Analysis of Infrastructure and Logistics Requirements for the Development of an Onshore Oil and Gas Industry in the Northern Territory

Department of Trade, Business and Innovation

Final Report

December 2019

Executive Summary

The development of the Northern Territory's (NT) oil and gas sector has significantly progressed in the past decade, with Darwin establishing itself as Northern Australia's offshore oil and gas operations and maintenance hub. While continuing to support and invest in unlocking further offshore activity, the Northern Territory Government (NTG) has commenced consideration of the opportunity presented by onshore exploration and production.

This aspiration has been outlined in the Northern Territory Gas Strategy (2019) (the Strategy). The Strategy builds upon the previous actions of the NTG to consider an evidence-based approach to the regulation of industry development. To support the Strategy, this study determines the planning, infrastructure, logistics, workforce and service requirements for development of the onshore oil and gas industry in the Beetaloo Sub-basin (the Sub-basin) from the Exploration phase through to the Production phase. This has been achieved through the development of a series of agreed scenarios for the potential development of the Sub-basin, combined with the technical analysis of the infrastructure investments that would be required to support these scenarios.

Scenarios for industry development

The feasibility of developing the Sub-basin is dependent on the presence of gas in sufficient quantities to be commercially attractive. This depends on the market price for gas, LNG and condensate, and the cost at which the gas can reasonably be extracted, processed and delivered to market.

This report finds that a positive outcome from the initial Exploration phase, followed by further appraisal and early development successes coupled with improvements in technology and reductions in development costs, could potentially lead to the development of a viable onshore oil and gas industry in the NT within the next decade.

Technical analysis undertaken by RISC Advisory for this report has highlighted a series of potential scenarios for the development of the Sub-basin.

Play	Case	Recovery rates / well	# of wells	Recoverable Volumes	Assumed Gas Market Demand	
Middle Velkerri Dry gas	Low	1.9 bcf	375	700 bcf	100 TJ/d domestic gas	-
	Mid	4.2 bcf	2,200	9,250 bcf	200 TJ/d domestic gas	2 x 4.5 Mtpa LNG trains
	High	7.8 bcf	2,225	17,350 bcf	300 TJ/d domestic gas	4 x 4.5 Mtpa LNG trains
Kyalla Liquids-rich gas	High	3.2 bcf 160 kbbl	3,520	11,200 bcf 563 mmbbl	200 TJ/d domestic gas	2 x 4.5 Mtpa LNG trains

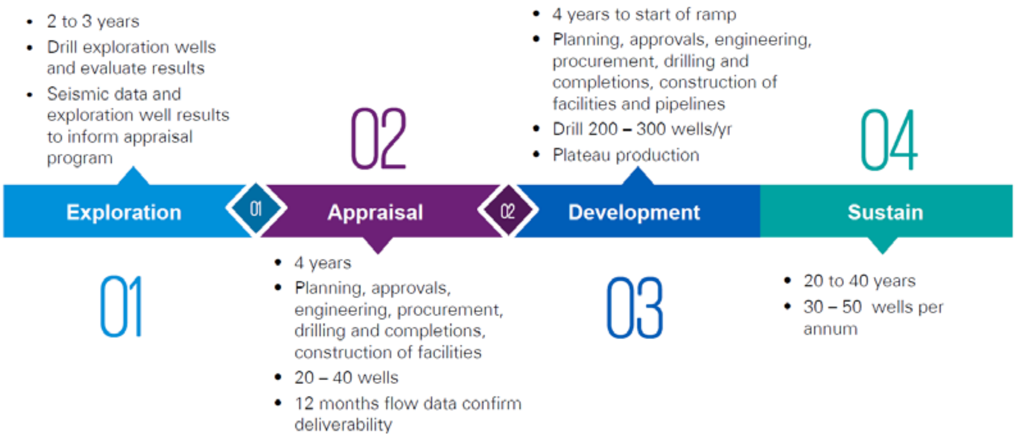
The analysis suggests that a commercial development of shale gas via LNG exports requires a high volume of gas and high well productivity case. The recovery of condensates may enhance the feasibility of the play if gas recoveries are sufficiently high. Analysis of the scenarios show that a per well recovery rate of 3-4 Bcf (liquids rich) and 5-6 Bcf (dry gas) is required for viable development. A breakeven gas price at Darwin of less than USD$4.80/MMbtu is anticipated to be required for the Mid-High case outcomes to be viable.

Scenarios Staging

The development schedule for any shale gas play is heavily influenced by a number of factors. The four most important of these factors are the state of appraisal of the underlying resource base; the potential scale of the development; the existing supporting infrastructure and logistics support available for the development; and the availability of a market for the sales products from the play.

For the Sub-basin, these factors are not currently favourable for a development schedule to proceed at rapid pace. The Sub-basin is at an early stage of exploration with very limited available infrastructure or logistics support. The potential scale of development is required to be very large in order to incentivise the development of the required infrastructure and logistics systems

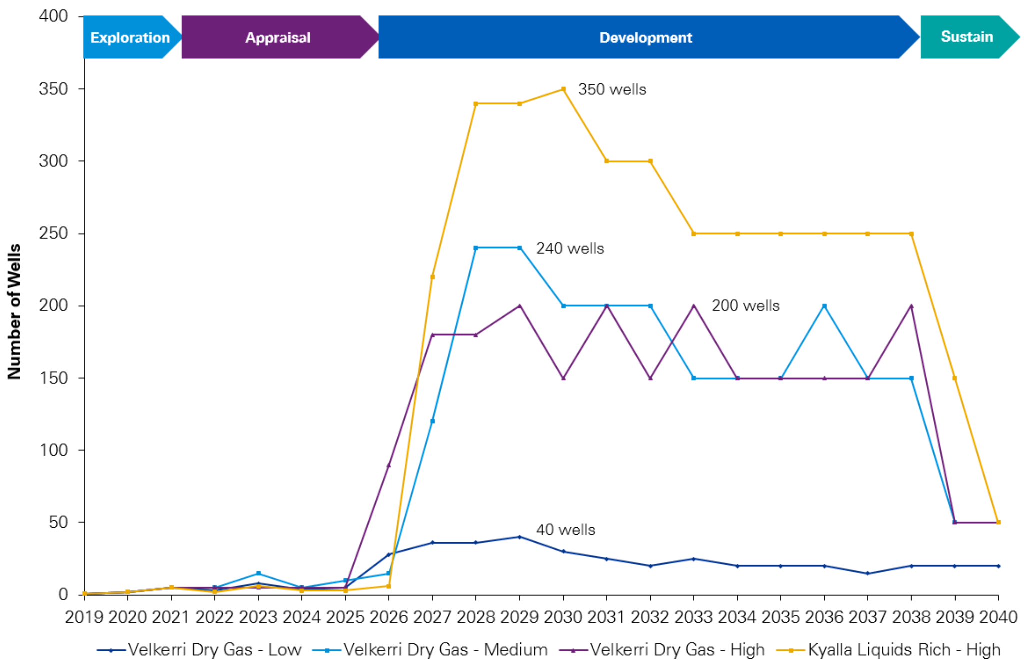
A reasonable "best estimate" / likely appraisal and development schedule for the Sub-basin can be characterised into four consecutive phases, as highlighted in the figure below. Critically, the graphic highlights two key gates (diamonds one and two) at which point progression to the next stage will need to be considered to unlock further investment. Given the frontier nature of the Sub-basin development, planning will be required to ensure there is consideration of the infrastructure and logistics requirements should investment progress past these key decision points for individual plays.



This development over time is reflected in the estimated well-build up profile for each of the proposed scenarios. As outlined in the figure below, the number of wells constructed during the exploration and appraisal periods are relatively low, with significant expansion occurring in 2026 with the transition to the Development phase.

Infrastructure Type	Production development scenario	Requirement	Timing	Probable capital cost estimate
Infrastructure Type - Roads				
Stuart Highway - Pavement rehabilitation program	Medium & High (Dry Gas), High (Liquids)	Business case development Program of works Procurement Construction	2024	$2M/km
Stuart Highway - Intersection upgrades	Medium & High (Dry Gas), High (Liquids)	Business case development Survey Confirm easement / title Design Approvals Procurement Construction	2023	$270K
Stuart Highway - Capacity Upgrades - Upgrade widening of carriageway (60km)	Medium & High (Dry Gas), High (Liquids)		2023	$60M
Carpentaria Highway - Upgrade to two lane sealed (140km)	All		2022	$150M
Western Creek Road (Ch 0 to 56) - Upgrade to two lane sealed (56km)	All		2024	$58M
Western Creek Road (Ch 56 to 92) - Upgrade to good gravel standard (36km)	All		2026	$27M
Buchanan Highway - Upgrade to two lane sealed (67km)	Medium & High (Dry Gas), High (Liquids)		2024	$70M
Gorrie Dry Creek Road - Upgrade to good gravel standard (84km)	Medium & High (Dry Gas), High (Liquids)		2026	$62M
Infrastructure Type - Airports				
Shared user airport would require consideration of distance to productive fields, land availability/suitability and provision of supporting services. Assume located at Larrimah, Daly Waters or Newcastle Waters	Medium & High (Dry Gas), High (Liquids)	Business case development	2024	$38M
Infrastructure Type - Waste Management				
Upgrades to existing landfills	Medium & High (Dry Gas), High (Liquids)	Capacity assessment	2024	$227 per m^2
Wastewater treatment facilities – cost based on PWC Katherine WTP	Medium & High (Dry Gas), High (Liquids)	Wastewater characterisation Treatment selection Design Construction	2024	$28M
Waste transfer station	Medium & High (Dry Gas), High (Liquids)	Land suitability assessment Concept design	2024	$710K

Infrastructure Type	Production development scenario	Requirement	Timing	Probable capital cost estimate
New landfill	Medium & High (Dry Gas), High (Liquids)	Approvals Detailed design Construction Approvals	2026	$3.2M
Infrastructure Type - Export Pipelines				
New gas pipeline	Medium & High (Dry Gas), High (Liquids)	Survey Confirm easement / title Design Approvals Procurement Construction	2024	$45K to $65Kper inch / km
Liquids pipeline	Liquids		2025	$45K to $65Kper inch / km
Infrastructure Type - Port				
Bulk liquids storage and loading gantry	Liquids	Design Approvals Procurement Construction	2024	Cost to be determined at business case phase.
Upgrade to facilities to load proppant to load rail cars	Medium & High (Dry Gas), High (Liquids)	Design Procurement Construction	2025	Cost to be determined at business case phase.



Infrastructure Requirements

The findings of the infrastructure analysis have highlighted a series of recommendations relevant to common user infrastructure requirements for each of the resource development scenarios. These findings are summarised in the table below, highlighting both the lead time for planning works as well as the delivery timeframes for key infrastructure investments. An estimate of probable costs have been prepared based on a brief description of the infrastructure required, without sites being nominated, site conditions unknown and without design. Therefore, these estimates should be regarded as being indicative of the cost as many factors will influence the cost.

Infrastructure Type	Production development scenario	Requirement	Timing	Probable capital cost estimate
Infrastructure Type - Rail				
Siding	Medium & High (Dry Gas), High (Liquids)	Survey Confirm easement / title Design Approvals Procurement Construction	2024	$16.2M

Notes to costing: Probable capital cost estimates include: Quantities, preliminaries, margin, design / construction contingency escalation to quarter 1 2021, escalation construction, consultants fees, NT build levy and GST.

