PLUTO LNG PLANT START-UP

Gerard Ransom
Woodside Energy Ltd.

ABSTRACT
The Pluto gas field was discovered in early 2005 in the North West Shelf area, approximately 180 km from the Burrup Peninsula and 100 km from the northern coast of Western Australia. Pluto LNG comprises an onshore processing plant on the Burrup Peninsula and associated LNG and condensate storage and export facilities. The onshore plant is linked to a series of offshore subsea wells and offshore riser platform via a 180km trunkline. Woodside Energy Ltd as Operator of the North West Shelf Joint Venture has successfully commissioned, started up and operated five LNG trains, however Pluto LNG is the first green-field LNG plant that Woodside Energy Ltd has started up in over 20 years. This paper discusses the challenges faced by the Commissioning and Startup Team and the solutions used to overcome them.

INTRODUCTION
Pluto LNG processes gas from the Pluto gas field, located in the Carnarvon Basin about 190 km north-west of Karratha, in north-west Western Australia. It is 90% owned and operated by Woodside with the remaining 10% owned in equal share by Tokyo Gas and Kansai Electric.

The Pluto field was discovered in 2005. The Greater Pluto region is currently estimated to contain 5 trillion cubic feet (Tcf) of dry gas reserves.

Project approval was granted in 2007 for the development of a single greenfields LNG train with associated storage, offloading, utilities and offshore infrastructure. The LNG train is propane / mixed refrigerant design with a capacity of 4.3 million tonnes per annum.

Commissioning of the first equipment began in 2010. The offshore facilities commenced production in late 2011, with the first LNG cargo shipped in May 2012.

Initial production has been extremely successful, with a facility utilisation of over 90% achieved in the second half of 2012.
The challenges associated with the Pluto LNG facility start-up included:

- Integration of simultaneous onshore and offshore start-ups,
- Early introduction of gas and management of simultaneous commissioning and construction activities
- Import of first fill propane and generation of mixed refrigerant within the LNG train
- Early cool-down of the storage and loading facilities
- Managing a number of equipment items which were new to Woodside as operator.

This paper describes the innovative methods used to tackle these challenges and describes the processes taken to ensure the start-up was a success.

OBJECTIVES

This paper describes a number of the technical challenges associated with the Pluto LNG start-up and the solution methods adopted by Woodside to overcome or deal with these challenges. A brief description of the facilities and an overview of the start-up logic and organisation is provided as background. A number of the technical challenges are then described in detail followed by a discussion on the success of the initial Pluto LNG production phase.

Facilities Description

The initial phase of Pluto LNG comprises an offshore platform in 85m of water, connected to five subsea wells on the Pluto gas field in 800m of water. Offshore MEG (mono-ethylene glycol) injection is used to prevent subsea hydrate formation. Gas, condensate and MEG flow from the subsea wells to a not-normally-manned offshore platform through dual 20-inch 27km long flowlines. The offshore platform contains hydraulic...
equipment (for subsea well control), pig-launching facilities and high-integrity pressure protective equipment for the downstream trunkline.

The production fluids are then piped through a 180km trunkline to the onshore facility, located on the Burrup Peninsula near Dampier in Western Australia. The fluids are separated into their three phases (gas, MEG and condensate) in an onshore slugcatcher.

Gas from the slugcatcher is routed to the LNG train which consists of an acid gas removal unit, molecular sieves, mercury removal vessel, liquefaction unit and associated fractionation train. The liquefaction train uses C3 / MR technology and contains two fixed speed refrigerant compressors (propane and mixed refrigerant) which are driven by Frame 7 gas turbines.

LNG from the train is pumped to two LNG tanks with a combined capacity of 240,000 m³.

Condensate from the slugcatcher is routed to 2 x 100% condensate stabilizers and stabilized condensate sent to one of 3 condensate tanks.

MEG from the slugcatcher is routed to a MEG regeneration facility where the produced water is removed before the MEG is pumped back offshore via a MEG injection line. The water is treated to very high purity in an effluent treatment plant before being discharged into the ocean.

A nitrogen rejection unit is provided to remove nitrogen from the LNG train end-flash gas. This nitrogen is used to provide the facility nitrogen requirements, while the reduced-nitrogen end-flash is used to supply fuel gas to the facility.

