Project Willow

An opportunity to establish a low carbon manufacturing hub in Scotland's industrial heartland

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HM Government

EY

Project Willow: Executive summary

Over the years, Grangemouth has evolved into one of Scotland's major manufacturing centres, forming a crucial part of its economy. The products manufactured here are vital to the daily operations of both the Scottish and UK economies. With its skilled workforce, extensive knowledge base, and critical infrastructure, Grangemouth plays a pivotal role in Scotland and the UK's transition to Net Zero.

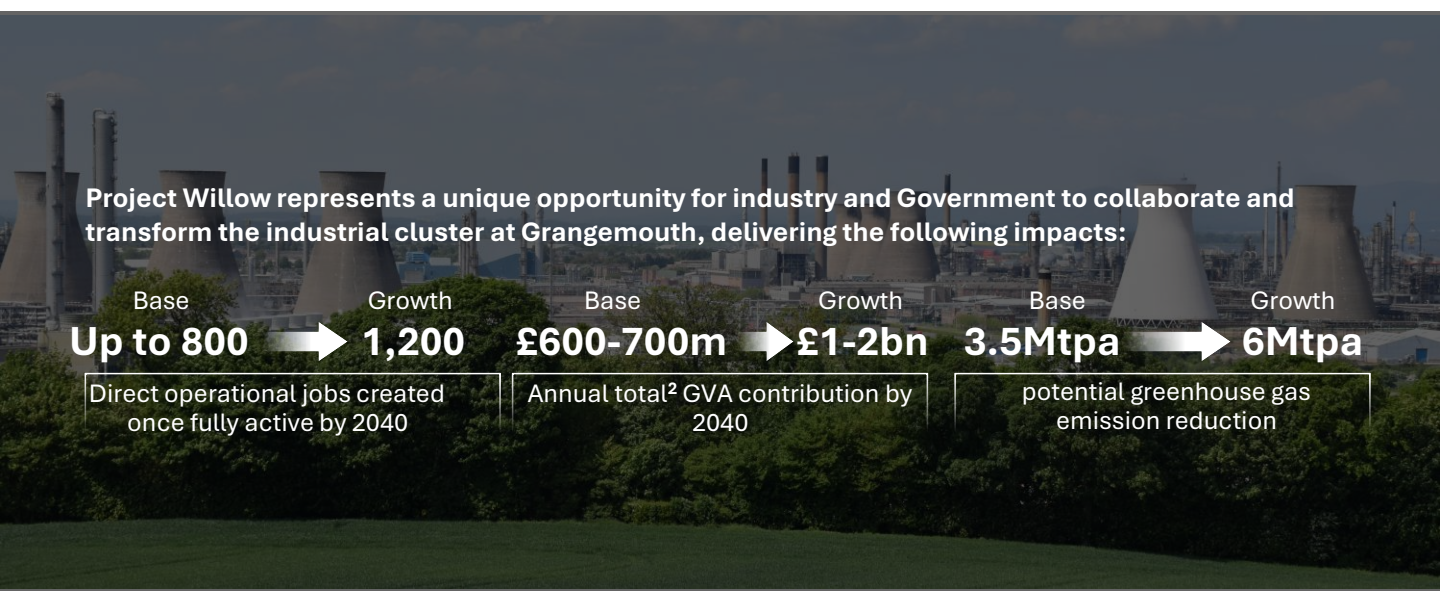
Following Petroineos' (PI) recent announcement to convert the refinery into a fuels import and distribution terminal, Grangemouth reached a pivotal moment requiring a swift and strategic assessment of potential site options. In response, His Majesty's Government (HMG), the Scottish Government (SG), and PI's shareholders, PetroChina and INEOS, launched Project Willow.

This initiative aims to conduct a comprehensive evaluation of various low-carbon technologies, considering factors such as technological readiness, feedstock viability, local skills and supply chains, and overall economic contributions. The study also seeks to identify policy and regulatory actions that could stimulate private sector investment.

Through extensive primary and secondary research involving a diverse range of stakeholders - including, technical specialists, unions, potential suppliers and customers, and the local community - Project Willow identified nine credible projects. These initiatives have the potential to significantly enhance low-carbon manufacturing across the UK and create a positive future for Grangemouth. However, the report also underscores the challenges of this transformation as low-carbon fuels and chemicals remain more expensive to produce than fossil alternatives. This will require substantial capital investment from the private sector (~£3.5b[1] capex) and development of new supply chains.

This report also outlines several recommendations for Government to address these challenges and attract potential investors and developers, without which these projects likely remain subeconomic (as some projects may require ongoing support for operational expenditure). It also highlights the benefits of these initiatives, including contributions to the Scottish economy, jobs (both in construction and plant operation), and reductions in emissions compared to the fossil hydrocarbons being replaced.

Following the conclusion of Project Willow, efforts will now focus on identifying the partners who, in collaboration with HMG and SG, can bring these projects to fruition, develop the detailed business plans, and establish a delivery vehicle.



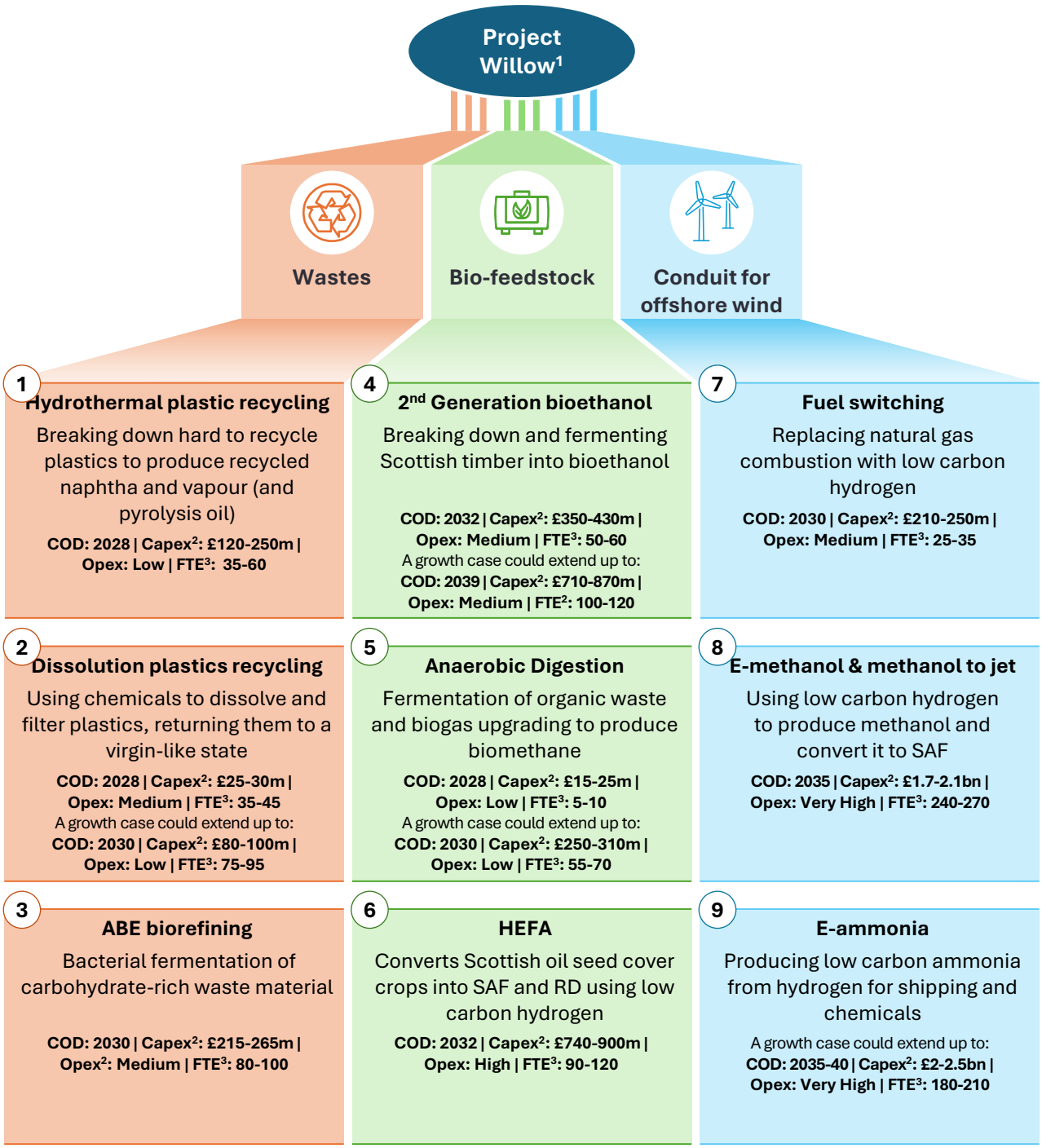
Project Willow represents a unique opportunity for industry and Government to collaborate and transform the industrial cluster at Grangemouth, delivering the following impacts:

Base	Growth	Base	Growth	Base	Growth
Up to 800	**1,200**	**£600-700m**	**£1-2bn**	**3.5Mtpa**	**6Mtpa**
Direct operational jobs created once fully active by 2040		Annual total[2] GVA contribution by 2040		potential greenhouse gas emission reduction	

1. £3.5b in capex investment for the base case, with potential to scale into growth case and beyond
2. Includes the undiscounted operational annual direct, indirect and induced impacts

Project Willow highlights

Project Willow evaluated over 300 technologies to identify those that could be effectively deployed in Grangemouth. This assessment was conducted through extensive secondary research and stakeholder interviews (over 120 stakeholders in total), resulting in nine potential projects that with public and private sector backing could unlock Grangemouth's growth potential.



Key:

Opex (£m p.a.):

Low: <100
Medium: 100-500
High: 500-1,500
Very high: >1,500

COD: XXXX | **Capex:** £X-Ybn | **FTE:** X-Y ← 1st deployment

COD: XXXX | **Capex:** £X-Ybn | **FTE:** X-Y ← Additional deployment if potential fully realised. Note growth case figures are inclusive of 1st deployment

1. Initial project set, subject to evolution
2. Includes capital expenditure plus development expenditure
3. FTE figures include only direct operational jobs, and does not include construction, indirect and/or induced impacts

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Introduction

The Grangemouth refinery, operated by Petroineos (PI) since 2011, is one of the six remaining refineries in the UK and Scotland's only crude oil refinery. The site is of strategic importance to Scotland's energy supply and regional economic development.

On 12 September 2024, PI announced its plans to convert the Grangemouth refinery into a fuel import terminal, citing both a continuing decline in profitability and the need for substantial new investment to keep the refinery running.

In response to this announcement, both His Majesty's Government (HMG) and the Scottish Government (SG) have been actively collaborating with PI and its shareholders, INEOS and PetroChina, to ensure a positive long-term future for the site.

As part of this commitment, in the Autumn of 2024, PI, SG and HMG launched Project Willow, a study exploring the options to secure a sustainable future for Grangemouth in a net zero age. This project builds on previous technical studies undertaken by PI, which indicated that there is no clear commercial pathway without Government intervention.

