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Compressed Hydrogen: An Alternative Approach to Shipping Hydrogen

Chris To, Maritime Engineer
WSP, Sydney, Australia

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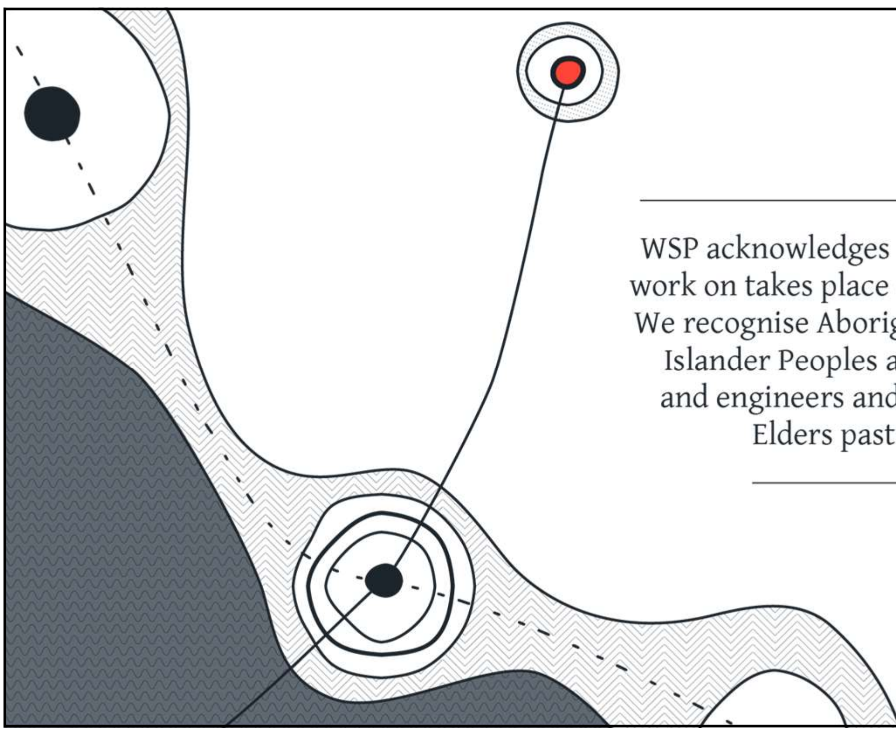

WSP acknowledges that every project we work on takes place on First Peoples lands. We recognise Aboriginal and Torres Strait Islander Peoples as the first scientists and engineers and pay our respects to Elders past and present.

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Outline

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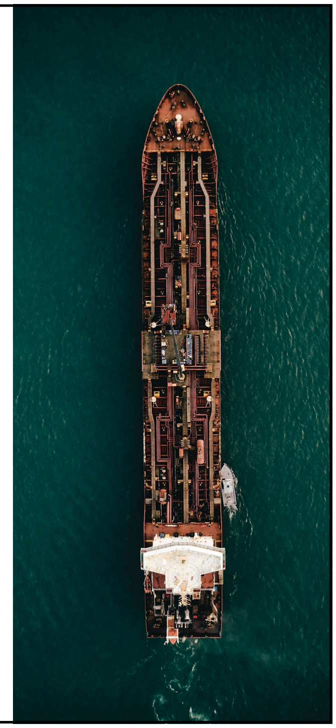

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Introduction

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Introduction

What is Hydrogen?

- Most basic and abundant element in the universe
- Common uses
  - Feedstock for ammonia synthesis
  - Industry (e.g. petroleum and metal refinement)
  - Fuel cells (e.g. transport and power)
- Most hydrogen is produced by steam reforming, using natural gas or methane as feedstock
- Growing interest of producing hydrogen using green methods, such as electrolysis using renewable power

