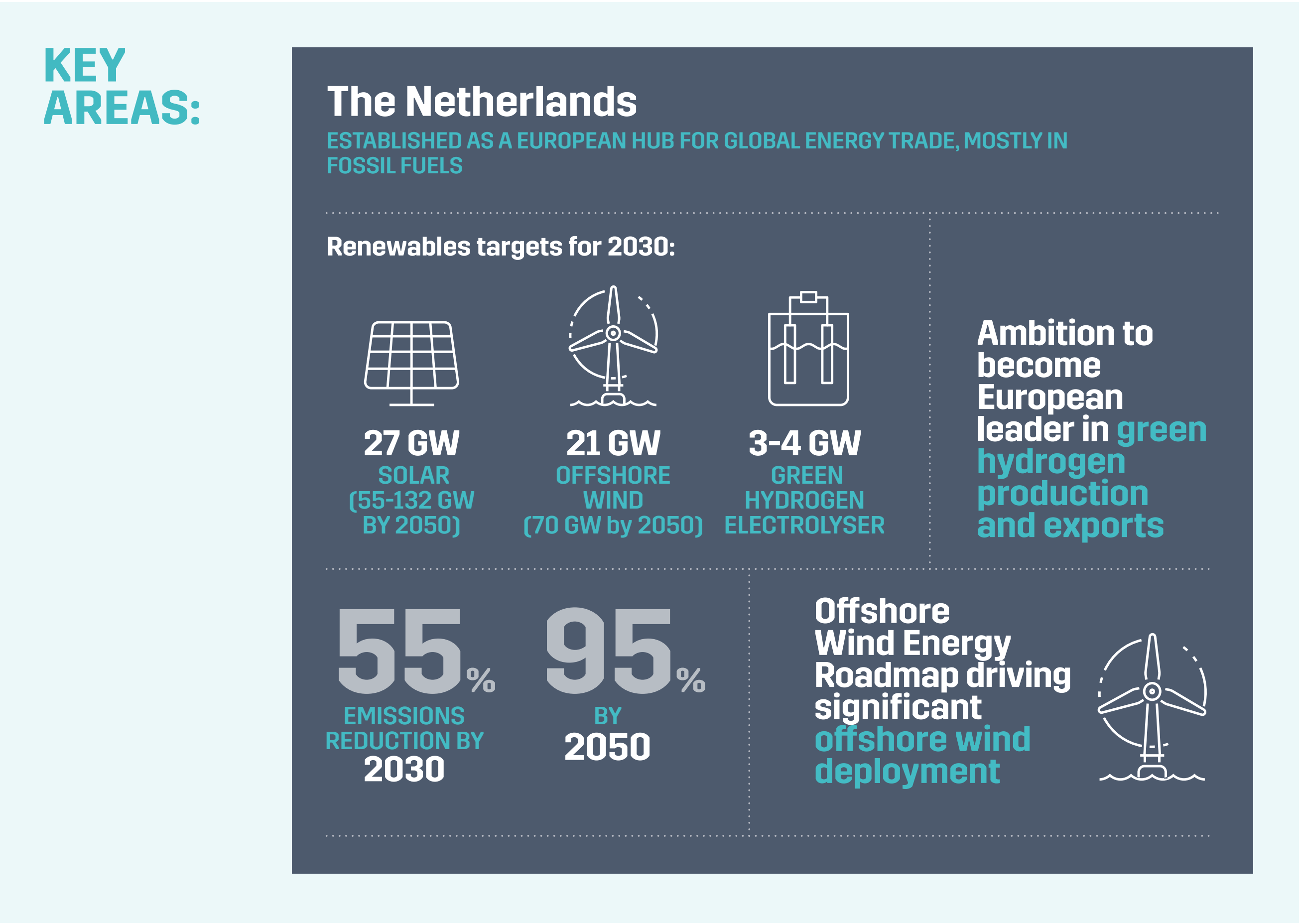
Further development of offshore wind is planned, with targets of 50 GW in 2040 and a maximum of 70 GW by 2050[95], which will be pivotal in terms of both providing clean electricity to the grid and establishing the Netherlands as a leading electrolytic hydrogen exporter to the rest of Europe.

In the Netherlands today 73% of energy use is relatively evenly split between direct gas use, transport, and in products/raw materials[96]. Where the use of gas remains, this will likely be replaced with electrolytic hydrogen and biogas gas. Significant emissions reductions (circa 14.3 $MtCO_2$) are planned in the industrial sector[97], especially in steel production and oil refineries, by transitioning to renewable energy and clean hydrogen.

To inspire technology innovation, the Dutch Government has introduced the S*timulation of Sustainable Energy Production Scheme*[98], which uses competitive auctions to award subsidies to renewables, hydrogen and carbon capture technologies, based on avoided CO_2 emissions. All technologies will compete with each other for cost effectiveness, and those technologies that are able to prevent the most CO_2 emissions at the lowest price will receive the subsidy. A 2022 budget of €13 billion (US$12.6 billion) was made available for all phases and categories combined.

The Dutch Government has also announced plans to oversee a new €35 billion (US$34 billion) climate transition fund. This includes €15 billion (US$15 billion) solely for the research and development of 'advanced renewable energy carriers'. Electrolytic hydrogen and e-fuels are expected to be at the top of the priority list[99].

The Dutch National Climate Agreement, passed in 2019, set legally binding targets to reduce GHG emissions by 49% by 2030 and 95% by 2050 (1990 baseline year), and for 100% of electricity to come from renewable sources by 2050. The 2030 target has subsequently been raised to 55%, to align with the establishment of EU targets[100]. However, no national net zero target has been confirmed.



Innovation Challenges by Technology

Renewables

Offshore wind

Area	Challenge
Electrical Infrastructure	• Optimisation of electrical infrastructure, highlighting synergies and max-imising benefit from emerging technology deployment
O&M and Lifecycle	• Improved autonomous systems (air, land and sea) • Optimisation of services associated with the operation, conditioning mon-itoring and maintenance of wind turbines across the asset lifecycle

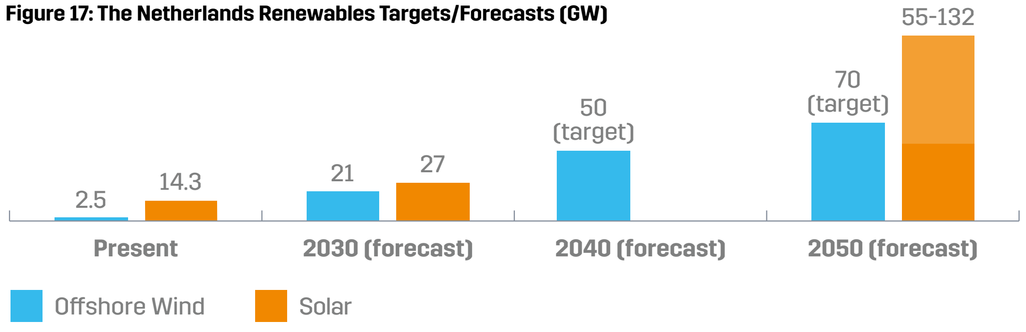
The Netherlands is aiming to align with European targets to increase its share of renewable energy to at least 32% of total energy consumption by 2030, targeting mainly solar and offshore wind[101]. There is also a strong focus on increasing renewable energy developments to support low-carbon hydrogen production, to prevent the Netherlands relying completely on importing hydrogen to reach 2050 targets.

Solar projects are also increasing yearly, second to wind developments. TNO forecasts solar capacity to increase from 14.3 GW in 2022 to 27 GW by 2030, and between 55 and 132 GW by 2050[102]. Given the high population density of the Netherlands, land space is limited and hence there are currently 14 floating solar parks, although the largest parks are still on land. The majority of wind energy in the Netherlands currently comes from onshore sources (some 60%)[103]. Seven Dutch offshore windfarms currently operate in the North Sea, and there are existing plans for considerable offshore wind expansion.

The Netherlands currently has around 2.5 GW installed offshore wind capacity, with the *Offshore Wind Energy Roadmap* driving deployment to take advantage of the North Sea's considerable offshore wind resource[87]. Following the Russian invasion of Ukraine, the Dutch Government published a new *Wind Strategy*, announcing plans to double wind production targets to reduce its dependency on Russian gas. The 2022 strategy designated three new areas for offshore wind farms and confirmed two previously designated, which will unlock a total of 10.7 GW additional capacity by 2030, on top of the previously planned 11 GW. The Netherlands is, therefore, aiming to install a total 21 GW capacity by 2030, which would consequently supply 75% of the country's current electricity consumption[104]. The Dutch Government also released updated growth ambitions for offshore wind, with targets of 50 GW in 2040 and 70 GW in 2050.

The Dutch Government is also ramping up its energy storage ambitions, with an estimated 29 to 54 GW of energy storage capacity expected to be required by 2050. The largest energy storage system in the country – Wärtsilä's GIGA Buffalo battery, with a 25 MW capacity – is currently in development to help stabilise the grid[105].

Figure 17: The Netherlands Renewables Targets/Forecasts (GW)



Low-carbon Hydrogen

Area	Challenge
Production	• Facilities and services for process demonstration to drive scale-up and cost reduction at pace • Biomass gasification technologies for hydrogen production • High-efficiency production technology of green ammonia • Improve electrolysis processes leveraging novel materials to address cost, efficiency and durability challenges • Large-scale storage of hydrogen in depleted reservoirs (onshore and offshore)

With the focus on renewables to supply electrical grid demand, the Dutch Government's *Strategy on Hydrogen* is instead targeting industrial clusters for hydrogen deployment, to heat buildings in parts of the country, and in refuelling stations for transport. The aim is for hydrogen to also support the intermittency of renewable energy supply.

Countries with cheap renewable energy will focus on the export of hydrogen, the Netherlands will be able to act as an energy hub for the future integration of clean hydrogen due to its favourable location, its ports (especially Rotterdam) and its extensive gas grid and storage capacity. Intercontinental transport will most likely take place by sea, while the transport of hydrogen across Europe by pipeline will be the cheapest option. Import of electrolytic hydrogen is expected to start around 2025 in the ports of Rotterdam and Amsterdam. Both liquid H2 and ammonia are being considered for import.