Power generation is supplied by 4 Frame 6 gas turbines, two of which are supplied with waste heat recovery units to supply heat to the plant utility systems via a hot water circuit.

A high level overview of the onshore facilities can be seen in figure 2.
Start-Up Organisation

Construction and commissioning of the onshore facilities to the point of hydrocarbon introduction was managed by the onshore managing contractor, a Foster-Wheeler Worley Parsons Joint Venture. The start-up of the facility was carried out on an area basis. At the time of hydrocarbon introduction control of each area was transferred to Woodside, and start-up took place using Woodside personnel, processes and systems.

The Woodside start-up team consisted largely of operational personnel with start-up and operational experience from other recent Woodside operated projects (North West Shelf Project LNG Phases IV and V and the Otway Gas Plant). Lessons learnt from the start-up and operation of these facilities were identified and embedded into the start-up procedures and methodologies for Pluto LNG.

In addition to leveraging Woodside’s own start-up experience, lessons learnt were gathered from other sites. This was done either through visits to other operational sites or through lessons-learned discussions with vendors and other operating companies. Woodside assessed these lessons and incorporated into the Pluto start-up methodologies where they were considered to represent best practice.

Start-Up Logic

The high level Pluto LNG start-up logic is shown in figure 3. Initial commissioning was restricted to the diesel generation equipment and essential utilities (instrument air, flare system, nitrogen, fire water) with the aim of preparing the plant for introduction of domestic gas.

The introduction of domestic gas allowed start-up of the main power generation facilities which broadened the scope of commissioning activities which could be carried out. As described later in this paper domestic gas was also used to allow early commissioning and start-up of the offshore facilities.

Also of note in the start-up logic is the importance of early start-up of the ETP and MEG systems, as these systems were required to complete early start-up of the offshore system.
Use of Domestic Gas for Commissioning Purposes

The Pluto LNG Park is located adjacent to a domestic gas pipeline. A tie-in to this pipeline was made during the construction of the facility which allowed the use of domestic gas for initial commissioning of the flare and fuel gas systems, power generation facilities, refrigerant compressors and the offshore system.

Initial power generation for commissioning activities was provided using the emergency diesel generators (EDGs) which provide black start capability during normal plant operation. The EDGs have limited capacity so no large electric motors could be run prior to start-up of the main power generation facilities.

The use of domestic gas as fuel gas allowed early start-up of the Frame 6 gas turbines, thus reducing diesel consumption and expanding the range of commissioning activities which could be conducted early. The power generation facilities are also equipped with waste heat recovery units which provide hot water to the utilities areas of the plant, this allowed early testing of heated water users in the MEG system and effluent treatment plant.

The LNG train gas turbines and compressors were commissioned using domestic gas as fuel gas. During the coupled compressor runs the compressors were run with air in the compressor circuit, rather than nitrogen which has been used previously. The use of air in the compressor circuit resulted in a significant risk reduction to personnel during this activity.

Impact of Flare Tower Replacement

It was identified during the project construction phase that the main Pluto LNG flare tower required replacement as it was not adequately designed for the high wind loading that occurs during cyclonic conditions at the Pluto LNG site.

This issue had the potential to cause significant disruption to the start-up activities as without a flare stack hydrocarbons could not be introduced to the facility.

To address this issue a small temporary flare stack was installed which was specifically designed to allow introduction of domestic gas to site for commissioning activities. Figure 4 shows an image of this flare stack.
Use of the commissioning flare stack allowed all planned commissioning and activities to continue while the main flare stack was replaced. As a result the impact of the flare tower on start-up schedule was mitigated.

**MEG & ETP Commissioning**

The onshore MEG system and the effluent treatment plant (ETP) posed a significant start-up challenge as they are complex process units which are not widely used in the LNG industry. Start-up of both the MEG and ETP were carried out early to ensure the maximum reliability of the units during the LNG train start-up.

During the design phase Woodside personnel visited other sites where MEG and ETP systems were in use to gather lessons associated with their start-up and operation. A number of operators and engineers in the start-up team had previous experience with MEG systems and in the water treatment industry. Woodside also utilised personnel and experience from the startup and operation of the Otway gas project MEG regeneration system, which Woodside operated between 2007 and 2009.

