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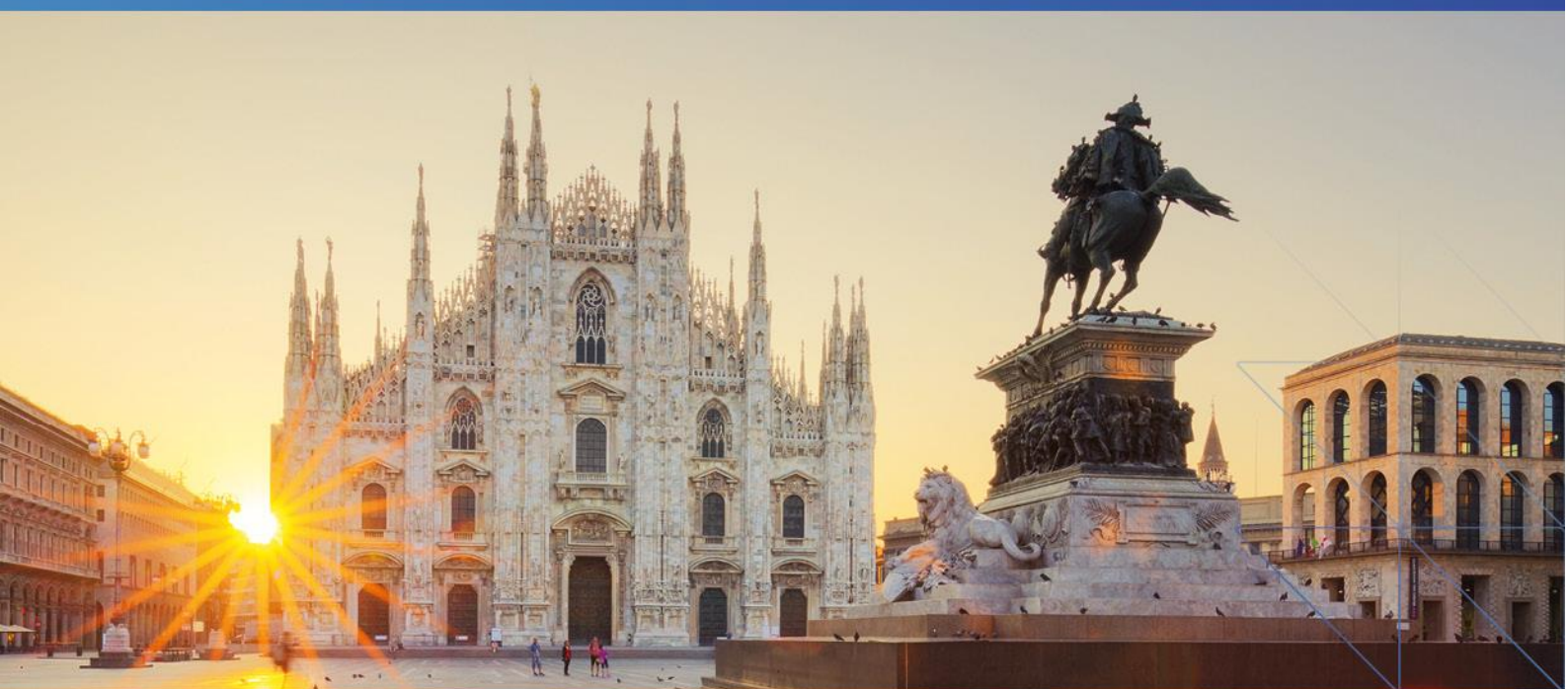
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# Pluto Train 2 Project – Lower Carbon Emission Intensity by Design



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## Abstract

On 22 November 2021, Woodside Energy (Woodside), a global leader in the reliable, safe operation of liquefied natural gas (LNG) facilities, approved the Final Investment Decision to sanction its Scarborough and Pluto Train 2 developments. The Scarborough Project consists of a world-class Scarborough offshore development of 11.1 Tcf dry gas (100%); whereas the onshore development will produce 5 Mtpa of LNG at Pluto Train 2, provide up to 3 Mtpa equivalent of feed gas for Pluto Train 1, and 225 TJ/day of new domestic gas capacity. With a composition of ~95% CH<sub>4</sub>, ~5.0% N<sub>2</sub>, ~0.1% CO<sub>2</sub> and a heavy hydrocarbon tail, feed gas from the Scarborough Field is well positioned to support Woodside's decarbonization goals. Furthermore, by utilizing Optimized Cascade® liquefaction technology, Pluto Train 2 will be one of the lowest carbon intensity projects for LNG delivered to customers in north Asia.

This paper will introduce Woodside's Climate Strategy and present an overview of four types of enhancements to Pluto Train 2's design that support this strategy and enable it to have a greenhouse gas intensity of ~0.26 tCO<sub>2</sub>e/tLNG:

- 1) the use of high efficiency aero-derivative gas turbines,
- 2) waste heat recovery,
- 3) inlet air chilling, and
- 4) process design optimizations.

The process design optimizations include the use of an OCP Nitro™ integrated nitrogen removal unit (NRU), as well as an OCP CryoSep™ heavies removal unit (HRU) that utilizes external solvent injection, recovery and circulation to process Scarborough's lean gas with its heavy hydrocarbon tail.



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## Woodside Energy – Who we are

Woodside Energy (Woodside) was founded in Australia and is the largest energy company listed on the Australian Stock Exchange (ASX), with a portfolio of world-class assets. Woodside has established itself as a world-class operator of oil and gas assets for over 35 years and is focussed on the safety, reliability, efficiency, and environmental performance of our operations. Woodside commenced first production of LNG at our North West Shelf Gas Project in mid-1980's with the first liquefied natural gas (LNG) cargo being shipped from these facilities to Tokyo, Japan, in 1989.



Figure 1: Woodside Energy assets

## What is our climate strategy?

Woodside's climate strategy is to reduce our net equity greenhouse gas emissions, while investing in the products and services that our customers need as they reduce their emissions. The use of fossil fuels for energy accounts for around three quarters of total anthropogenic greenhouse gas emissions. This means that efforts to meet climate change goals must include changes to the way that the world produces and consumes energy. These changes are referred to as the "energy transition" <sup>1</sup>.





Woodside aims to thrive through the energy transition by building a low-cost, lower-carbon, profitable, resilient and diversified portfolio. To achieve this, Woodside has made our climate strategy an integral part of our company strategy. Our climate strategy has two key elements: reducing our net equity Scope 1 and 2 greenhouse gas emissions and investing in the products and services that our customers need as they reduce their emissions.

Woodside reports and sets company-wide targets to reduce Scope 1 and 2 greenhouse gas emissions on a net equity basis, including both operated and non-operated assets. In 2020, Woodside announced targets for near- and medium-term emissions reduction below the gross annual average equity Scope 1 and 2 greenhouse gas emissions over 2016-2020. These targets are to reduce net equity Scope 1 and 2 greenhouse gas emissions by:

- 15% by 2025,
- 30% by 2030, and
- Towards an aspiration of net zero by 2050 or sooner.