Following the Russian invasion of Ukraine, and the consequent sanctions on Russian imports, energy security has become a major global concern, with many European countries especially assessing alternative options for fulfilling domestic energy demand (in 2021, the EU imported over 40% of its total gas consumption from Russia)[106]. The Netherlands, having become increasingly dependent on natural gas imports due to its domestic gas supply slowing over the last decade, is now placing greater emphasis on the development of a hydrogen market to fulfil domestic requirements and to position itself as an exporter of clean hydrogen to the rest of Europe.

Overall, European countries are focused on increasing low-carbon hydrogen capacity, both electrolytic and from natural gas with associated CCS. The greatest challenge remains in upscaling electrolyser capacity to allow for the production of electrolytic hydrogen through renewable sources. The Netherlands is targeting 3 to 4 GW of electrolyser capacity by 203086, which is a big leap given that current production in on the megawatt scale.

CASE STUDY:

PosHYdon

13 km off the coast of Scheveningen, Neptune's O&G platform Q13A is the first fully electrified platform in the Dutch North Sea. Following a feasibility study by TNO and Nexstep, the Q13A platform has been chosen for the two-year PosHYdon project to produce electrolytic hydrogen from seawater. The hydrogen production unit of 1 MW capacity is small enough to fit on the platform. Electricity is currently supplied from shore but the plan is to transition to offshore wind energy in the future and hence the expected fluctuations in electricity will be simulated in this project. The electrolytic hydrogen will be mixed with the gas and transported via the existing gas pipeline to the coast.

www.poshydon.com

Key info/numbers:

OFFSHORE ELECTROLYTIC HYDROGEN PRODUCTION, VIA A **1 MW** ELECTROLYSER

€3.6M ($US3.5 MILLION) SUBSIDY FROM DUTCH GOVERNMENT

FIRST **FULLY ELECTRIFIED** PLATFORM IN THE DUTCH NORTH SEA

Partners: Neptune, TNO, Nexstep, Dutch Government, 11 other partners

CCUS

Area	Challenge
General	• Timely, accelerated cluster delivery to achieve large-scale, full-chain projects
Transport	• Mature CO_2 transportation networks to drive a circular carbon economy
Storage	• Advanced digital technology to drive efficient geological behaviour prediction and modelling • Improved modelling strategies to support storage capacity appraisals and safe injection site mapping • Long-term liability and transfer of assets

The Dutch Government is encouraging CCS development in the North Sea, promoting permanent storage in depleted gas fields and also the utilisation of captured CO_2. CCS is seen as a transition technology in the Netherlands, with short-term deployment encouraged, and no new subsidies planned after 2035. The Dutch Government is focussed on CCS application in hard-to-abate sectors, which is reflected in Government policy.

The Netherlands' *2019 Climate Agreement*[90] sets a target to reduce industrial emissions by 14.3 million tonnes by 2030, with CCS a key enabler. CCS is also seen as a technology to support the short-term deployment of reformed hydrogen as part of a longer-term transition to electrolytic hydrogen.

CCS activities in the Netherlands take place under the CATO initiative, a national R&D programme for CO_2 capture, transport and storage. The programme is funded by government institutions and industry, features a consortium of nearly 40 partners, and is now in its third phase.

The Dutch Government introduced increased penalties for emitting CO_2 through a new carbon tax that tops up the EU emissions trading scheme (ETS) price, to stimulate CCS in the Netherlands. The Government is hoping this will incentivise further CCS projects in the region, alongside a contract for difference scheme (SDE++)[107]. CCS will be subsidised for a maximum of 7.2 Mt of the total 14.3 Mt of emissions reductions in the industrial sector by 2030[93].

The Netherlands currently has the most developed CCS project under EU regulation, Porthos, which will make a final investment decision in 2022 and is based in the Port of Rotterdam. If it reaches its operational phase, Porthos will store around 37 Mton CO_2 – approximately 2.5 Mton CO_2 per year for 15 years[108].

The second CCS project in development in the Netherlands is Aramis, which will also have a collection hub in Rotterdam but will store CO_2 in more northerly fields in the Dutch North Sea[109]. This project aims to come into operational phase in 2026 transporting and storing approximately 5 Mton CO_2 per year. Partners are Shell, EBN, Gasunie and TotalEnergies.

Hydrocarbon Emissions Reduction

Area	Challenge
Decarbonisation of power	• Electrification and alternative energy sources for offshore assets
Venting and flaring	• Enhanced gas recovery and storage options
Production	• Accurate detection and quantification of fugitive emissions

The Netherlands has previously targeted being completely gas-free by 2050, but the delicate geopolitical situation in Europe means plans to decrease hydrocarbon extraction are coming into question. The Netherlands operates the largest gas field in Europe (the Groningen gas field) which was due to cease production in mid-2022. The Russian invasion of Ukraine and concerns over long-term energy supply has led to the planned closure of this field being questioned, with Government advisors suggesting it should be used to help provide emergency winter reserves.

The Netherlands Oil and Gas Exploration and Production Association (NOGEPA – now ElementNL) – which represents 12 member companies with licences to explore for and produce O&G onshore and offshore – is calling for more clarity on the sector's direction, and for clear 2030, 2040 and 2050 targets, highlighting the UK's North Sea Transition Deal (NSTD) as an example.

Impact of the Transition

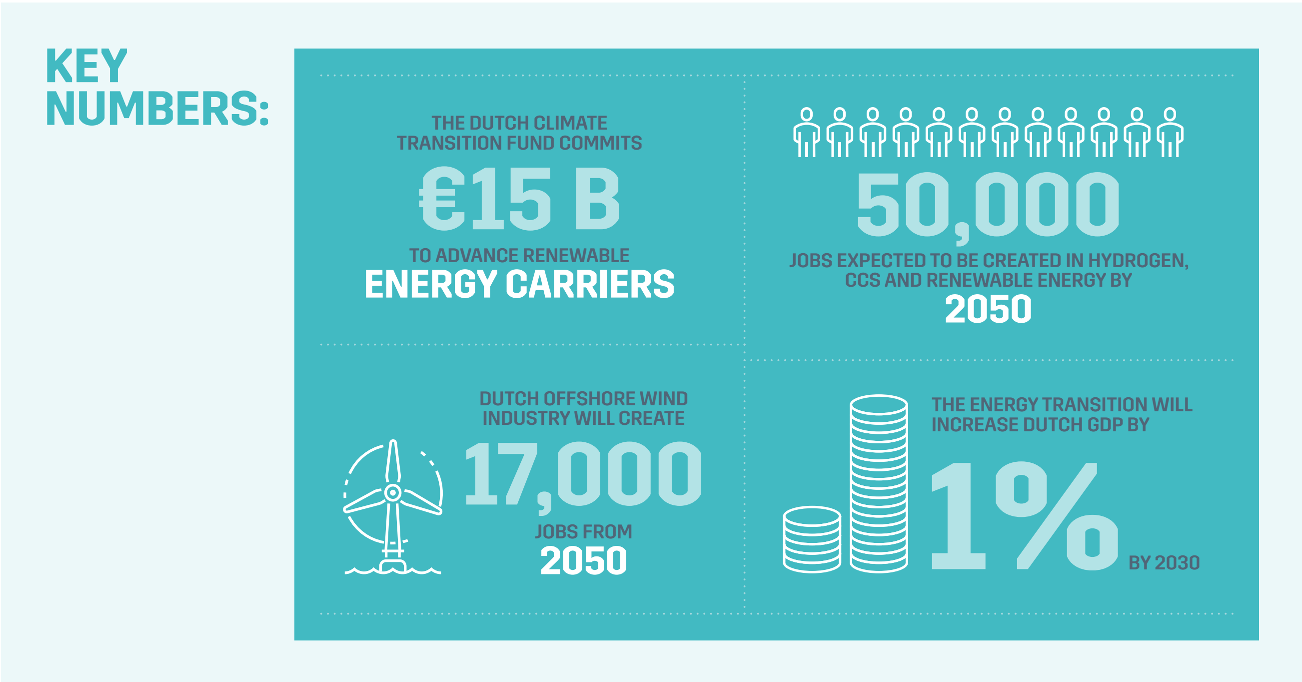
Economics

Employment in O&G in the Netherlands will naturally decline in the coming years, with jobs arising in alternative industries. Hydrogen, CCS and renewable energy could create up to 50,000 new jobs in the Netherlands by 2030 and increase GDP by almost 1%[110].

By 2050, however, the Dutch electrolytic hydrogen industry alone could preserve and create up to 100,000 jobs[111]. About two-thirds of these jobs, notably in heavy industry, would otherwise have been phased out with fossil fuels, while the remaining third are new jobs created by the introduction of hydrogen. The Netherlands' low and high demand hydrogen scenarios predict that twice the demand for electrolytic hydrogen would lead to four times as many jobs by 2050[112].

The Netherlands has the highest subsidies per GW of electrolyser capacity, committed at €1.43 billion (US$1.39 billion)[113]. This calculation leads to the assumption that the Dutch Government will put at least €5 billion (US$4.9 billion) aside for hydrogen out of the €15 billion (US$15 billion) committed to advanced renewable energy carriers in the Climate Transition Fund.

A study on what employment will look like in the Dutch offshore wind industry post-2030 indicates that offshore installation will supply 17,000 jobs, while operations and management employment will add around 600 jobs per installed 10 GW capacity[114].



Exports

The Netherlands has traditionally exported vast quantities of natural gas to European neighbours, with main export partners being the UK, Denmark, Belgium, Germany and Italy. However, TNO forecasts that, from 2050, the Netherlands will no longer export any fossil fuels.

However, the development of hydrogen export capabilities in the Netherlands will allow the country to maintain European trade relationships, predominantly with Belgium, France and Germany.

TNO also believes there may be opportunities to sell carbon sequestration in the North Sea to these countries.