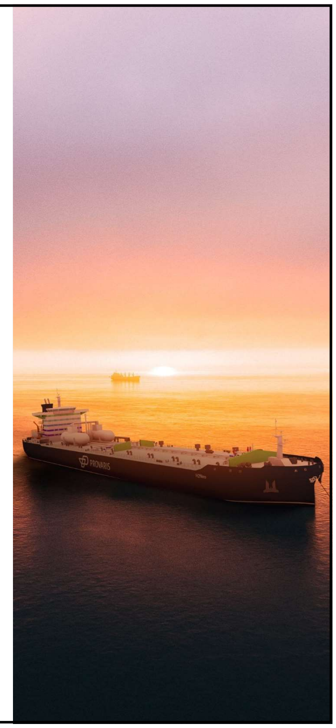
Introduction

Marine Transportation of Hydrogen

- Most commonly shipped as ammonia
- Shipping of hydrogen in its 'pure' form has limited precedent
  - Liquified hydrogen (LH2) shipping is in a pilot phase
- Other shipping methods developers are exploring include
  - Liquid organic hydrogen carriers
  - Methane and methanol
  - Compressed hydrogen

Suiso Frontier, World's First LH2 Carrier (Source: Offshore Energy)

Compressed Hydrogen Shipping



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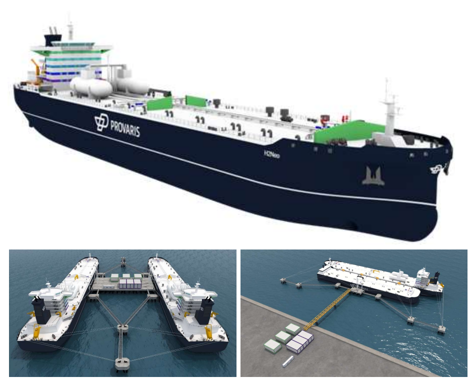
Compressed Hydrogen and Provaris Energy

- Provaris Energy has developed the design of two proprietary compressed hydrogen carriers
  - H2Neo – 430 t (26,000 m³) capacity
  - H2Max – 2,000 t (120,000 m³) capacity
- Both carriers have obtained Approval in Principle from the American Bureau of Shipping
- Novel pressure vessel design to resist hydrogen embrittlement and fatigue to ensure safety and containment of cargo
- Design approval for construction targeted for late 2022 and first shipping operations targeted for 2026



H2Neo Carrier and Jetty Concepts (Source: Provaris Energy)

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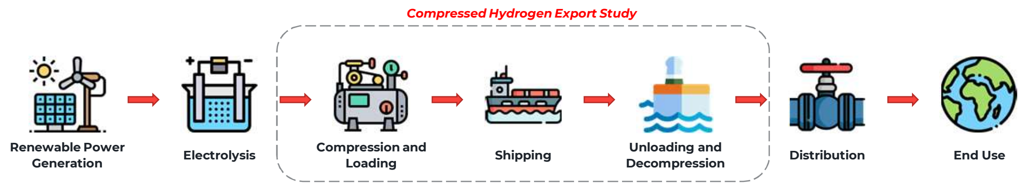
Compressed Hydrogen Shipping

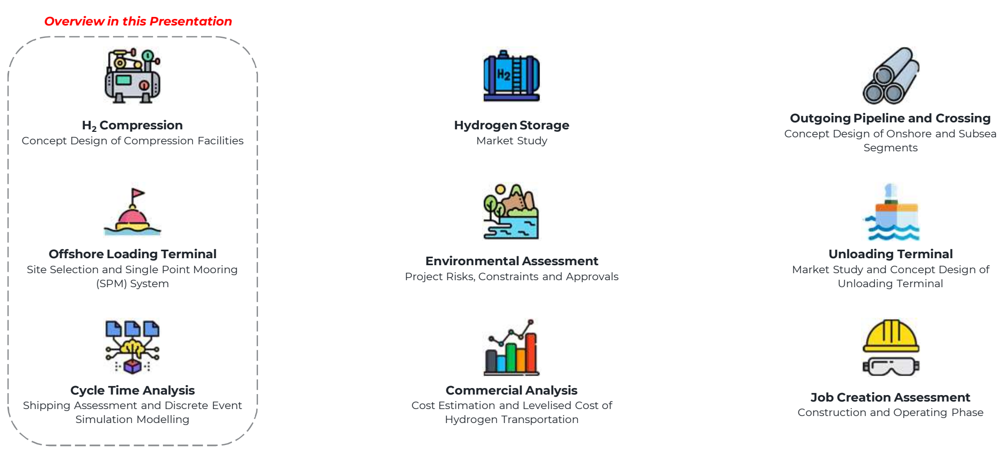
Compression in a Green Hydrogen Supply Chain