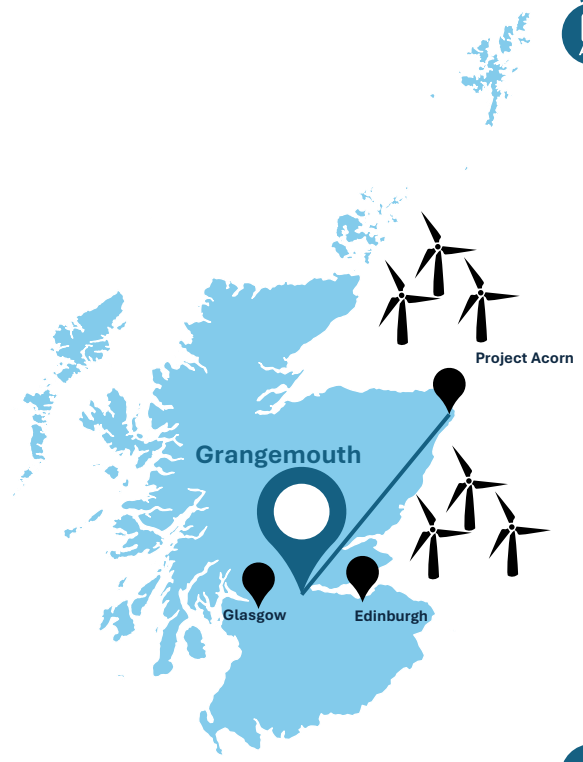
The success of Project Willow, in delivering growth for the Grangemouth industrial cluster, will require significant contributions from both the public and private sector.

This document outlines the potential future pathways to transform the Grangemouth Industrial Cluster and delineates the roles of both the Government (HMG and SG) and the private sector in achieving the objectives of Project Willow.

Site information

Cluster advantages

- Large scale site of prime industrial land
- Well serviced by three local railway stations and a rail freight terminal
- Close access onto the M8, M9, and M80 motorways
- Largest container terminal in Scotland, handling 9 million tonnes of cargo each year, representing up to 30% of Scotland's GDP
- First class utilities and product pipelines
- Site is part of the Forth Green Freeport initiative to support green investment
- Strong links to Forth Valley College, and central belt universities in Glasgow Edinburgh and Stirling, providing the next generation of employment



Not to scale

Location

- 25 minutes to Edinburgh Airport (20 miles) and 45 minutes to Glasgow Airport (40 miles)
- 40 minutes to Edinburgh City Centre (25 miles)
- 50 minutes to Glasgow City Centre (30 miles)

The role of Grangemouth in achieving Net Zero targets

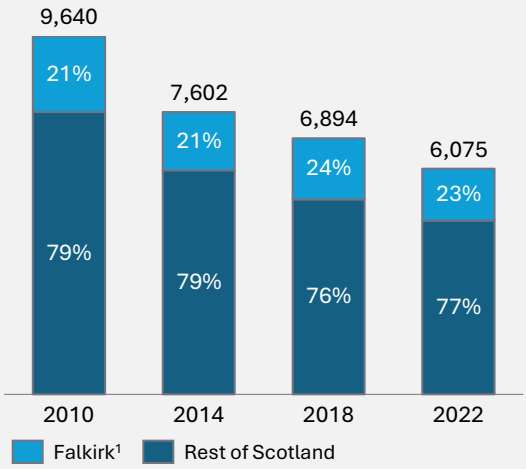
In response to climate change, both the Scottish and UK Governments have set ambitious climate change targets

Net Zero by 2045 (Scotland) and 2050 (UK)

Low carbon **hydrogen production capacity** by 2030 of **5GW** (Scotland) and **10GW** (UK)

Offshore wind capacity by 2030 of **11GW** and up to **50GW** for Scotland and the UK respectively

Scottish Industrial Greenhouse Gas Emissions, kt CO_2e



Source: Department for Energy Security and Net Zero

Grangemouth provides an opportunity to demonstrate how the UK's hydrocarbon industry can contribute to a wider industry transition, creating jobs, growing the economy, and supporting decarbonisation.

Climate change has mobilised consumer sentiment and triggered policy and regulatory responses from governments worldwide to reduce emissions. Both HMG and SG have set ambitious targets for Net Zero greenhouse gas emissions by 2045 and 2050 respectively.

To ensure these Net Zero targets are met, both HMG and SG have introduced new policy and regulatory requirements for corporations. Coupled with evolving consumer expectations, this has driven industries to seek technological solutions to reach Net Zero.

Energy and chemical suppliers need to build new capabilities and presence in emerging low carbon technologies, while energy consumers need to secure supplies of low carbon fuels and feedstocks from a nascent market with limited volumes.

Without investable clean energy propositions, the UK is likely to miss out on the growth and jobs driven by the energy transition. Additionally circular economy innovations offer the potential to maximise value of waste resources that might otherwise go to incineration or landfill. Failing to grasp these opportunities increase the risk of the UK falling behind on its commitments and increasing the country's dependence on imports.
Due to its productive and energy-intensive manufacturing processes, the Grangemouth Industrial Cluster is responsible for around 6% of Scotland's net greenhouse gas emissions and 27% of Scotland's total industrial emissions.

However, the cluster is also important to Scotland's economy and energy security, hosting a concentration of strategic energy infrastructure assets, a logistics hub, and a highly skilled workforce, contributing c£900m in total GVA to the UK's economy annually.

Given its strategic importance, both HMG and SG Ministers have emphasised the need to transition the Grangemouth cluster. The goal is to ensure it remains a key manufacturing base for the future, while also significantly decarbonising and realising its potential to support broader carbon reductions across Scotland and the UK.

This sentiment has been echoed by the UK's Committee on Climate Change, which has recommended specific focus on the Grangemouth cluster as it is crucial to Scotland's industrial decarbonisation and achieving Scotland's environmental targets.

1. Data for Falkirk local authority that contains Grangemouth

Project Willow Objectives

Project Willow presents a **unique opportunity to deliver against both HMG and SG's ambitions** for growth, to move towards net zero, and deliver energy security – ensuring a unified approach to tackle climate change in a sustainable manner.

Identify, prioritise, and scale credible **low carbon manufacturing** supply chains within the Grangemouth Industrial Cluster.

Support government to **unlock investment into the energy transition** by addressing key **policy roadblocks** and unlock funding.

Support UK and Scottish **Net Zero** agenda, driving growth through **economic value**, high-skilled **jobs**, and **reduced emissions** (including circular economy).

Project Willow - Approach

Assessment Dimensions

Project Willow looked to answer the following key questions:

Technical – What are the viable solutions to transform the Grangemouth refinery site into a low carbon manufacturing production centre following conversion to an import terminal?

Economic – What economic constructs and options should be created to execute, and thereafter operate, the new site configuration?

Commercial – What is the size (current and potential) and commerciality of the accessible market for low carbon products generated from the site and new feedstocks required for a new Grangemouth configuration?

Regulatory – What new, amended or continued regulatory frameworks are required to create conducive conditions for investment and commitment to long-term business activities by prospective future operators?

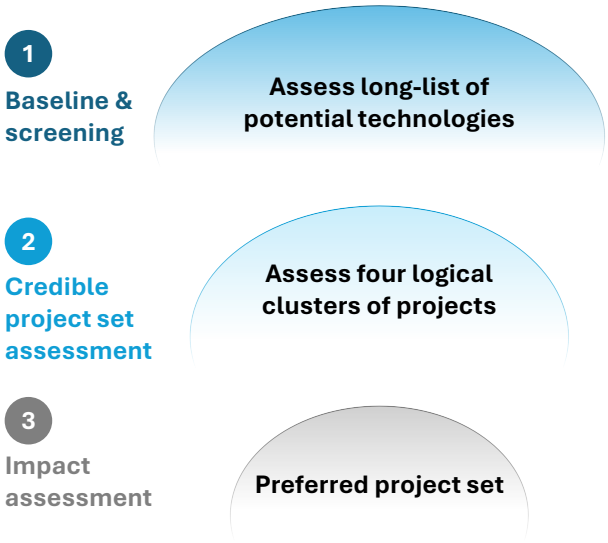
Environmental – What are the benefits and potential future positive and negative impacts on the environment of a new manufacturing configuration?

Community – How can a newly configured Grangemouth manufacturing site make a positive community impact?

Skills – What is the size and profile of the required potential workforce for a new site operating configuration, and the wider implications on skills in the community?

Methodology

A three-stage approach was adopted:



Phase 1: Establish Baseline and Screening Long List of Options – the development of a long list of technologies, which were then assessed against defined critical success factors.

Phase 2: Credible Project Set Assessment – the development of a set of project sets which provided a framework in which the technologies could be assessed against technical and commercial workstreams.

Phase 3: Impact Assessment – deriving a set of relevant technologies which could be developed together to gain synergies, defined as the 'Preferred Project Set'.

A detailed impact assessment on the Preferred Pathway was conducted to provide an overview of the benefits to the economy, the local community, the environment.

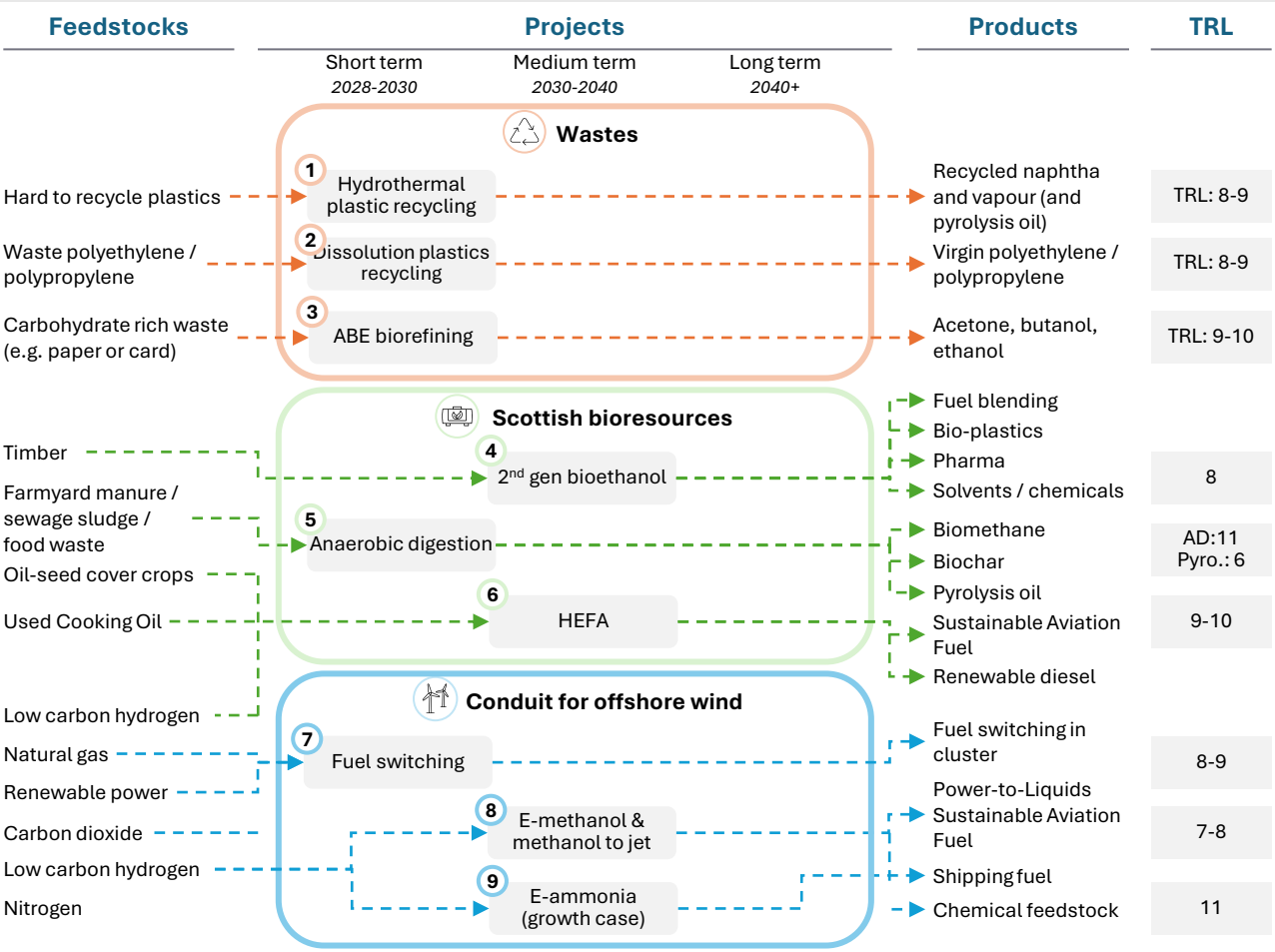
Project Willow evaluated over 300 technologies to identify those that could be effectively deployed in Grangemouth. This assessment was conducted through extensive secondary research and comprehensive stakeholder interviews (over 120 stakeholders in total), involving a range of technology providers, potential suppliers and customers, government departments, regulators, and academia.