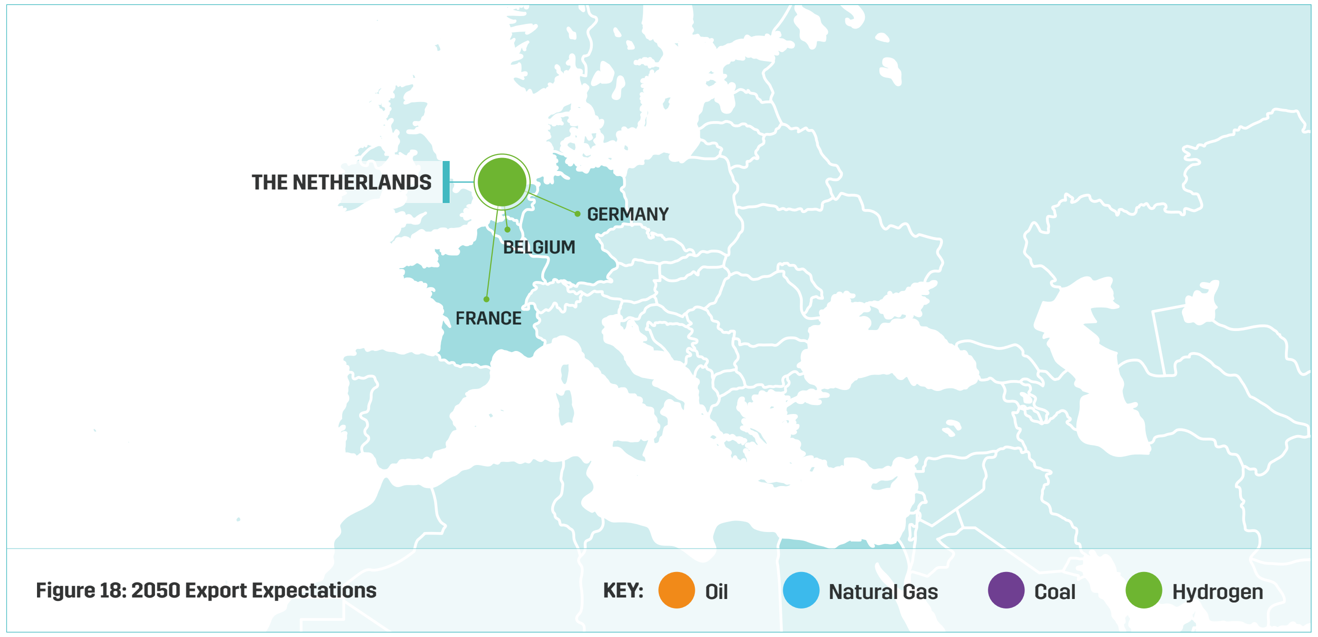


Figure 18: 2050 Export Expectations

Skills

The Netherlands has strong O&G expertise which could be utilised in depleted gas fields where they are used as CO_2 storage sites or at a smaller scale for energy storage (e.g. hydrogen reservoirs). For CCS particularly, the Netherlands has extensive knowledge on the characteristics of depleted gas fields which could be ideally suited for informing CO_2 storage. This knowledge could be transferred internationally where O&G fields are yet to become depleted.

A major skill currently required is in the installation and constructions sector given a strong need for technicians to install the required energy transition technologies. In 2018 it was noted that around half the companies in this sector had skills shortages that were difficult to fill[115].

Jobs will also be lost particularly in the coal sector, with the five remaining coal power plants set to close before 2035. These currently employ some 2800 people[109]. It is thought that an increase of jobs in the petrochemical sector and in producing wind turbine components may help to alleviate this job loss.

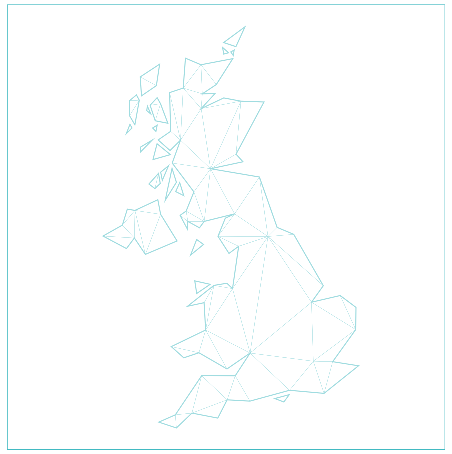
Evidence of the Transition

Nexstep has been established by the Dutch Government to stimulate collaboration in the re-use of O&G infrastructure in the Dutch North Sea. Nexstep is supporting industry and policy development to see if this infrastructure can be repurposed for CCS, geothermal energy, hydrogen production or offshore wind, prior to decommissioning.

Netherlands-based operators have repositioned over the past two years from 'oil and gas' to 'energy', investing heavily in renewables, hydrogen, biofuels, CCS and digital technology projects to decarbonise operations, enhance efficiency and deliver low-carbon energy alternatives.

O&G majors in the Netherlands, such as Shell, TotalEnergies, Neptune Energy and Taqa Energy are all investing in CCS. Neptune Energy is investing heavily in PosHYdon, which represents the world's first pilot project for offshore hydrogen production, and is currently under construction, while multiple large-scale electrolytic hydrogen production facilities connected to offshore wind have been announced by Shell, including the NorthH2 and Holland Hydrogen I projects.

In 2021, Shell was taken to court by a Dutch non-governmental organisation (NGO), in a landmark court ruling that could trigger legal actions against O&G companies in the Netherlands and all around the world, if they fail to reduce carbon emissions and set realistic net zero targets. Driven by strong public support, the Hague District Court ordered Shell, both directly and via its group companies, to cut scope 1, 2 and 3 carbon emissions by 45% by 2030, compared to 2019 levels[116].



UNITED KINGDOM: Context & Energy History

The O&G industry in the UK North Sea has been central to the UK's energy, industry and economy for the past 50 years, developing world leading offshore exploration and production capabilities.

While the UK is considered a world leader in decarbonisation policy and action, the war in Ukraine and soaring gas prices have also emphasised the importance of UK energy security.

As outlined in the UK Government's landmark *British Energy Security Strategy*, the UK is striving to deliver greater clean energy independence and a homegrown low-carbon economy, with a short-term focus on improving energy efficiency and exploiting domestic oil and gas reserves, and a long-term focus on accelerated deployment of renewable and low-carbon technologies.

The UK has the highest potential for wind generation capacity across Europe, mainly from offshore wind potential in the North Sea. When combined with the UK's expertise in offshore design, engineering and operation and its history of innovation, the country is well-positioned to be a global leader in offshore wind, both floating and fixed.

The UK Government has committed to a 'twin track' approach to hydrogen, with the *British Energy Security Strategy* doubling previous targets to 10 GW of low-carbon hydrogen capacity by 2030. This supports both electrolytic hydrogen – which will make up at least 50% of the total target – and hydrogen produced by the steam reforming of methane[117]. World-leading offshore wind, electrolyser capability and CCS clusters will all be pivotal.

Energy technology innovation is central to the UK's decarbonisation strategy. The flagship *Net Zero Strategy*[118] commits to investment across the transition, including offshore wind (£380 million (US$419 million)), GHG removals (£100 million (US$111 million)), and £1.5 billion (US$1.7 billion) to support net zero innovation projects.

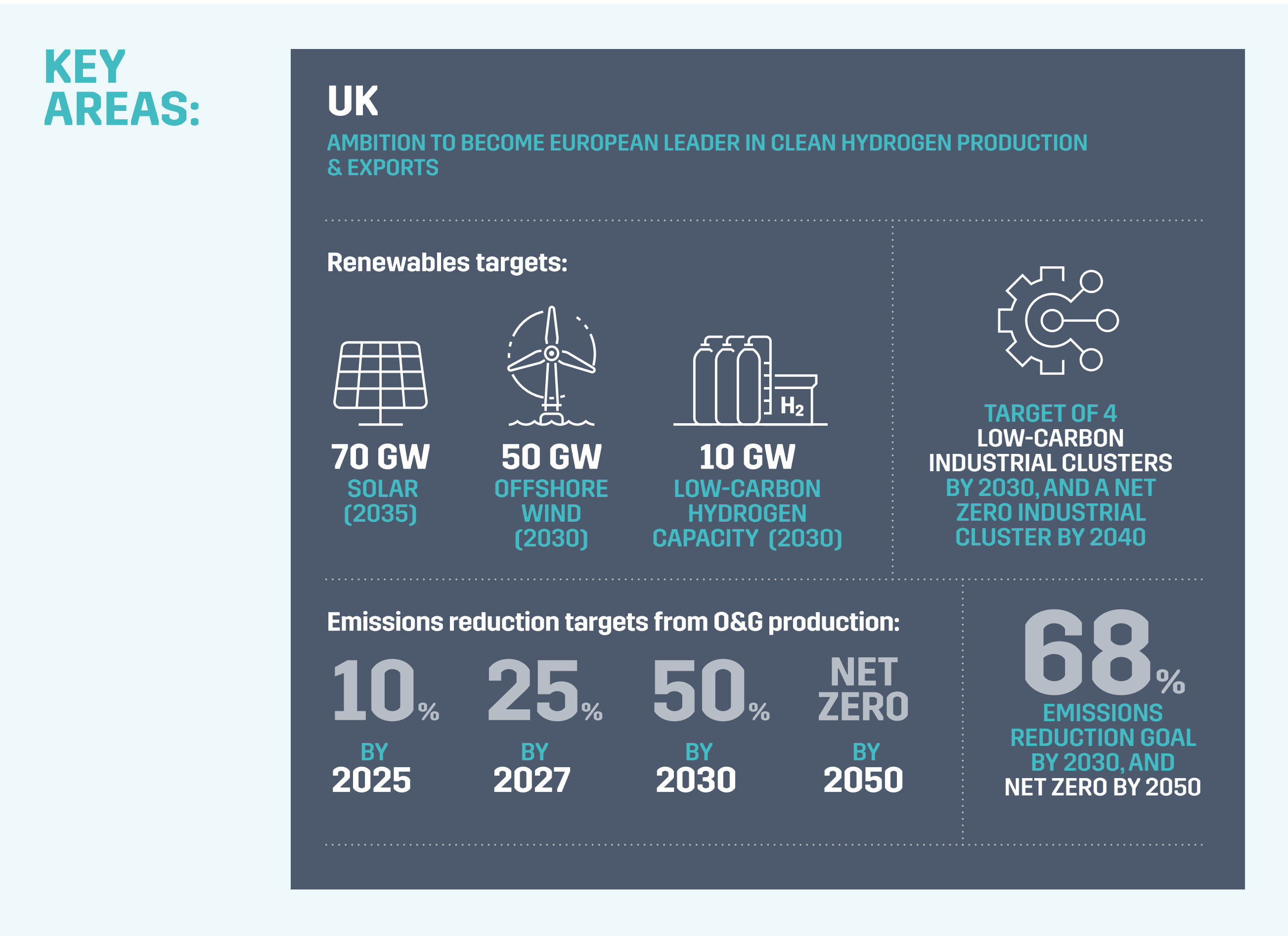
The *UK Hydrogen Strategy* included £240 million (US$266 million) for a Net Zero Hydrogen Fund111, while the NSTD[119] – which seeks to harness the power of UK offshore O&G to deliver net zero – has committed to delivering up to £16 billion (US$17.7 billion) of investment in new energy technologies by 2030.