- Compressed Hydrogen Export Study undertaken for green hydrogen project in Western Australia
- Study consortium led by Provaris Energy with support from WSP
- Key study outcomes will be made available in a Public Knowledge Sharing Report published later this year

Compressed Hydrogen Shipping

Compressed Hydrogen Export Study



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Hydrogen Compression Facility

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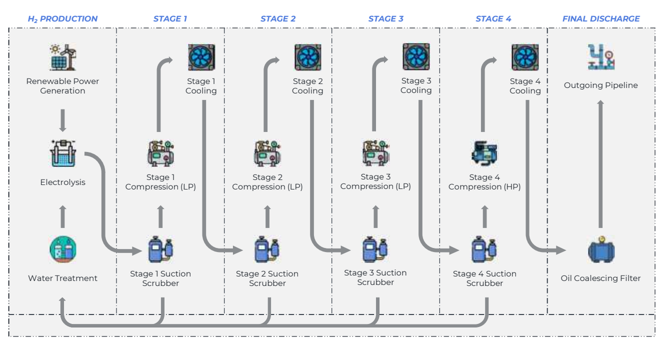
Hydrogen Compression Facility

Compression Process

- Design flowrate of 200,000 tpa of hydrogen
- Multistage reciprocating compressor trains to pressurise hydrogen to 250 bar
- Variable discharge pressure to minimise power consumption
- Low power to compress and load vessels, ~1.68 kW per kg of hydrogen
- Fast ramp up/down to match renewable power generation and hydrogen production profiles



Hydrogen Compression Process Diagram

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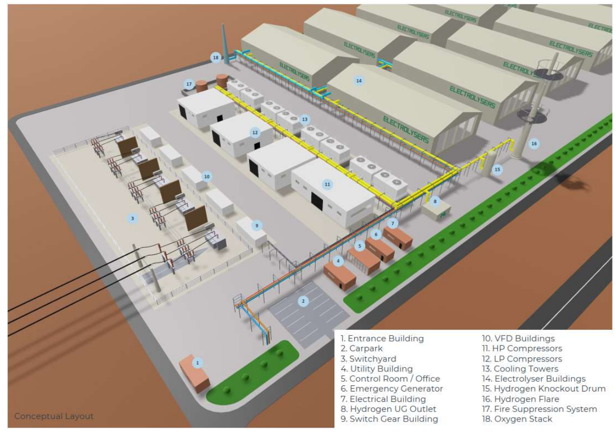
Hydrogen Compression Facility

Compression Facilities

- Collocated with electrolyser facilities
- Small relative footprint ~2.6 ha including ancillaries
- By comparison electrolyser facilities expected to be ~10 ha



3D Conceptual Layout of Compression Facilities

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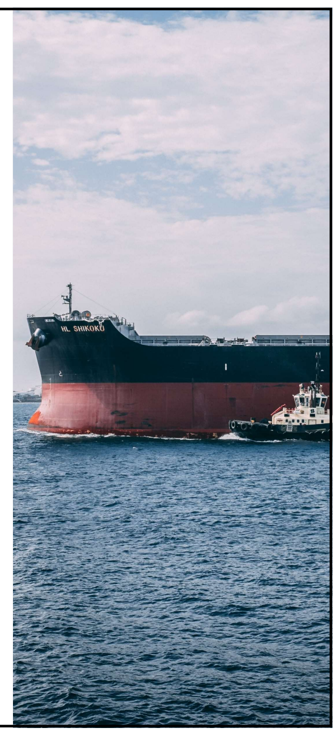
Offshore Loading Terminal