Opportunities

The prioritised technology pathways underpin a preferred project set, deployed across three time horizons, with increasing levels of uncertainty into the future. These have been built around Grangemouth's unique attributes, resulting in nine projects that fall into three categories:

Wastes	• Making use of proximity to Edinburgh, Glasgow and the Central Belt for concentrated feedstock • Synergies with adjacent Grangemouth industries for outputs
Scottish bioresources	• Grangemouth's ongoing role as the entry point for the majority of Scottish fuel, creates a logistical advantage to supply SAF and low carbon biofuels • Situated in proximity to Scottish farmland
Conduit for offshore wind	• Existing and close-by grid connections as well as potential pipelines to aggregate hydrogen • Liquid fuels handling infrastructure / logistics

Feedstock and product overview across the nine projects



IEA Technology Readiness Level (TRL) Scale

Concept
1. Initial idea
2. Application formulated
3. Concept needs valuation

Small prototype
4. Early prototype

Large prototype
5. Large prototype
6. Full prototype at scale

Demonstration
7. Pre-commercial demonstration
8. First of a Kind commercial

Market uptake
9. Commercial operation in relevant environment
10. Integration needed at scale

Mature
11. Proof of stability reached

1. ABE = Acetone–butanol–ethanol

Waste projects overview

Hydrothermal plastic recycling

Breaking down hard to recycle plastics to produce recycled naphtha and vapour (and pyrolysis oil)

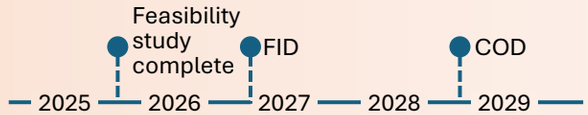
Feedstocks

Plastic waste (including films and other hard to recycle items)

Demand source

Recycled naphtha and vapour (and pyrolysis oil) can be fed into plastic production processes or refineries (e.g. for RD and SAF)

Potential project timeline[1]

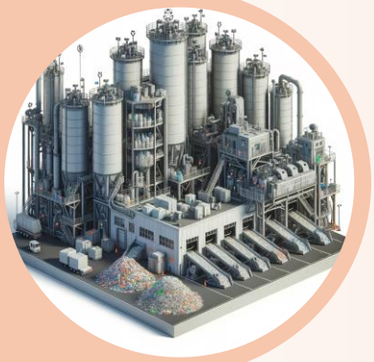


Recommendations for Government

- Provide devex and capex support (whether through grant, debt or equity)
- Implement policies to increase plastic collection, separation, and aggregation

Key figures

	Base	Growth[2]
Capex (£m)[3]	150-250	150-250
Opex[4]	Low	Low
Total GVA (£m)[5]	640-700	640-700
Direct operational jobs	35-60	35-60
Emission savings (ktpa CO_2e)	~125	~125



Dissolution plastic recycling

Using chemicals to dissolve and filter plastics, returning them to a virgin-like state

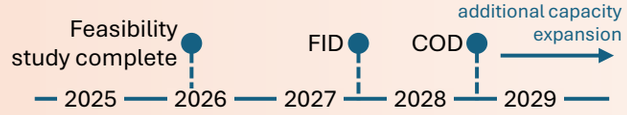
Feedstocks

Polyethylene/polypropylene plastic waste

Demand source

PE/PP for plastic products and packaging

Potential project timeline[1]



Recommendations for Government

- Provide devex and capex support (whether through grant, debt or equity)
- Implement policies to increase plastic collection, separation, and aggregation
- Implement policies to accelerate adoption of recycled plastics across sectors

Key figures

	Base	Growth[2]
Capex (£m)[3]	25-30	80-100
Opex[4]	Low	Low
Total GVA (£m)[5]	230-250	840-900
Direct operational jobs	35-45	75-95
Emission savings (ktpa CO_2e)	~30	~140

ABE biorefining

Bacterial fermentation of carbohydrate-rich waste material

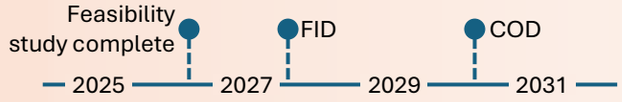
Feedstocks

Scottish by-products and wastes from sectors such as food, drink, packaging and agriculture

Demand source

Acetone, butanol, ethanol for low carbon chemical products

Potential project timeline[1]



Recommendations for Government

- Provide devex and capex support (whether through grant, debt or equity)
- Implement policies to accelerate transition to low carbon chemicals

Key figures

	Base	Growth[2]
Capex[3]	215-265	215-265
Opex[4]	Medium	Medium
Total GVA (£m)[5]	1,700-2,100	1,700-2,100
Direct operational jobs	80-100	80-100
Emission savings (ktpa CO_2e)	~90	~90

Note: Images are AI generated impression based on existing Proof of Concept projects

1.Subject to developer identification and input
2.Growth case is inclusive of base case. Where there is limited opportunity for further expansion, Growth is set the same as Base
3.Includes capital expenditure plus development expenditure
4.Operational expenditure (£m p.a.): Low=<100, Medium=100-1,000, High=1,000-2,000, Very High = >2,000
5.Cumulative GVA figures are discounted at 3.5% and are in real terms and are comprised of direct, indirect and induced impacts. These figures are based on the construction and operational phases.

Scottish bioresources projects overview

2nd generation bioethanol

Breaking down and fermenting Scottish timber into bioethanol

Feedstocks

Sustainably sourced Scottish timber and timber waste

Demand source

Bioethanol used in fuel blending, cosmetics, pharmaceuticals

Biogenic CO_2 for e- fuels /sequestration

Potential project timeline[1]

Feasibility study complete — 2026
FID — 2028
COD — 2032
Potential for additional capacity expansion — 2034
2030

Recommendations for Government

- Provide devex and capex support First of Kind project
- Field studies to increase forestry productivity and test environmental impact
- Implement policies to accelerate adoption of bioplastics
- Promote adoption of 2nd over 1st generation biofuels

Key figures

	Base	Growth[2]
Capex (£m)[3]	350-430	710-870
Opex[4]	Medium	Medium
Total GVA (£m)[5]	1,410-1,510	2,610-2,710
Direct operational jobs	50-60	100-120
Emission savings (ktpa CO_2e)	~510	~1,020

Anaerobic Digestion

Fermentation of organic waste and biogas upgrading to produce biomethane

Feedstocks

Animal waste, sewage sludge, food waste

Demand source

Biomethane for consumption by local industry or grid injection

Biogenic CO_2 for e- fuels /sequestration

Biochar for soil improvement / water treatment

Potential project timeline[1]

Feasibility study complete — 2025
FID — 2026
COD — 2028
Potential for additional capacity expansion — 2029
2027
2030

Recommendations for Government

- Extension of GGSS beyond 2028
- Inclusion of biochar from digestate in agricultural use policy

Key figures

	Base	Growth[2]
Capex (£m)[3]	15-25	250-310
Opex[4]	Low	Low
Total GVA (£m)[5]	90-110	900-950
Direct operational jobs	5-10	55-70
Emission savings (ktpa CO_2e)	~40	~230

HEFA

Converts Scottish cover crops into SAF and RD using low carbon hydrogen

Feedstocks

Fats Oil and Grease (FOGs), cover crops

Low carbon hydrogen (processing)

Demand source

Sustainable Aviation Fuel to fulfil the SAF mandate

Renewable diesel to fulfil the RFTO

Potential project timeline[1]

Feasibility study complete — 2026
FID — 2028
COD — 2032
2030
2034

Recommendations for Government

- Provide devex and capex support to mitigate scaling risk
- Support field studies for cover crop viability
- Permit oil-seed cover crop feedstock under SAF mandate
- Seek HEFA cap exemption for domestic feedstock
- Seek delay to HEFA cap implementation
- Support oil seed supply chain mobilisation
- Low carbon hydrogen support (see next page)

Key figures

	Base	Growth[2]
Capex (£m)[3]	740-900	740-900
Opex[4]	High	High
Total GVA (£m)[5]	4,300-4,400	4,300-4,400
Direct operational jobs	90-120	90-120
Emission savings (ktpa CO_2e)	~1,760	~1,760

Note: Images are AI generated impression based on existing Proof of Concept projects

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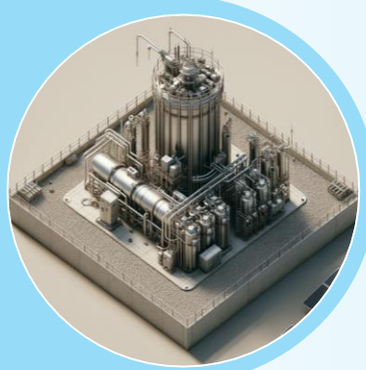
Conduit for offshore wind projects overview



Fuel switching

Replacing natural gas combustion with low carbon hydrogen

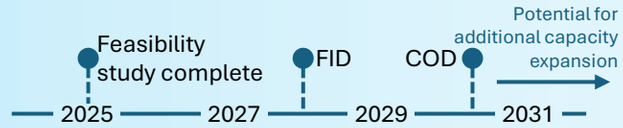
Feedstocks

- Renewable power
- Water

Demand source

- Combustion processes using natural gas/fuel gas in industrial processes

Potential project timeline[1]



