CHALLENGES OF LARGE SCALE GREEN HYDROGEN DEPLOYMENT

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Cranfield University Hydrogen Showcase

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Strong track record; deep capability

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>200 MILLION
average annual direct construction work-hours

>US$1.75 BILLION
procurement average spend per year

31 OFFICES
across 29 countries

>4.5 MILLION
annual engineering work-hours

+200
major projects delivered

+100
client assets supported

41 YEAR
track record

8,200
employees worldwide

Adding value across the asset life

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DESIGN

Project Development and Engineering

- Development planning
- Concept design
- Screening
- Selection
- Pre-FEED
- FEED
- LLI procurement
- Detailed design
- Site support

BUILD

Project Execution

- Project management
- Detailed engineering
- Procurement
- Construction
- Commissioning
- Installation
- Operations readiness

OPERATE

Asset Support

- Operations and maintenance
- Modifications
- Well engineering
- Asset performance improvement
- Due diligence
- Transition management
- Fully managed services

TRAIN

Training and Competence

- National workforce development
- Training centre design and management
- Vocational training
- Competence assurance
- Digital training

DECOM

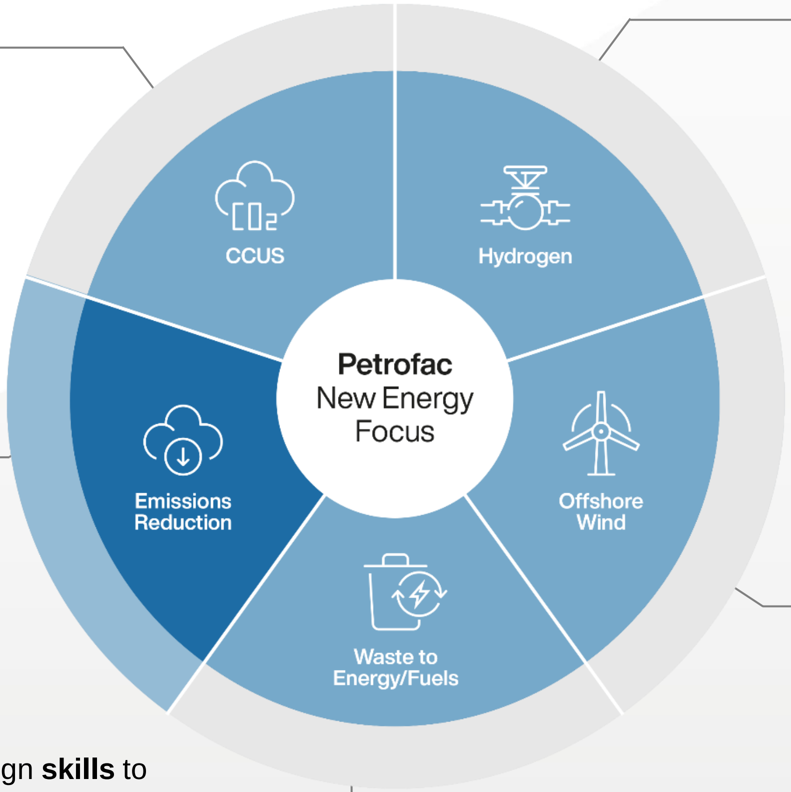
Late Life Services

- Late life asset management
- Decommissioning preparatory support
- Well decommissioning
- Fully managed services, including removal and disposal

New energy **Focus**

Using our expertise in **gas processing**, transport and storage to safely and economically **capture** and **store carbon**

Our **wind**, **solar** and **gas** capabilities allow us to design and build **green** hydrogen projects. Our **hydrocarbons experience** enables us to deliver large-scale **blue** hydrogen solutions



Leveraging our years of **experience** in **designing** and **operating** oil and gas assets, we support **in reducing** the **carbon intensity** of operations

Over 10 years' of **expertise** in **designing** and operating **offshore** electrical substations, both **HVAC** and **HVDC**

Using our **petrochemical** design **skills** to transform **waste feedstocks** into valuable products: road and sustainable aviation fuels