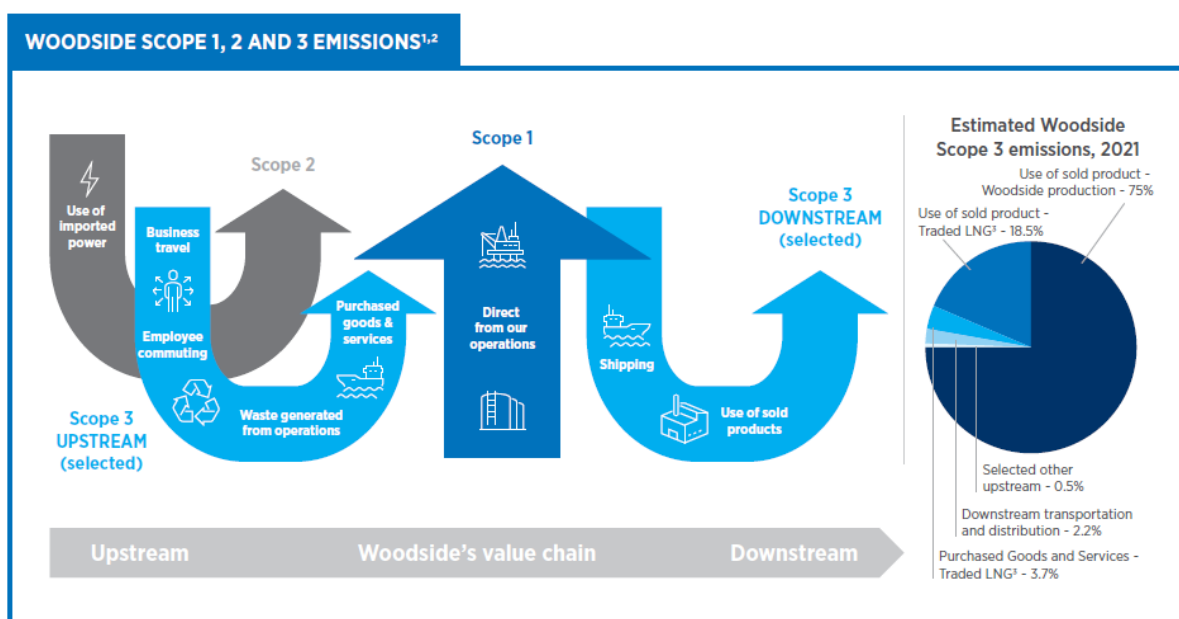


Figure 2: Woodside Energy Scope 1,2 and 3 emissions



## Scarborough Development and Pluto Train 2

The Pluto LNG Park (PLP) is located on the Burrup Peninsula in Western Australia and consists of a single LNG processing train (Pluto Train 1) and associated facilities required to process the Pluto field gas and export the LNG and condensate products to Asian markets. These facilities were constructed by the Pluto foundation project, with LNG production commencing in 2012. Pluto Train 1 is a single, modular Shell propane pre-cooled mixed refrigerant (C3MR) LNG train of approximately 4.7 MTPA capacity and includes the necessary associated support utilities and infrastructure to process the gas and export the product. During this development, the Pluto foundation project was designed with the requisite allowances to enable future expansion of the site to support additional LNG processing, up to the capacity of the trunkline system.

Woodside has chosen the PLP site to process its Scarborough gas field, which was acquired by the Company over a period between 2016 and 2018, into LNG. The Scarborough gas field is located approximately 375 kilometres WNW off the coast of the Burrup Peninsula. The Scarborough gas field has an estimated capacity of 11.1Tcf and will be developed via an offshore Floating Production Unit (FPU), a dedicated pipeline to shore for gas processing and conditioning at the PLP site, partially through the existing Pluto Train 1 and also via a new train, Pluto Train 2, to be constructed at the PLP.