Recommendations for Government

- Provide devex and capex support to mitigate technology scaling risk
- LCHA amendments (e.g. CO2 T&S cross chain risk, offtaker volume risk etc)
- Power market reform to provide reduced power price to H2 projects

Key figures

	Base	Growth[2]
Capex (£m)[3]	210-250	210-250
Opex[4]	Medium	Medium
Total GVA (£m)[5]	-	-
Direct operational jobs	25-35	25-35
Emission savings (CO_2e)	~660	~660

E-methanol & methanol to jet

Using low carbon hydrogen to produce methanol and convert it to SAF

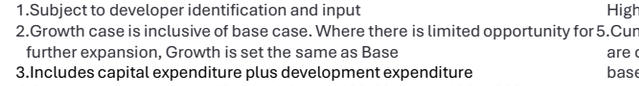
Feedstocks

- Renewable power
- Water
- CO2

Demand source

- Methanol for shipping / chemicals
- SAF

Potential project timeline[1]



Recommendations for Government

- As in fuel switching
- Decision on Project Acorn FID
- Permit H2 projects supporting e-fuels to access HPBM
- Revise PtL SAF buy-out price to reflect UK costs
- Relax temporal and additionality req. on renewable power into e-fuels
- Drive policy to accelerate low carbon chems and shipping

Key figures

	Base	Growth[2]
Capex (£m)[3]	1,700-2,100	1,700-2,100
Opex[4]	Very high	Very high
Total GVA (£m)[5]	1,140-1,240	1,140-1,240
Direct operational jobs	240-270	240-270
Emission savings (CO_2e)	~440	~440

E-ammonia

Producing low carbon ammonia from hydrogen for shipping and chemicals

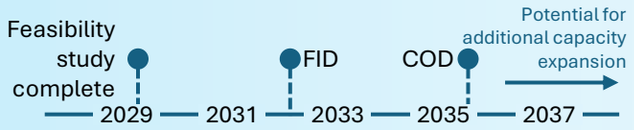
Feedstocks

- Renewable power
- Water
- Nitrogen

Demand source

- Ammonia for shipping / chemicals

Potential project timeline[1]



Recommendations for Government

- As in fuel switching
- Drive policy to accelerate low carbon chems and shipping

Key figures

	Base	Growth[2]
Capex (£m)[3]	-	2,000-2,500
Opex[4]	-	Very high
Total GVA (£m)[5]	-	6,700-7,300
Direct operational jobs	-	180-210
Emission savings (CO_2e)	-	~1,830

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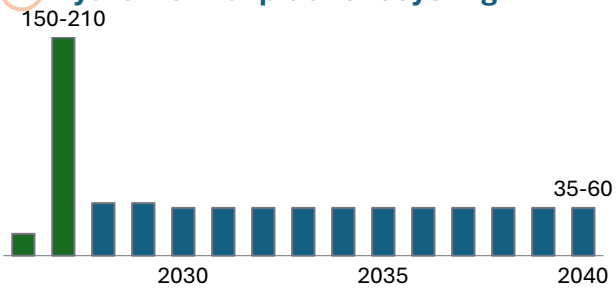
Direct jobs

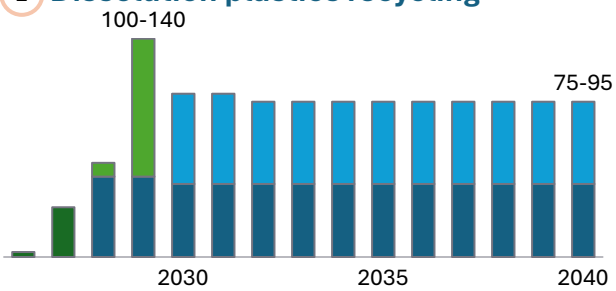
The projects proposed in Project Willow could generate a range of jobs across the construction and operational phases, as well as jobs through the different supply chains (not shown here).

Construction - base
Construction - growth
Operational - base
Operational - growth

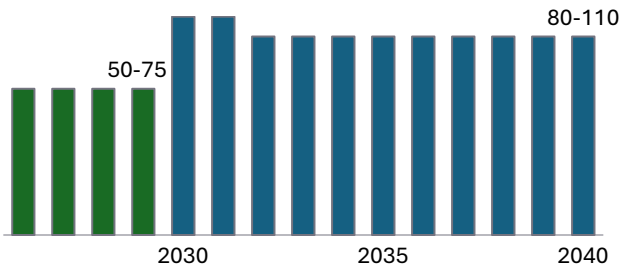
1 Hydrothermal plastic recycling



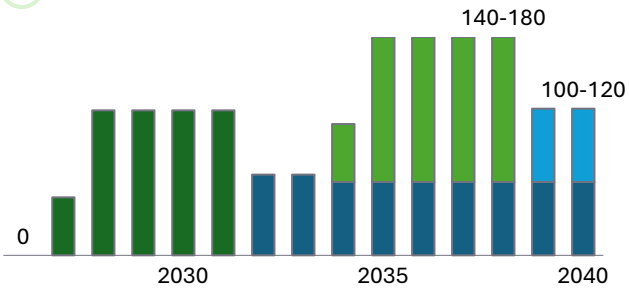
2 Dissolution plastics recycling



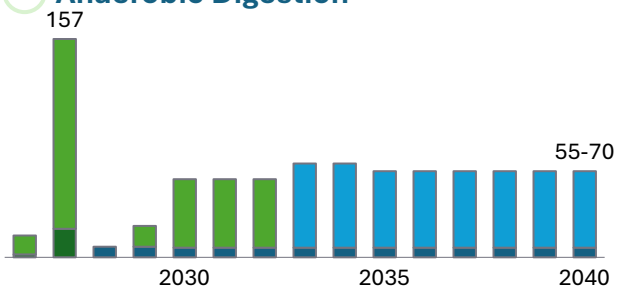
3 ABE biorefining



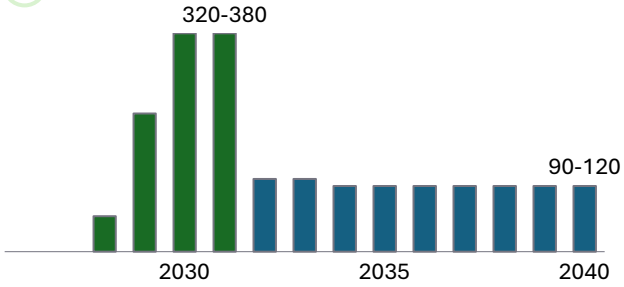
4 2nd Generation bioethanol



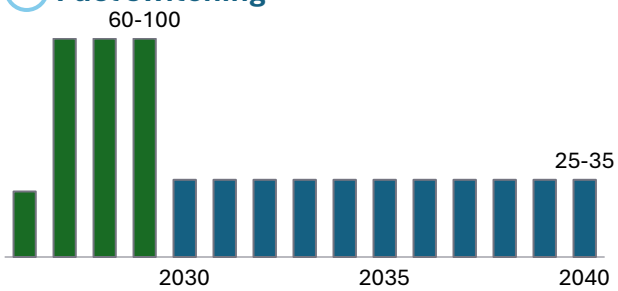
5 Anaerobic Digestion



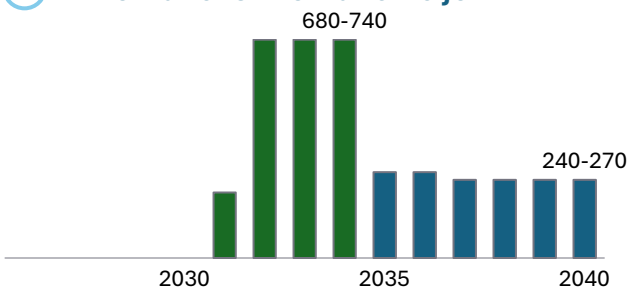
6 HEFA



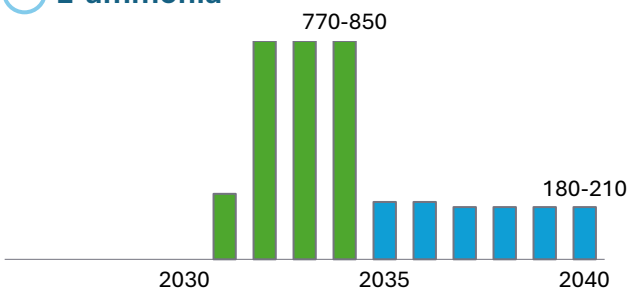
7 Fuel switching



8 E-methanol & methanol to jet

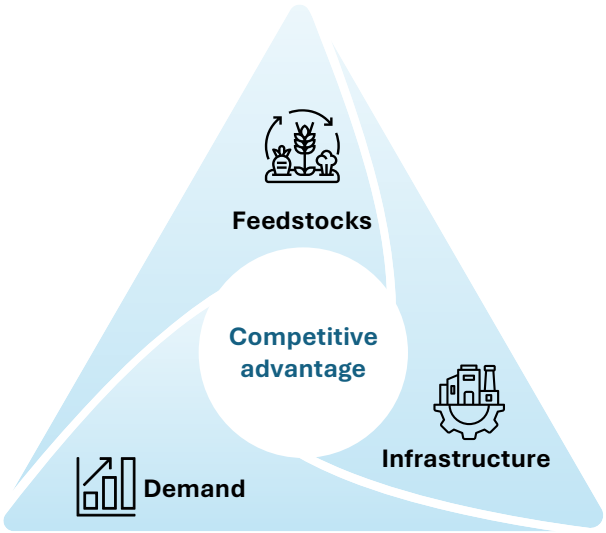


9 E-ammonia



Viability (demand / feedstocks / infrastructure)

Project Willow has identified several projects which leverage the unique capabilities of the Grangemouth site.



Feedstocks

The projects proposed in Project Willow have been sized to balance both available Scottish feedstocks and potential demand, with capacity additions proposed through to the Growth case where markets are forecasted to grow and potential for export could exist.

Securing domestic feedstock supply is critical to cementing a plant's competitive advantage, however it is recognised that not all of these pathways are currently enabled under Government policy (see recommendations).

Waste Projects

These projects seek to support the circularity of Scotland's waste streams – to reduce landfill volumes and create valuable products.

Hydrothermal plastic recycling technology can take a mixed plastic waste feedstock to produce products such as recycled naphtha and vapour (and pyrolysis oil) that can be refined into a number of products (e.g. renewable diesel and SAF). This creates an offtake opportunity for hard-to-recycle plastics that are currently sent to incineration and landfill. Plastic waste generation in Scotland is estimated to be c.300ktpa, with 85ktpa being recycled currently, leaving 215ktpa potentially addressable if it can be diverted from landfill/incineration.

Dissolution plastic recycling has the potential to take certain types of plastic back to a virgin-like state. This is a step-change from existing recycling technology where mechanically recycled plastics often end up being downcycled due to degradation of the polymer. This does require a separated plastic stream which will support the current Scottish and UK recycled products market. The initial proposed feedstock for this project is Bottle Top Regrind (BTR), which is expected to grow, particularly driven by the Deposit Return Scheme planned to launch in 2027. When combined with additional feedstocks, such as flexible plastic films collected from supermarkets and councils and households from 2027, there will be sufficient supply to scale the plant gradually in several stages, reaching up to a total capacity of 40ktpa.