Agenda

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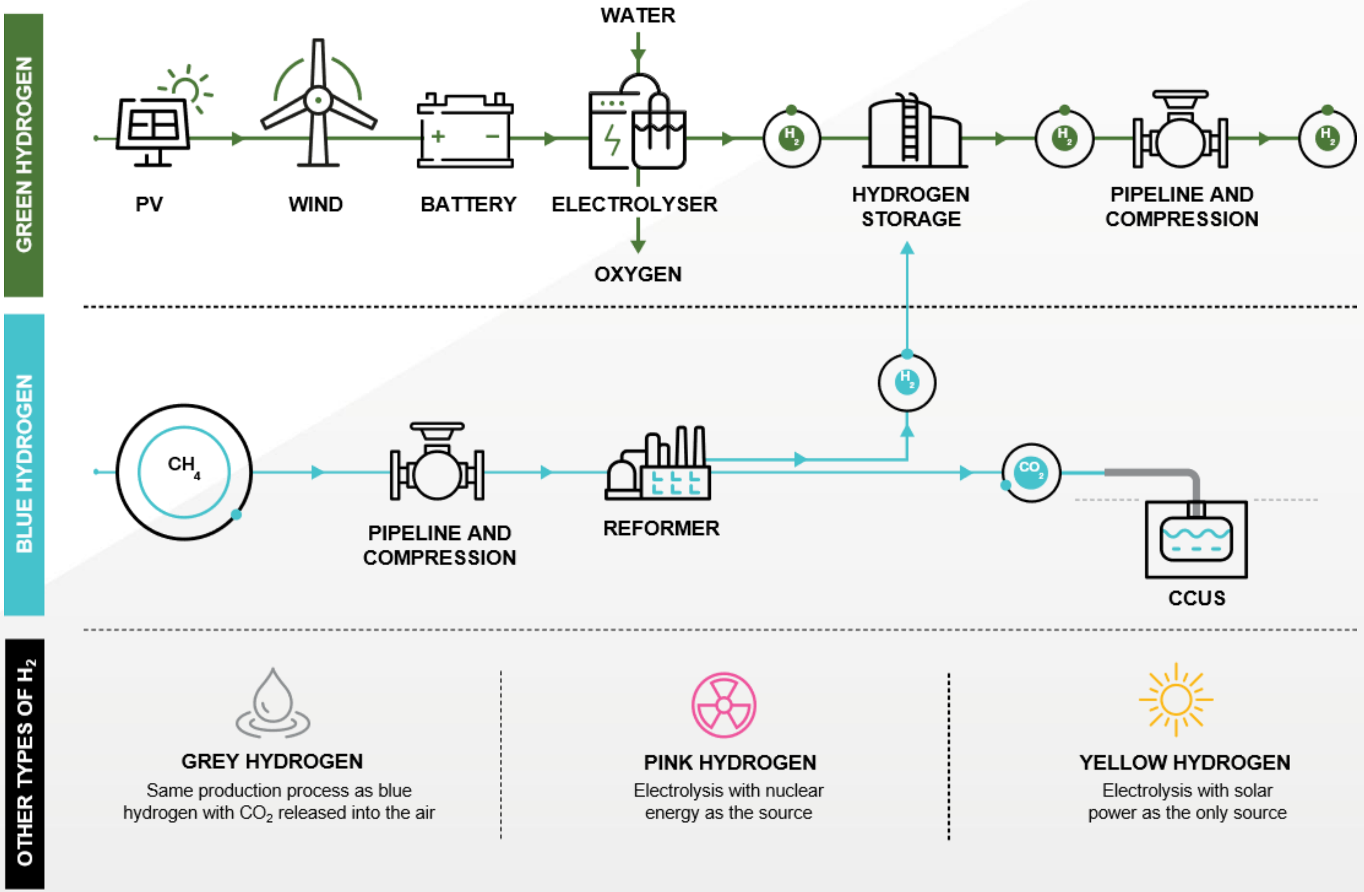
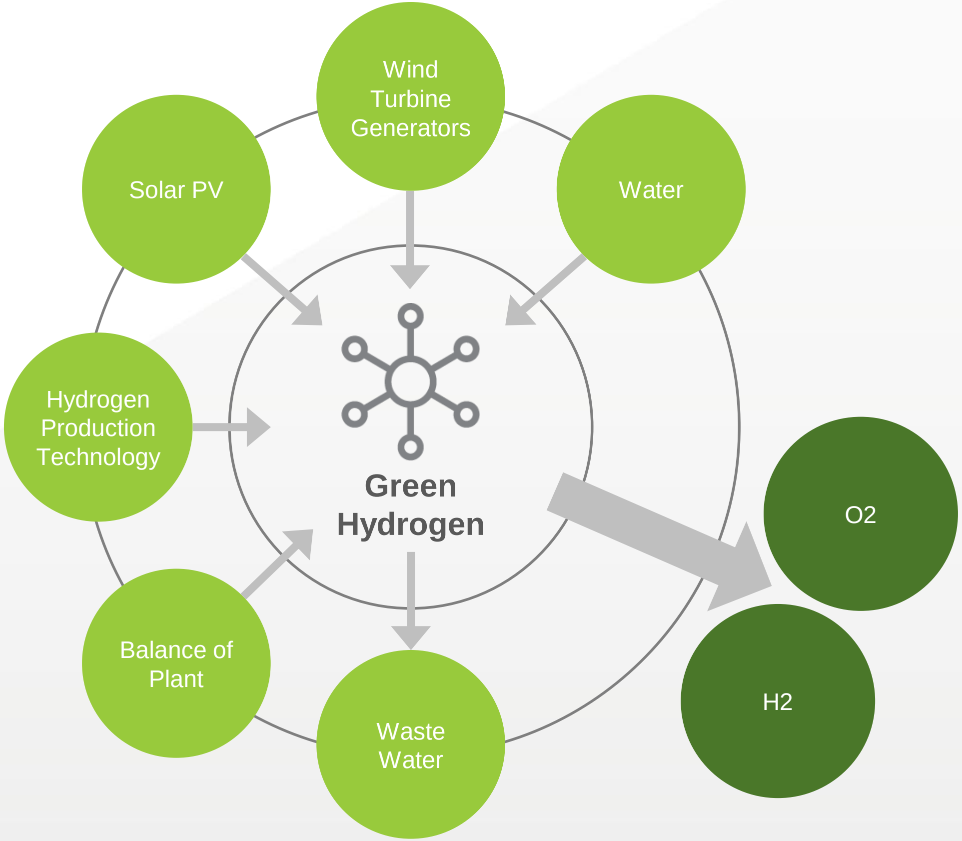
1. INTRODUCTION
2. ARROWSMITH STAGE 1 FEED PROJECT
3. DESIGN CHALLENGES
4. DEPLOYMENT OF GREEN H_2
5. CONCLUSIONS