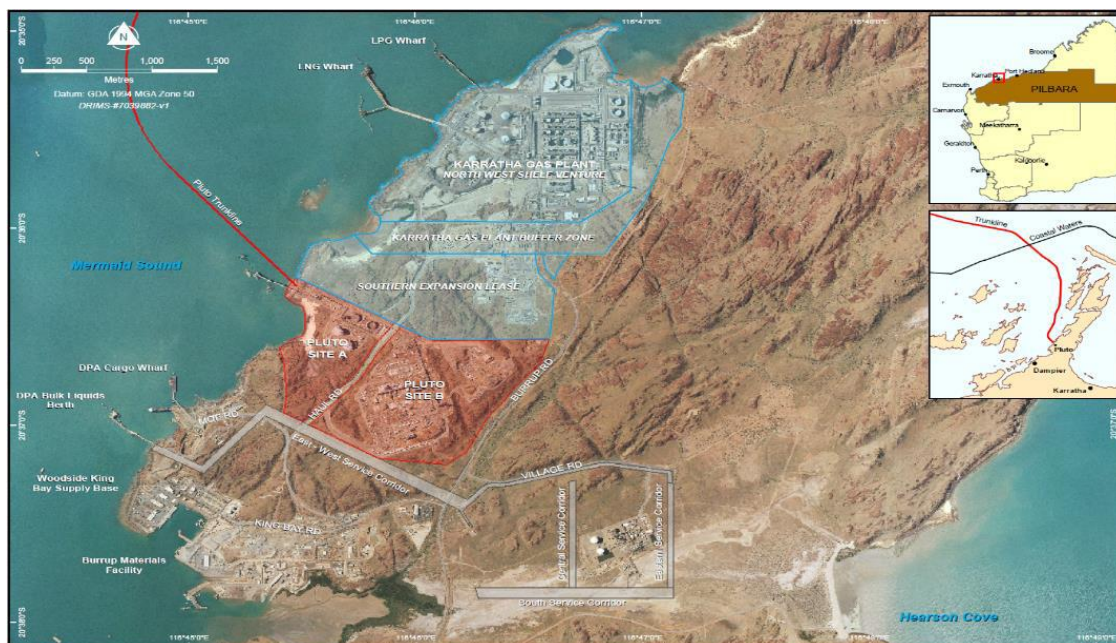


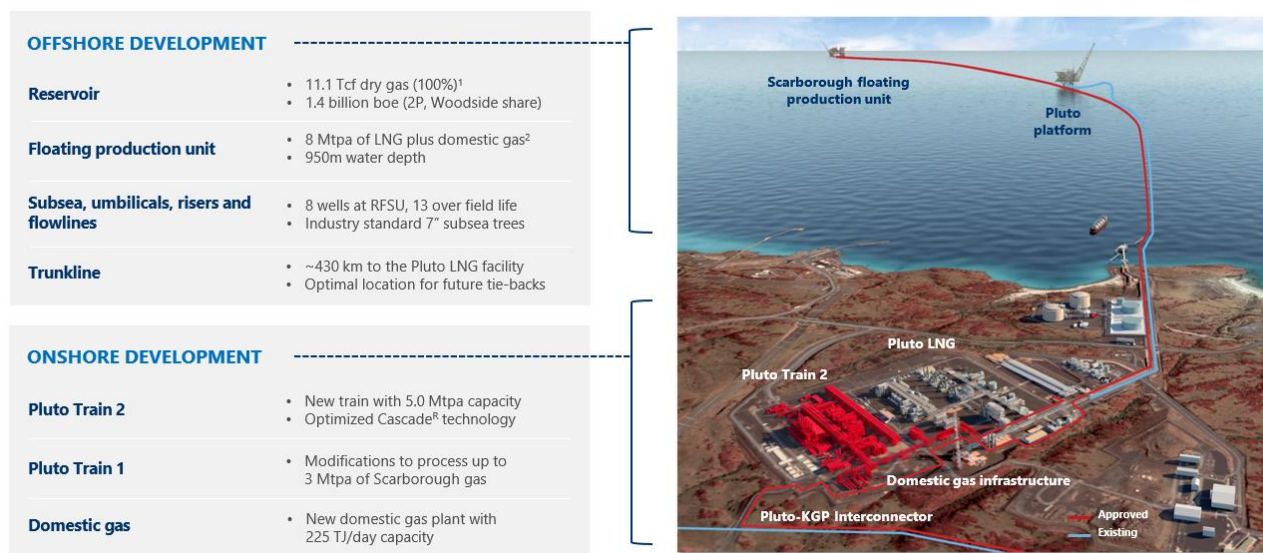
Figure 3: Location of Pluto LNG Park

Pluto Train 1 is fed from the Pluto area field which is located offshore and produces a rich feed gas with up to approximately 2 mol% carbon dioxide and 8 mol% nitrogen. The rich composition of this feed gas allows Pluto Train 1 to remove heavier hydrocarbon components from the feed gas and produce refrigerant through a scrubbing column extraction process and fractionation plant. The high-nitrogen content gas is managed via a slip stream NRU from which the excess fuel gas is then recycled back to the inlet of the process train.

The Scarborough field gas is different from Pluto field gas, as it is a biogenic lean gas with traces of heavier hydrocarbon components, little ethane, and a very low carbon dioxide and nitrogen content. Scarborough gas will be dehydrated offshore on the FPU and then exported via a single trunkline to the PLP for processing through the existing Pluto Train 1 (~ 1.5 MTPA to be comingled with Pluto feed gas) and the new Pluto Train 2 (5 MTPA of 100% Scarborough gas) to be constructed at the PLP. A portion of the Scarborough feed will also be produced as Domestic Gas (Domgas) via these new facilities.



## Targeting first cargo in 2026



Conceptual image, not to scale.  
1. Net of non-saleable inerts and upstream fuel and flare.  
2. Feedgas equivalent.

Figure 4: Scarborough Development

The Pluto Train 2 Project ("Project") is the project that will be constructing the new Pluto Train 2. The Pluto Train 2 design is based on a reference train which applies the ConocoPhillips Optimized Cascade Process LNG Liquefaction Technology and has a planned production rate of 5.0 MTPA annualised based on availability. The pre-treatment section of the train includes an acid gas removal unit, a recuperative thermal oxidiser to treat acid gas, a mercury removal unit and a dehydration unit. The Pluto LNG Plant will be the first location to feature both a Shell C3MR and a ConocoPhillips Optimized Cascade Process train operating on a single LNG processing site.

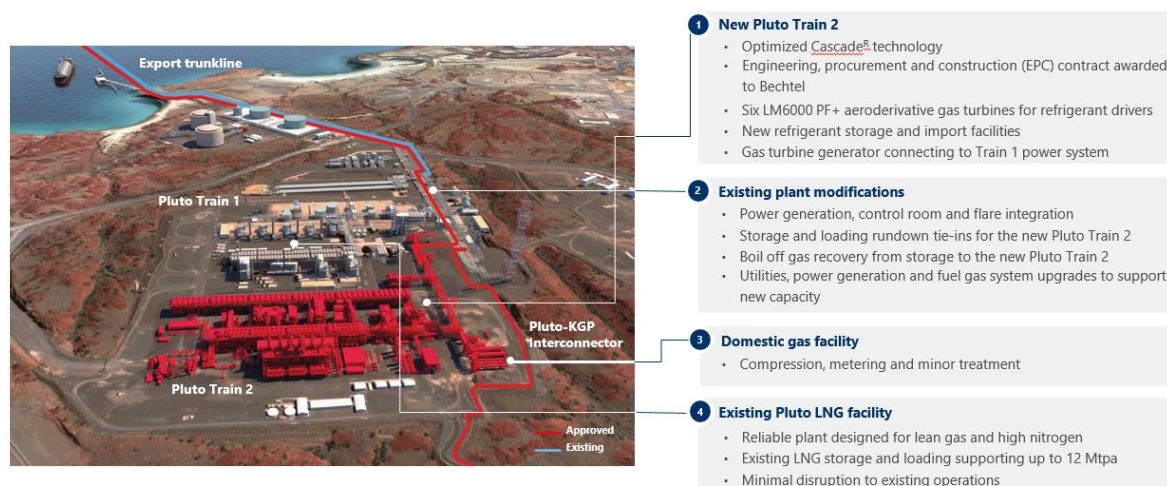
The process gas refrigeration section consists of three refrigerant circuits (propane, ethylene and methane) each with 2x50% compressor strings (six in total). The design enables one of the six compressor strings in service to be shut down for maintenance or other purposes, while still retaining significant production through the train. Each compressor string will be driven by a GE LM6000 PF+ gas turbine (six in total), which is an approved deviation from the reference train design. Pluto Train 2 also includes an NRU and a thermal oxidizer, waste heat recovery for hot oil heating configured to the ethylene compressors, refrigerant storage bullets, and plant / instrument air and nitrogen generation packages.



Domgas facilities will be provided to export up to 250 TJ/day (when combined with existing capacity) and will comprise of 1x100% mercury guard bed, 1x100% compression with associated after cooling and fiscal metering. These Domgas facilities will be fed by Scarborough gas and will utilise the existing Dampier to Bunbury Natural Gas Pipeline to supply a proposed urea plant as the major long-term customer.

Utilities and auxiliaries at the PLP will be expanded as required to support the new Pluto Train 2 and Domgas facilities. Additional boil off gas (BOG) compression is also required to support Pluto Train 2 and will be installed adjacent to the existing boil off gas compression unit.

### **Onshore development utilising existing facilities**



Conceptual image, not to scale.

Figure 5: Pluto Train 2 onshore development



## Pluto Train 2 and the Climate Strategy

Natural gas is the dominant product in Woodside's portfolio, representing approximately 81% of equity production in 2021. Most of the natural gas is sold as liquefied natural gas (LNG) and thus the development of Woodside's portfolio of natural gas assets, including the Scarborough gas field, is not only key to optimising value and shareholder returns, but is an imperative to supporting Woodside's climate strategy and the energy transition.

In order to support the corporate strategy which targets to reduce net equity Scope 1 and 2 greenhouse gas emissions by 15% (by 2025) and 30% (by 2030) towards an aspiration of net zero by 2050 or sooner, Woodside commissioned an internal report to identify opportunities for reducing emissions of greenhouse gases, and to demonstrate that the best available technology was being used on the Pluto Train 2 development to reduce greenhouse gas emissions to air.

The report addressed the following main areas of focus for the Project to address Scope 1 and 2 emissions:

- 1) Minimise flaring,
- 2) Design out, and
- 3) Construction execution opportunities

### Minimise Flaring

The Project is tying into the existing Pluto foundation project's flare system, including main flare and marine flare systems and thus the majority of opportunities in this area have been incorporated in the Pluto foundation project design. In this original design, flaring has been minimised through the application of numerous control options, which include:

- Designed for "No Continuous Flaring"
- Operational flaring minimised by:
  - 1) Fuel Gas System Balancing (gas recycling)
  - 2) Gas recovery systems (recovery and boosting)
  - 3) Pressure control valves (prior to relief to flare)
  - 4) Advanced Process Control,
- Emergency flaring has been minimised to as low as reasonably practicable (ALARP) without compromising plant safety, and



- Flare design, including integration of smokeless reduction techniques such as multi-stage flare, with air assist, fuel gas assist and a mixture of sonic and conventional flare tips.