The **ABE biorefining** requires a carbohydrate rich feedstock, which could come in the from a wide variety of Scottish secondary by-products and wastes from sectors such as food, drink, packaging and agriculture. This broad range of potential feedstock options will mean that a plant of c.30ktpa end product capacity can find the waste feedstock sources required. As an example, across the UK around 6Mt of paper and cardboard waste is generated (240ktpa in Scotland), which is around 50 times the proposed plant feedstock capacity, before considering additional feedstock sources.

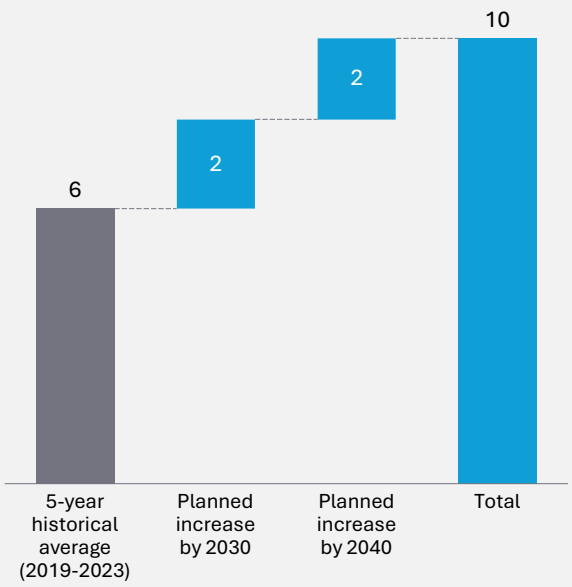
Viability (demand / feedstocks / infrastructure)

Bio-Feedstock Projects

In the Bio-Feedstock projects, Scotland's potential to produce bioresources is recognised.

The **2nd generation bioethanol plant** looks to scale with Scotland's planned c3.9Mtpa increase in soft wood production by 2037. Engagement with participants in the Scottish forestry sector suggests appetite to support 2nd generation bioethanol as a new high value offtake for sustainably sourced timber or timber waste.

Scottish timber production (Mtpa)



Source: Forest research, EY Parthenon research and analysis

The **biomethane value chain** project could initially utilise local wastewater and farmyard manure feedstock, scaling up to potentially take the ABE biorefining effluent. A 2022 study estimated that there was c.13Mtpa of potentially available animal waste feedstock and 1Mtpa of sewage sludge. Being wet feedstocks, distance is a limiting factor in the aggregation potential, challenging project economics. Estimating the feedstock within the local area (assumed c.20km), this reduces to a total of 150-200ktpa, before considering any synergies with other plants in a growth case.

A **HEFA** (Hydrotreated Esters and Fatty Acids) plant will require hundreds of kilotonnes of Fats, Oils, and Greases (FOGs) each year to be producing at a commercial scale. Internationally there are around 700Mt of FOGs that are practically available each year however much of this capacity is undeveloped. Of the permissible feedstocks that are used for HEFA, Chinese imported Used Cooking Oil (UCO) is the most widespread in jurisdictions (including the UK) that do not allow food oils to be used as a feedstock. As SAF production scales in China, the industry expects supplies of this feedstock to dry up in the mid 2030s, putting plants without alternative sources of supply at risk of closure. Therefore it is critical for any plant to have line of sight to a Scottish supply chain.

Scotland is estimated to have an available FOG supply made up of a mix of UCO, tallow, and fish oil however these are not at a scale that can support a commercial HEFA plant. In one interview an experienced FOGs aggregator estimated that an optimistic domestic feedstock supply for HEFA at Grangemouth could be 120ktpa with assertive pricing, which is still below a typical plant size. Oil-seed cover crops may provide a potential solution to this feedstock constraint. These non-food crops have been used in the US and Canada to produce biofuel feedstocks between cereal harvests. With the adoption of cover cropping practices, it could be possible to produce 300-400ktpa of oil that would support a commercial HEFA plant. Making a decision to invest in such a plant would be heavily dependent on successful crop studies, showing crop viability and limited impact to food production.

Additionally, a HEFA plant will require a material supply of low carbon hydrogen, which is discussed further in the next section.

Viability (demand / feedstocks / infrastructure)

Conduit of Offshore Wind Projects

Across these projects a reliable supply of low carbon hydrogen will be required. This can be generated from methane (natural gas) and carbon capture, the blue hydrogen route, or from renewable electricity, the green hydrogen route.

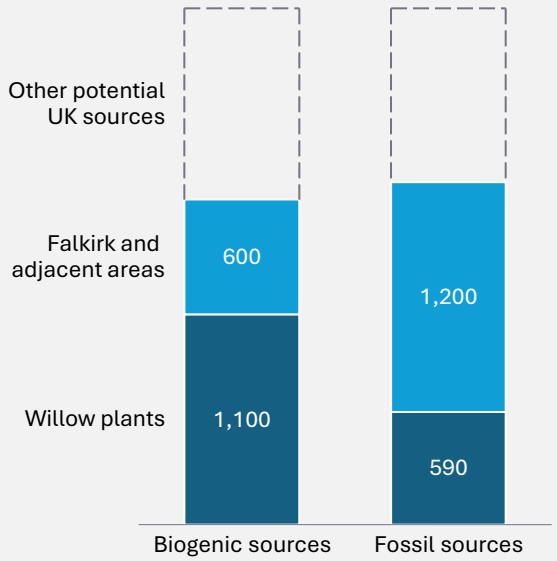
Scotland's ambitious targets of 11GW offshore wind and 5GW renewable / low carbon hydrogen by 2030, rising to 25GW by 2045, highlighting its offshore wind potential. Should this offshore wind capacity be built out, Project Willow's hydrogen projects aim to provide industrial offtake for these green electrons. By converting these to gaseous and liquid molecules via **green hydrogen** they can be more easily stored and transported to where they are needed, potentially reducing the need for costly grid reinforcement to transport power south.

Grangemouth, through Project Acorn, also has the potential to develop **blue hydrogen**, which would see natural gas converted to hydrogen and the carbon captured and sent to St Fergus for offshore storage. This would also facilitate the decarbonization of the wider cluster and central belt both through the potential conversion of fuel gas by-products from the chemical cluster and by creating an injection point for captured CO2 from the local area.

The split between green and blue hydrogen that is required to supply the projects in Willow has not been determined and this will have to be examined through feasibility studies in later stages. If the projects tend towards the higher end of the cases explored it is likely that green hydrogen at the gigawatt scale will be required. In this scenario it is likely that much of the green hydrogen will be produced at sites elsewhere in Scotland and transportation networks will be required to move the hydrogen to Grangemouth.

In addition to the hydrogen, the **e-methanol** project will require a source of CO_2 to produce methanol. In the UK's SAF mandate e-fuels produced from fossil CO_2 are qualifying however in the EU CO_2 must come from biogenic sources. The e-methanol project for Project Willow has a range of sources to draw from, with material sources of biogenic CO_2 potentially coming from the anaerobic digestion and bioethanol projects.

Available CO2, (ktpa)



Source: Department for Energy Security and Net Zero, stakeholder interviews, company data, EY Parthenon research and analysis

Demand

Feedstocks have been balanced with the demand for the products of the plants. Sizing reflects Scottish demand, then national demand, and finally some international demand, if markets meet growth forecasts.

Plastic recycling and bioplastics

In 2018 the UK government set a target of eliminating avoidable plastic waste by 2042 and has introduced a range of policies to reduce plastic packaging and boost recycling. Plastic packaging waste generation is at approximately the same level now as 10 years ago, having peaked in 2021 and across that period recycling/recovery rates have increased 13% to 53%. Unfortunately, the degradation in plastic quality that results from the most common form of recycling, mechanical recycling (where recycled plastics are sorted, shredded, and reformed), limits the applications for which the plastics can be reused. Dissolution plastic recycling creates virgin-like polymers that can be used in much the same way as the original plastic created from fossil fuels. It also has the benefit of being able to accept a broader range of plastics such as films which in 2019/20 had a collected for recycling rate of c.17%. This virgin-like plastic would count as recycled content for companies looking to change their exposure to the UK Plastic Packaging Tax.

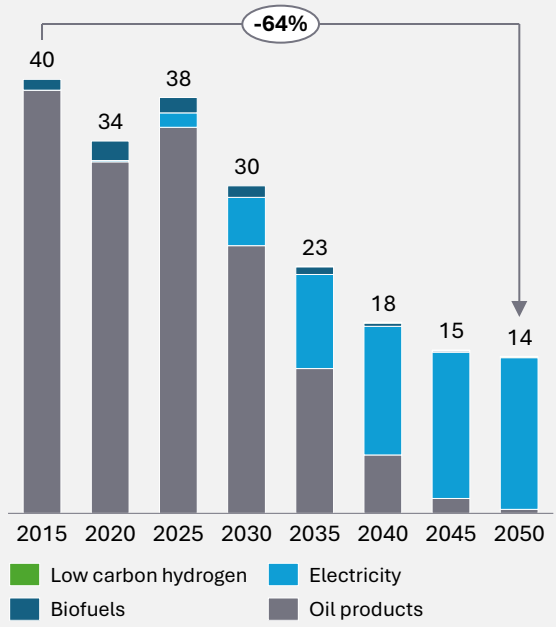
Viability (demand / feedstocks / infrastructure)

An alternative to recycling and an opportunity to avoid fossil fuel consumption in the production of plastics is to look at options to produce plastic from biological sources. Currently around 1% of European plastics production is from bio-based feedstocks, however these have the potential to scale significantly if their ability to lock in carbon starts to be recognized by governments and corporates. By producing plastics from biological sources (such as polyethylene from bioethanol) the carbon captured by the plants in their growing cycle from the atmosphere can be locked into useful products that can endure for many years before being recycled into other products. The challenge facing this solution will be one of traceability, making sure those plastics are kept in circulation either being reused or recycled.

Chemicals

Chemical production in Europe and the UK is challenged with high energy and labour prices regularly highlighted as hindering competitiveness comparted to international imports. Against that backdrop of relatively stagnant production levels, there are greens shoots where Europe has the potential to lead. With the EU And UK ETS and CBAMs, European companies have an incentive to explore innovative low carbon alternatives even if at relatively small scale to start with. As the transition accelerates, interviews with industry experts suggest that scaling primary chemicals like ethanol, methanol, hydrogen, and ammonia will provide the feedstocks for future low carbon chemical demand, while also having adjacent applications as energy vectors that provide optionality to a plant as the market emerges.