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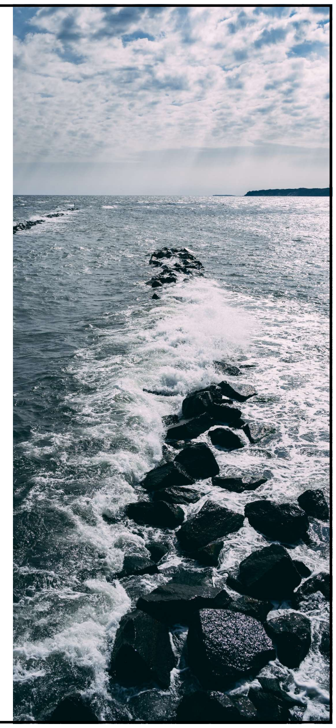
Offshore Loading Terminal

Why an Offshore Loading Terminal?

Site conditions

- Relatively shallow water depth and gentle seaward gradient
- Dredging for a nearshore terminal would be environmentally and cost prohibitive
- Environmental sensitivities present along the coastline
- Area of study relatively well protected from swells



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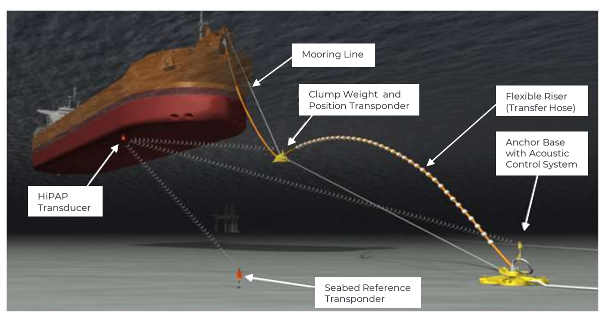
Offshore Loading Terminal

Why a Single Point Mooring System?

- Single Anchor Loading (SAL) system designed by APL NOV
- Appropriate for compressed hydrogen
  - Used for high pressure gas
  - No requirement for insulated piping
  - Minimal risk to marine environment from leakage
- Small footprint and minimal visual impact
- Operability limits, connection can occur at H_s = 4.5 m and disconnection at H_s = 7.0 m



SAL System (Source: APL NOV)

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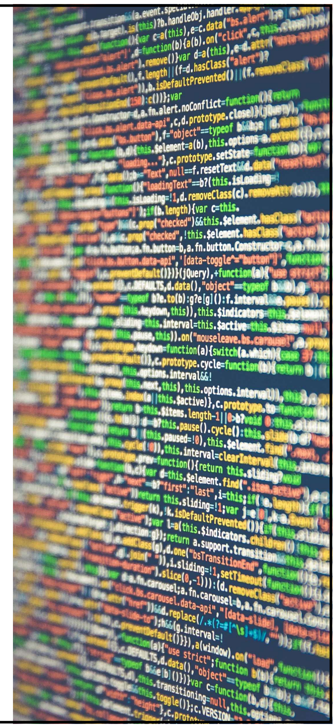
Cycle Time Analysis



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Cycle Time Analysis

Modelling Objectives

- Simulate the compressed hydrogen supply chain
- Analysis by discrete event simulation modelling and Monte Carlo simulations
- Key objectives
  - Calculate the vessel cycle time (to determine the optimal number of vessels and fuel consumption per vessel cycle)
  - Determine storage requirements and economics of storage
  - Estimate annual hydrogen throughput with and without storage

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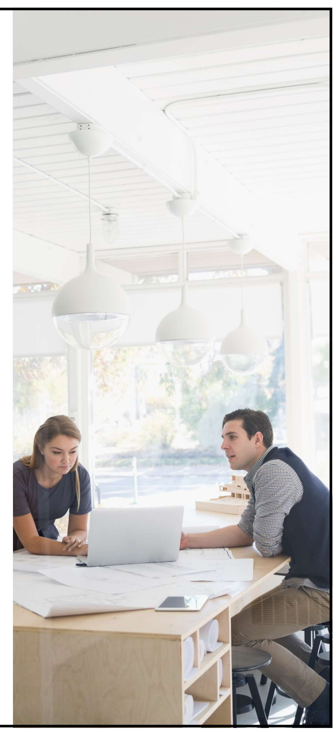