Types of hydrogen



Green hydrogen elements



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1 INTRODUCTION

2 ARROWSMITH STAGE 1 FEED PROJECT

3 DESIGN CHALLENGES

4 DEPLOYMENT OF GREEN H_2

5 CONCLUSIONS

ARROWSMITH

Arrowsmith Green Hydrogen Plant

SCOPE

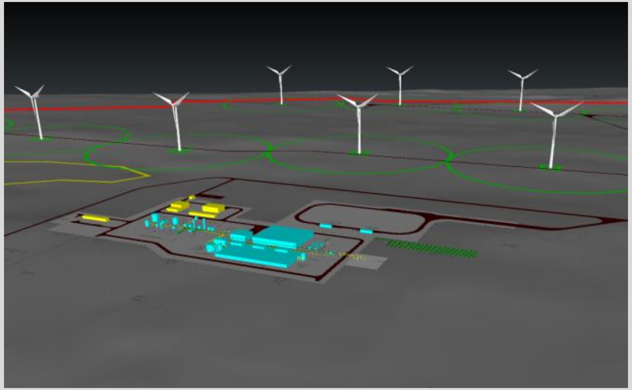
In October 2020 Petrofac was awarded the FEED for the Arrowsmith Hydrogen Plant Stage I by Infinite Blue Energy.