UK road transport energy demand, CCC balanced pathway scenario (Mtoe)



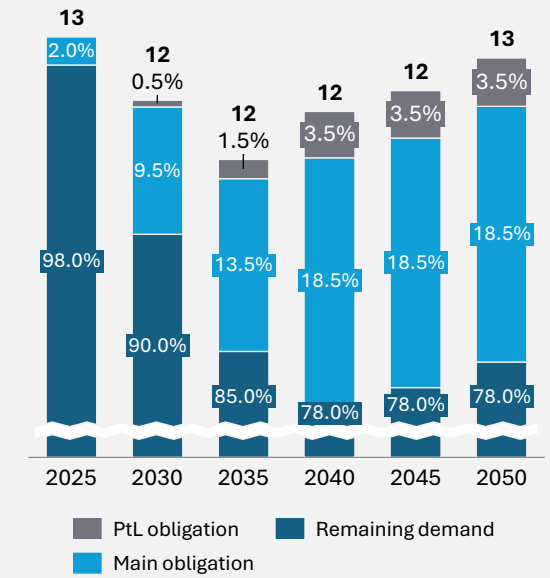
Source: Climate Change Committee, Department for Energy Security and Net Zero, EY Parthenon research and analysis

Road fuels

UK petroleum product demand for road transport has been declining since 2015, driven by a combination of increased fuel efficiency and the rise of electric vehicles. Looking forward road transport energy demand is expected to fall 37% out to 2040, with petroleum products falling from 95% of supply to 58%. This transition will vary across vehicle types, with passenger and light commercial vehicles increasingly electrifying, while heavy goods vehicles potentially requiring biofuel and potentially hydrogen-derived alternatives. These harder-to-decarbonize vehicle types will mean that there will be UK demand for drop in alternatives for fossil fuels that can meet the RTFO standard such as renewable diesel.

Viability (demand / feedstocks / infrastructure)

UK aviation fuel demand under the SAF mandate, CCC balanced pathway scenario (Mtoe)



Source: Climate Change Committee, Department for Energy Security and Net Zero, EY Parthenon research and analysis

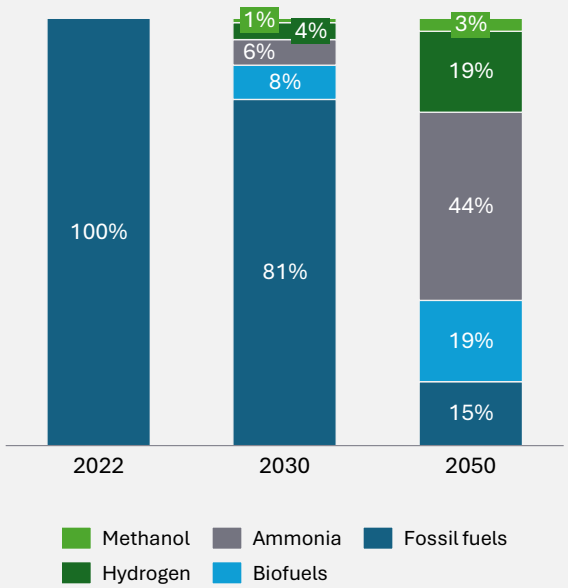
Aviation and shipping

Both shipping and aviation energy demand is harder to decarbonize than road transport given the currently available technologies. As both will require new supply chains to scale and deliver new fuel types the transition for these segments will start to gain momentum later in the 2030s and into the 2040s, hence the timing of the projects serving these demand areas being later in the timeline. Given the nascency of the transition in these sectors there is significant uncertainty in the exact product mix that will be deployed, so developments will need to be monitored to inform project decision making.

In the UK, the government has introduced the SAF mandate to support the deployment of Sustainable Aviation Fuel (SAF). This gradually ramps up the proportion of fuel that needs to be from lower carbon intensity sources, with both a main obligation using mainstream SAF (eg HEFA) and a Power to Liquid (PtL) mandate. This is intended both to increase the supply of SAF overall and to encourage the development of novel fuels that can be produced from low carbon hydrogen. There are a number of challenges to producing SAF in the UK (outlined in the Government recommendations section) however the mandate gives a clear indication to the market of the volumes that are required. Additionally, the EU has also put in place SAF requirements that could provide additional demand for a Grangemouth plant, either with physical supply or on a book and claim basis.

For shipping fuel, the certainty around demand is less firm, given the absence of a mandate equivalent to that for SAF. However, there are clear signals that the market is starting move and secure decarbonization pathways. Driven by the amendments to the EU ETS and FuelEU emission intensity limits, orders for methanol fuelled/dual fuelled ships have risen to over 220, and shipping companies like Maersk and Cosco are taking steps to secure supply by signing MoUs for low carbon fuel offtakes or investing in production. While in the short-term looking at low carbon shipping order books, demand appears skewed towards methanol, over longer-term Ammonia is expected to rise to prominence, breaking the dependence on CO_2 supply that will potentially limit methanol production.

International shipping share of final energy consumption, Net Zero Scenario



Source: IEA, EY Parthenon research and analysis

Viability (demand / feedstocks / infrastructure)

Infrastructure

The projects proposed also draw on the competitive advantage of the access to local available infrastructure.

Integrated logistics aggregation

The projects will leverage existing infrastructure to bring feedstock to site and distribute finished product.

Grangemouth port is the largest container terminal in Scotland, handling 9 million tonnes of cargo each year, representing up to 30% of Scotland's GDP. It has jetties for loading and unloading liquid fuel and bulk commodity handling facilities. Additionally, there is a rail freight terminal connected into the port and refinery location.

70% of Scotland's population live within a 1hour drive with access onto the M8, M9, and M80 motorways, meaning Scotland's largest airports of Edinburgh and Glasgow are 20 and 45 minutes away.

Synergies within the cluster

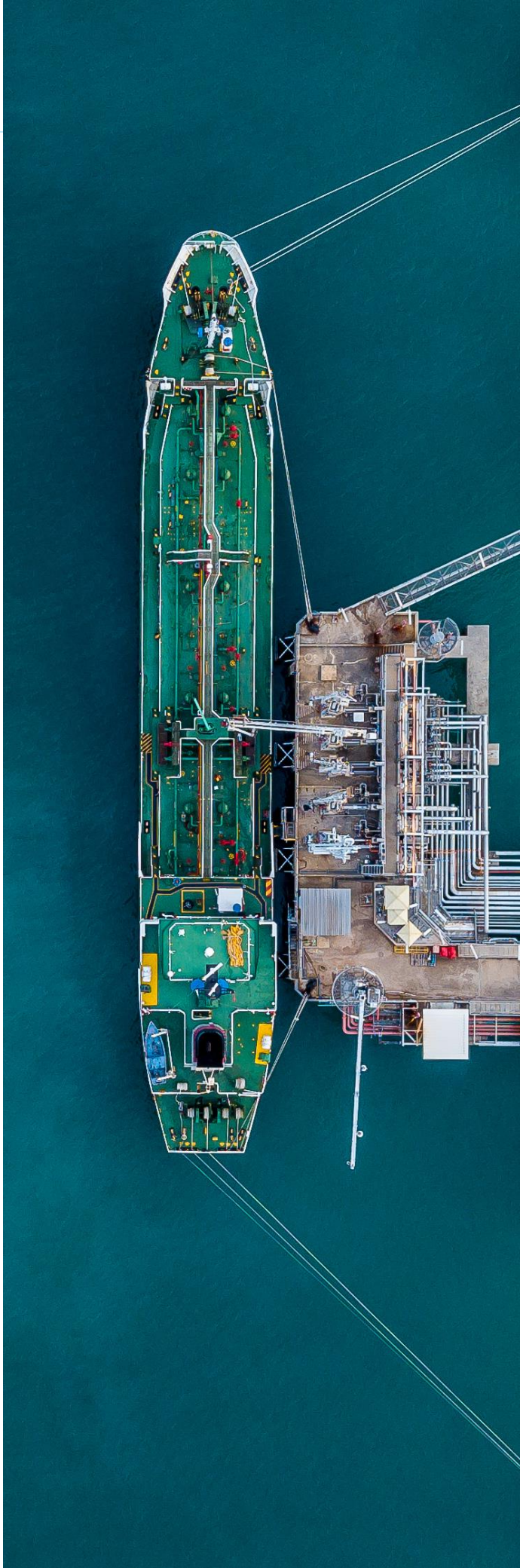
There are synergies through the existing fuels distribution networks and access to water treatment, heat and power, and other utilities.

There is a strong link between the clusters existing businesses and the local Forth Valley College, as well as central belt universities in Glasgow Edinburgh and Stirling, providing the next generation of employment and innovation.

Leverage existing assets

There are also opportunities to reuse existing tank storage, ethanol facilities, and other ancillary assets at the site, that will be further explored in detailed feasibility studies.

The scale of development put forward therefore reflects a shared ambition both of Government and Industry, not only for Grangemouth but also for the UK to be a leader in low carbon manufacturing.



Project synergies

The uniqueness of Project Willow lies in the combination of multiple projects set out in a long-term, collective programme to leverage synergies between different technologies.

There are a number of interactions between projects included in the preferred project set which unlock additional scale and value across the full timeline view of Project Willow.

These relate to both cross-project integration opportunities and wider benefits derived from the co-ordination across the cluster which Project Willow represents.

Cross-project integrations

Across the project portfolio there are significant opportunities to unlock technologies at scale, utilising the product and by-products to build out value chains. Examples of these potential synergies include utilising the biogenic CO2 from anaerobic digestion to create e-fuels or utilising the carbohydrate rich byproduct of bioethanol production to create low carbon chemicals.

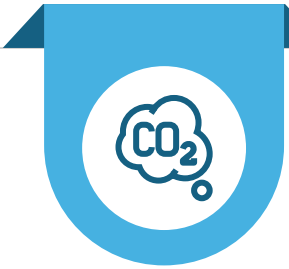
Portfolio coordination synergies

A coordinated approach to delivering the portfolio also has a variety of benefits in the efficient planning and construction of plants. A shared vision allows for support services such as effluent treatment, grid connections, or logistics terminals to be right-sized. Similarly, coordinating construction allows for efficient deployment of resources and skills as well as potentially reducing community impact.

Additionally, having central oversight builds confidence that both government and the private sector will be held to account, providing certainty and improving transparency that attracts investors.