The *British Energy Security Strategy* sets out a number of further ambitions, including a 50 GW offshore wind target – with 5 GW of floating offshore wind – and a tripling of nuclear output to 24 GW by 2050, which will be key to helping meet the country's future electricity demand.

The strategy also states that "*net zero is a smooth transition, not an immediate extinction, for oil and gas*"[120]. A quarter of the gas used in the UK today may still be being consumed in 2050. Some O&G production will continue, to extract some of 7.9 billion barrels of oil and 560 billion cubic metres of gas that remain under UK seas.

The UK Government's *Industrial Decarbonisation Strategy* also outlined the aim to establish four low-carbon industrial clusters by 2030, and a net zero cluster by 2040[121]. The cluster approach refers to the decarbonisation of places where related, energy-intensive industries – such as chemicals, glass, oil refining, iron and steel – are co-located. The clusters in the UK are responsible for approximately 50% of the country's industrial carbon emissions.

The UK has already delivered a 50% reduction of its GHG emissions since 1990, but further efforts are required. In 2019, the UK became the world's first major economy to legislate a 2050 net zero target, in addition to a 68% reduction in emissions by 2030 and 78% by 2035 (1990 baseline year)[122].



Innovation Challenges by Technology

Renewables

Offshore wind

Area	Challenge
Electrical Infrastructure	• Optimisation of electrical infrastructure, highlighting synergies and max-imising benefit from emerging technology deployment
Substructures	• Standardisation of designs for floating substructures that improve perfor-mance
O&M and Lifecycle	• Optimisation of services associated with the operation, conditioning mon-itoring and maintenance of wind turbines across the asset lifecycle

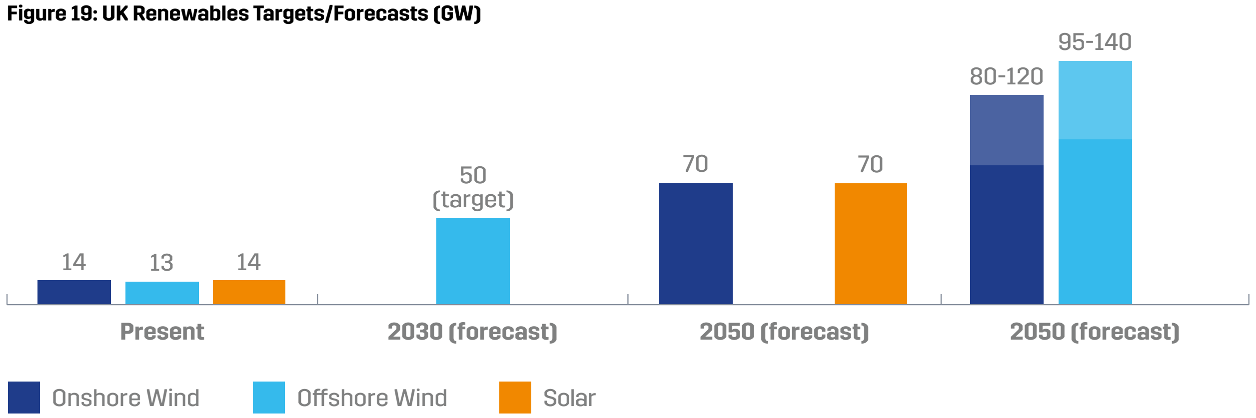
The UK's onshore wind capacity currently sits at around 14 GW. The UK's Climate Change Committee – the advisor to the UK Government on emissions targets – advised a doubling of this to 25 to 30 GW in all its net zero scenarios by 2050, while the industry trade body, RenewableUK, has urged government to set a capacity target of at least 30 GW by 2030. However, no official target has yet been confirmed[123].

The *British Energy Security Strategy* does not set a firm target for solar power, but the Government has an expectation for it to increase five-fold to 70 GW by 2035, rising from today's 14 GW[124]. Solar Energy UK, which represents over 300 members, predicts that as much as 80 to 120 GW may be required by 2050[125].

However, the main focus of UK renewable policy has been on the offshore wind sector to leverage the UKCS's considerable offshore wind resource, building on the currently installed 13 GW[126]. The Offshore Wind Sector Deal[127] commits to £48 billion (US$53.1 billion) investment in UK infrastructure by 2030, and the UK has targeted 50 GW of offshore wind capacity by 2030, of which 5 GW will be floating (following on from the building of the world's first floating offshore wind farm off the Aberdeenshire coast). By 2050, the CCC's *Balanced Net Zero Pathway* includes 95 GW of offshore wind capacity[128], rising to 140 GW in its most ambitious scenario.

Despite a lack of concrete renewables targets for 2030 and 2050, the CCC scenarios provide pathways for the rollout of renewables compatible with net zero by 2050 (the figure below shows the *Balanced Net Zero Pathway* scenario and the most ambitious *Widespread Innovation* scenario). Across all scenarios, offshore wind is the backbone of electricity generation in the UK, with onshore wind doubling in capacity but playing a declining role in the coming decades. Meanwhile, solar provides 10 to 15% of generation across all scenarios in 2050.

Figure 19: UK Renewables Targets/Forecasts (GW)



Crown Estate Scotland has also secured almost £700 million (US$774 million) through the ScotWind offshore wind leasing round, selecting 20 projects to reserve rights to specific areas of seabed, to develop offshore wind capacity. The expected capacity totals nearly 30 GW, with floating wind farms accounting for almost 18 GW[129].

Low-carbon Hydrogen

Area	Challenge
Production	• Facilities and services for process demonstration to drive scale up and cost reduction at pace • Seawater electrolysis to enable offshore hydrogen production • Improve electrolysis processes leveraging novel materials to address cost, efficiency and durability challenges
Transport and storage	• Large-scale storage of hydrogen in depleted reservoirs (onshore and off-shore)

The UK's *Hydrogen Strategy* and *British Energy Security Strategy* commit to a 'twin track' approach to hydrogen production, supporting both blue and electrolytic production.

Following the Russian invasion of Ukraine and the consequent sanctions on Russian imports, the UK doubled its low-carbon hydrogen target from 5 to 10 GW by 2030. At least 5 GW of this target will be electrolytic (including 1 GW by 2025).

While production in the early 2020s will be from small projects of up to 20 MW (rising to 100 MW by the mid-2020s), the first low-carbon hydrogen production facilities will be developed within industrial clusters, which will be used as significant potential demand centres111. Unlocking demand will help scale-up the hydrogen economy and support the development of a UK hydrogen network. The UK expects to have multiple large-scale facilities by 2030, following which a wider range of technologies could emerge, including hydrogen from nuclear along with carbon-negative bio-hydrogen with CCS.

In addition to the UK's *Hydrogen Strategy*, Scotland also has a designated *Hydrogen Action Plan* that commits to a 5 GW target for low-carbon hydrogen by 2030 and 25 GW by 2045. The 5GW goal translates to approximately 27.5 TWh of hydrogen, nearly a sixth of Scotland's 161 TWh total annual energy demand[130].

The ScotWind leasing round, and subsequent rapid deployment of offshore wind technologies, is intended largely to help position Scotland as an early leader in electrolytic hydrogen production.

CASE STUDY:

HyNet North West

The HyNet Low Carbon Hydrogen Project comprises the development and deployment of a 100 kNm3/hr hydrogen production and supply facility, including CCS. The project will produce, store and distribute hydrogen to decarbonise the North West of England and North Wales. Together with CCS, these technologies have the potential to reduce emissions by 10 mT CO_2 every year by 2030.

www.hynet.co.uk

Key info/numbers:

LOW-CARBON **HYDROGEN AND CCS** DEPLOYMENT

WILL REDUCE EMISSIONS BY **10 MTCO₂** EVERY YEAR BY 2030

WILL CREATE **6000** JOBS

OPEX OF **£29.1B** (US$32.2 BILLION)

Partners: Progressive Energy, Cadent, CF Fertilisers, Eni UK, Essar, Hanson, INOVYN, University of Chester

CCUS

Area	Challenge
Capture	• Novel capture materials to drive down the cost of CO_2 capture and increase deployment of CCS technology
Transport	• Design of CO_2 specifications for full CCS chain • Mature transportation networks to drive a circular carbon economy
Storage	• Advanced digital technology to drive efficient geological behaviour prediction and modelling

The UK's Climate Change Committee, an independent government advisor, expects a *Net Zero Pathway* to require significant deployment of CCS across the UK economy, reaching 176 MtCO_2 captured and stored per year by 2050[131].

To affect this scale-up, the British Energy Security reiterated plans – first stated in the U*K Net Zero Strategy* – to deliver four low-carbon industrial clusters by 2030. The target is to capture 20 to 30 MtCO_2 across the economy (including 6 MtCO_2 of industrial emissions) per year and deliver at least one net zero industrial cluster operating by 2040[112].