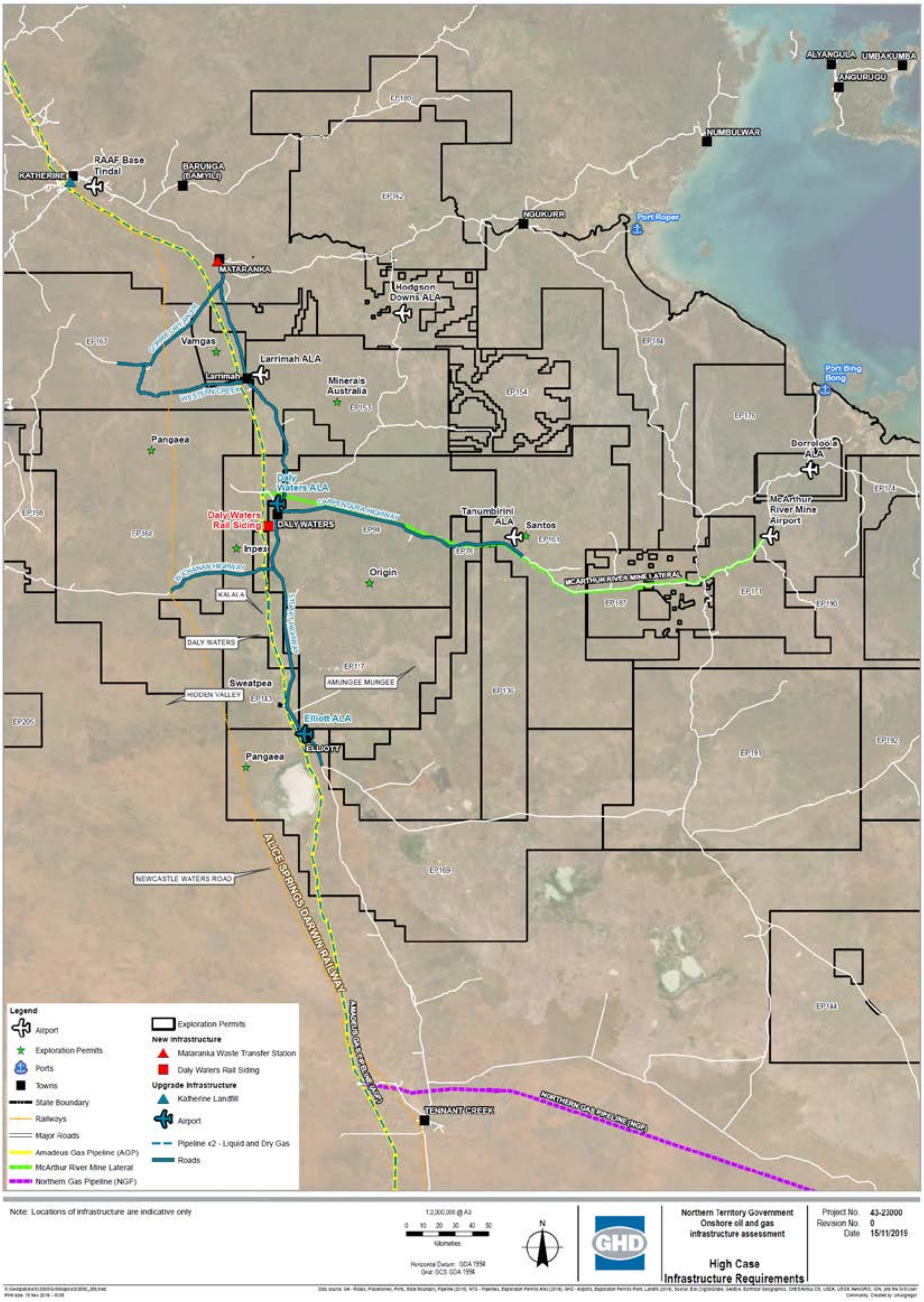
For the purposes of this estimate, it is assumed that commencement would be the first quarter of 2021, allowing for design regulatory and planning approvals, with various construction periods. The individual proponent's project delivery cost for each project are excluded.

In addition to these identified works, it is recommended that the following early priority actions occur:

- **Industry engagement:** Convene a working group with industry and government to confirm common user infrastructure requirements, align program schedules and determine approach for a Gas Community Benefit Fund to achieve the provision of works as outlined above.
- **Pipelines:** Progress a pipeline easement study to secure a corridor to dry and liquid gas transmission from the Sub-Basin north to Darwin.
- **Roads:** Commence planning and business case activities for the Carpentaria Highway upgrade.
- **Gravel:** Confirm the quantities of bulk extractive supply required for identified upgrades and model sources capacity. This includes analysing condition data for the Stuart Highway to confirm pavement rehabilitation requirements.
- **Waste:** Prepare landfill capacity assessments for listed waste at Katherine and Shoal Bay landfill sites, undertake land suitability assessments for waste management sites, and transfer stations at Elliott, Daly Waters and Mataranka.
- **Cumulative impacts:** Consider the cumulative infrastructure requirements of other regional developments, including those associated with gas development in the McArthur Basin, and the broader resources, agricultural and tourism sectors.
- **Supporting services:** Continue to identify opportunities to grow the local service and supply industry through a supporting services opportunity and needs assessment.

- **Regulation:** Confirm the approach to provision of resourcing and associated requirements for regulation activities.

The location of key assets identified in the table above have been mapped in the figure below.



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Inherent Limitations

This Report has been prepared as outlined in the Methodology section of our Proposal dated 19 April 2019. The services provided in connection with this engagement comprise an advisory engagement, which is not subject to assurance or other standards issued by the Australian Auditing and Assurance Standards Board and, consequently no opinions or conclusions intended to convey assurance have been expressed.

KPMG have indicated within this Report the sources of the information provided as per our methodology. We have not sought to independently verify those sources unless otherwise noted within this Report.

KPMG is under no obligation in any circumstance to update this Report, in either oral or written form, for events occurring after the paper has been issued in final form. The findings in this Report have been formed on the above basis.

Third Party Reliance

This Report is solely for the purpose set out in the Methodology section of our Proposal and for the Northern Territory Department of Trade, Business and Innovation's information, and is not to be used for any other purpose or distributed to any other party without KPMG's prior written consent.

This Report has been prepared at the request of the Northern Territory Department of Trade, Business and Innovation in accordance with the terms of Proposal dated 19 April 2019. Other than our responsibility to the Northern Territory Department of Trade, Business and Innovation, neither KPMG nor any member or employee of KPMG undertakes responsibility arising in any way from reliance placed by a third party on this report. Any reliance placed is that party's sole responsibility.

Acronyms

Acronym	Definition
AADT	Annual average daily traffic
AAPA	Aboriginal Areas Protection Authority
ACCC	Australian Competition & Consumer Commission
AEMO	Australian Energy Market Operator
AEP	Annual Exceedance Probability
APPEA	Australian Petroleum Production and Exploration Association
BCF	Billion Cubic Feet
CAPEX	Capital Expenditure
CLA	Cambrian Limestone Aquifer
CLC	Central Land Council, Northern Territory
CSG	Coal seam gas
DENR	Department of Environment and Natural Resources, Northern Territory
DIPL	Department of Infrastructure Planning and Logistics, Northern Territory
DOEE	Department of the Environment and Energy, Commonwealth
DPIR	Department of Primary Industry and Resources, Northern Territory
E&P	Exploration and Production
EAW	East Arm Wharf
EUR	Estimated Ultimate Recovery
FD	Future development
FIFO	Fly-in fly-out
FX	Foreign Exchange Rate
GDP	Gross domestic product
GHD	GHD Pty Ltd (GHD)
GI	General Industry
GSM	Global system for mobile communication
GST	Goods and services tax
GWP	Gross world product
HV	Heavy vehicle
INPEX	INPEX Corporation
IRI	International Roughness Index
JKM	Japan Korea Marker
KBBL	1,000 Barrels
KPMG	KPMG Pty Ltd
LACA	Land Access and Compensation Agreement
LACA	Land Access and Compensation Agreement
LGAs	Local Government Areas
LI	Light Industry
LNG	Liquefied Natural Gas
LPG	Liquefied petroleum gas

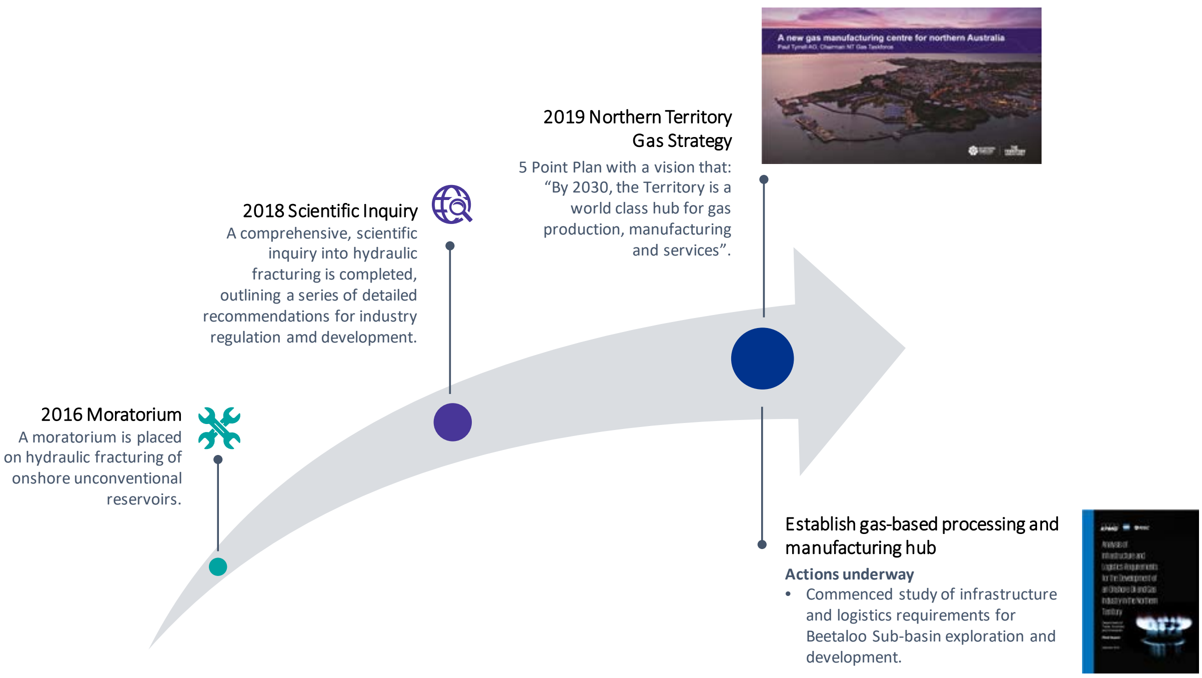
Acronym	Definition
Mbtu	1,000 British Thermal Units
ML	Mega Litres
MMBBL	1,000,000 Barrels
MTPA	Million Tonnes Per Annum
MW	Mega Watts
NACOG	North Australian Centre for Oil and Gas
NGERS	National Greenhouse and Energy Reporting Scheme
NT	Northern Territory
NTEPA	Northern Territory Environment Protection Authority
NTG	Northern Territory Government
OPEX	Operating expense
PFAS	Per- and poly-fluoroalkyl substances
PJ	Petajoules
PWC	Power and Water Corporation
RISC	RISC Advisory Pty Ltd
SAR	sodium absorption ratio
SEAAOC	South East Asia Australia Offshore and Onshore Conference
SIA	Social Impact Assessment
SREBA	Strategic regional environmental and baseline assessment
TBC	To be confirmed
TDS	Total dissolved solids
TEU	Twenty-foot equivalent unit
TIA	Traffic Impact Assessment
TJ/D	Terajoules per Day
Tpa	Tonnes per annum
US	United States
USD	United States Dollars
VSAT	Very Small Aperture Terminal

1 Introduction

The development of the Northern Territory's (NT) oil and gas sector has significantly progressed in the past decade, with Darwin establishing itself as Northern Australia's offshore oil and gas operations and maintenance hub. This operations and maintenance hub has been augmented by the Darwin LNG Plant, Ichthys LNG Plant, the establishment of the North Australian Centre for Oil and Gas (NACOG) and a purpose-built marine supply base to support offshore operations.