How Willow supports Government policy

Growth



Net Zero

Circularity

HM Government

Shared government ambition

Scottish Government
Riaghaltas na h-Alba

- Deliver growth that can be felt in every nation and region
- Drive innovation, investment and the adoption of technology
- Create long-term high quality jobs

- Achieve the 2045 and 2050 Net Zero targets
- Make Britain a clean energy superpower
- 5GW low carbon hydrogen in Scotland by 2030
- SAF fulfilling 15% of UK jet fuel supply by 2035

- Maximise value from waste materials
- Enhance domestic resource resilience
- Increase plastic packaging recycling rates to 65% by 2030
- Stimulate investment in technologies that enable resource circularity

Project Willow contributions

- Unlock infrastructure investments in Grangemouth
- Create up to 800 direct jobs by 2040
- Provide confidence to Scottish and UK supply chains to invest in UK capacity

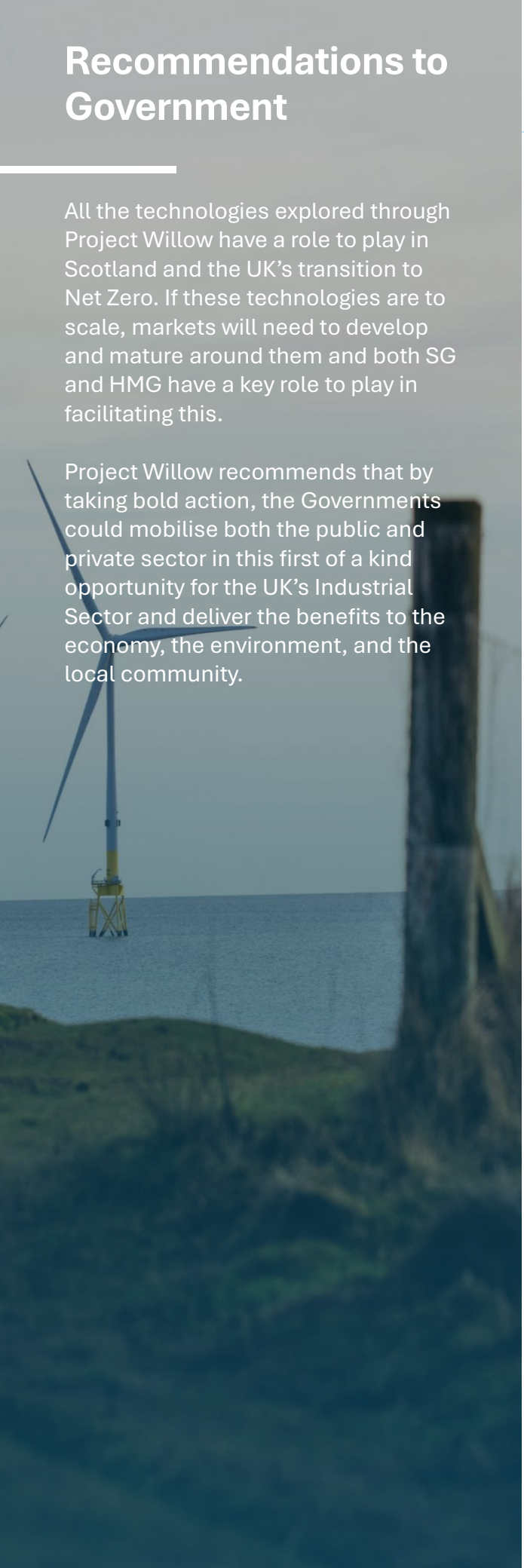
- Reduce Scottish emissions by up to 4% of 1990 levels
- Develop material capacity in low carbon technologies that target hard to decarbonise sectors
- Create a real offtake opportunity for Scottish low carbon hydrogen at scale

- Create new pathways for hard to recycle plastics
- Establish recycling capacity that maintains the plastics original value
- Build plants that create high value chemicals from waste streams

Recommendations to Government

All the technologies explored through Project Willow have a role to play in Scotland and the UK's transition to Net Zero. If these technologies are to scale, markets will need to develop and mature around them and both SG and HMG have a key role to play in facilitating this.

Project Willow recommends that by taking bold action, the Governments could mobilise both the public and private sector in this first of a kind opportunity for the UK's Industrial Sector and deliver the benefits to the economy, the environment, and the local community.



Project Willow has identified a range of recommendations for both HMG and SG. These recommendations will help unlock significant private investment required to realise Grangemouth's full potential:

Grant funding	• Ensuring coordination between existing Government initiatives to maximise the value of funding e.g., Green Freeport, Falkirk and Grangemouth Growth Deal, to ensure that the cluster is given required attention
State Sponsored Investment	• Utilising Government investments as keystones to unlock private financing • Leveraging the mandates set out for the National Wealth Fund (NWF) (committed at least £5.8bn investment in sectors such as green hydrogen and carbon capture) and Scottish National Investment Bank (SNIB)
Hydrogen economy support	• Supporting efforts to reform electricity markets to bring down the cost of renewable power • Scaling deployment of the low carbon Hydrogen Production Business Model • Evolving the RTFO and SAF mandate to better accommodate hydrogen derived fuels • Addressing terms in the LCHA that increase producer risk
Biofuels market reform	• Test the potential for Scottish agriculture to scale oil seed cover crops and explore changes to the SAF mandate to permit such feedstocks • Consider potential extensions / replacements for the Green Gas Support Scheme • Mobilise bio-feedstock supply chains supporting farmers and forestry
Low carbon demand stimulation	• Develop policy to accelerate adoption of low carbon chemicals and plastics • Examine options to drive decarbonisation of shipping

Detailed recommendations to government

To unlock private investment to support the projects identified in Project Willow the Government will need to show progress against a number of recommendations.

Project category	Recommendation
Wastes projects	Provide devex and capex support (whether through grant, debt or equity)
	Implement policies to increase plastic collection, separation, and aggregation
	Implement policies to accelerate adoption of recycled plastics across sectors
	Implement policies to accelerate transition to low carbon chemicals
Scottish bioresources	Provide devex / capex support (e.g. grant, debt or equity) to de-risk scaling
	Field studies to increase forestry productivity and test environmental impact
	Implement policies to accelerate adoption of bioplastics (e.g. carbon credits, mandates, revenue support, etc.)
	Promote adoption of 2nd over 1st generation biofuels (e.g. EU RED II)
	Mobilise forestry industry to support bioethanol with support for pre-processing plants, temporary price guarantees, etc.
	Extension of GGSS beyond 2028
	Inclusion of biochar from digested in agricultural use policy
	Support field studies for cover crop viability and optimisation
	Permit SAF produced from oil-seed cover crops under SAF mandate
	Seek HEFA cap exemption for domestic cover crop feedstock
	Seek delay to HEFA cap implementation for 10 years to allow UCO imports to be permitted as cover crop supplies scale up
	Support oil seed supply chain mobilisation (eg price guarantees, support for crushing facilities etc)
	Low carbon hydrogen support (see below)
Conduit for offshore wind	LCHA amendments (eg CO2 T&S cross chain risk, offtaker volume risk)
	Decision on Acorn FID
	Power market reform to provide reduced power price to H2 projects
	Continued support for projects under HPBM scaling to larger plants
	Connections reform to accelerate / reduced the cost of new connections
	Provide devex and capex support to mitigate technology scaling risk
	Permit H2 projects supporting e-fuels to access HPBM and SAF mandate/RTFO
	Revise Power to Liquid SAF buy-out price to reflect UK production costs
	Drive policies to accelerate low carbon chemicals and shipping fuels
	Relax temporal and additionality req. on renewable power into e-fuels

Impact of Project Willow

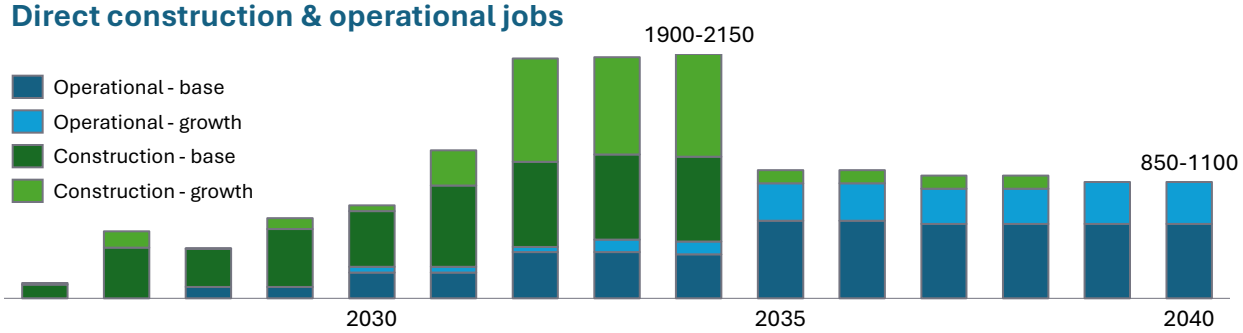
Project Willow could be deployed over the next 20 years, with the right support, to create a flourishing low carbon hub in Grangemouth. At its full potential, it could bring the following benefits to the local community, Scotland and the rest of the UK.

GVA[1]

	Base				Growth			
	Direct	Indirect	Induced	**Total**	Direct	Indirect	Induced	**Total**
Peak construction annual GVA (£m)	225-245	180-200	60-80	**460-500**	460-510	400-440	120-180	**900-1100**
2040 operational annual GVA (£m)	(820)–(780)	1,250-1,310	150-180	**590-690**	(1,420)-(1,380)	2,440-2,520	280-320	**1,330-1,430**
Cumulative GVA by 2060 (£m)	(8,500)-(8,000)	15,500-16,000	2,200-2,400	**9,200-10,400**	(13,700)-(13,100)	28,550-29,350	3,700-4,300	**19,200-19,800**

Jobs

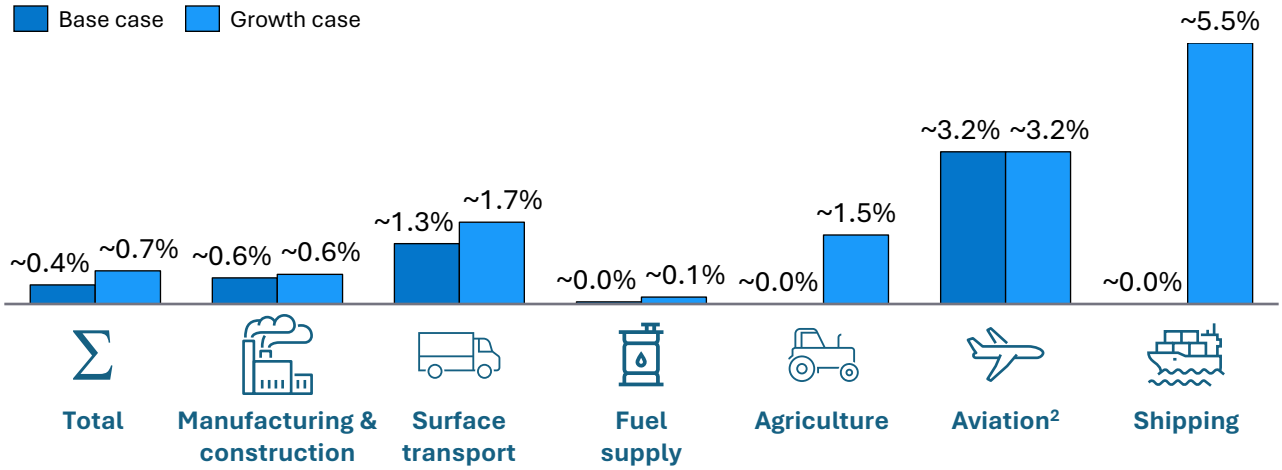
Direct construction & operational jobs



The breadth of skills required across the preferred project set are broader than the existing site. The majority of roles are forecast to be operators, maintenance technicians and engineers at the core of a new low carbon energy hub. The additional roles, particularly for the newer technologies, could include scientists and laboratory workers.