The clusters aim to kickstart a new CCS industry in the UK, with significant export potential. Benefits of the cluster approach include deploying and utilising shared infrastructure, enabling industry to reduce the unit cost for each tonne of carbon abated, as well as opportunities for resource and energy efficiency and learning and innovation sharing.

A CCUS cluster sequencing process has been undertaken by the UK Government to select and support a logical sequence of CCUS projects in the UK. The process has identified two industrial clusters (HyNet and the East Coast Cluster) whose readiness suggests they are best suited to deployment in the mid-2020s, plus a further reserve cluster in Scotland.

Projects within these clusters will have the first opportunity to receive support under the Government's CCUS Programme, including the £1 billion (US$1.1 billion) CCS Infrastructure Fund (primarily capital) and support to develop business models.

Hydrocarbon Emissions Reduction

Area	Challenge
Decarbonisation of power	• Alternative solutions for electricity storage (onshore and offshore) • Electrification and alternative energy sources for offshore assets
Venting and flaring	• Enhanced gas recovery and storage options • Efficient brownfield retrofit solutions for closed flare systems

The UK's *Net Zero Strategy* pledged to regulate the O&G sector to minimise GHG emissions, notably through the revised Oil and Gas Authority (OGA) strategy. This empowered the OGA, now renamed the North Sea Transition Authority (NSTA), to assess operators' plans to reduce their emissions levels against a net zero 'test'.

In line with the UK Government's North Sea Transition Deal, emissions reduction targets from O&G include a 10% reduction by 2025, 25% by 2027, 50% by 2030, and to be a net zero basin by 2050, against a 2018 baseline. Investment of £2 to £3 billion (US$2.2 to US$3.3 billion) in transport and storage infrastructure is expected from the O&G sector to decarbonise its operations, underpinning the widespread rollout of capture technologies[113]. A focus on the growth of the domestic energy sector as well as export markets will support the transformation of the O&G supply chain to service low-carbon energy sectors as UKCS O&G production declines.

Platform electrification holds great potential for hydrocarbon emissions reduction. With some 70% of all upstream O&G emissions resulting from power generation, the NSTA estimates that platform electrification could result in the abatement of 8.7 $MtCO_2e$ of cumulative emissions up to 2050, with a potential of 18.2 Mt CO_2e in the most ambitious scenario[132].

The NSTA also requires new developments to be planned with no routine flaring or venting, with zero routine flaring and venting permitted for all operators by 2030. Meanwhile, Offshore Energies UK (OEUK) (formerly Oil and Gas UK) published its *Methane Action Plan* and is targeting a 50% methane emissions reduction by 2030[133].

Digital Transformation

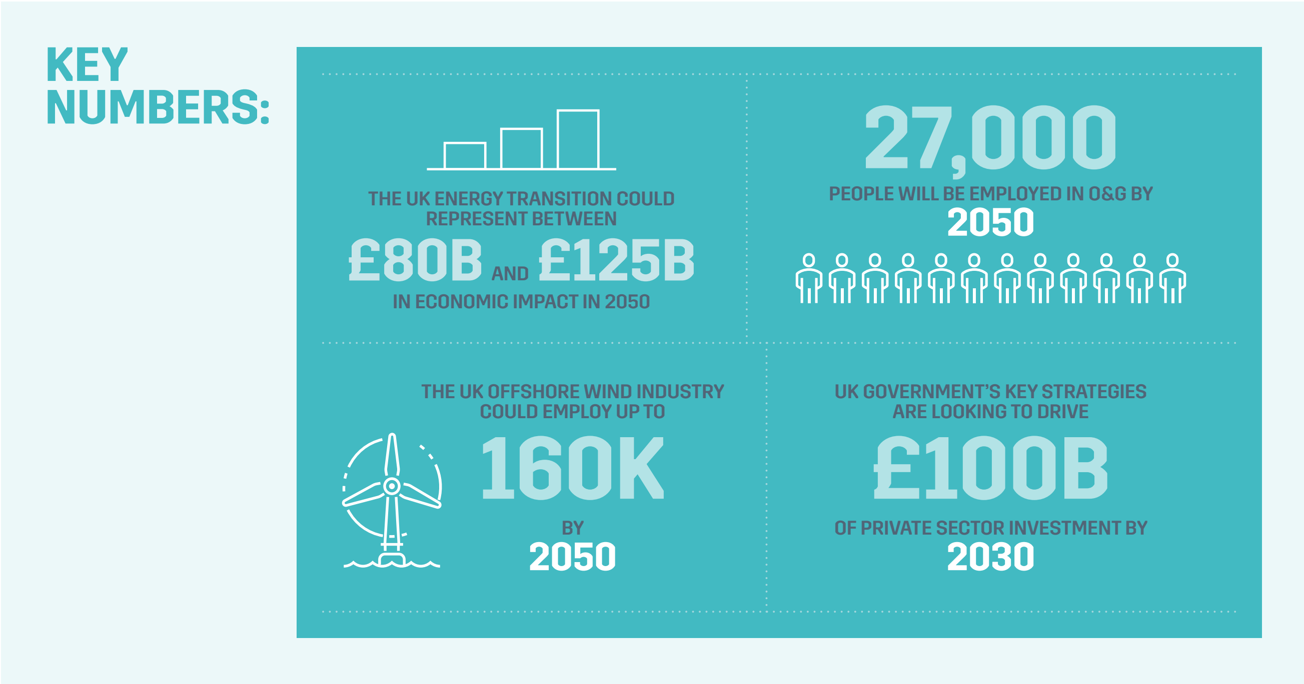
Area	Challenge
Advanced process control	• Shared data trusts to enhance analytics capability and support decision making AI/ML applications for large data volumes
Remote and autonomous operations	• Intuitive human-machine interfaces to improve trust and risk awareness among users
Sensors	• Low cost, light touch and low maintenance sensors for harsh environments, enabling production systems monitoring and non-intrusive retrofitting

Impact of the Transition

Economics

Analysis of three possible 2050 net zero scenarios (*Emerging*, *Progressive* and *Transformational*) in NZTC's *Reimagining a Net Zero North Sea: An Integrated Energy Vision for 2050* found the energy transition could represent between £80 billion (US$88.5 billion) and £125 billion (US$138.3 billion) in total economic impact to the UK in 2050[134]. The three scenarios take into account renewables, hydrogen, O&G and CCS, and specifically how these variables could balance the UK's 2050 energy portfolio. Annual investment on cross sector buy-in, industrial-scale private sector investment and government support is predicted to be between £6.5 billion and £13.4 billion (US$7.2 to 14.8 billion), accumulating a total of £202 billion to £416 billion (US$223.6 to 460.4 billion) through to 2050.

The *Emerging* scenario, with focus placed on natural gas and hydrogen produced by steam methane reforming, sees reduced employment in the offshore energy sector, from approximately 140,000 in 2020 to 113,000 in 2050. The *Progressive* scenario puts more drive behind offshore wind, with its employment jumping to 158,000. In a *Transformational* scenario, employment largely benefits from offshore renewables and electrolytic hydrogen, supporting 232,000 jobs in 2050, increased from 140,000 in 2020. These technologies taking a leading role leads to



reduced contribution from natural gas and lowers CCS requirements. Overall, employment in offshore wind, for both power and production of hydrogen, could total nearly 160,000. CCS could support up to 28,000 posts, while low-carbon hydrogen could potentially employ 35,000.

Meanwhile, the UK Government's key strategies – *Net Zero Strategy, Energy Security Strategy*, and T*en Point Plan for a Green Industrial Revolution* – are looking to drive £100 billion (US$110.7 billion) of private sector investment by 2030 into new British industries such as offshore wind.

Like many other nations, O&G will remain an important industry in terms of the UK supply chain, but it must continue to decarbonise towards 2050. Domestic O&G jobs are expected to be around 27,000 by 2050. Job losses under any 'business as usual' case will be significant, particularly until 2035 when employment in O&G is expected to drop by around 60,000[128].

Exports

The UK's O&G industry has traditionally exported to mainland Europe (predominantly via the Netherlands and France), and to Asian markets such as China and South Korea.

While O&G exports from the UK will be ceased by 2050, the UK will continue its status as a major energy exporter to mainland Europe. The UK is expected to export hydrogen to Belgium, France, Germany and the Netherlands.

Scotland in particular, sees huge opportunities in hydrogen exports. The *Scottish Hydrogen Assessment* estimates that by 2045 Scotland could produce 37 GW of renewable generation producing 126 TWh of renewable hydrogen, of which 94 TWh will be to supply export demand to Europe[135].

The UK also sees opportunities in selling carbon sequestration to these countries, along with South-West European countries Spain and Portugal.