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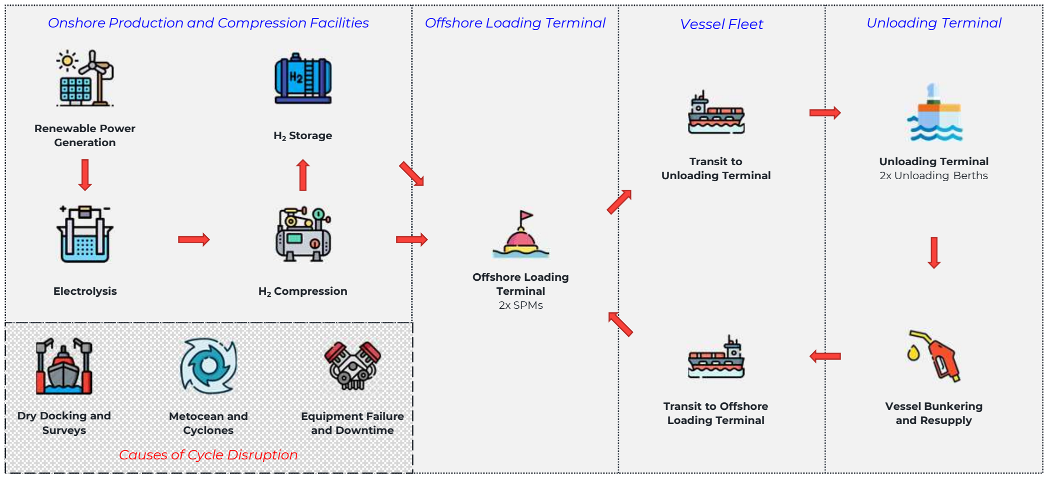
Cycle Time Analysis

Discrete Event Simulation Model



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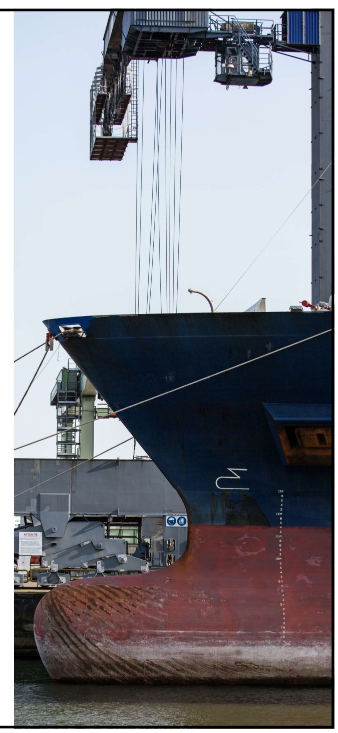
Cycle Time Analysis

Key Modelling Inputs

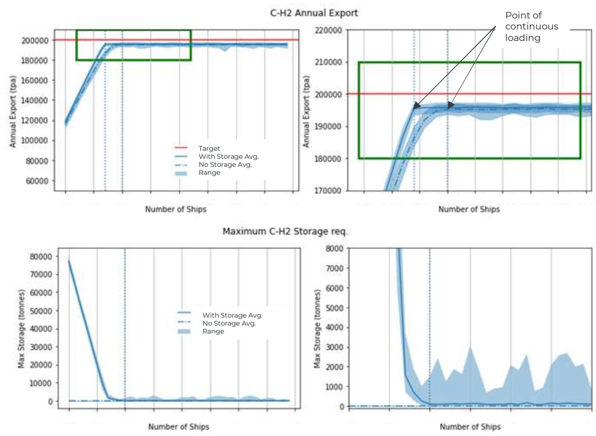
- Hydrogen production profiles
- Time of vessel activities as probability distributions
- Equipment downtime and failure rates as probability distributions
- Metocean and cyclone data at the (un)loading terminal and along various segments of the vessel transit route
- Operability limits and vessel speed as a function of H_s