Environment

UK emissions reduction vs UK 1990 emissions (%)



1. Annual GVA figures are in real terms and not discounted. Cumulative GVA figures encompass both operations and construction impacts across all projects and are discounted at 3.5%. Growth case GVA figures are inclusive of Base Case equivalent GVA. GVA figures exclude any government support hence negative direct GVA values.
2. Aviation emissions are based on 2019 data to account for the increase in emissions since 1990

Impact of Project Willow

Community

Given the intrinsic links between the industrial cluster and the wider town of Grangemouth, it is clear that whatever changes lie ahead through the transition to Net Zero, will have an impact on the social, natural and built environment of the town. The Draft Grangemouth Just Transition Plan has identified the following key areas of feedback from the Community:

Industrial strategy not a green plan

The plan should emphasise that Grangemouth will continue to have a future as an industrial centre. But its future will be in the green, clean, net zero economy

Transparent communication

It should set clear, achievable long-term goals while also incorporating tangible short-term projects.

Improving Quality of Life

A successful Just Transition Plan should prioritise job protection and skills development to ensure that as many existing workers as possible are included in future industries.

Education, skills and jobs

The benefits should extend beyond simply creating jobs in the industrial cluster.

Incorporating existing industries and people

Avoid using the 'green future' as the key narrative driver. Instead focus on pushing the narrative of '21st-century industrial policy' as the phrase is understood. Include existing industries in the transition plan.

Project Willow could be deployed over the next 20 years, with the right support, to create a flourishing low carbon hub in Grangemouth. At its full potential, it could bring the following benefits to the local community, Scotland and the rest of the UK.

Jobs
Project Willow sets out job levels for the selected technologies on the Grangemouth site

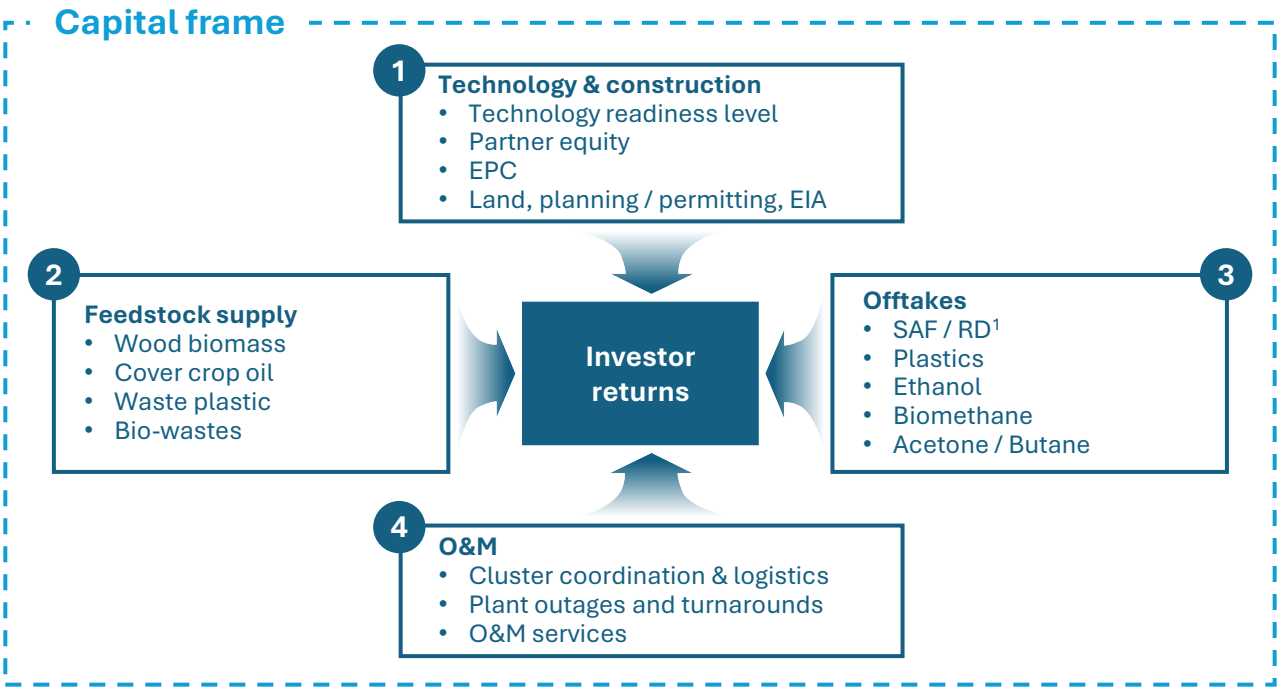
Skills
The projects would require a range of roles and skills required to support the construction and operation of the technologies selected

Tangible opportunities
Identifies tangible ways to decarbonise and grow the existing industries which could bring investment to the local area

Community engagement
Stakeholder engagement will continue, through forums like GFIB, to ensure alignment of the community, industry and public sector objectives

Investment opportunities

A capital frame encompasses the processes that govern how capital is raised, invested, and monitored to achieve desired outcomes. It helps to ensure that resources are utilised efficiently and effectively, aligning financial decisions with overall goals and risk tolerance. **The capital frame of Project Willow** coordinates both physical and financial flows across stakeholder contracts.



Investment Opportunities

We are seeking ambitious, interested parties who are excited to be part of the Project Willow programme:

Developers and technology providers with experience in the nine projects and who are willing to work with Government and landowners to realise these opportunities. Project Willow provides a platform to demonstrate products at scale.

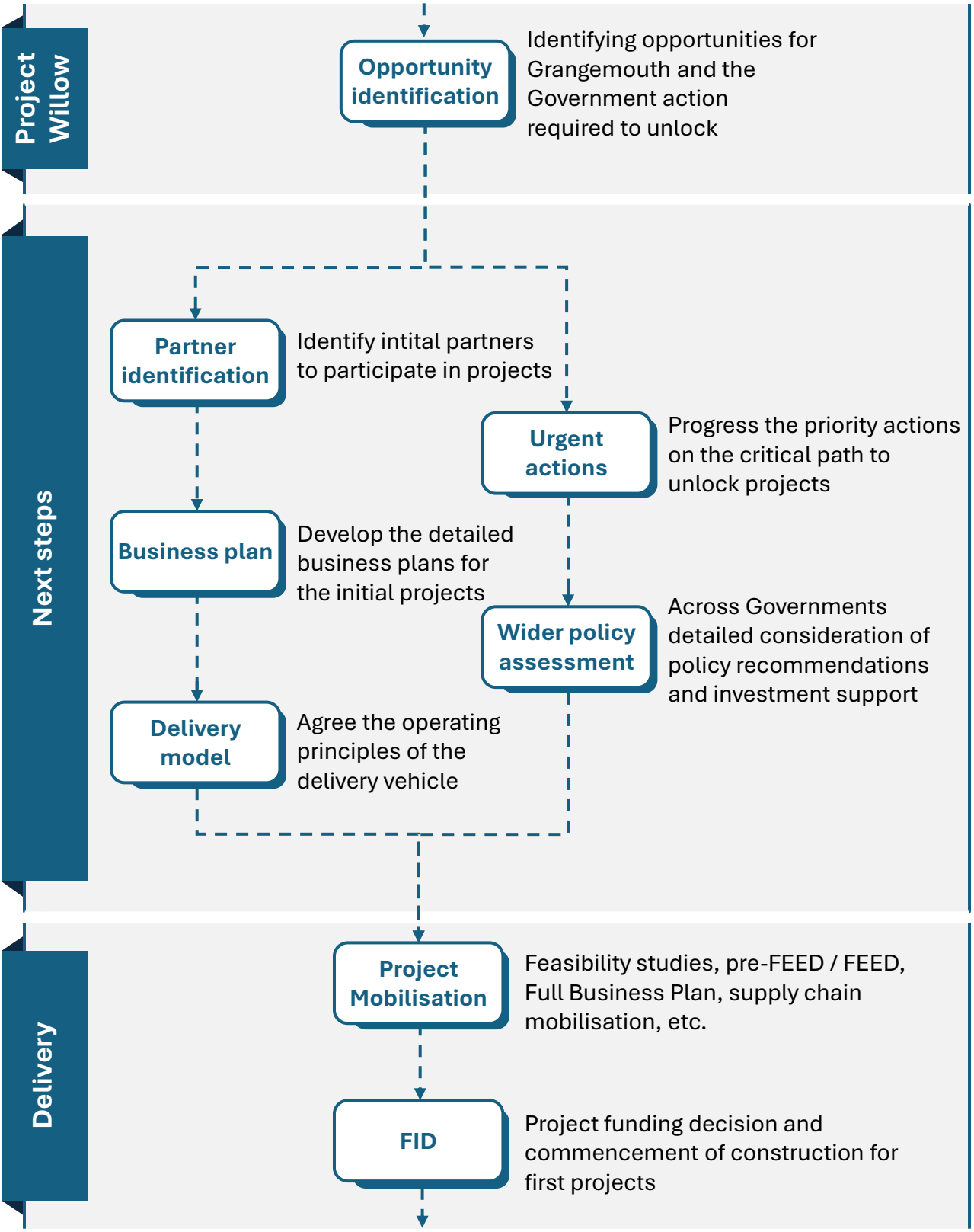
Feedstock suppliers who have capacity and interest in working with us to maximise the supply chain for low carbon manufacturing.

Corporate partners and offtakers interested in securing the low carbon products that will be manufactured at Grangemouth, and building capability and credibility that can be deployed elsewhere.

Investors interested in financing commercial low carbon manufacturing projects at Grangemouth.

Development timeline and next steps

Project Willow has successfully identified a portfolio of projects that could be developed to transform the Grangemouth Industrial Cluster into a low carbon manufacturing hub. The following next steps have been identified in the critical pathway to success:



Contacts

Project Willow is a combined project working in collaboration with HMG, SG, and Petroineos.

To understand how your organisation could contribute to the growth of Grangemouth's future, contact the Project Willow delivery team.

Contacts

Submit an enquiry about Grangemouth or email Scottish Enterprise at Grangemouth@scotent.co.uk

Scottish Enterprise

Glossary

Abbreviation	Term
ABE	Acetone-Butanol-Ethanol
BTR	Bottle Top Regrind
CO2e	Carbon Dioxide equivalent
COD	Commencement of Operations Date
ETS	Emissions Trading System
EU	European Union
FEED	Front-End Engineering Design
FID	Final Investment Decision
FOGs	Fats Oil and Grease
FTE	Full Time Equivalent
GDP	Gross Domestic Product
GGSS	Green Gas Support Scheme
GVA	Gross Value Add
GW	Gigawatt
H2	Hydrogen
HEFA	Hydrogenated Esters and Fatty Acids
HMG	His Majesty's Government
HPBM	Hydrogen Production Business Model
HVO	Hydrotreated Vegetable Oil
LCHA	Low Carbon Hydrogen Agreement
MoU	Memorandum of Understanding
NWF	National Wealth Fund
PE/PP	Polyethylene/Polypropylene
RD	Renewable Diesel
RFTO	Renewable Transport Fuel Obligation
SAF	Sustainable Aviation Fuel
SG	Scottish Government
SNIB	Scottish National Investment Bank
T&S	Transport and Storage
UCO	Used Cooking Oil
UK	United Kingdom

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