Skills

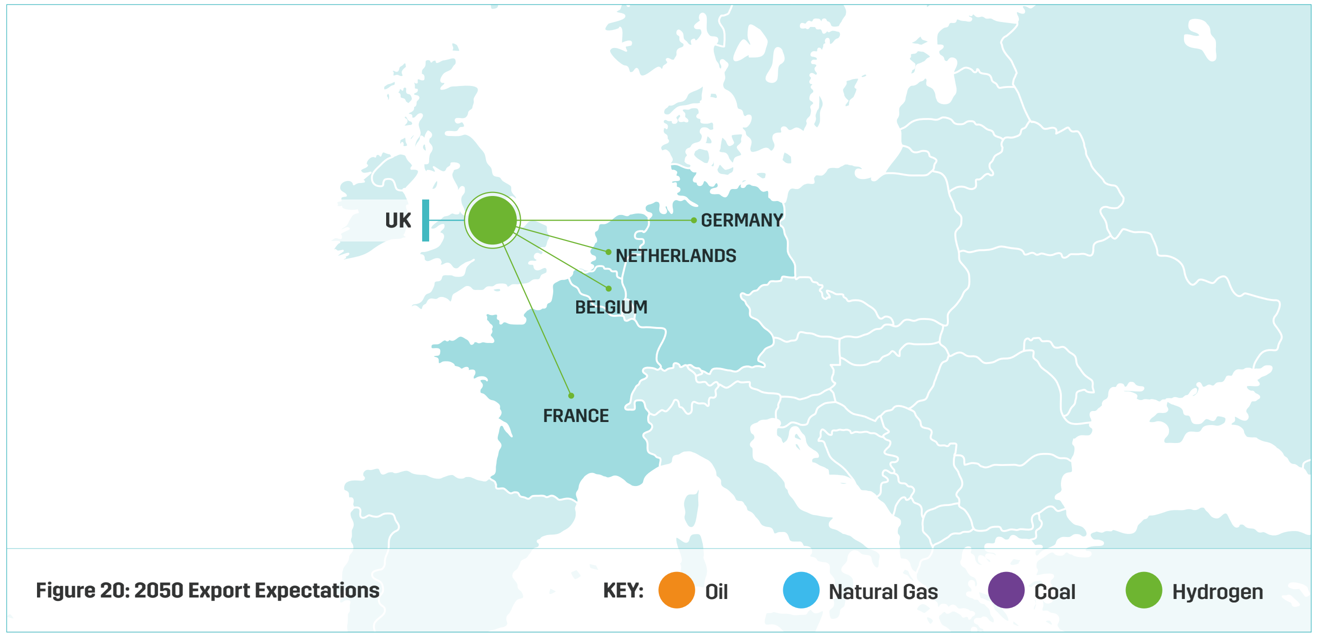


Figure 20: 2050 Export Expectations

The Offshore Petroleum Industry Training Organisation (OPITO) is a UK-based not-for-profit skills body established in the energy industry, that works in partnership with the O&G sector, to ensure highly qualified personnel can meet the needs of the industry, both now and in the future. As well as O&G, OPITO also works across hydrogen, CCS, energy storage and solar.

The NSTD outlines how the UK O&G sector's expertise in offshore operations and infrastructure will be a key enabler in CCS projects execution, supporting the Government's commitment to deploy two carbon capture clusters, including multi-skilled workers, by the mid-2020s and another two by 2030.

O&G majors in the UK are also thinking about the skillsets of tomorrow's workers. bp's UK operations are committing more than £1 million (US$1.1 million), as part of the successful ScotWind bid with EnBW, to X-Academy in Scotland in a five-year deal, supporting both reskilling experienced workers and the creation of entry-level energy transition roles[136].

ScottishPower, Shell and the National Energy Skills Accelerator (NESA) have also established a programme to maximise employment opportunities linked to the development of floating offshore windfarms in Scotland. The proposed Floating Wind Skills Accelerator will bring together academia, industry and the wider offshore wind supply chain to build a comprehensive skills programme[137].

The Offshore Wind Industry Council also highlights apprenticeships and the future workforce as key priorities in its *Offshore Wind Skills Intelligence Report*[138].

Evidence of the Transition

The UK O&G industry is exploring the potential to reuse and repurpose infrastructure for alternative technologies. Despite not receiving funding in Phase 1 of the UK CCUS Cluster Sequencing Process, the Acorn project in North-East Scotland is still expected to be operational by 2030. It will use repurposed gas pipelines to take CO_2 directly from the onshore St Fergus gas terminal to the offshore Acorn CO_2 storage site.

UK-based operators have generally repositioned over the past two years from 'oil and gas' to 'energy', investing in renewables, hydrogen, biofuels, CCS and digital technology projects to decarbonise operations, enhance efficiency and deliver low-carbon energy alternatives.

In the UK, bp has committed to investing up to £18 billion (US$20 billion) in the UK's energy system by 2030, including the development of two large-scale hydrogen production facilities (blue from H2Teesside and green from HyGreen Teesside). When combined, these will produce 1.5 GW of low-carbon hydrogen by 2030 – 15% of the UK Government's national target.

bp is also investing in two 60-year offshore wind leases in the Irish Sea, with a combined potential generating capacity of 3GW.[139] Similarly, in early 2022, Shell secured joint offers for seabed rights to develop large-scale floating wind farms as part of Crown Estate Scotland's ScotWind leasing. Their two sites represent a total of 5 GW off the east and north-east coasts of Scotland.

Shell is also part of the Project Cavendish consortium, aiming to develop a 700 MW hydrogen production facility with CCS technology on the Isle of Grain.

Both bp and Shell are part of the Northern Endurance Partnership, to serve the East Coast Cluster (ECC). The ECC has recently been named as one of the UK's first CCS projects and aims to remove nearly 50% of all UK industrial cluster CO_2 emissions.

Most major operators in the UK have self-imposed emissions mandates and net zero operations targets, often driven by ESG investing principles, cost reduction, and public perception benefits.

bp has set a 2050 goal and will be net zero across the full value chain (including scope 3 emissions and emissions associated with energy products sold). Shell also has a 2050 net zero target, with a further goal to halve absolute emissions by 2030 compared to 2016 levels, but this applies only to scope 1 and 2 emissions. Harbour Energy has ambitions of reaching net zero by 2035 across its scope 1 and 2 emissions.

UNITED STATES OF AMERICA: Context & Energy History

The USA continues to rely heavily on its own O&G reserves, both for domestic use and exports. As Russian exports have fallen following the war in Ukraine, the USA's LNG exports increased by 12% in the first half of 2022 compared with the second half of 2021, making it the world's greatest LNG exporter[140].

However, the USA's energy mix is undergoing significant change, with reduced coal production over the past decade, combined with rapid growth in renewable electricity (mainly in onshore wind and solar power), diversifying the energy production picture.

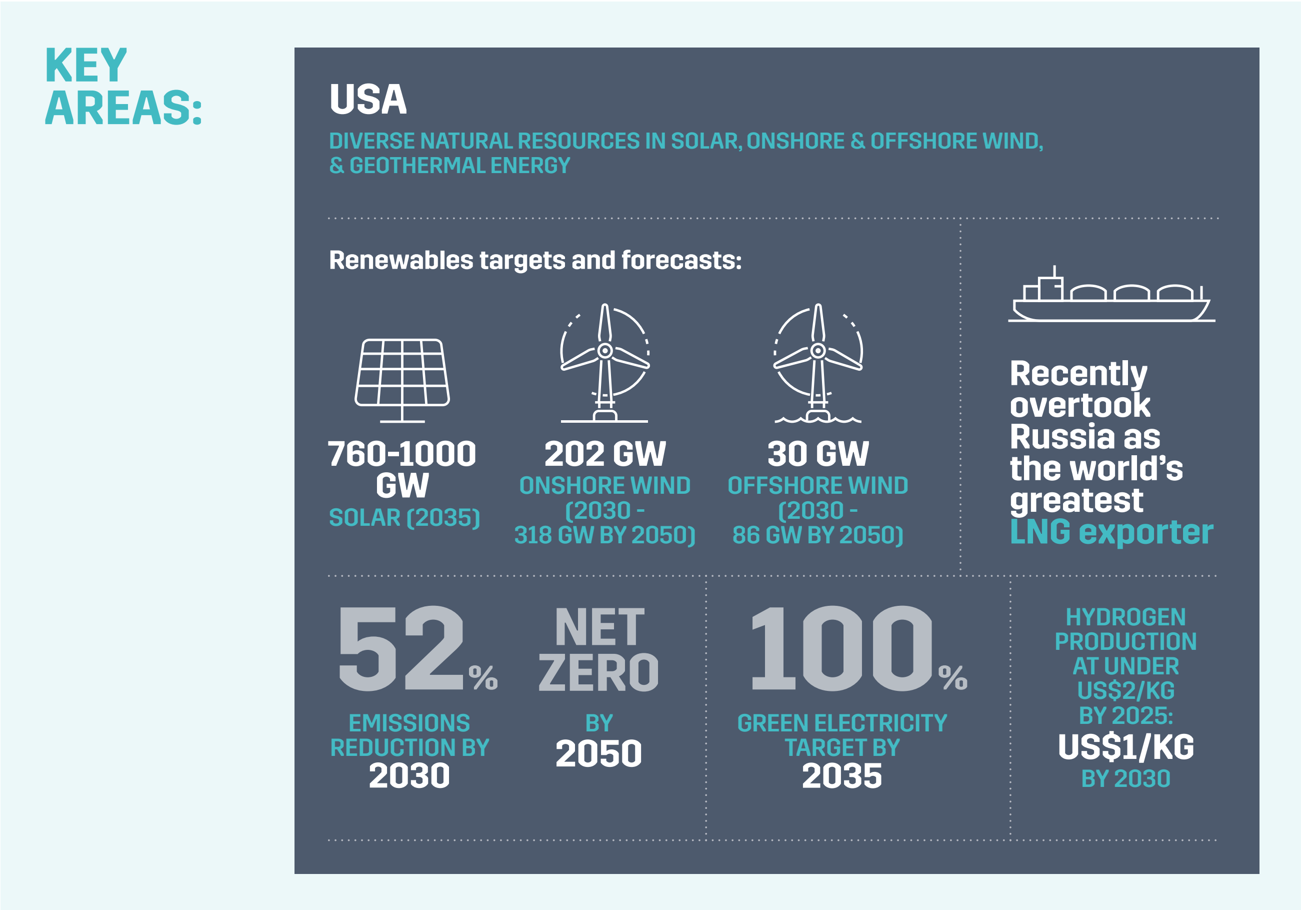
The US Government is introducing various policies to reduce impacts from fossil fuel use. The *Infrastructure Investment and Jobs Act* commits US$21 billion to clean up superfund (locations polluted with hazardous material substances) and brownfield sites, reclaim abandoned mine land and cap orphaned O&G wells[141]. The US Environmental Protection Agency has also updated regulations to reduce methane emissions from both current and existing point sources.

Decarbonisation, especially in hard-to-abate sectors, will be driven by expansions in onshore and offshore wind, solar plants and microgrids. Industrial emissions will be reduced by investing in CCS and hydrogen technologies, while reducing methane and hydrofluorocarbon emissions. The target to reach 100% 'carbon pollution-free' electricity by 2035 will rely heavily on technology innovation to reduce costs, rather than through policy measures[142].

In August 2022, a landmark bill was passed by the US Senate in the *Inflation Reduction Act*, which included a US$369 billion commitment for climate action – the greatest investment in the space in US history. The accelerated development of clean technologies such as solar and wind was earmarked as a key priority for the investment, evidenced by the commitment to create a US$27 billion 'clean energy technology accelerator' to help advance these technologies[143].