The Pluto Train 2 design continues to look for ways to reduce flaring via design of the process control system and philosophies, equipment selection and operating and maintenance strategies which minimises, or avoids entirely, venting or flaring where it is safe to do so.

## Design Out

The project was able to identify several opportunities to minimise greenhouse gas emissions and improve the overall plant efficiency. These opportunities fit broadly into the following two categories:

- Process Technology Selection and Design, and
- Equipment Selection and Technology Assessment

## Process Technology Selection and Design

As mentioned previously, the Project selected the ConocoPhillips Optimized Cascade Process LNG Liquefaction Technology for processing the Scarborough gas. Heavy hydrocarbons in the feed gas that would normally freeze when exposed to the colder temperatures in the liquefaction process would reduce the performance of the LNG train, if left unattended. Similarly, excess nitrogen in the feed gas that drops the heating value of plant fuel gas below the operator's minimum specification reduces the performance of the LNG train, if left unattended. The ConocoPhillips Optimized Cascade Process design for Pluto Train 2 includes an OCP CryoSep integrated heavies removal unit (HRU) and an OCP Nitro integrated nitrogen rejection unit (NRU) to achieve Woodside's LNG train performance, efficiency, and economic targets. The integrated functional designs of both the HRU and NRU minimize the amount of energy those processes require.

The design also focussed on ensuring efficiency of operation, specifically within the design of the acid gas removal unit (AGRU) which was specifically designed for processing Scarborough field gas.

### Acid Gas Removal Unit (AGRU) Design



The design of the AGRU unit incorporated the following best practices to ensure emission minimisation:

- The rich amine flash drum in the AGRU is designed for low pressure operation and extended residence time in order to minimize solubility and enhance removal of dissolved or entrained hydrocarbons from the circulating amine solvent. The flashed hydrocarbon vapour is separated and recovered for use as fuel gas. Consequently, there is less hydrocarbon in the acid gas stream from the solvent.
- Regenerators, resulting in a reduction in atmospheric pollutants. The selection and design of the BASF aMDEA process, instead of a Sulfinol product for the AGRU and the formulation of the circulating solvent minimises the amount of hydrocarbon which is dissolved or entrained in the circulating amine solvent, thus reducing the volume of hydrocarbon in the acid gas stream from the solvent regenerator, resulting in reduced emissions.

### Nitrogen Rejection Unit Design

Pluto Train 2 utilizes the Cold NRU option of ConocoPhillips' OCP™ Nitro NRU technology suite, which provides an integrated solution with a high thermal efficiency to reliably reject unwanted nitrogen and withstand upstream upsets. An NRU is usually required in an LNG liquefaction train when the nitrogen (N<sub>2</sub>) in the feed gas stream exceeds the plant fuel gas higher heating value (HHV limits). Typically, this occurs when the feed gas stream contains greater than 1.5 mole% N<sub>2</sub> downstream of the acid gas removal unit. In Optimized Cascade Process trains, the NRU is integrated into the methane system. It is a cryogenic auto-refrigeration processes that relies on the pressure reduction of each successive column bottoms liquid to produce lower temperatures, which can be used to condense the successive column feed streams. The product specification for N<sub>2</sub> in LNG is  $\leq 1$  mol%, and the typical Optimized Cascade Process Train produces N<sub>2</sub> in LNG that is  $<0.5$  mol%. The ConocoPhillips' Cold NRU also is expected to reliably achieve an N<sub>2</sub> vent purity requirement of  $\leq 1$  mole% CH<sub>4</sub> in the vent stream.

Methane (CH<sub>4</sub>) has made the second largest contribution to human-induced climate change after CO<sub>2</sub> and is believed to have contributed to around 30% of the global temperature to date. According to the IEA, tackling methane emissions from fossil fuel operations represents one of the best near- and medium-term opportunities for limiting the worst effects of climate change because of its short-lived nature in the atmosphere and the large scope for cost-effective abatement, particularly in the oil and gas sector.





Minimising methane emissions has been a priority for Woodside because if leaked at significant levels, methane could create a safety risk on our assets and result in a loss to our production of LNG. This focus on containing methane effectively, has resulted in our methane emissions in 2021 being less than 0.1% of our production by volume. This is already well below the Oil and Gas Climate Initiative (OGCI) 2025 methane intensity target of below 0.2%. Woodside is also a signatory of the Methane Guiding Principles, an initiative to reduce methane emissions across the natural gas value chain and has made it an imperative that new plant designs consider best in class practices for reducing fugitive emissions.

The combustion of methane was the key consideration when selecting whether a thermal oxidizer would be installed in the process, given methane's impact to climate change. A greenhouse gas (GHG) evaluation was performed that estimated the emissions if the NRU vent stream was to be emitted direct to atmosphere, instead of being combusted using a thermal oxidizer. For direct atmospheric venting of the NRU, it is expected that the emission rate would be equivalent to 253kg/hr methane with an equivalent GHG emissions of 46,627 tonnes per year. When combusted in a thermal oxidizer, including allowances for a small amount of methane slip, the equivalent GHG emissions are expected to be reduced by approximately 10,000 tonnes per year to 36,048 tonnes per year.

A Recuperative Thermal Oxidizer (RcTO) has been selected to control emissions from the low value, unrecoverable waste gas streams from ARGU and NRU. The waste gas streams to the RcTO contains trace methane (CH<sub>4</sub>), hydrogen sulfide (H<sub>2</sub>S) and volatile organic compounds (VOC's) including benzene, toluene, ethyl-benzene and xylenes (BTEX). The RcTO will be operating at a firing temperature greater than 760°C and with more than one second residence time to achieve a destruction efficiency of greater than 99% of incoming levels for BTEX, CH<sub>4</sub> and H<sub>2</sub>S. The outlets of the thermal oxidizer stacks will be of similar height to that of the existing stacks onsite (being approximately 35-40 metres (m) high) to allow adequate dilution and to disperse any emissions such that ground level impacts on air quality are minimal. Note, these heights are subject to further engineering.

The energy efficiency of the RcTO is improved further by utilising process heat from turbine exhaust gas to pre-heat the feed streams to the RcTO (acid gas and combustion air), to reduce fuel consumption. This significantly reduces fuel gas demand within the system thus resulting in less emissions.



## Equipment Selection and Technology Assessment

One key driver for the Project selecting the ConocoPhillips Optimized Cascade Process LNG Liquefaction Technology was the relative energy efficiency the technology provides compared to similar technologies. The aero-derivative driven process is also considered best practice technology for LNG developments in Australia. Over the period since 2014, five LNG plants have commenced production in Australia, of these; four out of five have installed the aero-derivative driven process. Following the selection of the process technology, the Project shifted focus and considered sources of emissions from major equipment, concentrating on key emitters of CO<sub>2</sub>, nitrogen oxides (NO<sub>x</sub>) and carbon monoxide (CO).