The development of the onshore exploration and production sector is recognised as a globally significant economic development opportunity. Geoscience Australia has estimated that the Beetaloo Sub-basin (the Sub-basin) is larger than any of the North West Shelf conventional gas resources and is comparable with several of the major US shale gas basins. In a time of economic downturn for the NT, the development of this resource presents a significant opportunity to generate economic activity and social benefits for the NT and Territorians for some years to come.

The Northern Territory Government (NTG) has outlined its aspiration to grow the oil and gas sector in the Northern Territory Gas Strategy (2019) (the Strategy). The Strategy builds upon the previous actions of the NTG to consider an evidence-based approach to the regulation of industry development. The diagram below highlights these previous steps as well as the role that the KPMG-led Infrastructure and Logistics Requirements for the Development of Onshore Oil and Gas Industry study plays in the continued development of the sector.



The Strategy outlines a vision for the sector as well as the key strategies set out below:

By 2030, the Territory is a world-class gas production, manufacturing and services hub.

1 Expand the world-scale Darwin LNG export hub	Gas to expand the LNG hub could be sourced from offshore reserves, onshore gas developments, or both. Land has been secured for five additional trains - one at Darwin LNG and four at Ichthys LNG.
2 Grow the NT's service and supply industry	The NTG has invested in dedicated infrastructure at the East Arm Logistics Precinct to support offshore projects. Opportunities exist to support the offshore gas industry, including the operations of Darwin LNG, Ichthys LNG and Prelude FLNG. Opportunities exist to support the development of the onshore industry, particularly shale gas. The NTG is partnering with operators and the Industry Capability Network Northern Territory to identify opportunities to grow the local service and supply industry.
3 Establish gas-based processing and manufacturing	Opportunities exist for methane-based products, energy intensive industries, condensate refining and production of ethane-based products. Early opportunities from offshore gas fields lend themselves to methane-based products. Future opportunities from onshore gas fields may expand opportunities to include ethane-based petrochemicals. Land is available for gas-based manufacturing industries near existing LNG facilities.
4 Grow research, innovation and training capacity	Opportunities exist for strategic engagement and partnerships with Charles Darwin University, including through the North Australian Centre for Oil and Gas, the Advanced Manufacturing Alliance, and vocational education and training.
5 Contribute to Australia's energy security	Proven large-scale offshore gas reserves and highly-promising onshore resources of global significance can contribute to national energy security, and supply gas to Australia's east coast markets.

In order for the oil and gas sector to sustainably grow and unlock the economic and investment opportunities aspired to in the 5 Point Plan, both government and industry require greater clarity and transparency around the next steps for the development of the industry through the development of a series of empirically-based supply and demand scenarios. This study provides a high-level analysis of the infrastructure requirements to unlock industry development and will support the NTG to:

- Undertake strategic land use planning;
- Guide initiatives to attract investment;
- Prioritise infrastructure development
- Support NT and Commonwealth Government collaboration;
- Engage with industry, key stakeholders and the community in key regions; and
- Inform economic and local content planning.

1.1 Project Scope

The analysis of the infrastructure and logistics requirements for the development of the onshore oil and gas industry in the NT presents a critical next step for both government and industry. The NTG's initial focus is on continued exploration and development of onshore oil and gas in the Sub-basin.

To support the NTG's delivery of the 5 Point Plan, this study will determine the planning, infrastructure, logistics, workforce and service requirements for development of the onshore oil and gas industry in the Sub-basin from the Exploration phase through to the Production phase. To achieve this, it will deliver a set of pragmatic scenarios outlining how the onshore oil and gas sector could develop, identifying the potential high-level infrastructure and logistics implications, by:

- Determining forward-looking **development scenarios** to guide government and industry decision making regarding developmental opportunities the liquids rich and dry gas plays in the NT; and
- Undertaking a **high-level scan of infrastructure and logistics requirements** to support development of the Sub-basin (the Sub-basin) and associated industrial development.

These outcomes will be delivered through the collation and analysis of available information, including:

1) **Industry Engagement** – engagement focussed on understanding insights into supply and demand scenarios as well as industry and infrastructure development to enable both government and industry to have a strong alignment of the next steps for industry development.
2) **Review of Available Data on Recoverable Supply** – the development of supply estimates for the development of the Sub-basin, as informed by exploration activity already undertaken.
3) **Review of Global Demand Data** – examination of the impact of global and domestic influences on the demand for oil and gas to inform the development of forward-looking demand. The three demand scenarios (low, medium and high) will be generated in a consistent framework that makes explicit the links between the demand for oil and gas, the level and structure of economic activity in the global economy and the role of energy prices in reconciling demand and supply for oil and gas globally.
4) **Available Data on Infrastructure Capacity** – a desktop assessment of existing infrastructure networks relevant to the development of the Sub-basin and associated industrial development. This baseline captures both the enabling infrastructure and the requirements for gas and liquids development across the value chain.

The project team has developed a series of responses that will identify the potential industry infrastructure and logistics requirements during each phase of development across the gas lifecycle for each scenario.

1.2 Industry Engagement

Hearing the voice of industry around the likely factors that will influence their investment decisions (both those within and outside of NTG's control) is critical to ensuring that the NT and Commonwealth Governments has the information they require to set appropriate policies and to facilitate infrastructure investment that is conducive to unlocking and accelerating significant industry investment into the Sub-basin and downstream manufacturing.

Over the course of this engagement, we have engaged extensively with key industry stakeholders that have a vested interest in the development of the NT's onshore oil and gas sector in order to test our assessments, insights and analysis. Engagement has included:

- **Direct Engagement:** Throughout the engagement, we met directly with a number of industry stakeholders, several on multiple occasions, to gather their views and test our analysis throughout the engagement. Stakeholders consulted include Santos, Origin Energy, INPEX, ConocoPhillips, Power and Water Corporation, Pangaea Resources and Empire Energy.
- **Industry Reference Group:** During the South East Asia Australia Offshore and Onshore Conference (SEAAOC) in September 2019, we provided a project overview to an upstream industry meeting convened by the Chairman of the Gas Taskforce. This group included a number of NTG and Commonwealth Government stakeholders, as well as industry stakeholders, including APPEA, ConocoPhillips, eni, INPEX, Neptune Energy, Shell Australia, Armour Energy, Central Petroleum, Origin Energy and Santos.

Industry engagement throughout the project has resulted in a robust and pragmatic Final Report with insights and recommendations that have been informed by industry feedback.

1.3 Purpose of the Final Report

This Final Report delivers an infrastructure gap analysis against a series of low, medium and high demand scenarios that have been informed through industry consultation and technical estimation of the potential pathways for Sub-basin development. Specifically, this report outlines:

- **Confirmed Scenarios:** a summary of key findings from technical analysis into the price environment for gas and associated products as well as the potential commercial viability of extraction of these resources. These have informed a series of potential scenarios for Sub-basin development against which the infrastructure analysis in subsequent sections has be prepared.
- **Infrastructure Requirements:** an assessment of the infrastructure requirements for each demand scenario.
- **Infrastructure options:** an outline of the infrastructure options relating to transport and transmission, potential common user facilities and other infrastructure as required by industry and timescale.
- **Recommendations:** confirm the implementation viability of infrastructure options outlined, ensuring that they are readily implementable, pragmatic and relevant to both technical and non-technical audiences.

2 Development of the Sub-basin

The development of the Sub-basin will be determined in large part by a combination of market forces around the price environment for natural gas and condensate, as well as the cost of logistics and processes associated with the extraction of these resources. While it is recognised that these concepts were explored in detail as a component of the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory (the Scientific Inquiry), this report provides an updated perspective.

The analysis undertaken to inform this report builds on the Scientific Inquiry to develop an independent, current view on the potential price environment for gas in the coming decade, as well as the potential cost associated with the development of plays in the Sub-basin. It identifies that while the cost profile will likely be high, there are a range of scenarios within which the Sub-basin could develop and that further investigation into the implications of these scenarios is warranted.

Building on the findings of this analysis, a set of scenarios for the development of the Sub-basin have been proposed to inform the infrastructure and logistics analysis in **Chapter 3**.

2.1 Global and Domestic Willingness to Pay

Natural gas is a tradeable commodity and, over the longer term, its price will be determined by supply and demand conditions on global markets. Natural gas comes in various forms (e.g. at a basic level wet and dry gas) and competes with other fuel sources (coal, oil, nuclear, renewables etc.). While it is beyond the scope of this report to consider the gas in the context of the spectrum of fossil fuels, it is important to recognise that the prices of fossil fuels, particularly over longer horizons, are linked because they are highly substitutable. Processing and transportation costs, as well as other technological constraints, introduce wedges between the prices of different hydrocarbons. These wedges are unlikely to change systematically over time unless there is a technological breakthrough that drives low production, processing and transportation costs.

The purpose of this analysis is to identify a plausible price range for natural gas over the next 25 years.

2.1.1 Our Approach

This section outlines the approach to developing the demand scenarios. KPMG-Macro, a global macro-econometric model, is used to support the analysis. Energy is an important input in the global production system. There is a strong relationship between economic growth and energy prices. Other things being equal, high energy prices increase production costs and slow down economic growth. Energy price shocks have disrupted economic activity over history, in some cases, leading to recession and major dislocation. However, such shocks are, by their nature, largely unpredictable and temporary in nature. This analysis focusses on longer-term trends, abstracting from temporary supply or demand shocks in the energy market. This does not mean that the reactions of economies to short-run energy shocks are ignored. Energy shocks make businesses and governments focus on energy security and on energy efficiency, which can result in permanent changes in production technology and in energy supply.

In standard applications of KPMG-Macro, the supply side of the energy market is assumed to accommodate demand. Loosely speaking, growth in economic activity depends on, among other things, energy prices, which in turn depend on growth in economic activity. In this framework, faster economic growth tends to push up energy prices, which has a damping effect on growth.

Over a longer horizon, the key drivers of gas demand will be:

- The price of gas relative to the price of substitute fuels (ranging from close substitutes through to not-so-close substitutes);
- Growth in economic activity, including the regional and industrial composition of growth;
- Public sentiment and the influence on private sector investment;
- Technological change driving improvements in energy efficiency. This may be partially driven by policy settings; and
- Environmental and other policies designed to increase energy efficiency and change the energy mix.

Over a longer horizon, the key drivers of gas supply will be:

- The market price of gas; and
- Availability of reserves and the cost of extracting, processing and delivering the fuel to users relative to other fuel sources.

2.1.2 Energy Market Backdrop

Energy consumption is analysed through a prism of global growth, including the regional and industrial composition of growth, and energy efficiency. We then consider how the energy mix has changed over time, focusing on how the share of fossil fuels in total energy usage has changed over time and how the mix of oil, gas and coal has changed within the fossil fuel bundle. On the supply side, we analyse how proven oil and gas reserves have changed over time and relate production in various regions to reserves.