Designed to produce 25 tonne/day of green hydrogen from raw water using electrolysis and renewable energy sourced from an onsite solar (70MW) and wind farm (96MW) with green grid connection back-up. Liquid and compressed Hydrogen will be delivered to the local transportation market.

The project will be delivered by an integrated Petrofac team from bases in Australia (Perth) and the UK (Woking).

Next steps:

Petrofac is seeking to follow through to the EPCm phase of the project in 2021.



Plant is 320km north of Perth

Will save CO_2e of 83,103 t/annum

Production expected by the end of 2022

Arrowsmith Green Hydrogen Plant

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LEVEL 1 DOMESTIC

- 25 t/day H_2
- 83,103 t/y CO_2 avoided
- Transport and electricity focussed markets
- AUD 420 million capital cost per plant

LEVEL 2 EXPORT

- 130 t/day H_2
- 737,137 t/y CO_2 avoided
- Export and electricity focussed markets
- AUD 2.3 billion capital cost per plant

LEVEL 3 WORLD SCALE

- 255 t/day H_2
- 1,519,770 t/y CO_2 avoided
- Export and manufacturing markets
- AUD 2.1 billion capital cost per plant

LEVEL 4 ASIA PACIFIC

- Import and gasification hubs
- Bundling with high carbon exports (e.g. iron ore, petroleum products) to decarbonise industry sectors

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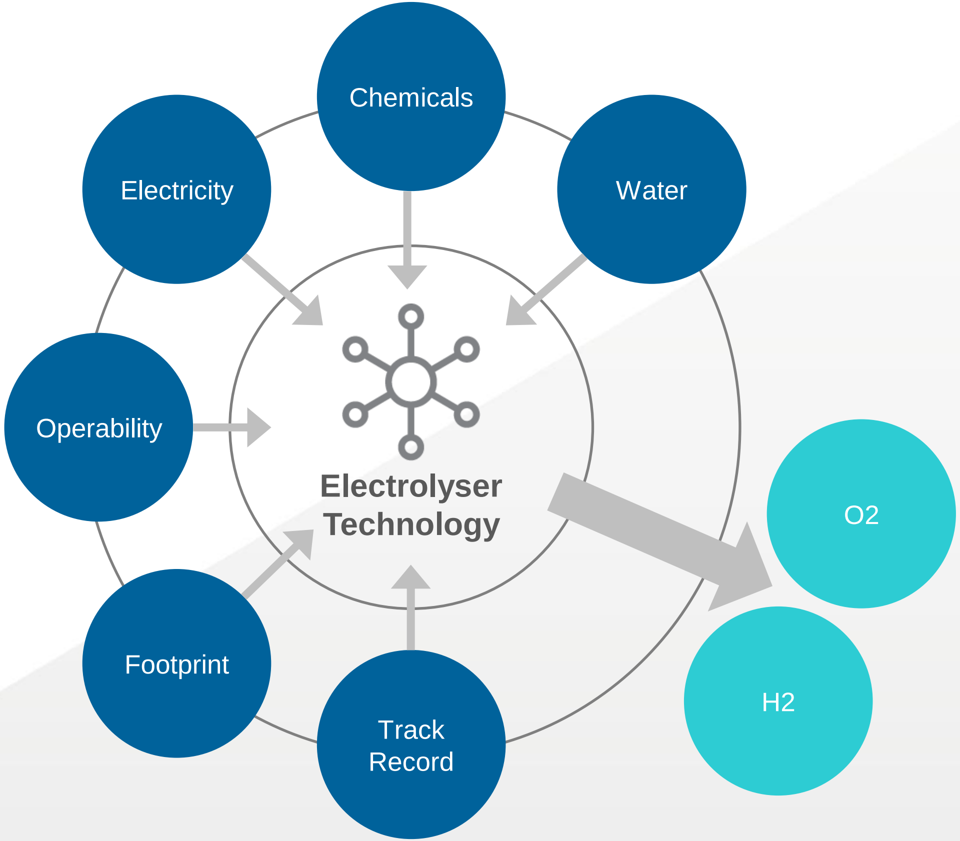
Design challenges

1 Electrolyser technology selection



CHALLENGE

- The choice of electrolyser technology depends on several factors covering economic considerations and technical requirements.
- Alkaline vs PEM.