The Project acknowledged the Pluto Train 2 major equipment (primarily gas turbines) will also generate other pollutants beside nitrogen oxides (NO<sub>x</sub>), including N<sub>2</sub>O, CO<sub>2</sub>, CO, SO<sub>x</sub>, and water vapour when they combust fuel gas. However, of these, CO and SO<sub>x</sub> are considered localised pollutants, whilst N<sub>2</sub>O and CO<sub>2</sub> are Greenhouse Gases (GHGs). The emission of SO<sub>x</sub> is a direct function of the sulphur content of the fuel gas, and in the specific case for this Project, the gas has negligible sulphur content (i.e. is 'sweet') and hence the production of SO<sub>x</sub> is not considered further. CO is not produced in concentrations considered significant in terms of air pollution, and any produced CO will tend to eventually oxidise naturally to CO<sub>2</sub>. Particulate matter emissions are considered negligible due to turbine selection and fuel gas composition.

Given the abovementioned decision frame and context, the Project assessed technology options for the main turbine drivers, with a focus to reduce greenhouse gas emissions to air, by considering:

- 1) Refrigeration gas compressor drivers; and
- 2) Power generation driver

### Refrigeration Gas Compressor Driver Selection

Turbine driver selection is an important aspect in influencing the Project's greenhouse gas emissions, namely as it relates to managing CO, CO<sub>2</sub> and NO<sub>x</sub> emissions. The Project considered a number of criteria, over the plant's operating range of LNG production rates up to 5.3mtpa, when selecting the turbine drivers. These criteria included: number of gas turbines and the gas turbine's thermal efficiency, power margins, emission rates, operability, reliability, and compatibility with ConocoPhillips Optimized Cascade Process.



The Project used the most obvious means to managing greenhouse gas emissions in making its selection of turbine drivers: optimising turbine efficiency. The Project considered turbine efficiency across the full power range and demand curve and optimised driver selection for the range that the turbine will operate under the majority of cases, under normal conditions (see Figure 5). This resulted in minimising combustion products.

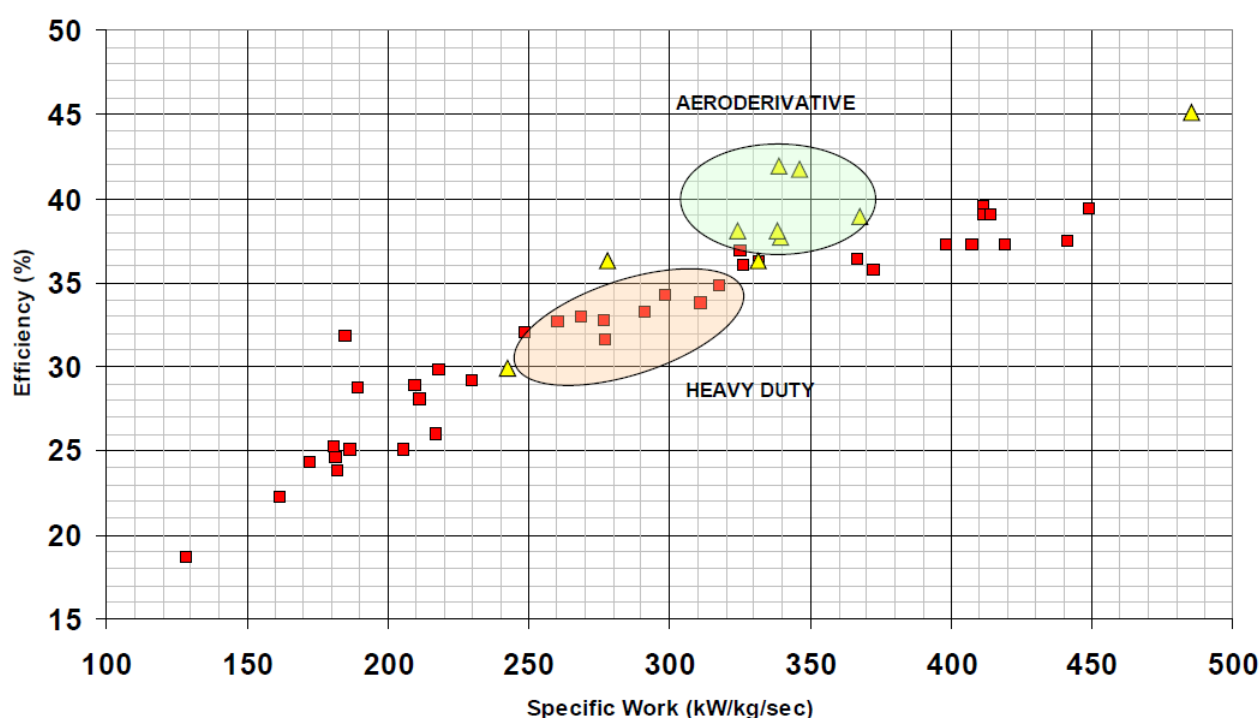


Figure 6: Energy Efficiency aero-derivatives versus industrial frame turbine

The Project assessed several gas turbine drivers for the refrigeration gas compressors and the GE LM6000PF+ aero-derivative gas turbine with inlet air chilling (IAC) and DLE were selected as the driver for the main refrigeration compressors. Aero-derivative drive units have been successfully integrated with the Optimized Cascade Process, have the lower NO<sub>x</sub> emissions over a wide range of power loads, and are considered best practice for this type of process. Aero-derivative drive units have been integrated in to four of the five most recent LNG developments in Australia.

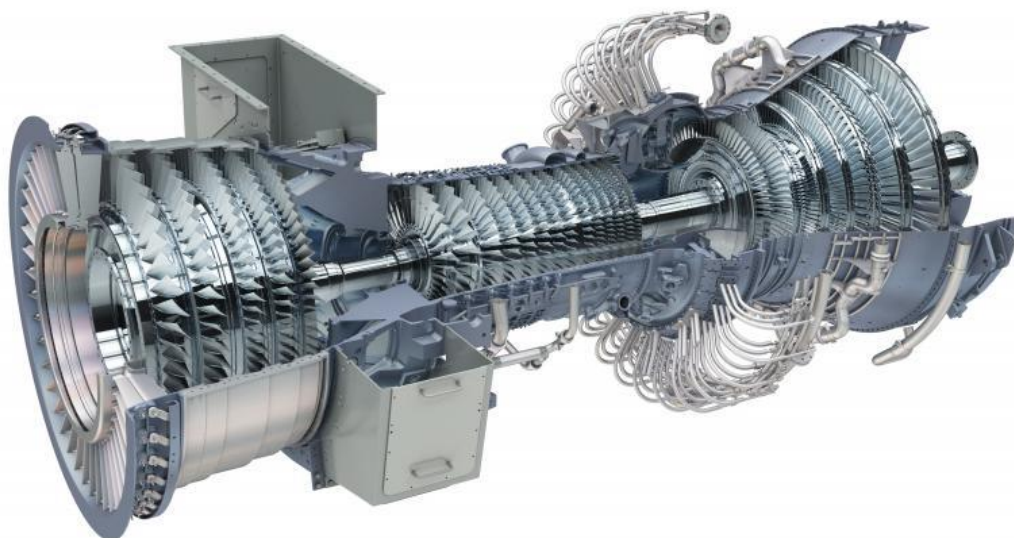


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*Figure 7: GE LM6000PF+ aero-derivative gas turbine*

Aero-derivative gas turbines have a higher thermal efficiency, a lower turndown and greater operational flexibility, allowing the process to be optimised to ensure maximum energy efficiency and lower emissions when compared to similarly sized industrial frame turbines.