The USA has also rejoined the Paris Agreement, pledging to reduce GHG emissions by 52% by 2030 (2005 baseline year)[144]. An executive order committing the USA to achieve net zero by 2050 has been signed, but this is not enshrined in law.

Innovation Challenges by Technology



Offshore wind

Area	Challenge
Electrical Infrastructure	• Optimisation of electrical infrastructure, highlighting synergies and max-imising benefit from emerging technology deployment
Substructures	• Standardisation of designs for floating substructures that improve perfor-mance
O&M and Lifecycle	• Optimisation of services associated with the operation, conditioning mon-itoring and maintenance of wind turbines across the asset lifecycle

The *Inflation Reduction Act* will help propel the USA to the forefront of a clean energy economy, largely powered by renewable energy. It is expected that the tax credits within the Act will accelerate deployment of solar and wind technologies, and could enable clean electricity to provide between 72% and 85% of total USA supply by 2030[145]. The USA has set a goal to reach 100% carbon-free electricity by 2035 and view the milestone as a first step in achieving net zero. A considerable 118 GW of onshore wind has been deployed already, with 202 GW forecast by 2030 and 318 GW by 2050, to revamp the national electricity system[146].

Driven by policy incentives, the USA is also accelerating rollout of solar technologies. Despite a current solar capacity of 80 GW, 2050 net zero scenarios estimate that 760 and 1000 GW will be required by 2035. Top solar developers in the USA have a project pipeline of 51.2 GW of solar power incoming out to 2026, suggesting that greater deployment is required to achieve national net zero goals.

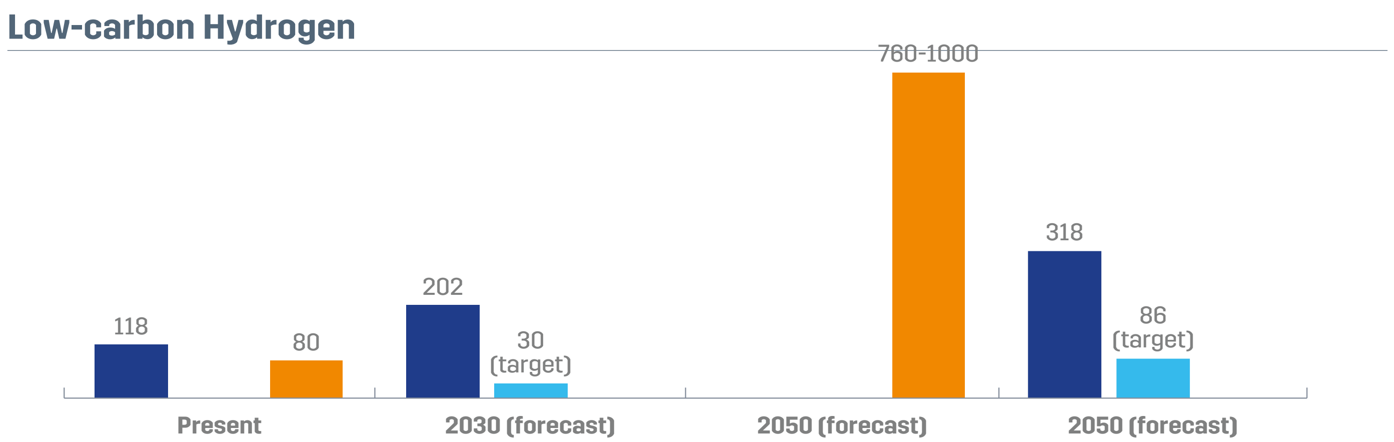
The USA is another country in the preliminary stages of developing an offshore wind industry. Feasibility projects have been conducted, and consequently the USA is estimated to have a current offshore wind capacity of 0.042 GW. However, ambitious scale-up goals have been set – 30 GW capacity is targeted by 2030[149] and 86 GW by 2050[140].

To affect an accelerated rollout, the US Government has also announced an extension of investment and production tax credits for wind, solar and other renewable energy sources, estimated at US$30 billion[137].

As renewable capacities increase, energy storage capabilities must also improve, and this is a key focus area in the USA. The US Department of Energy's (DOE) *Energy Earthshots* programme identified three 'Earthshot' areas, to accelerate breakthroughs in more abundant, affordable and reliable clean energy solutions within the next decade. The *Long Duration Storage Shot* aims to achieve affordable grid storage for clean power by reducing the cost of grid-scale energy storage by 90% for systems that deliver 10+ hours of duration within the decade[150].

This was supplemented by the DOE's *Long Duration Energy Storage for Everyone, Everywhere* programme, a US$505 million initiative that includes funding for technology demonstrations, to support the development and commercialisation of long-duration energy storage[151].

Figure 21: US Renewables Targets/Forecasts (GW)



Area	Challenge
Production	• Facilities and services for process demonstration to drive scale-up and cost reduction at pace • Improve electrolysis processes leveraging novel materials to address cost, efficiency and durability challenges
Transport and storage	• Materials compatible with hydrogen at high pressures/low temperatures

To encourage R&D in what is expected to be an extremely lucrative industry for the USA, the US DOE established its *Hydrogen Program*, led by the Hydrogen and Fuel Cell Technologies Office (HFTO). Funding planning for major hydrogen hub facilities in the USA is also under way.

The Fuel Cell and Hydrogen Energy Association (FCHEA), a national industry association containing over 80 leading companies advancing hydrogen technologies (including Air Liquide, Amazon, BMW and Toyota) has been established, and published a *USA Hydrogen Economy Roadmap*.

The DOE reported an electrolytic hydrogen production cost of between US$5/kg and US$6/kg in 2020[152], and is targeting production at US$2/kg by 2025 and US$1/kg by 2030 via net zero-carbon pathways, in support of another 'Earthshot' goal – reducing the cost of clean hydrogen by 80% to $1/kg within the decade.

The DOE believes a US$1/kg price point by 2030 will unlock a five-fold increase in demand, and result in vastly increased numbers of clean energy jobs.

CCUS

Area	Challenge
General	• Timely, accelerated cluster delivery to achieve large-scale, full-chain projects
Capture	• Novel capture materials to drive down the cost of CO_2 capture and increase deployment of CCS technology
Storage	• Improved modelling strategies to support storage capacity appraisals and safe injection site mapping

The Global CCS Institute sees North America as a world leader in the development of CCS and CCUS technologies, with over half of the world's 55 large-scale CCUS projects located in Canada and the USA. Most of these are CO_2-EOR projects.

The USA forecasts between 212 and 252 MtCO_2 by 2025[153], and the national government has moved to incentivise scale-up by ensuring carbon capture technologies qualify for additional subsides. To further spur technology development in carbon management technologies, a final 'Earthshot' goal was set by the US DOE. The Carbon Negative Shot goal was set, to achieve meaningful capture and storage scale of CO_2e at US$100/net metric tonne[154]. This featured an all-hands-on-deck call for innovation in technologies and approaches.

The Inflation Reduction Act also included an extension and expansion of credits for CCS, which will allow fossil fuel plants to maintain production as long as they install equipment that can capture 75% or more of their carbon emissions output[137].

Hydrocarbon Emissions Reduction

CASE STUDY:

CalCapture

The California Resource Corporation (CRC) is currently in the process of permitting a CCS project to sequester carbon emissions from their 550MW natural gas power plant that provides power for their O&G operations. They will utilize storage capacity in depleted oil reservoirs on site. The project would capture carbon dioxide from the Elk Hills power plant and inject it into underground oil formations. This would displace remaining oil, while permanently trapping the carbon dioxide deep underground. The project will utilize two subsidies: a US$200/ton from the California Low Carbon Fuel Standard and US$50/ton from the federal tax credit.

www.crc.com/images/documents/publications/Infographic_CRC_CarbonCaptureStorage.pdf

Key info/numbers:

LARGE-SCALE **CCS** DEPLOYMENT

WILL SEQUESTER **1.5M** METRIC TONS OF CO_2/YEAR BY 2030

CALIFORNIA'S **FIRST CCUS PROJECT**

OPERATIONAL BY **2025**

Partners: California Resource Corporation, NEXT Carbon Solutions (NCS), The Electric Power Research Institute and Fluor Corporation

Area	Challenge
Decarbonisation of power	• Alternative solutions for energy storage (onshore and offshore) • Electrification and alternative energy sources for offshore assets
Venting and flaring	• Enhanced gas recovery and storage options • Efficient brownfield retrofit solutions for closed flare systems

The USA plans to reduce industrial carbon emissions by investing in carbon capture and hydrogen technologies while reducing methane and hydrofluorocarbon emissions. O&G production accounts for a third of total methane emissions in the USA. In response, the US Environmental Protection Agency updated regulations to reduce methane emissions from both current and existing point sources, that will require O&G operators to aggressively detect and repair methane leaks. The proposal will require companies to monitor 300,000 of their biggest well sites every three months, ban the venting of methane into the atmosphere, and require upgrades to equipment such as storage tanks, compressors, and pneumatic pumps.

The *Methane Emissions Reduction Program*, included in the *Inflation Reduction Act*, introduced a fee on the O&G industry's methane emissions, aiming to force companies to plug leaks and halt deliberate venting during drilling, transport, storage and processing. It aims to achieve this by charging companies for excess emissions, starting at

US$900 per metric tonne in 2024, and rising to US$1500 by 2026[137]. However, this fee does only apply to companies that emit less than 25,000 metric tonnes of CO_2e per year and therefore the largest O&G majors are exempt, who are responsible for around 60% of industry emissions.

The new rules will most likely take effect in 2023 and will be aimed at slashing methane from O&G operations by 74% from 2005 levels by 2035.