The decision to test the units early was worthwhile as unexpected challenges occurred in both the MEG and ETP systems during commissioning. The early commencement of testing meant that these issues were successfully resolved and both units were operating reliably prior to introduction of gas from offshore.

**MEG start-up**

A first fill of MEG was shipped to the onshore system approximately 12 months before the commencement of the LNG train start-up. The volume of MEG imported was 9,000 m³.
The MEG was imported via chemical tanker which berthed at the Pluto LNG offtake jetty. The MEG was discharged from the tanker and routed to the permanent onshore MEG storage tanks via a hard-piped line which had been installed specifically for the first fill.

Following first fill the MEG was diluted with water down to a MEG concentration of 90%, this was done to reduce the viscosity and freezing temperature of the MEG prior to injection into the offshore system. Once the required MEG concentration was achieved the offshore MEG pipelines were filled from onshore.

A further portion of the MEG was diluted further to enable start-up and testing of the MEG reconcentration facilities. These facilities remove water from the MEG via distillation. Problems with the reliability of radar level instruments in the unit were encountered during this activity which was resolved by changing the transmitters with a different transmitter type. Following the resolution of these issues the unit was successfully ramped up.

Effluent treatment plant start-up

The Pluto LNG effluent treatment plant contains a biological treatment facility for removal of MEG from the produced water. This bioreactor has limited capacity to remove hydrocarbons and so the ETP also contains corrugated plate interceptors and a macro-porous polymer extraction (MPPE) unit for removal of both free and dissolved hydrocarbons.

Following initial commissioning of all units using water it was necessary to establish the biological mass in the bioreactor. The unit was seeded using feed from the local waste-water treatment plant. Following seeding the unit was dosed with MEG to acclimatise and increase the biomass concentration.

Acclimatisation of the biomass proved challenging. The MEG initially used for bioreactor dosing contained a small concentration of amine corrosion inhibitor which proved toxic to the biomass. A further setback occurred when power was lost to the unit meaning that the aeration blowers on the bioreactor could not be operated.

Overall it took approximately 3 months to establish a healthy biomass. Once this milestone was achieved it was possible to route water from the MEG reconcentration facilities into the ETP and discharge the water.

At all times during the commissioning and start-up of the unit the discharge water from the ETP remained on specification. There have been no instances of off specification product being sent to the environment.

Storage and Loading Cool-Down

Cool-down of the Pluto LNG storage and loading facilities was performed in advance of the LNG train start-up using cold gas and LNG supplied from an externally sourced LNG cargo.

The procedures for the LNG import and tank cool-down were developed using best practice techniques gathered from reviews of cool-down experience on other projects. Woodside also worked with the Pluto LNG joint venture partners, Tokyo Gas and Kansai Electric, to gather learning’s from their experience with LNG import terminal start-up and operation.

During the cool-down operation LNG vapour and liquid were routed via the LNG loading arms to the onshore facilities. The temperature and flowrates of the vapour and liquid streams required for the cool-down were specified by the onshore facility and controlled from the ship.

The cool-down activity was completed in a number of stages. The total duration for these activities was approximately 8 days.

1. Cool-down of the loading lines and tanks with cold vapour
2. Filling of LNG loading lines with LNG
3. Cool-down of LNG tanks

4. Bulk unloading of LNG into cold tanks

The activity was carried out very successfully and without incident.

Following filling of the LNG tanks the in-tank LNG pumps were tested and LNG circulated through the loading lines to maintain cryogenic temperatures. This mode of operation continued until start-up of the LNG train had occurred.

Figure 5: Pluto LNG Storage and Loading Cool-Down

Refrigerant Supply

Propane

A first fill of refrigerant grade liquid propane was supplied via trucks from Perth, a distance of approximately 1600 km by road. The volume of propane delivered was sufficient to fill both the propane circuit and meet the initial propane fill requirements of the mixed refrigerant circuit. The propane was supplied via 23 truck deliveries.