Two (2) 50% compressors strings driven by two (2) LM6000PF+ units are used in parallel for each refrigerant service; propane, ethylene and methane. A load balancing control program is provided among the compressors to optimize LNG production. Each machine may be started, shutdown, or placed on recycle without significant upset to the system as a whole, provided plant throughput is adjusted accordingly. This system design eliminates a significant amount of flaring when compared against the Pluto Train 1 design which is based on one (1) 100% compressor string driven by one (1) Frame 7EA machine.

The inlet air chilling (IAC) system is provided to chill the ambient air fed to each of the six liquefaction/refrigeration compressor gas turbine drivers. Chilling the inlet air not only increases the driver horsepower but also makes the driver less vulnerable to the fluctuations in the ambient air conditions, it has the added benefit of reducing emission rates by improving driver efficiency and reliability. The chilling duty is provided by a closed-loop primary refrigeration system.





The Project elected to install waste heat recovery units (WHRU) in the exhaust ducts of each of the ethylene refrigeration compressor gas turbines. These WHRU's are a closed-loop design with a hot oil heating medium which is used to transport heat from the WHRUs to supply major users, including the AGRU and dehydration units for regeneration of the beds. There is sufficient heat for the process heating requirements for Pluto Train 2, no additional WHRU systems are required on the propane or methane circuits and there is no need for any fired heaters to meet Pluto Train 2 heat demands.

It has been demonstrated that NO<sub>x</sub> such as those from turbine exhaust systems interact with trace gases in the upper atmosphere which ultimately results in a net enhancement of the greenhouse effect. It has also been stated that the global warming potential (GWP) for NO<sub>x</sub> is comparable to that of methane (Greenhouse effect of NO<sub>x</sub> [Greenhouse effect of NO<sub>x</sub> - PubMed \(nih.gov\)](https://pubmed.ncbi.nlm.nih.gov/16111111/)). This highlights the importance of identifying and managing NO<sub>x</sub> emissions which the Project considered as a key factor in equipment selection.

Strategies for reducing thermal NO<sub>x</sub> emissions can be categorized into the following control options:

- 1) Primary Controls - pre-combustion controls that minimize NO<sub>x</sub> formation during combustion.
- 2) Secondary Controls - post-combustion controls that chemically reduce NO<sub>x</sub> formed during combustion to elemental nitrogen (N<sub>2</sub>), these controls are commonly termed 'ultra low' NO<sub>x</sub>; and
- 3) A combination of pre- and post-combustion controls.

The Project considered a number of primary NO<sub>x</sub> control technologies which are listed below:

- Water/Steam injection,
- Low NO<sub>x</sub> combustion technology,
- Selective catalytic reduction (SCR), and
- Selective non-catalytic reduction (SNCR).

The Project started out by comparing the relative benefits of water/steam injection and low NO<sub>x</sub> combustion technology and concluded that, when compared to water/steam injection, the use of dry low emission (DLE) combustors is the preferred primary NO<sub>x</sub> control technology. When compared with DLE combustors, water/steam injection systems have:

- an efficiency penalty to the flame zone,
- an increased GHG, CO and volatile organic compounds (VOC) emissions as a result of water injection, and



- a requirement for ongoing injection of large quantities of demineralised water.

Following this initial assessment, the Project then evaluated both SCR and SNCR as secondary control technologies, however soon determined these unsuitable, on the basis that the additional complexities, novelty and risks associated with implementing such secondary control measures outweighed the benefits of a minor reduction in NOx emissions. Further key risks associated with these secondary controls include:

- Increased health and safety risks to personnel associated with ammonia transport, storage and handling,
- Increased air quality impact of ammonia and ammonium salt emissions,
- Technical and commercial risk of attempting to use SCR/SNCR in a first of a kind service in an LNG plant,
- Decreased plant efficiency and increased operational complexity,
- Increased power demand onsite leading to additional greenhouse gas emissions, and
- The requirements for handling and disposal of a heavy metal-based catalyst.

The Project selected DLE 1.5 combustor systems as the best practicable measure to reduce NOx emissions from the liquefaction gas turbine drivers (refer Figure 7). The Project will implement a number of measures to improve the ability of the DLE 1.5 systems to manage changes in fuel gas composition, and control any stage down event leading to a loss of power. These include:

- Fuel gas chromatographs and Wobbe meters to be incorporated into the control system,
- DLE system performance mapping to be performed during the commissioning phase, after each major maintenance overhaul, and as required, to determine the optimum operating boundary conditions,
- Remote monitoring and remote DLE mapping to be evaluated,
- Single point instrument failure has been eliminated by adding redundant instrumentation and 2 out of 3 voting and control logic, and
- The inlet air filter system is designed to reduce the fouling of the gas turbine axial air compressor; thus, periodic shutdowns for off-line water washing can be eliminated.