In undertaking this analysis, it is important to recognise that, over a long time frame, different types of energy are reasonably substitutable. This means that persistent changes in the relative prices of different energy sources will, other things being equal, result in the energy mix changing in favour of the relatively less expensive energy source. In addition, government policy, particularly in relation to reducing carbon emissions, can also skew the energy mix towards low carbon energy sources.

The historical analysis provides a useful context for understanding the projections reported below and the key underlying assumptions. The key relevant findings of the historical analysis can be summarised as follows:

- There is a close relationship between energy demand and global growth;
- Global production appears to have become steadily more energy efficient;
- Improvements in energy efficiency appear to have dominated any regional or industrial compositional changes in determining energy demand;
- Gas has become a larger component of the energy mix over the historical period;
- The real price of energy is currently around the levels experienced in the early 1990s, although in the intervening period, there has been a significant cycle;
- The real prices of oil, gas and coal are highly correlated, although the price of gas has fallen significantly relative to the prices of oil and coal since the first half of the 2000s;
- Global energy reserves and technologies for accessing these reserves commercially have, together with the adoption of energy-saving technologies, generally allowed energy supply to accommodate demand although

there is evidence that, over the decade between 2005 and 2015, the rapid growth in the world economy, and China in particular, put pressure on energy supply and, consequently, on energy prices; and

- Increases in proven reserves of oil and gas, expansion in energy production as well as moderation of activity in the Chinese economy and the broader global economy has put downward pressure on energy prices over the last few years.

In developing the future demand scenarios for gas demands and prices, views need to be formed about the persistence of the above relationships and trends.

2.1.3 Future Demand Scenarios

2.1.3.1 Central global demand scenario

The central demand scenario is based on KPMG's current global macroeconomic forecasts for 2019 to 2045. **Figure 2-1** shows KPMG's projections for real Gross World Product (GWP). The main feature of these forecasts is that global growth over the next 25 years is expected to be lower than that recorded in the previous 25 years.

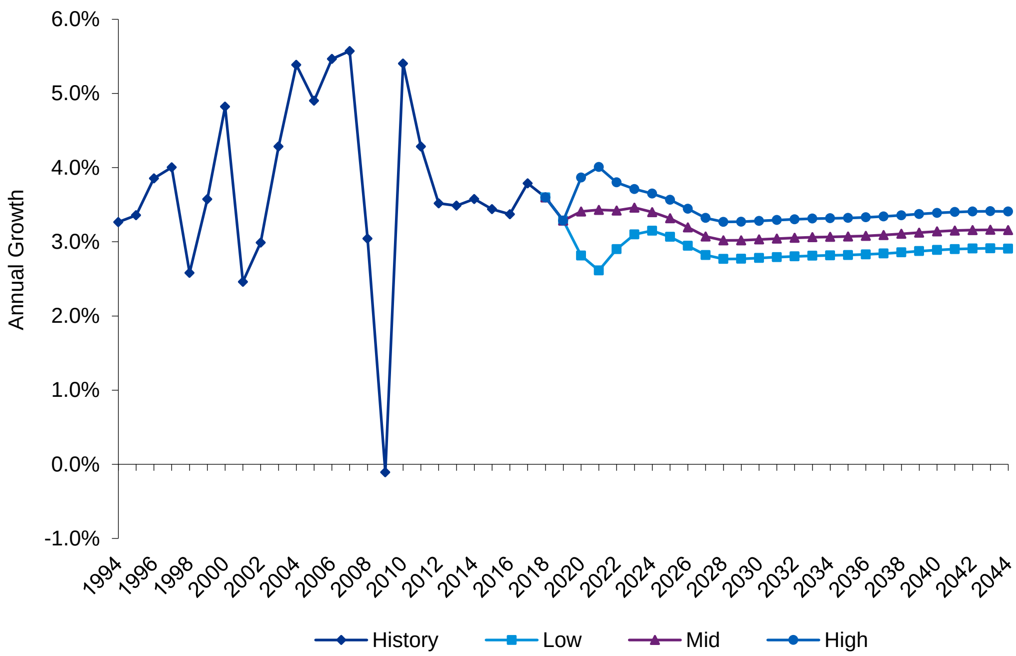


Figure 2-1: KPMG-MACRO real Gross World Product forecast, 2019-2045

It is also worth noting that in our base case of global macroeconomic forecasts, we do not have any major spurts of exceptional growth, analogous to the China experience in the recent past, for large developing economies such as Africa and India. While growth rates in these two regions are elevated over the forecast horizon, they are not assumed to accelerate during a rapid Development phase before trailing off as the economies mature. Our maintained hypothesis is that the Chinese growth phenomenon will be hard to replicate in other large developing economies because they have very different political / economic systems.

In developing the central demand scenario, we have incorporated the following key assumptions about the industrial composition of the global economy, the energy intensity of the economy and the share of fossil fuels in the energy mix.

Industry composition of the economy

At the global level, the industrial composition of the global economy has not changed significantly in recent years. A small downward trend in industrial production as a share of GWP is evident between 1995 and 2018. In the central case scenario, we have assumed that this trend will continue with the share of GWP accounted for by industrial production in 2045 falling to 27.3%, down from 28.2% in 2018. This assumption decreases the rate at which energy consumption increases for a given increase in global economic growth.

Energy efficiency

At the global level, a downward trend in the intensity of energy of global production is evident. Our central case has the current trajectory continuing. This implies that in 2045, at the global level, 0.50kg of oil equivalent energy inputs are required to generate one real $USD of GWP (see **Figure 2-3**) This assumption reduces the rate at which energy consumption increases with global economic growth.

Share of fossil fuels in the energy mix

The share of fossil fuels in the energy mix is assumed to continue falling in the central case scenario, moving from its current level of 85% to 71% in 2045 (see **Figure 2-4**).

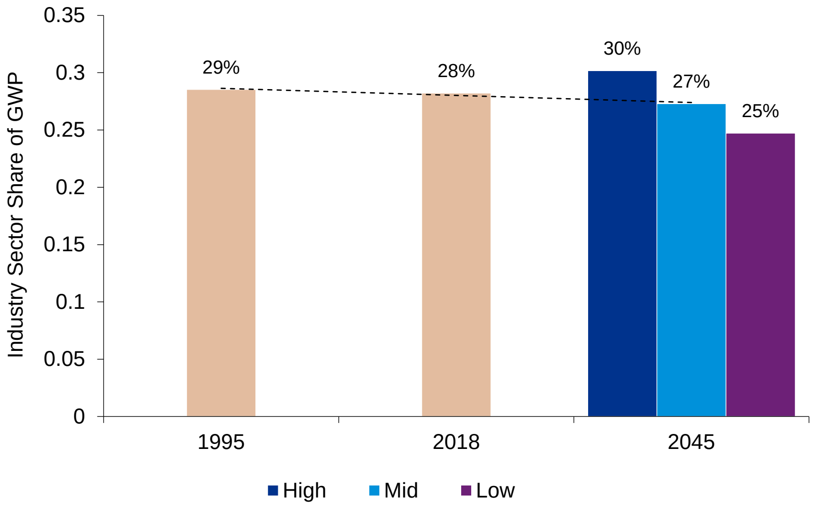


Figure 2-2: Global Trend: Industry Share of GDP

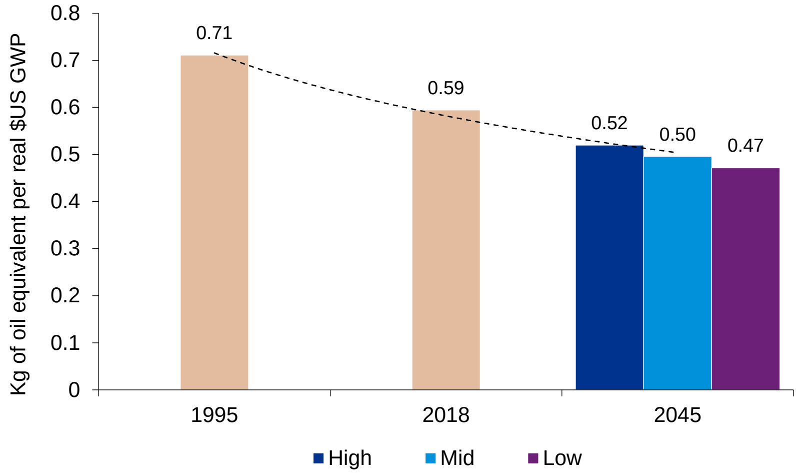


Figure 2-3: Global Trend: Energy Efficiency

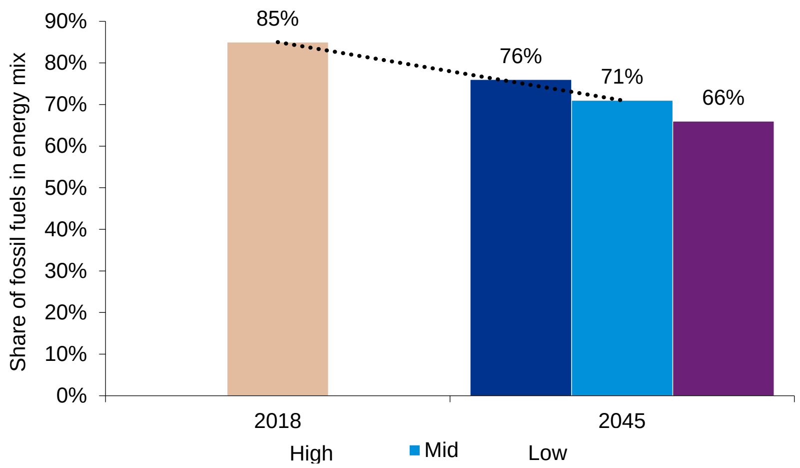


Figure 2-4: Global Trend: Share of Fossil Fuels in Energy Mix

These specific energy market assumptions, together with other assumptions underlying KPMG's global macroeconomic forecasts, yield a central case projection for global energy demand. **Figure 2-5** shows that we are forecasting global energy demand to increase from 13,900 Mtoe in 2018 to 23,400 Mtoe in 2045 (a 70% increase in aggregate energy demand).

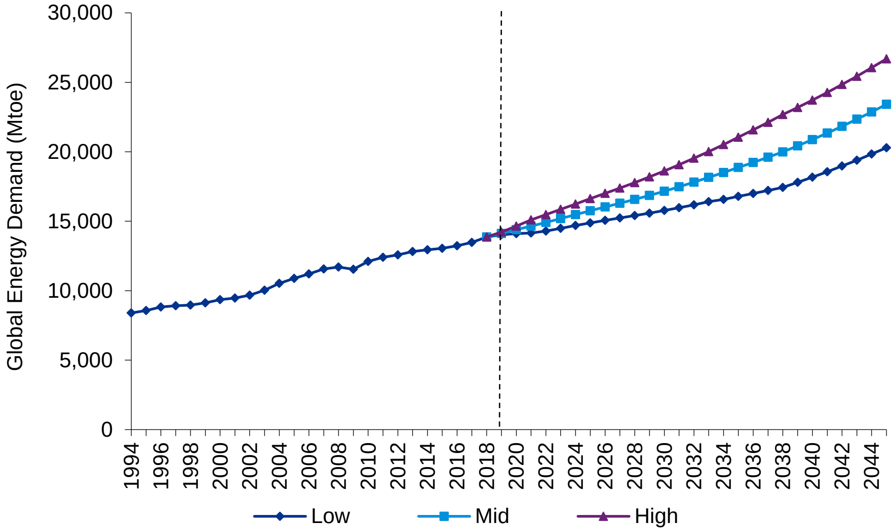


Figure 2-5: Global Demand for Energy, 1994-2045

Source: BP, KPMG

2.1.3.2 Alternative global demand scenarios

The central case scenario outlined above represents our best estimate of the expected outcome which is a 70% increase in global demand by 2045. However, we recognise that there are many alternative outcomes with reasonable likelihoods occurring. To give some guidance on the possible range of outcomes, we consider two alternative scenarios either side of our central case. For convenience, we refer to these scenarios as "optimistic" and "pessimistic". Note that these labels relate to the prospects for gas prices. For example, other things being equal, an increase in energy efficiency may be negative for gas prices but positive for the economy overall. Although the alternative scenarios have not been formulated in a formal probabilistic framework, we judge them to have reasonable likelihoods of occurring (i.e. we do not consider them to be in the tails of the distribution of possible outcomes).