Initial vapour purging of the sphere was carried out by routing liquid propane through a temporary vaporiser to the sphere. Loading of the propane sphere was then carried out using temporary unloading facilities.
Due to the hazardous nature of this activity a large exclusion area was applied to the propane storage facility and the activity was carried out late during the commissioning phase when site construction numbers had reduced. The activity was completed without incident and in sufficient time to allow a full propane inventory for the LNG train start-up.

**Ethane**

Mixed refrigerant for the Pluto LNG start-up was generated using the “Once through MR” process. This process leverages from Woodside’s operational experience of managing small internal leaks within the LNG train main cryogenic heat exchangers (MCHEs) and involves bleeding natural gas into the mixed refrigerant (MR) circuit whilst operating the MR compressors to circulate the gases through the refrigerant circuit.

This circulation of natural gas results in the formation of a temperature gradient in the main cryogenic heat exchangers, which is used to separate and remove the lighter components (methane and nitrogen). The continuous introduction of natural gas and removal of light components results in an increase in the composition of “heavy” components in the circuit and eventually the generation of significant quantities of ethane rich liquid refrigerant.

Using this method sufficient mixed refrigerant for a train start-up and ramp-up to 70% was made within two days, this represents a large improvement over traditional approaches for ethane generation which can take several weeks.

Further details of the once-through MR process are described in a separate paper being presented at LNG17.

**Commissioning and Start-Up of Offshore Facilities**

Approximately 12 months prior to the LNG train start-up the offshore system was pressurised with natural gas taken from the domestic gas pipeline that runs close to the Pluto LNG facilities. Pressurisation of the trunkline and flowlines was required to provide sufficient backpressure to prevent low temperatures during initial flow from the Pluto LNG wells. The domgas was heated onshore with an electric heater to prevent low temperatures in the onshore and near-shore pipelines during the pressurisation.

Pressurisation of the offshore system also allowed early hydrocarbon commissioning of the offshore platform and subsea system with the offshore system being declared ready for start-up (RFSU) approximately 5 months prior to the LNG train start-up.

The Offshore RFSU milestone and the availability of supporting Onshore MEG export allowed the Pluto LNG wells to be started and well performance proven by packing and unpacking the Offshore system. This early offshore start-up resulted in a significant risk reduction during the LNG train start-up as the offshore system had already been successfully operated.

Careful monitoring of offshore pipeline condensate and MEG inventories was necessary during the initial operation of the wells. Any liquids from the wells accumulated in the flowlines and trunkline could not be removed by pigging until a flow path to the onshore plant was available, so it was important that the volume of liquids accumulated in the trunkline during this phase did not exceed the slugcatcher capacity. This monitoring was performed by a dedicated offshore engineering team who were located at the onshore facilities for the duration of the start-up.

**Flow assurance issues during first start-up**

Wellstream gas was introduced to the onshore facilities once the onshore gas pre-treatment facilities were ready for start-up. The flow of gas to shore was initially at relatively low rates, as dictated by onshore fuel gas and commissioning requirements with offshore trunkline liquid inventories managed by periodic running of liquid management pigs.

Early running of pigs allowed start-up of the condensate stabilisation facilities to be carried out prior to LNG train start-up. Initial operation of the stabilisers was very successful with no significant issues found.
Estimates of trunkline liquid inventories and hence pigging trigger points during this period were made based on the cumulative production rates, building on the experience gained in the early Offshore commissioning. Although liquid volume estimates were found to be accurate, when pigging at low rates significant biasing was seen in liquid receipt between the two slugcatcher halves. This was manageable as pigging trigger points had been set early enough to allow for this type of uncertainty. The magnitude and direction of flow biasing changed with every pig run, however biasing has not been evident in subsequent pig runs at full production rates.

Based on experience from other sites there were concerns that significant volumes of solids (e.g., sand, corrosion products) would be bought to shore during initial pigging activities and additional temporary filtration capacity was installed in the MEG system to cater for this. Overall the number of filter change-outs in the Onshore liquid handling systems has been manageable which is attributed to successful management of the offshore system during hydro-testing and preservation which resulted in low formation of corrosion products, and good well completion management which resulted in relatively low levels of well solids.