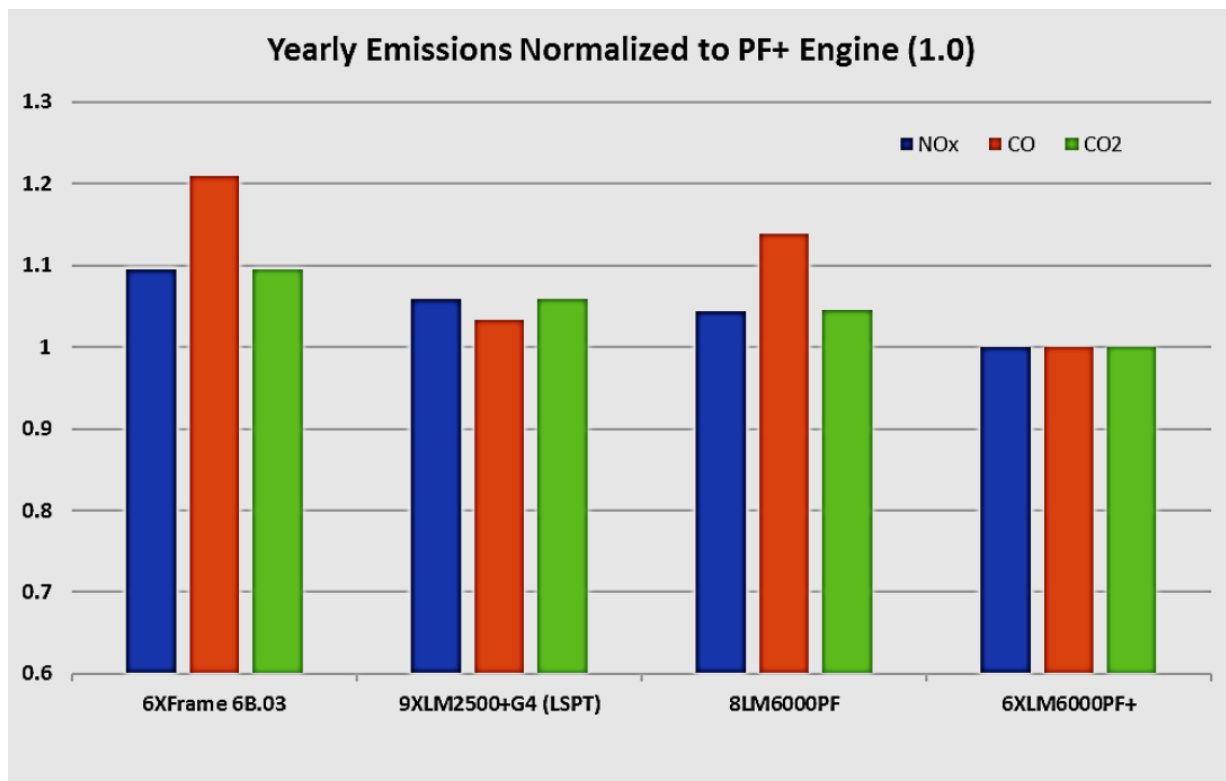


Figure 8: Alternatives Normalized to LM6000PF+ with DLE 1.5 combustors

In summary, the Project determined that the use of high efficiency aero-derivative gas turbine compressor drivers, with inlet air chilling (IAC), DLE combustors, combined with unfired waste heat recovery units (“WHRUs”), meets the criteria for best practice technology for LNG service. This selection also results in approximately a 27% reduction in NOx emissions intensity when compared against the Pluto Train 1 design (Woodside, 2007 and 2011) which utilises industrial frame turbine drivers for the liquefaction process.

#### Power Generation Driver Selection

Supply of stable power to Pluto Train 2 will be essential in maintaining steady state operations and maximum efficiency of the Pluto Train 2 and Domgas trains. A benefit of selecting ConocoPhillips Optimized Cascade Process LNG Liquefaction Technology over competing technologies is that it has significantly lower auxiliary power demand.

A number of power solutions were investigated as part of the Project. Currently Pluto Train 1 has four (4) GE Frame 6B heavy duty industrial gas turbine generators for auxiliary power generation, with a total installed capacity of 144 MW.

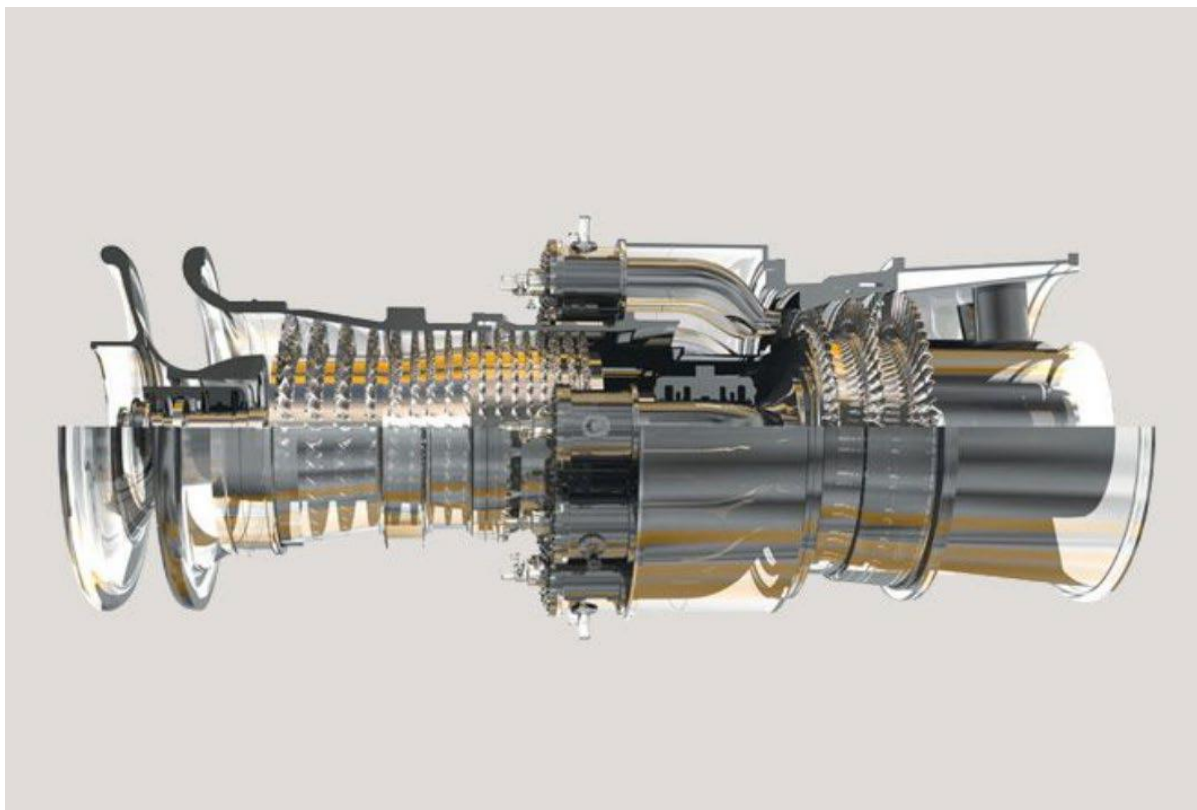


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*Figure 9: GE Frame 6B Heavy Duty Gas Turbine*

The installation of an aero-derivative gas turbine similar to that of the refrigerant drivers was assessed and dismissed on a technical basis given the requirement to integrate into the existing heavy duty industrial driven power system. The stability of the power supply is essential in maintaining steady state operations of the LNG and Domgas trains. The average loading for the turbine under normal operating conditions is expected to vary between 70% and 85% and would further increase should any of the turbines from Pluto Train 1 trip. Installing an aero-derivative machine with lower inertia increases the risk of an unreliable electrical power supply, which would result in the LNG processing trains operating at less than peak efficiency, or in the worst case, a plant blackout requiring an





unplanned shut down. Such events could result in significantly increased emissions due to flaring and inefficient operations.

As such, while the selection of an aero-derivative gas turbine versus an industrial gas turbine has an improved efficiency and lower emissions, for the reasons described herein, and in particular the ability to integrate and optimise the PLP power generation system, Woodside selected a GE Frame 6B industrial gas turbine for power generation with DLE combustors. The benefit of this selection is enhanced further by operator's experience with optimising the GE Frame 6B industrial gas turbine.

## Construction Execution Opportunities

The Project considered a number of execution methodologies and supply chain related activities to seek opportunities to reduce Scope 1 and Scope 2 emissions. The below were the main opportunities considered:

- Utilise gas power generation in lieu of diesel construction generators,
- Concrete specification – the production of cement is a considerable contributor to the overall global greenhouse gas emissions (in the order of 5-8%). The Project requires 62,000 cubic metres to complete the scope,
- Solar panels were installed at the module yard to power the wifi grid,
- Planting trees to offset the emissions from the batch plan. Since the site has limited areas for tree/vegetation planting we will undertake community tree planting programs expected to start in 2023,
- Using a different compressor for temporary work,
- Installing solar panels on the CMT offices, and
- Use of tricycles instead of pick-up trucks to commute around the module yard.

Of the above opportunities the only items not implemented was the initial item utilising gas power generation in lieu of diesel construction generators, due to safety related issues.



## Results and Conclusions

Woodside is a world-class operator of oil and gas assets with a focus on the safety, reliability, efficiency, and environmental performance of our operations. Woodside has developed a climate strategy within our overall Corporate Strategy that targets to reduce net equity Scope 1 and 2 greenhouse gas emissions by 15% (by 2025) and 30% (by 2030) towards an aspiration of net zero by 2050 or sooner. Woodside is committed to supplying the world the energy it needs as it navigates through the energy transition. With its recent announcement of the final investment decision for its Scarborough development, Woodside actively pursued opportunities to reduce greenhouse gas emissions to air.