TARGET

- High reliability with proven track record for large scale hydrogen production.
- Low CAPEX.
- Established supply chain and manufacturing capacity.

APPROACH

- Petrofac engaged with licensors to compare technologies on a like-for-like basis.
- Using licensor data allowed the team to design the balance of plant integration.
- Cost considerations must include balance of plant.

Design challenges

2 The intermittency of renewable power

CHALLENGE

- Solar PV and Wind Turbine energy is intermittent, effected by the daily and seasonal fluctuations
- The process requires a steady supply of power to maintain production capacity
- Alkaline electrolysers require about 15 minutes to shutdown safely in a controlled manner in the event of loss of power

TARGET

- Steady reliable power supply to the process to meet H_2 production requirements.
- The ability to turndown the process safely in the event of total power failure.

APPROACH

- Provide connection to the local grid with electrical metering. Ability to sell excess power and buy back power when required
- Redundancy in power, 70MW Solar PV and 96MW Wind whilst process requires circa to 80MW
- Provide batteries for safe shutdown

Design challenges

3 Wastewater management

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CHALLENGE

- The initial design for 25tpd hydrogen electrolysis required 537tonnes/day of feed water.
- Of which 50% is utilised for electrolysis and 50% is reject water.
- Size of evaporation pond for reject water disposal.

TARGET

- Electrolysers require demineralised water
- Minimise amount of reject water produced
- Elimination of the requirement for an evaporation pond

APPROACH

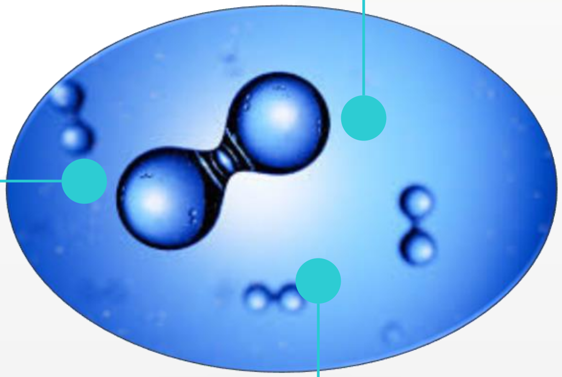
- Bore water identified as the best source for the feedstock fresh water.
- Petrofac engaged local water treatment companies to optimise the water treatment process to reduce reject water streams and ensure that stream meets regulatory requirements.
- Explore discharging the water to a natural lake.

Design challenges

4 Large scale hydrogen storage

CHALLENGE

- 7 days storage of liquid hydrogen
- Storage of gaseous hydrogen required at 350 barg
- Mechanical limitations on vessel diameters with required wall thickness
- Composite tanks are small and scale-up not available for quantities required



TARGET

- Large scale hydrogen storage required
- Gas and liquid hydrogen offtakes negotiated by client

APPROACH

- Cryogenic liquid hydrogen storage - liquid hydrogen liquified at -253 ºC and at low pressures
- Reduced gas requirements and stored in Buffer Tank for vehicle refuelling at site