**Ramp up of wells during LNG train start-up**

Well ramp up rates were restricted during early operation to allow the wells to stabilise and minimise the risk of formation damage and sand production. During final cool-down and ramp-up of the LNG train there is a very rapid increase in natural gas flow which is faster than can be met by ramp-up of the wells. This discrepancy required the Offshore and Onshore start-up teams to work closely together to manage the competing flow, pressure and liquid management objectives. Ramp-up of the offshore system commenced several hours prior to LNG train ramp-up, with close monitoring of system flowrates and pressures required to ensure sufficient margin from high pressure limits on the trunkline and onshore facilities. Start-up plans had to ensure liquid inventory accumulation in the offshore system remained within a defined operating envelope to avoid flooding the Onshore facilities during the LNG ramp-up.

**Nitrogen Rejection Unit**

The nitrogen rejection unit (NRU) is designed to remove nitrogen from the Pluto LNG end-flash gas. This is necessary to allow the end-flash gas to be burnt in the fuel gas system. The start-up of the NRU requires end-flash gas from the LNG train and thus cannot be commenced until after the LNG train has been started.

The NRU is a new equipment unit for Woodside and so vendor personnel (Linde) were present on site to assist with first start-up and operator training.

Cool-down of the NRU is a lengthy process with a cool-down and ramp-up from ambient conditions taking several days. Process conditions change very slowly which means changes made to flows or pressures may not impact the cool-down until several hours later.

This means the start-up operation spans several shifts and it is essential to have robust procedures and shift handovers to ensure the success of the cool-down. Woodside worked with Linde during the start-up operation to improve start-up methodology for the unit resulting in procedures which can be reliably carried out by operations personnel without on-site engineering or vendor assistance.

**Impacts of Smokeless Flaring and Resultant Design Challenges**

**Storage and loading flare**

The flares at the Pluto LNG facility were designed to minimise dark smoke during plant production.

In order to meet this requirement the Pluto LNG storage and loading flare was provided with air-assist technology, which reduces smoke formation by using air blowers to force mixing of air and hydrocarbons close to the flare-tip.

During the first LNG offloading operation high backpressures were experienced in the storage and loading flare header which caused the LNG loading operations to be halted. Upon investigation it became apparent that ice formation was occurring at the storage and loading flare-tip, caused by the introduction of humid air
into the cold flare gas. Turning off the air assist gas and switching to the offline flare stack eliminated this problem.

A significant contributor to the ice formation issues was the mechanical design of the flare tip, which restricted the area available for flow of gas and air flow. This design was intended to promote stable flame formation and minimise dark smoke to the maximum possible extent. This restricted area available for gas flow meant that a relatively small amount of ice build-up could cause a significant increase in backpressure.

The problem was eliminated and operations were able to be continued with the air assist turned off. Re-design of the flare tip is being progressed to remove the mechanical flow restrictions and move to a more “open pipe” design. This is expected to allow the use of assist air and minimise dark smoke without any increase in backpressure.

Ramp-Up Performance

The culmination of the described start-up techniques was a safe, reliable and successful start-up of the Pluto LNG facilities.

Figure 6 shows the capacity and reliability performance of the Pluto LNG facilities over the first few months of operation. The train achieved production rates close to design capacity within 3 months of operation, with a system reliability greater than 90% in the second half of 2012.

![Figure 6: Pluto LNG Rundown vs. Time](image)

This good start-up performance has resulted in 39 LNG cargoes being delivered from the facility in 2012. This better than expected production from Pluto resulted in Woodside upgrading its production forecast twice during 2012.

CONCLUSIONS

The start-up of the Pluto LNG facilities is considered to be a great success, with a rapid ramp-up and high reliability over the initial operational period. This is considered testament to the level of planning and preparation, the high quality team and the innovative start-up methodologies which were employed.

The start-up presented a number of technical challenges which were overcome by leveraging off the experience from within the Woodside start-up team. Best practice techniques from previous Woodside start-
ups were employed in addition to identifying new start-up methodologies using Woodside’s operational experience.

Through the successful commissioning, start-up and initial operations, Pluto LNG has demonstrated Woodside’s world-class capability as an LNG operator. We will continue to build on this capability for use on future LNG projects.