We have chosen to structure the alternative scenarios by focusing on assumptions relating to the rate of:

- Global economic growth;
- Increase in energy efficiency;
- Increase of non-fossil fuels in the energy mix; and
- Decrease in the share of industry in global GDP.

The alternative assumptions relating to energy efficiency, the energy mix and industrial composition are set out in **Figure 2-2** to **Figure 2-4** above. In addition to these energy market specific assumptions, the alternative scenarios have different settings for risk and global trade parameters designed to capture an economic environment with higher risk and greater barriers to free trade in the pessimistic scenario and vice versa for the optimistic scenario.

2.1.4 Long-run price projections

Figure 2-6 below shows our long-run projections for a reference real (2018 dollars) Japan Korea Marker (JKM) price of LNG. In the central case, the real JKM price for LNG falls gradually from USD$9.76 per Mbtu in 2018 to around USD$7.34 per Mbtu in 2044. In the high scenario, the real JKM price for LNG rises to almost USD$10 per Mbtu, while in the low scenario the prices falls away to around USD$5.30 per Mbtu.

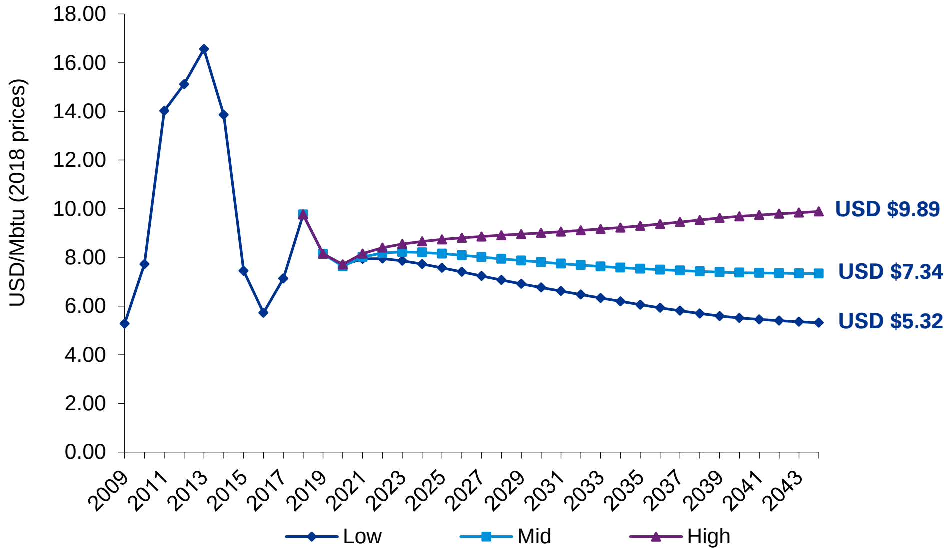


Figure 2-6: Projections for the Real Price of LNG (Japan Korea Marker)

Source: BP, KPMG

Projections for the real price of oil (Brent) are presented in **Figure 2-7** below. In the central case scenario, the real price of Brent falls gradually from just over USD$71 per barrel in 2018 to around USD$48 per barrel in 2044. In the optimistic scenario, the real price of Brent remains close to the current price in real terms, while in the pessimistic scenario, the price falls away to around USD$35 per barrel.

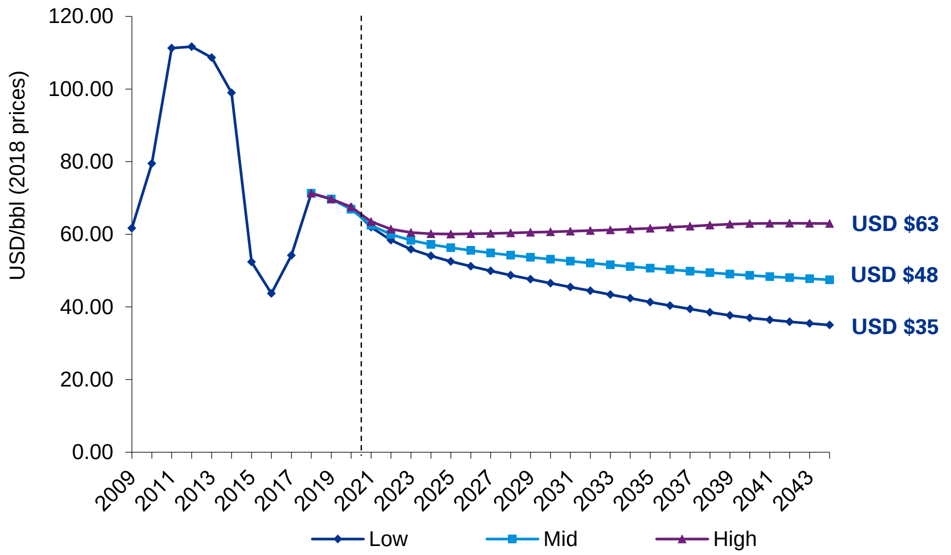


Figure 2-7: Projections for the Real Price of Oil (Brent) *Source: BP, KPMG*

In the central case, the real JKM price for LNG falls gradually from USD$9.76 per Mbtu in 2018 to around USD$7.30 per Mbtu, and the real price of Brent falls gradually from just over USD$71 per barrel in 2018 to around USD$48 per barrel in 2044.

2.2 Domestic Market Considerations

The analysis in the previous section provides a global perspective on gas demand and long-term pricing. As a globally traded commodity that competes with substitute fuels, gas demand and price, particularly over the longer term, needs to be considered at the global level. This does not mean that demand and supply conditions in domestic fuel markets are unimportant. Rather, domestic market conditions that result in persistent deviations of domestic prices from global prices (on a netback basis) will elicit a response on the demand and / or supply side.

The behaviour of the east coast gas market in Australia shows how a significant increase in gas demand, which commenced in 2015 with the commissioning of the Curtis Island LNG projects, can result in a convergence (on a netback basis) of domestic and international gas prices. Indeed, evidence that the domestic gas prices on the east coast market were at times greater than the international price led to significant debate resulting in the Australian Competition and Consumer Commission (ACCC) publishing gas export parity prices to assist with transparency and the Federal government introducing the Australian Domestic Gas Security Mechanism. Since 2017, domestic gas prices on the east coast have tended to be below the LNG netback price, but they are significantly higher than the prices experienced before 2015.

In its latest Gas Statement of Opportunities, the Australian Energy Market Operator (AEMO) has projected that demand-supply conditions are finely balanced given supply for existing and committed gas developments. AEMO projects that supply gaps may begin to appear in 2024 without additional supply and infrastructure. Potential sources of new supply identified by AEMO include one or more of the following:

- Exploration and development of new southern resources,
- LNG import terminals to supply gas to southern states, and / or
- Pipeline infrastructure expansions to deliver Queensland and Northern Territory gas southwards.

AEMO warns that these new sources of supply are likely to be at higher cost than existing supplies.

The higher domestic gas prices impact the demand side of the markets. Where it is technically and economically feasible, businesses and households will seek to reduce their exposure to gas by adopting more energy efficient technologies and switching to lower cost energy. Trade-exposed businesses that are, directly or indirectly, intensive users of gas will become less competitive and may close or contract unless they can reduce their exposure to gas. Industry representatives and the ACCC have warned that businesses are closing or relocating as a result of high gas prices.[1] Our maintained assumption is that the development of the LNG industry has inexorably linked the domestic and global gas markets. Businesses will need to plan on the basis that, over the longer-term, domestic gas prices will be closely tied to global gas prices.

[1] See for example, https://www.accc.gov.au/speech/state-of-the-east-coast-gas-industry and https://www.aigroup.com.au/policy-and-research/mediacentre/releases/higher-gas-prices-20Dec/.

The tightness of the east coast gas market offers market opportunities to potential Sub-basin gas producers. Sourcing gas from the NT is one of the potential solutions identified by AEMO for bolstering supply in the southern states. This study will provide some preliminary evidence that will be useful in any assessment of how this solution compares on a cost-basis against the other possible sources of additional supply.

The development of the Sub-basin and infrastructure to transport gas to Darwin may encourage the re-location of existing gas-intensive businesses to Darwin from other regions, including overseas. For example, gas-intensive businesses currently located in the southern states may find it advantageous to relocate to Darwin if the reduction in the cost of gas (due to lower transport costs) is significantly greater than any increase in the costs of doing business in Darwin (e.g. due to reduced access to supply chains, customers, workforce etc.). Similarly, the availability of a competitive, secure source of gas in Darwin may be an attractive proposition for new gas-intensive businesses considering global location options, particularly given the proximity of Darwin to Asian markets.

The development of the Sub-basin and infrastructure to transport gas to Darwin may encourage the re-location of existing gas-intensive businesses to Darwin.

Similarly, the availability of a competitive, secure source of gas in Darwin may be an attractive proposition for new gas-intensive businesses considering global location options.

2.3 Scenarios for Extraction and Supply

The feasibility of developing the Sub-basin is dependent on the presence of gas in sufficient quantities to be commercially attractive. This depends on the market price for gas, LNG and condensate, and the cost at which the gas can reasonably be extracted, processed and delivered to market. At present, exploration in the Sub-basin is relatively immature and, as such, the resource estimates presented in this section reflect a potential range of pathways that align to available data in the public domain.

One exploration well is underway in 2019. Additional wells are planned for 2020 depending on the success of this initial well, and the data from all wells are critical to informing future investment and development decisions by oil and gas exploration and production companies.

2.3.1 Approach

Through the course of this analysis, engagement was undertaken with Exploration and Production (E&P) companies that are currently holding acreage within the Sub-basin in order to better understand the expectations and resource estimates of the Sub-basin, from a resource potential perspective. Additionally, RISC Advisory Pty Ltd (RISC) has also undertaken an independent assessment of the resource potential of the Sub-basin based on available public data. This analysis has informed the findings outlined in this chapter.

The findings from this assessment are presented in summary below as the basis from which to consider a range of informed potential development scenarios. As outlined above, this assessment is based on the available information in the public domain and sources have been identified where appropriate. This analysis could change with the additional data planned to be acquired as each additional well is drilled and further modelling completed.

2.3.2 Reservoir Volume Potential

The reservoir size and production potential of the Sub-basin was characterised by RISC using an approach known as Common Recovery Segment Mapping. The input parameters which are considered to affect the recovery potential of the play are reservoir thickness, reservoir depth, reservoir quality (as a function of porosity and water saturation), regional structure and source rock maturity.

For each of the Middle Velkerri and Kyalla plays, RISC produced low, medium and high development scenarios, which were endorsed by the NTG. The scale of development in any given scenario is matched to the volume of gas available in the best quality sweet spots of the Sub-basin identified through the common recovery sector mapping. The volumes of gas developed in each scenario should not be interpreted as the maximum gas in place in the Sub-basin, rather they reflect the volume with the best resource quality which can be realistically targeted for development. The potential production volume for each scenario was determined through analysis of development costs and well productivity (see further discussion in the following sections).