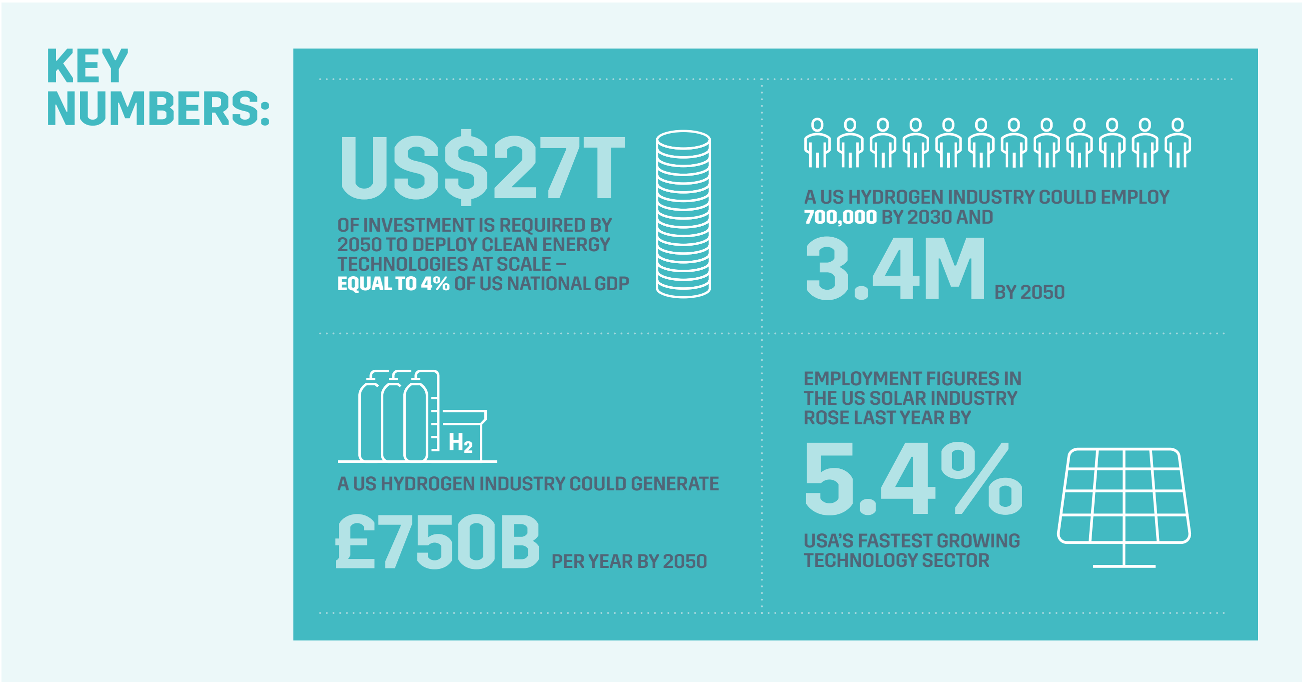
Impact of the Transition

Economics

The US Hydrogen Economy Roadmap, developed by FCHEA and a group of 20 private sector organisations including Shell and Microsoft, states a low-carbon hydrogen economy could generate US$140 billion per year in revenue for the US economy by 2030, and US$750 billion per year by 2050[155]. It is predicted that a low-carbon hydrogen economy could generate 700,000 jobs in the US by 2030, and 3.4 million by 2050.

The USA is well-prepared for the switch to clean transport, already securing hundreds of millions of dollars in public and private investment per year and boasting more than half the world's fuel cell vehicles. In the *American Jobs Plan*, the Biden Administration is prioritising the creation of new jobs and economic opportunities that support the build out of a resilient electric grid and clean energy deployment, plugging old and abandoned oil wells, and investment in EV manufacturing and charging jobs.

The transition to renewable electricity generation is hugely boosting employment opportunities. Over 3 million out of the 7.8 million jobs (40%) involved with the USA energy sector are in areas associated with the goal of a net zero country. Solar was the fastest growing technology in 2021, with 17,212 additional jobs and 5.4% growth in 2021[156].



The American offshore wind industry is set to add tremendous value to the economy. Project development, construction and operations could support between 19,000 and 45,000 jobs by 2025, potentially increasing to 83,000 by 2030. The investment in the industry is estimated to annually provide between US$12.5 and US$25.4 billion in economic output by 2030[157].

According to a McKinsey study, US$27 trillion will be req uired through to 2050 if climate solutions are to be deployed at scale. This is equal to 4% of 2021 national GDP in the USA[158].

Exports

The USA has been a growing exporter of O&G since 2015, when the export ban on crude oil imposed by the US Congress was lifted. The USA became a net energy exporter in 2020[159]. Exports run north and south to Canada and Mexico[160], and the country also services Asian markets, such as India and South Korea.

While the USA does not expect to export any oil in 2050, the country will continue to export natural gas to Canada and Mexico. The USA also expects to sell carbon sequestration to these countries.

With regards to hydrogen exports, the USA sees huge global opportunities. As well as to its North American neighbours Canada, and Mexico, the USA will export hydrogen to Japan, and to mainland European countries such as France, Germany and the Netherlands.

Skills

In the USA, a large network of drilling service skills in the O&G sector can be leveraged to enable cheap geothermal production. Programmes are also being developed for job training and workforce development in O&G producing

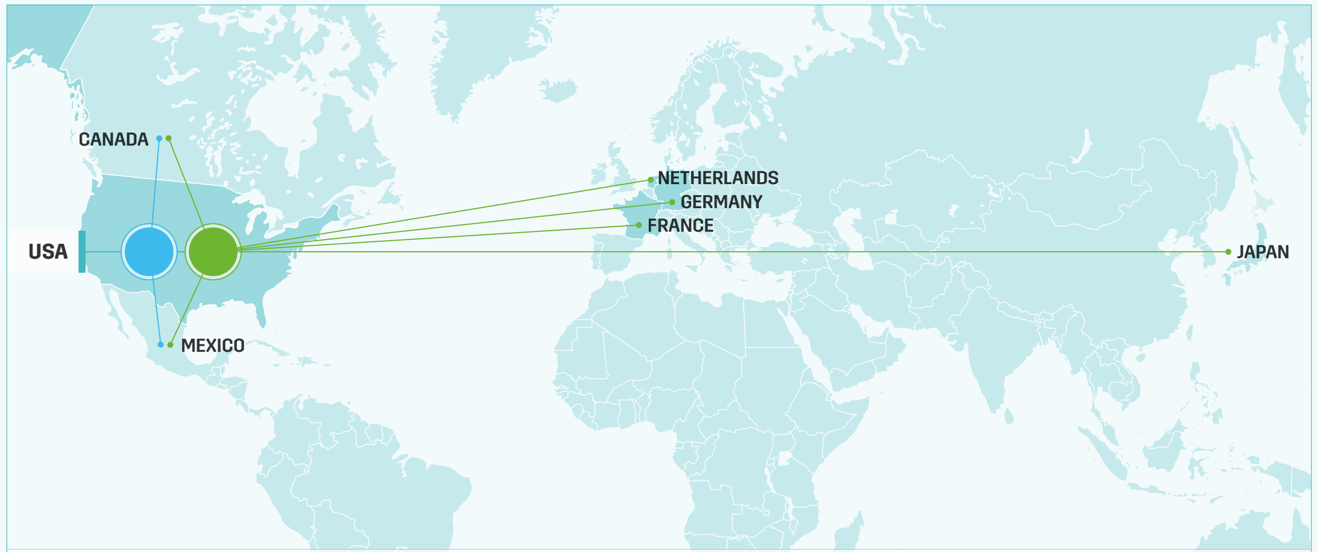


Figure 22: 2050 Export Expectations KEY: Oil, Natural Gas, Coal, Hydrogen

communities.

The National Renewable Energy Laboratory (NREL), one of the contributors to this study, offers an Executive Energy Leadership Academy, which provides industry and community leaders with an opportunity to learn about advanced energy technologies to guide their organisations in energy-related decisions and planning.

Evidence of the Transition

A number of O&G majors in the USA are exploring the potential for O&G infrastructure reuse by converting offshore platforms to wind farms, utilising existing pipelines for hydrogen, converting O&G wells to geothermal, and using depleted subsurface oil fields for energy storage or sequestering carbon. O&G majors are also undertaking a shift in their operations, to publicise their investments and diversified focus across next-generation energy technologies.

Occidental Petroleum Corporation (Oxy) undertook a shift in late 2020 and publicised its ambition to become a 'carbon management' company. Oxy's plan to become net zero by 2050 will rely heavily on large-scale carbon storage and direct air capture, and it intends to open its first commercial-scale carbon storage site and a facility to remove carbon dioxide directly from the atmosphere by 2025[161].

Equinor is also investing heavily in the energy transition in the USA. It has recently launched the Offshore Wind Innovation Hub in New York City, acquired a 100% stake in the battery storage company, East Point Energy LLC, and signed an MoU with U.S. Steel to examine the potential for hydrogen and CCS development in the steel industry in Ohio, Pennsylvania and West Virginia.

Rio Grande LNG, located in the Port of Brownsville in Texas, will soon become the first USA LNG project capable of CO_2 emissions reduction of over 90% via CCS, to produce up to 27 million metric tonnes of low-carbon intensive LNG[162]. The project is being funded by a host of industry organisations including Air Products, Bechtel, Enbridge, BakerHughes, and ABB. Many of these O&G service companies are seeking to support and enable their customers to transition to low-carbon energy production. For example, Baker Hughes has committed to both net zero by 2050 and offering a portfolio of solutions for its O&G clients to reach net zero.

None of the biggest O&G producers in the USA have committed to setting scope 3 net zero targets. ConocoPhillips publicised its rationale in a public statement following an annual shareholder meeting where shareholders voted against proposals to make scope 3 net zero commitments[163] – "*while we recognise many stockholders are concerned about scope 3 end-use emissions, the vote supports our view that setting a scope 3 target is not the right solution for an E&P company with transition-oriented portfolio and production.*"

Of the 24 biggest North American O&G producers (the vast majority of which are US-based), only three currently have 2050 net zero goals that encompass scope 3 emissions: Canadian oil sands producer Suncor Energy Inc., Occidental Petroleum Corp., and pipeline giant Williams Cos. Inc[164].

Net Zero Technology Centre

Technology Driving Transition

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