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Deployment of green H_2

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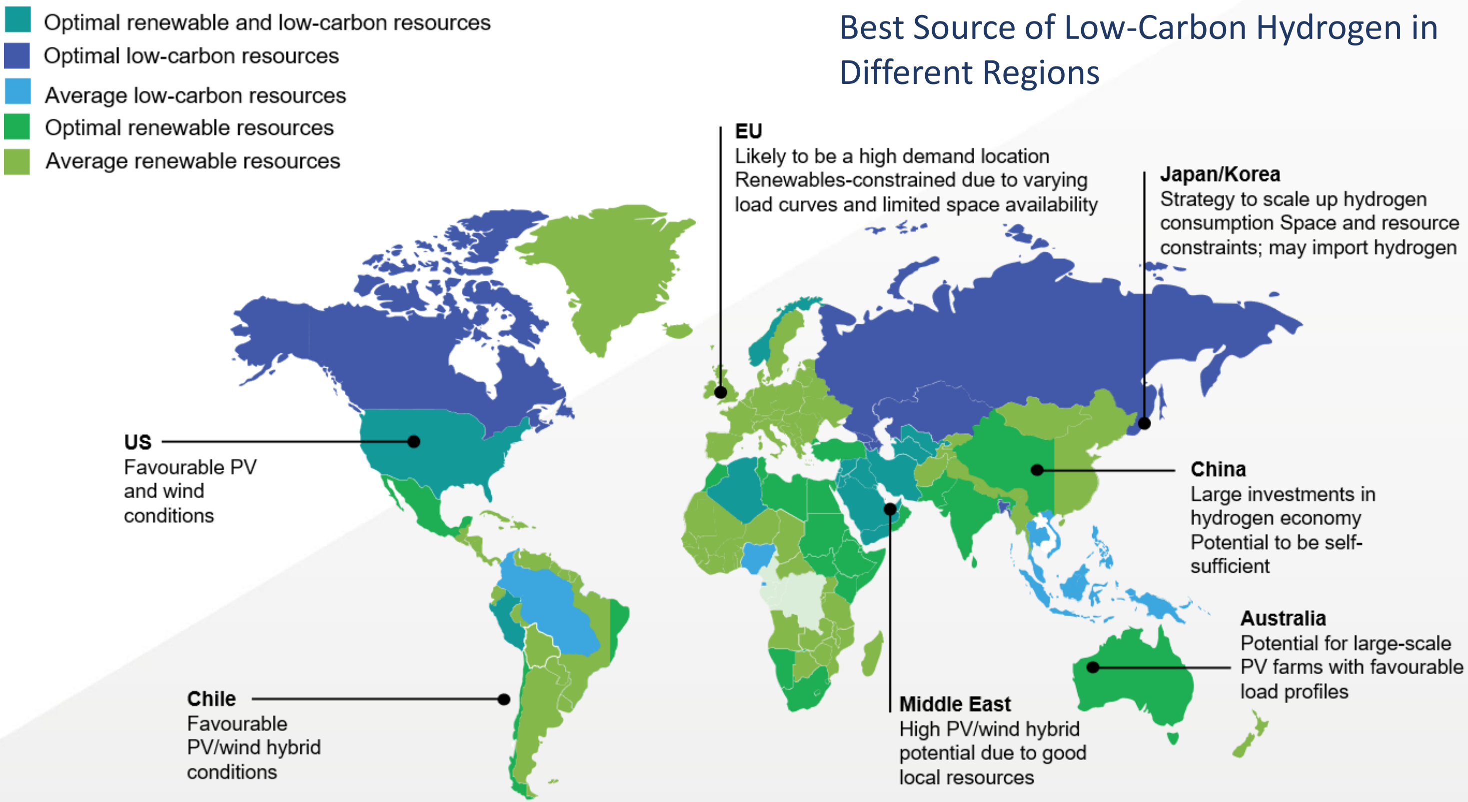
Best Source of Low-Carbon Hydrogen in Different Regions



Source: Wood Mackenzie (2019), “Green Energy Production – Landscape, projects and costs”

- Presently, location of the plant is a primary enabler of Green H_2 production
- Production costs are influenced by cost of renewable energy and cost of the electrolysis unit (and to a lesser degree, the utilisation factor)
- As costs fall, Green H_2 can achieve cost parity with blue H_2 by 2030