2.3.3 Well Productivity

An important aspect of the upcoming exploration and appraisal activity in the Sub-basin is an understanding of flow rate and overall productivity that is achieved in the wells. Gas in-place estimates in unconventional plays, particularly frontier and emerging unconventional plays such as those in the Sub-basin, can be misleading because they often do not address the associated development requirements.

RISC's initial estimates of ultimate recovery (EUR) per well for the Middle Velkerri shale gas play were based on upscaling of the Amungee NW-1H well test results to a notional 2km lateral, and are indicated in Table 2-1.

Table 2-1: Estimates of ultimate recovery for the Middle Velkerri shale gas play

	Low	Medium	High	Basis
RISC (Independent, 2 km lateral) Bcf / well	2.2	4.4	6.6	Based on upscaling of the Amungee NW-1H well

Source: RISC, 2019

2.3.4 Agreed Development Scenarios

A positive outcome from the initial Exploration phase, followed by further appraisal and early development successes coupled with improvements in technology and reductions in development costs, could potentially lead to the development of a viable, onshore oil and gas industry in the NT within the next decade.

Further work by RISC included the development of individual well production models (type curves) using industry standard simulation software. This resulted in a slightly broader range of recovery per well based on a 20 year well life. This broader range was used in the agreed development scenarios.

Using the estimated range of the reservoir gas volumes and the well productivities, an estimated well count is provided for each development scenario. The production volume also links to possible gas market demands – such as supplying treated gas into the domestic gas systems or using the gas as feedstock into LNG production facilities or downstream developments (e.g. methanol). Example gas market demands are provided to demonstrate a holistic development scenario. A summary of the agreed development scenarios for the two main plays in the Sub-basin in this report is shown in the table below.

Table 2-2: Unconventional gas development scenarios

Play	Case	20 year recovery rates / well	# of wells	Recoverable Volumes	Assumed Gas Market Demand	
Middle Velkerri Dry gas	Low	1.9 bcf	375	700 bcf	100 TJ/d domestic gas	-
	Mid	4.2 bcf	2,200	9,250 bcf	200 TJ/d domestic gas	2 x 4.5 Mtpa LNG trains
	High	7.8 bcf	2,225	17,350 bcf	300 TJ/d domestic gas	4 x 4.5 Mtpa LNG trains
Kyalla Liquids-rich gas	Low	0.6 bcf 30 kbbl	3,521	2,050 bcf 106 mmbbl	200 TJ/d domestic gas	-
	Mid	1.7 bcf 85 kbbl	3,520	5,880 bcf 300 mmbbl	50 TJ/d domestic gas	1 x 4.5 Mtpa LNG trains
	High	3.2 bcf 160 kbbl	3,520	11,200 bcf 563 mmbbl	200 TJ/d domestic gas	2 x 4.5 Mtpa LNG trains

The low-medium-high cases are differentiated by the Estimated Ultimate Recovery per well or (EUR/well) assumed for each case. The range is designed to straddle the most likely outcome at an 80% confidence level (i.e. only a 10% likelihood of a result falling lower than our low estimate or higher than our high estimate). The scale of development for each case is not a differentiator but is driven by the well productivity and hence the available volume in the sweet spot area identified using the common recovery segment mapping process.

All profiles assume gas is supplied to Darwin for sale to new LNG, petrochemical or domestic gas facilities. For the Kyalla liquids-rich shale gas play, produced liquids are assumed to be available to market in Darwin whether for export or downstream processing industries.

2.3.5 Economic Viability

The mid and high case scenarios for both plays have been analysed economically to provide a guide to the likelihood of success for the Sub-basin and the attractiveness of further investment. RISC has carried out economic modelling based on gas supply up to Darwin using independent production and cost scenarios. These were generated using a bottom-up estimating methodology based on RISC's experience and benchmarked against other shale gas plays.

2.3.5.1 Development cost estimation

Development costs have been estimated based on actual costs reported for onshore, Australian developments in recent years. Public domain data exists from a number of sources detailing costs to drill, complete and tie-in both tight gas wells (Cooper Basin) and shale wells (Beetaloo Basin). The development well costs are based on actual costs being delivered for wells in Australia in 2019.[2] Due to the limited amount of tight gas drilling and stimulation being undertaken in Australia and the immature nature of tight gas development, these costs are significantly higher than what can be achieved in North America. Drilling and completion costs have been largely generated from costs for vertical wells with a small number of hydraulic fracture stages (1-5) drilled in the Cooper and Beetaloo Basins and extrapolated to estimate the cost of a 2,000 m horizontal well with 40 frac stages.

[2] As identified by RISC Advisory in their work estimating well costs in other Australian locations.

As part of the cost estimation process, it was assumed that development cost efficiencies will be achieved once large scale development programs are rolled out. This concept of "learning" cost reduction is well understood and has precedent both in North America where Shale gas well costs have declined by over 60% over the past five years and also within the Australian CSG industry. Within the CSG projects of Queensland, the well costs have been reduced by 60-80% since the early wells were drilled in the 2000s. Costs for drilling and completing shale gas wells are assumed to be reduced by 40% over the cost basis outlined above achieved over a four year period of drilling more than 100 wells per year. If the number of tight gas wells being drilled can be increased to reach greater than 100 wells per year, it is reasonable to expect major cost reductions will be achieved.

Costs for gas processing and pipeline transport have been estimated based on RISC's knowledge of costs for new gas processing and transport facilities in the Cooper and Surat Basins. For each scenario, two phases of processing and transport have been assumed. An Appraisal / Pilot Production phase at appropriate scale for the Development scenario (10-50 TJ/d) with gas delivered into the existing Amadeus Gas Pipeline and liquids trucked to Darwin is assumed to run for 4-5 years. This is followed by full-scale development, with gas and liquids piped to Darwin for sales following initial treatment in the field. Liquids are assumed to be co-mingled in the liquids pipeline to Darwin where separation and further treatment occurs prior to export or supply to downstream industries.

Cost estimates are proponent agnostic and address the development of two entire Sub-basin plays (Velkerri and Kyalla). Costs have been independently prepared by RISC Advisory for each of the three scenarios under each of these two plays in line with the assumptions noted over the remainder of this section.

2.3.5.2 Capital costs

A summary of the assumed development costs of the total costs for the two main plays in this report is shown in the table below.

Table 2-3: Unconventional gas development scenario capital cost assumptions

Cost component	Play					
	Velkerri			Kyalla		
	Low	Medium	High	Low	Medium	High
Exploration and Appraisal pilot program costs (AUD$ million)	645	1,395	870	675	1,891	843
Drill/complete/connect development well cost (AUD$ million)	4,900	28,300	28,700	46,500	45,380	46,080
Average well cost (AUD$ million)	15	13.7	13.5	12.6	12.6	12.5
Gas Processing costs (AUD$ million)	77	1,314	2,580	606	1,780	3,922
Transport costs (AUD$ million)	50	1,330	1,750	560	980	1,330
Unit capital cost AUD$/GJ (Velkerri) or AUD$/Boe (Kyalla)	7.8	3.7	2.1	104	44	24

Source: RISC, 2019

Note that the exploration and appraisal program costs are higher in the medium cases than the high cases as the number of wells required to properly appraise the development is considered to be higher due to the more marginal nature of the resource.

Average well costs are lower for the Kyalla play as it is slightly shallower than the Velkerri play. Average gas processing costs are higher for the Kyalla fluid as the significant volume of natural gas liquids and condensates require significant gas processing facilities to be installed as well as a liquids export terminal.

In the Velkerri low case scenario, the development scenario is significantly lower than the full potential of the low outcome sweet spot. This has been modelled in this way as the low case outcome is considered to be the result of a failed appraisal program and the development is of low commercial attractiveness. The development scenario is assumed to be a limited continuation of the appraisal pilot program carried on by a small-scale operator with limited access to funding. Note that an outcome may exist where a very small sweet spot is identified within the basin which provides resource quality similar to our high case assumptions, however is limited in total area (and volume) and is only able to support a domestic gas scale of development. This scenario has not been modelled; however, by using the high case scenario outcome for breakeven gas price, the approximate commercial attractiveness of this outcome can be understood.

2.3.5.3 Operating costs

Operating costs for the various scenarios have been built using a "bottom up" process using estimates for costs such as well head maintenance and monitoring costs, manning and personnel costs, gas processing costs, facilities maintenance costs and administration costs. These have been estimated over a forecast horizon of 38 years. A summary of the operating costs is shown in **Table 2-4** below.

Table 2-4: Unconventional gas development scenario operating cost assumptions

Cost component	Play					
	Velkerri			Kyalla		
	Low	Medium	High	Low	Medium	High
Total Operating costs (AUD$ million)	676	7,315	12,036	7,474	20,329	22,597
Average annual cost (AUD$ million)	19.3	222	365	214	598	685
Unit capital cost AUD$/GJ (Velkerri) or AUD$/Boe (Kyalla)	0.97	0.84	0.74	16	18	10

Source: RISC, 2019

2.3.5.4 Abandonment costs

Abandonment costs have been based on industry norms for onshore well and facility decommissioning cost estimates. Wells are assumed to cost AUD$1 million each to abandon. Onshore facilities and pipeline decommissioning costs are based on a percentage of capex share for the various components of each scenario.

2.3.5.5 Estimating a Breakeven Price

To fully understand the attractiveness, quality, and resource potential of an unconventional play, it is important to consider the resource potential together with the number of wells required to develop the resources and the gas price. The most important economic consideration for any shale or tight gas play is the EUR / well and the corresponding breakeven wellhead gas price.

RISC has considered economic considerations such as well drilling costs, distance to export infrastructure, and reservoir depth.

As expected, estimates of ultimate recovery increase with higher gas prices, but the efficiency of the play (the average recovery per well (Bcf) decreases.

By assuming that development cost efficiencies can be achieved during large scale development, we are able to estimate breakeven development pricing – in this case, based on a 40% cost reduction from today's development costs.

The breakeven gas price at Darwin was calculated based on:

- Using mid-range product pricing: $7.30/Mmbtu; $48/bbl;
- FX rate: 0.7 USD:AUD;
- Liquefaction cost: $2/MMBtu;
- Transport cost: $0.5/MMBtu;
- Development economics of 10% rate of return;
- 2% cost and price inflation; and
- All applicable Australian taxes and royalties are included.

Table 2-5: Development Scenarios Economic Summaries

Base Prices (PV10 AUD$ MM)		Production Volumes	Well Count	B/E Price (gas at Darwin) (US$/mmbtu)	Total Cost to Market (JKM) (US$)
Velkerri Dry Gas	Mid	9,250 bcf	2200	5.81	8.31
	High	17,350 bcf	2225	3.22	5.72
Kyalla Liquids Rich	Mid	5,880 bcf 300 mmbbl	3520	11.48	13.98
	High	11,200 bcf 563 mmbbl	3520	6.30	8.80

It can be seen that the mid Velkerri dry gas case will deliver gas / LNG to market (JKM) for a cost lower than the high long-term LNG price forecast in section 2.1.4 ($9.76). The High Velkerri case will deliver gas below the forecast mid case price ($7.30). This leads to the conclusion that mid-high case well recovery and volumes of dry gas resource could deliver a commercial gas development in the Sub-basin. A minimum ultimate recovery of approximately 5-6 Bcf/well is estimated to be required to enable the development of these dry gas scenarios.

Smaller quantities of gas could also be delivered into the domestic market under a low case scenario should sufficient demand exist.