Building on Woodside's commitment to design out greenhouse gas emissions, Woodside was able to assess a number of technologies and utilise best-in class solutions to substantially reduce the emission intensity of Pluto Train 2. The areas assessed across the project were:

1. Reducing flaring
  - Pluto Train 2 ties into the existing Pluto Train 1 flaring system which has been designed to reduce greenhouse gas emissions, including:
    - Designed for “No Continuous Flaring”,
    - Minimising operational flaring minimised by:
    - Minimising emergency flaring, and
    - Smokeless flare design and a mixture of sonic and conventional flare tips.
2. Design Out opportunities including:
  - Process Technology Selection and Design
    - Project selected the ConocoPhillips Optimized Cascade® Process LNG Liquefaction Technology, due to:
      - Energy efficiency compared to other technologies, and
      - Efficient NRU recovery, and Recuperative Thermal Oxidizer (RcTO) design
  - Equipment Selection and Technology Assessment
    - Project assessed refrigeration compressor drivers and selected GE LM6000PF+ aero-derivative gas turbine with inlet air chilling (IAC), DLE 1.5 combustors for their relative efficiency and WHRU's for heating, and

- Project assessed power generation drivers and selected the GE Frame 6B industrial gas turbine with DLE combustors, to ensure best electrical system stability and reliability.

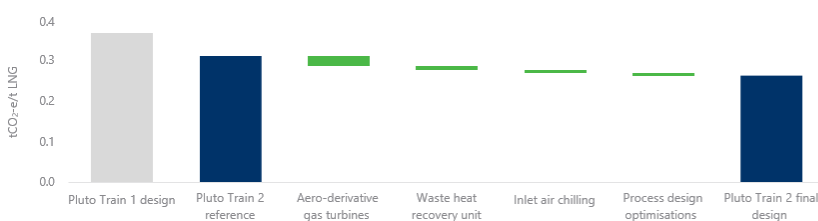
### 3. Construction Execution Opportunities

- The Project collaborated with the Contractor to identify and implement a number of execution opportunities and supply chain initiatives to reduce Scope 1 and Scope 2 emissions.

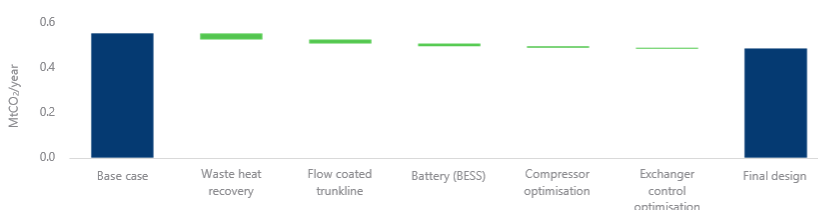
As a result, Woodside was able to reduce Pluto Train 2 greenhouse gas intensity materially when compared with Pluto Train 1 and with the Pluto Train 2 the reference design, making it a best-in-class design for reducing carbon intensity due to emissions:

## Emissions reduced through design out

Pluto Train 2 design improvements in greenhouse gas intensity



Offshore design improvements achieving ~12% reduction in emissions



1. Baseline is set as the gross average equity Scope 1 and 2 emissions over 2016-2020 and may be adjusted (up or down) for potential equity changes in producing or sanctioned assets, with an FID prior to 2021. Baseline will be adjusted for the combined Woodside and BHP petroleum portfolio subject to final agreements and approvals.

Assessing other opportunities to reduce emissions

Path to net zero includes Scarborough development

**15%**  
by 2025

**30%**  
by 2030

**Net zero**  
aspiration by 2050

Woodside's equity emissions reduction targets<sup>1</sup>

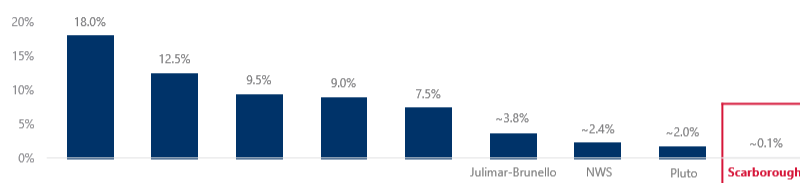
Figure 10: Design Out Emissions Reduction

Scarborough is a world-class resource with low reservoir CO<sub>2</sub> (0.1%) content and, when considered in conjunction with the design improvements and adopted technologies, Woodside was able to significantly lower the overall greenhouse intensity of Pluto Train 2

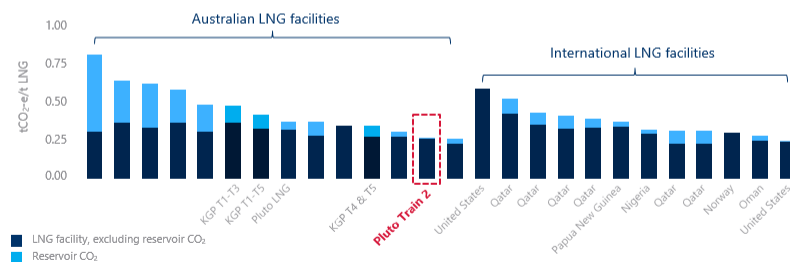
to approximately 0.26tCO<sub>2</sub>-e/tLNG, making it amongst the lowest carbon intensity LNG sources.

## Contributing to a lower-carbon future

Reservoir CO<sub>2</sub> in relation to other Australian LNG projects<sup>1</sup>



Amongst the lowest carbon intensity LNG sources<sup>2,3</sup>



1. Source: Scarborough Offshore Project Proposal. Dataset includes Barossa, Browse, Gorgon, Ichthys and Prelude. Where a range for reservoir CO<sub>2</sub> was disclosed for other reserves, midpoint value taken for the chart.
2. Source: publicly available company information.
3. Scarborough gas processed through Pluto Train 2.

LNG assists coal-to-gas switching in Asia

Aligned with our customers' decarbonisation goals

Will be one of the lowest carbon intensity projects for LNG delivered to customers in north Asia<sup>3</sup>

Figure 11: Scarborough and Pluto Train 2 Carbon Intensity





## References

1. Woodside Climate Report 2021 [Climate Report 2021 \(woodside.com\)](https://www.woodside.com.au/~/media/woodside/Climate-Report-2021.pdf)
2. Greenhouse effect of NOx [Greenhouse effect of NOX - PubMed \(nih.gov\)](https://pubmed.ncbi.nlm.nih.gov/32345678/)

## Acknowledgements

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## Notes

This presentation contains forward looking statements that are subject to risk factors associated with oil and gas businesses. It is believed that the expectations reflected in these statements are reasonable but they may be affected by a variety of variables and changes in underlying assumptions which could cause actual results or trends to differ materially, including but not limited to: price fluctuations, actual demand, currency fluctuations, drilling and production results, reserve estimates, loss of market, industry competition, environmental risks, physical risks, legislative, fiscal and regulatory developments, economic and financial market conditions in various countries and regions, political risks, project delay or advancement, approvals and cost estimates.

All references to dollars, cents or \$ in this presentation are to US currency, unless otherwise stated.

References to “Woodside” may be references to Woodside Energy Group Ltd. or its applicable subsidiaries.