Cycle Time Analysis

Methodology and Analysis

- Vessel sensitivity to determine the optimal number of vessels (1 year simulation)
- Analyse how storage affects throughput and assess economics of storage
- Select the optimal number of vessels to simulate for the full project life with consideration of
  - Continuous loading to maximise throughput
  - Effects on levelised cost by adding and removing vessels



Vessel Sensitivity Results

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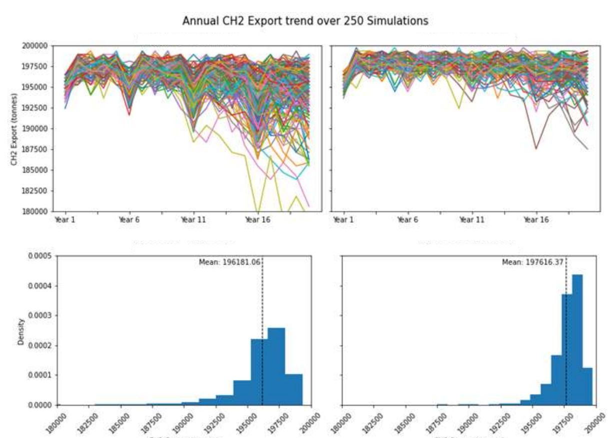
Cycle Time Analysis

Key Modelling Results

- More vessels increases the robustness of the compressed hydrogen supply chain
  - Cycle is less affected by major disruptions (e.g. dry docking, surveys and cyclones)
  - Higher throughput consistency (and smaller lower tail in probability distribution)



Throughput Simulation Results for 'n' and 'n+1' Vessels

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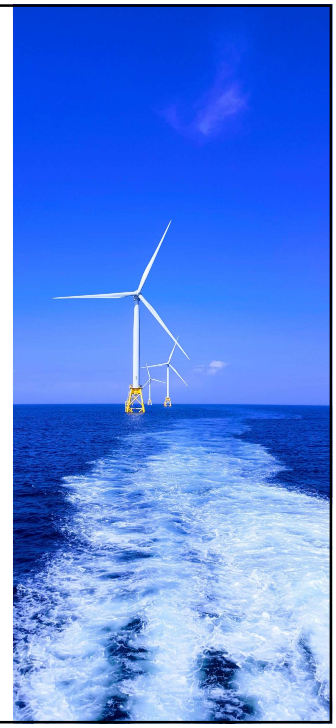
Summary



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Summary

Compressed Hydrogen Summary

- Compression forms a simple hydrogen supply chain and does not require complex or power intensive processes
- Demonstrated for onshore applications such as storage and transportation
- Compression has the ability to follow variable renewable power generation and hydrogen production profiles
- Hydrogen compression and vessel loading has low power consumption
- Viable for small scale (pilot) projects and can grow with market demand
- Compression facilities are small in footprint

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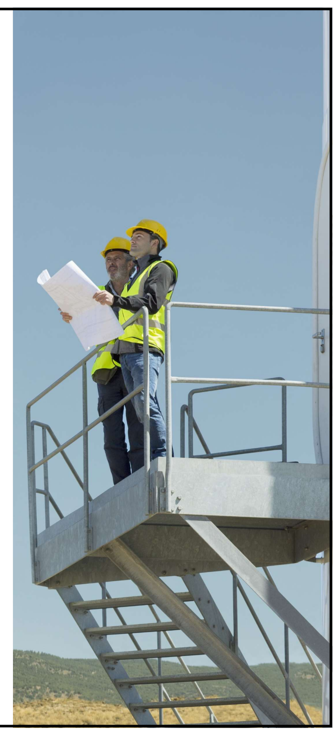

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Thank you

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