The liquids rich cases require a high case Kyalla resource outcome and gas and oil prices at the upper range of the ranges forecast in section 2.1.4 (up to $9.76). The gas recovery / well assumed for the Kyalla high case is significantly lower than the assumption for the Velkerri high case, resulting in a significantly higher well count, and thus a higher development cost for similar rates of produced gas. This is due to the higher fluid density and viscosity of the wet gas assumed in the Kyalla case, and is analogous to the unit well recovery of other plays globally. It should be noted that there is no flow data available for the Kyalla, therefore data from the Velkerri flow test has been used to estimate fluid flow characteristics in the Kyalla. Therefore, a critical piece of data is missing to reliably estimate recovery per well in this play. The analysis needs to be revisited once Kyalla well test data becomes available which may lead to a different outcome.

2.3.5.6 Development Analysis Conclusions

From the analysis completed and through engagement with industry proponents, the Sub-basin has some potential to be a significant gas production area. However, with the limited data available that this analysis has been based on, there is wide ranging uncertainty. Additional data gained from exploration and appraisal drilling would allow improved estimates of well recovery rates, reservoir volumes, presence of liquids and hence the potential of the considered plays.

The analysis suggests that a commercial development of shale gas via LNG exports requires a high volume of gas and high well productivity. The recovery of condensates may enhance the feasibility of the play if gas recoveries are sufficiently high. Analysis of the scenarios show that a per well recovery rate of 3-4 Bcf (liquids rich) and 5-6 Bcf (dry gas) is required for a viable development. A breakeven gas price at Darwin of less than USD$4.80/MMbtu is anticipated to be required for the mid-high case outcomes to be viable, as demonstrated above. Therefore, based on these conservative estimates, it can be seen that there are scenarios whereby the development of the Sub-basin is economically viable.

From an infrastructure needs perspective, the analysis is recommended to be based on the maximum well count scenario – that is, development of the Kyalla. Following consultation with the NTG, four scenarios have been progressed to infrastructure analysis. These include:

- Velkerri Dry Gas – Low;
- Velkerri Dry Gas – Medium;
- Velkerri Dry Gas – High; and
- Kyalla Liquids Rich – High

2.3.6 Agreed Development Schedules

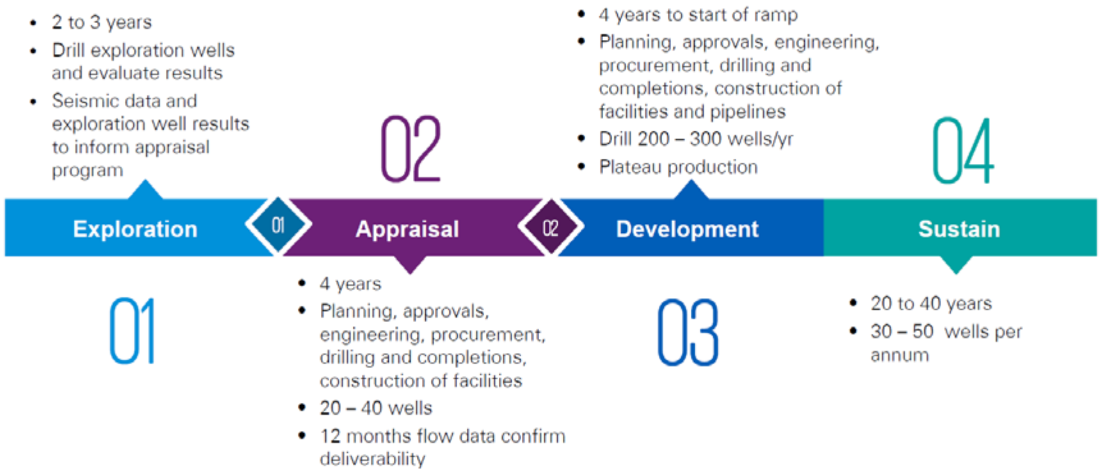
The development schedule for any shale gas play is heavily influenced by a number of factors. The four most important of these factors are:

1) The state of appraisal of the underlying resource base;
2) The potential scale of the development;
3) The existing supporting infrastructure and logistics support available for the development; and
4) The availability of a market for the sales products from the play.

For the Sub-basin, these factors are not currently favourable for a development schedule to proceed at a rapid pace. The Sub-basin is at an early stage of exploration with very limited available infrastructure or logistics support. The potential scale of development is required to be very large to incentivise the development of the required infrastructure and logistics systems. The existing domestic gas market in the NT is very small and currently over-supplied (as illustrated by the beginning of gas exports from the NT to Queensland via the Northern Gas Pipeline).

Looking into the longer term, RISC is of the opinion that the potential for large-scale LNG developments fed by the Sub-basin shows a more positive outlook. Darwin is now home to two LNG exporters with multiple trains of LNG export capacity. There is room and existing approvals for expansion of these facilities if suitable feedstock can be supplied.

A reasonable “best estimate” / likely appraisal and development schedule for the Sub-basin can be characterised into four consecutive phases, see Figure 2-8 below. Critically, the graphic highlights two key gates (diamonds one and two) at which point progression to the next stage will need to be considered to unlock further investment. Given the frontier nature of the Sub-basin development, planning will be required to ensure there is consideration of the infrastructure and logistics requirements should investment progress past these key decision points for individual plays.



Source: RISC, KPMG

Figure 2-8 Shale gas development timeline

As highlighted in the figure above, if the schedule of exploration could be considered to have begun in 2019 then a reasonable expectation would be to have ***an informed view of the resource potential in 2-3 years (2022)***. If this phase is positive then an appraisal and pilot program could yield the data necessary to plan and ***approve a large-scale development after another 3-5 years (2026)***. Large-scale development programs will typically run from 3-5 years depending on the scale and the requirement for supporting infrastructure to be built (gas pipelines, LNG trains, etc.). In the example of the Sub-basin, ***the beginning of large scale gas production could be potentially achieved by 2029***.

This development over time is reflected in the estimated well build-up profile for each of the proposed scenarios. As outlined in Figure 2-9 below, the number of wells constructed during the exploration and appraisal periods are relatively low, with significant expansion occurring in in 2026 with the transition to the Development phase.

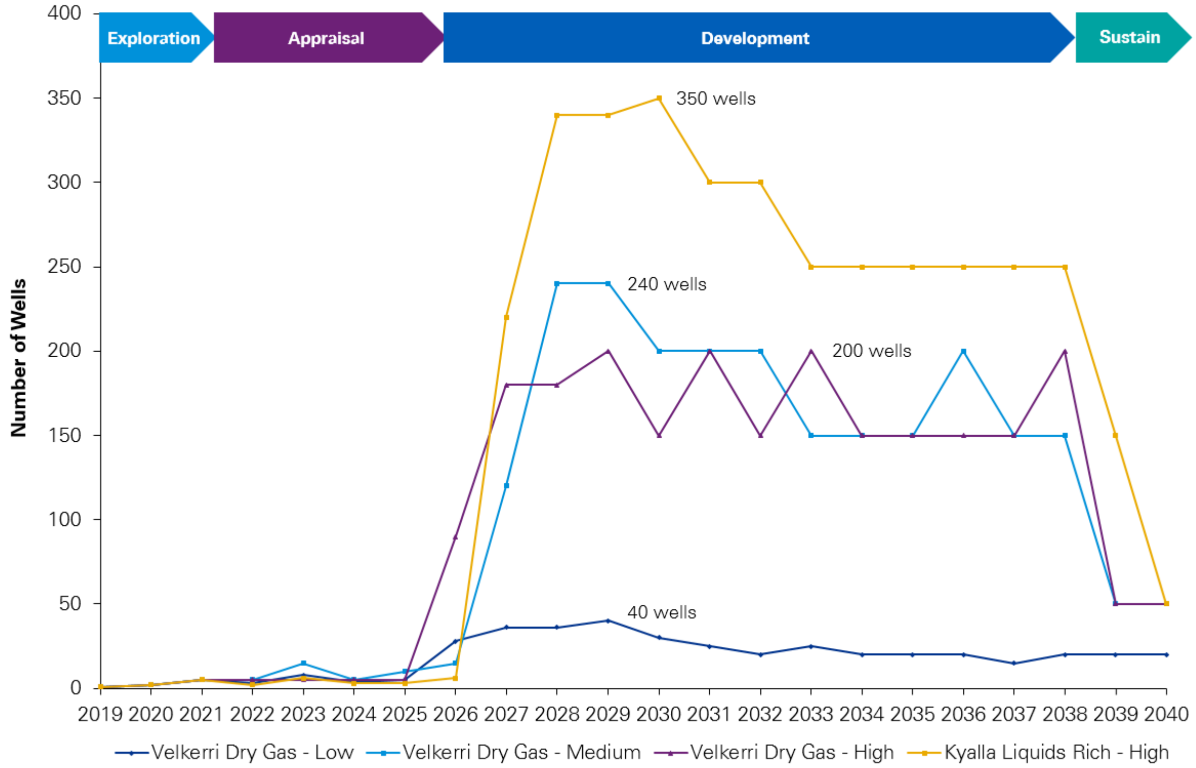


Figure 2-9 Well Build Up Profile

These well build-up profiles have been utilised as the foundation for the infrastructure analysis of logistics requirements and industry demand in the next chapter of this report.

3 Infrastructure and Industry Requirements

This section quantifies the infrastructure and logistics requirements through the exploration, appraisal, development and production phases of the Sub-basin. It builds on the well construction profiles from each scenario outlined in the previous section to estimate the infrastructure implications of construction and operation activities.

3.1 Approach

GHD Pty Ltd (GHD) was engaged to provide advice in the development of the onshore oil and gas industry in the NT, specifically the industry and infrastructure requirements to support the development of the Sub-basin. This was achieved by:

- Undertaking a baseline infrastructure assessment, including industry infrastructure;
- Undertaking analysis of likely logistics choices based on freight modelling; and
- Identifying enabling infrastructure and industry requirements which will support the development of the Sub-basin.

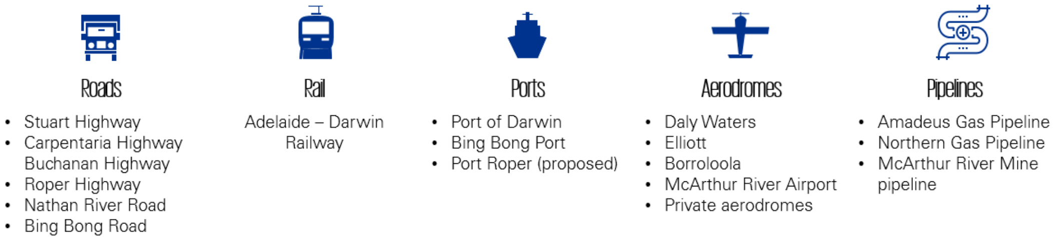
The findings of this analysis has been detailed in the remainder of this report.

3.2 Baseline Assessment

The infrastructure included in the baseline assessment includes both economic enabling infrastructure and infrastructure to support industry requirements, including:

- Roads;
- Rail;
- Ports;
- Aerodromes;
- Pipelines;
- Direct workforce numbers;
- Equipment and operators;
- Accommodation;
- Waste management;
- Power;
- Water infrastructure;
- Telecommunications; and
- Civil works, including extractive supply.