Deployment of green H_2

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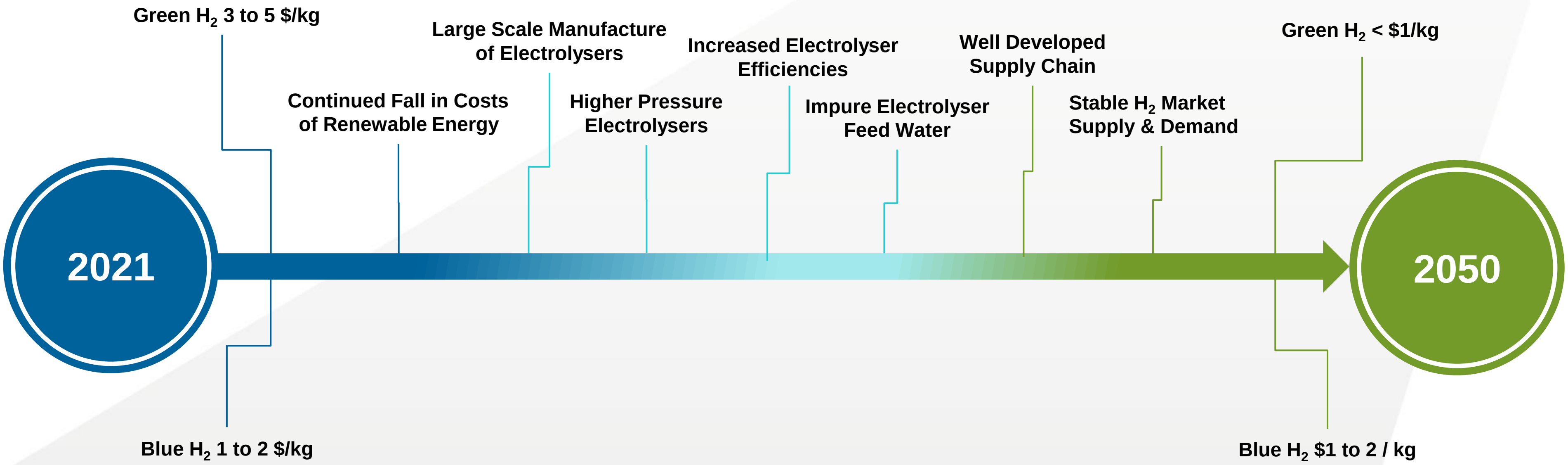

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Conclusions

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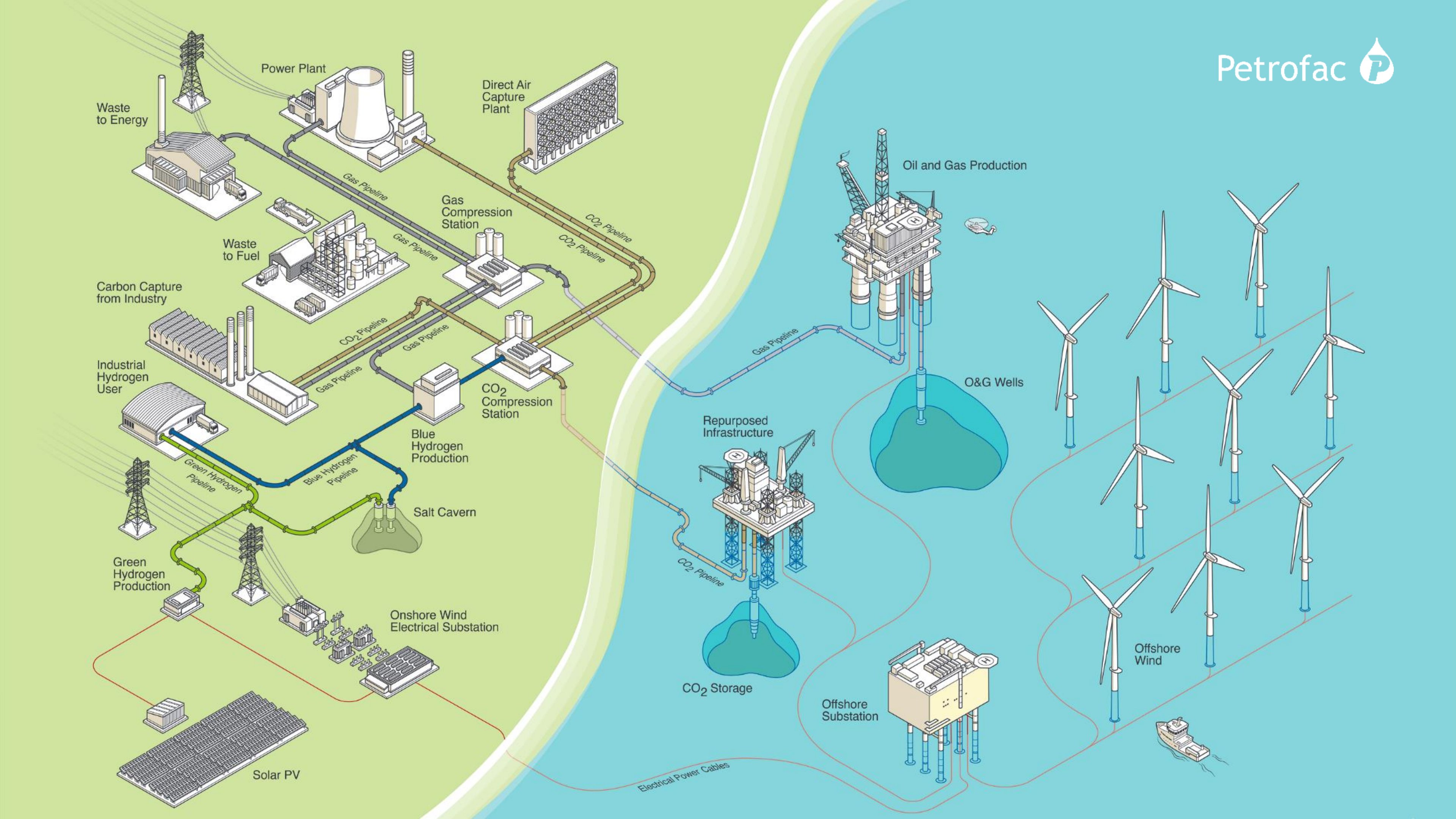
- Project requirements of reliable electrolysers with proven track record, along with lower costs has favours alkaline electrolysers, however a rigorous evaluation that considers balance of plant is needed.
- Intermittency of renewable power for Green H_2 production can be mostly managed by combining renewable power asset e.g. wind and solar PV in Western Australia.
- Western Australia possesses consistent winds blowing for around 18 hrs per day, as well as abundant solar irradiance during daytime.
- Wastewater management must be considered as electrolysers require demineralised water as feed, which may result in the production of significant amounts of reject water, depending on the quality of the feed water.
- Large scale hydrogen storage is challenging with cryogenic storage requiring large amounts of energy and high-pressure H_2 gas storage constrained by material considerations.
- A few companies have proven track record for H_2 electrolysis units, hence early engagement with multiple vendors is essential to establish capabilities and conduct technical assessments.
- Presently, the location of the plant is a primary enabler of Green H_2 production.
- Production costs are influenced by cost of renewable energy and cost of the electrolysis unit (and to a lesser degree, the utilisation factor).
- Green H_2 production costs will fall with falling renewable & electrolysis unit cost to reach parity with blue H_2.


Power Plant
Waste
to Energy
Direct Air
Capture
Plant
Oil and Gas Production
Gas Pipeline
Gas
Compression
Station
CO_2 Pipeline
CO_2 Pipeline
Waste
to Fuel
Gas Pipeline
Carbon Capture
from Industry
CO_2 Pipeline
Gas Pipeline
Gas Pipeline
Gas Pipeline
Industrial
Hydrogen
User
CO_2
Compression
Station
O&G Wells
Repurposed
Infrastructure
Blue
Hydrogen
Production
Green Hydrogen
Pipeline
Blue Hydrogen
Pipeline
Salt Cavern
Green
Hydrogen
Production
CO_2 Pipeline
Onshore Wind
Electrical Substation
Offshore
Wind
CO_2 Storage
Offshore
Substation
Solar PV
Electrical Power Cables
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