As illustrated in **Figure 3-1**, the key existing transport and pipeline infrastructure supporting the Sub-basin



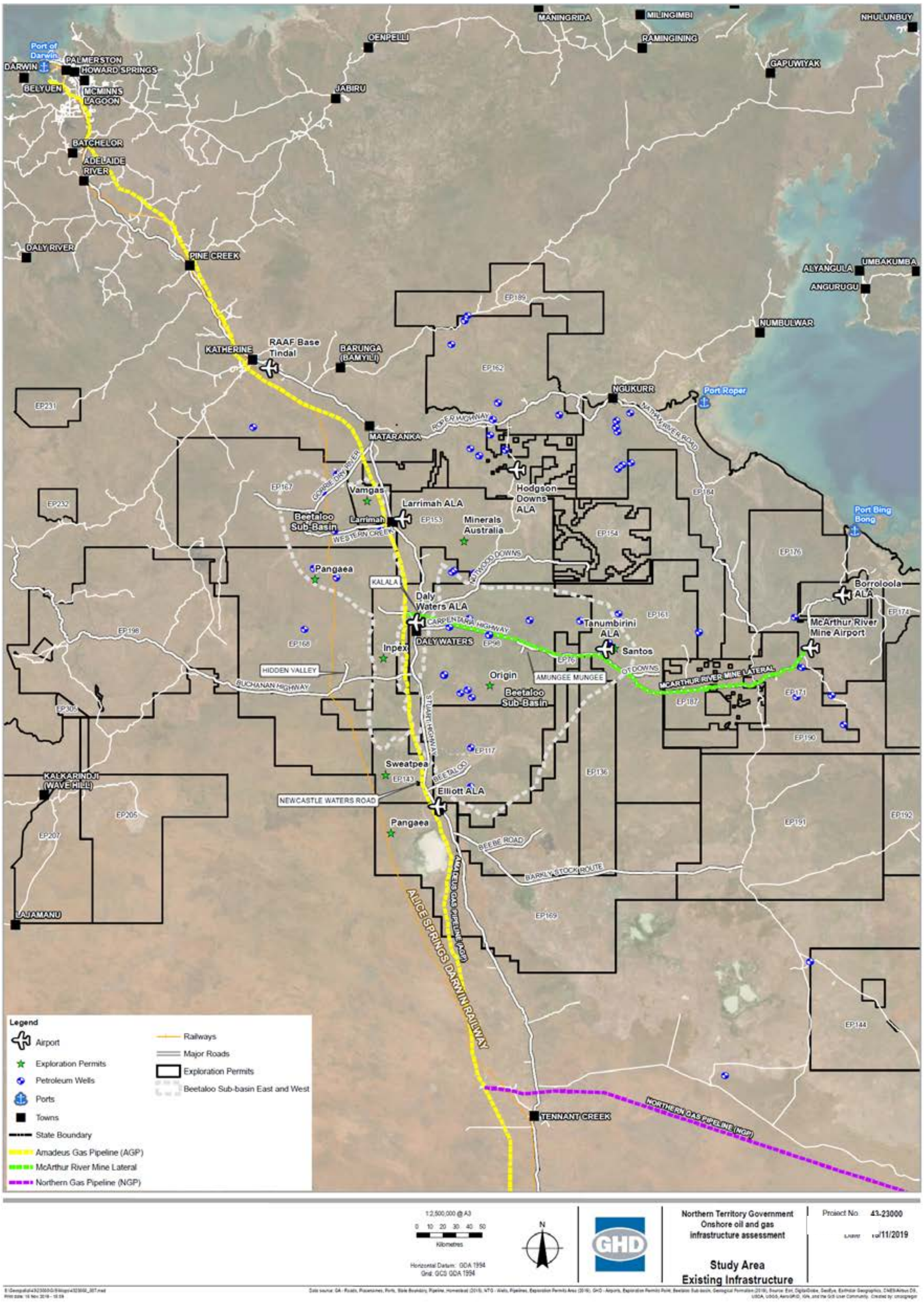


Figure 3-1 Key existing infrastructure

3.2.1 Enabling Infrastructure

There are a raft of infrastructure requirements that will be located outside of the industry tenements. These include transport, pipelines and essential service infrastructure.

The available infrastructure assets that could support the development of the Sub-basin have been summarised in **Table 3-1** below.

Table 3-1: Available Infrastructure

Infrastructure	Comment
Ports	
Port of Darwin	Existing port facility
Bing Bong	Glencore own and operate the Bing Bong Port for the purpose of exporting concentrate from their McArthur River Mine.
Port Roper	Potential greenfield shallow draft port location investigated previously as an iron ore export location.
Major Roads	
Stuart Highway	National highway, extending from Darwin to Adelaide. The Sub-basin is approximately 600 km from Darwin.
Carpentaria Highway	Rural arterial road extending 200 km from the Stuart Highway to the eastern edge of Santos Lease at Borroloola.
Buchanan Highway	Rural arterial road. The area of interest extends 136 km from the Stuart Highway to the western edge of the Pangaea Lease.
Western Creek Road	Local road. The area of interest extends approximately 56 km from the Stuart Highway to the Pangaea "sweet spot".
Roper Highway / Nathan River Road	Rural arterial road. The area of interest extends 173 km from the Stuart Highway to the turnoff to Nathan River Road.
Existing Sub-basin Access Roads	Multiple access roads to the Sub-basin ranging from 5 km to 100 km.
Rail	
Adelaide to Darwin Line	Existing rail siding at Katherine approximately 306 km from Darwin and 275 km north of Daly Waters by road. Potential for a greenfield rail siding located near the Sub-basin (e.g. west of Daly Waters).
Aerodromes	
Daly Waters	NTG owned, with an old seal which requires maintenance. Metro 23 Aircraft (19 seats) permitted to land. Central to Sub-basin
Elliot	NTG owned, sealed runway. Pilatus PC-12 (approximately 10 seats) permitted to land.
Tanumbirini Station	Privately owned and located at Tanumbirini Station with approximate length of 1400 m long. (approximately 10 seats) Central to Santos Exploratory Permit.
Pipelines	
Amadeus Gas Pipeline	A bi-directional, natural gas transmission pipeline that can be supplied from either the Amadeus Basin in central Australia or from the Timor Sea (Bonaparte Gulf). Also connects to the east coast gas market.

3.2.1.1 Transport Infrastructure Capacity

A detailed baseline assessment of the transport infrastructure capacity and current standards was undertaken. A summary of the findings is presented in **Table 3-2** below.

Table 3-2: Existing Transport Infrastructure Capacity

Infrastructure	Current Standard/Capacity	Comments on Capacity
Ports		
Port of Darwin	Currently operating at 25% capacity	40% spare capacity until efficiency is impacted. Bulk freight handling from ship to rail to be considered.
Bing Bong	MRM use varies 12 to 28 days / month	Limited capacity impacted by current use and potential future iron ore use. Limited to transhipment operations.
Key Roads		
Stuart Highway	82% meets Department of Infrastructure, Planning and Logistics minimum width of 10m	Capacity available to support additional traffic. However, pavement rehabilitation, including widening, will be required.
Carpentaria Highway	20% meets single lane seal standard	Insufficient capacity to support additional traffic. Upgrade to two lane sealed road required including bridge crossings.
Buchanan Highway	53% meets rural arterial gravel road standard (unsealed)	Insufficient capacity to support additional traffic. Upgrade to two lane sealed road required including bridge crossings.
Western Creek Road	2% meets rural local pastoral standard	Insufficient capacity to support additional traffic. Upgrade to two lane sealed road required.
Roper Highway / Nathan River Road	31% meets single lane seal standard (Nathan River – low standard unsealed road)	Insufficient capacity to support additional traffic. Upgrade to sealed road standard required including bridge crossings.
Existing Beetaloo Sub-basin Access Roads	Low standard unsealed roads	Suitable for exploration only.
Rail		
Adelaide to Darwin Line	Has capacity for more than 23 return trips weekly	Sufficient capacity available to support additional train trips.

Transport network limitations

Table 3-3 summarises the limitations of the ports and road and railway networks supporting the development of the Sub-basin. Quad road trains may be used within the NT to deliver dry bulk product to sites for either domestic and / or internationally imported freight from all three identified potential port gateways. Break bulk product, such as tubing/pipeline, may be restricted to a Type 1 road train due to their long lengths.

Port Bing Bong and Port Roper are limited in the types of products that they can handle as freight must either be trans-shipped or transported direct on shallow barges, which have higher transport costs and lower payloads.

Table 3-3: Transport network limitations from product origin to site

Product origin	Road network		Train network	Port infrastructure
International	**Dry bulk**	**Break bulk (pipes)**		
Port of Darwin	Quad road trains	Type 1 road train	Maximum weight of trains is 3,500 t; Maximum train length of 1,500 m	Supports direct calling of import and export vessels
Bing Bong	Quad road trains	Type 1 road train	n/a	Transhipment vessels and barges only
Port Roper	Quad road trains	Type 1 road train	n/a	Transhipment vessels and barges only
Domestic				
Local area (<50 km)	Quad road trains	Type 1 road train	n/a	n/a
Darwin	Quad road trains	Type 1 road train	Maximum weight of trains is 3,500 t; Maximum train length of 1,500 m	n/a
East Coast of Australia	A-double	Type 1 road train	n/a	n/a
Adelaide	A-double	Type 1 road train	Maximum weight of trains is 3,500 t; Maximum train length of 1,500 m	n/a

3.2.1.2 Pipeline Capacity

The Amadeus Gas Pipeline (owned by APA Group) is the main gas pipeline running north-south toward the western edge of the Sub-basin. The McArthur River Mine Pipeline (owned by the Power and Water Corporation) connects to the Amadeus Pipeline through the Sub-basin, delivering gas to the McArthur River main area for power generation.

The baseline assessment of the existing gas pipelines within the Sub-basin indicates that the Amadeus Gas Pipeline may only have capacity for the onshore gas industry up to an Appraisal phase. Therefore, a new pipeline or series of piplines from the Sub-basin north to Darwin will be required for the Development phase.

3.2.1.3 Essential Services

Water

Regional towns in the Sub-basin are currently gazetted under the *Water Supply and Sewerage Services Act* and are provided water services through non-regulatory licences issued to the government-owned PWC by the NT Utilities Commission. These include discrete supplies for Mataranka, Larrimah, Daly Waters and Elliott as outlined in the table below. Any developments within these towns will require a determination of load and impact on the water source sustainability, headwork's capacity and serviceability from PWC and are likely to trigger a capital upgrade.

Table 3-4: Township water supply

Town	Water Supply
Mataranka	• Groundwater source • Water storage and reticulation • Upgrades to chlorination achieved in 2016
Larrimah	• Groundwater source • Upgrades to water storage and reticulation likely required • New chlorination system installed in 2016
Daly Waters	• Groundwater source • Upgrades to water storage likely required
Elliott	• Groundwater source • Upgrades to water storage likely required

Waste Water

The towns of Katherine and Tennant Creek are sewered and offer black water discharge points for disposal to treatment facilities. These sites could be used for disposal of effluent from field camps if required. The remaining towns in the region are currently un-sewered and rely on common effluent drains and septic systems. The ability for these systems to handle increased volumes of waste is limited and may not be appropriate for use in the larger development scenarios.

Waste Management

Currently, waste management in the Sub-basin is the responsibility of the relevant local government.

Roper Gulf and Barkly Shire manage landfill sites at Mataranka and Elliott respectively. The capacity of these landfills and appropriateness to handle the waste streams of the industry may not be sufficient for the development of the Sub-basin. These sites could be redesigned and used as transfer stations to sort the waste material into salvageable and non-salvageable waste.

The waste within the townships of Larrimah and Daly Waters is currently managed through the towns' progress societies. These sites in their current form and management would not be acceptable to handle the waste streams from the gas industry.

The Katherine Town Council and Tennant Creek Town Council landfills may need to be expanded to handle the volumes of non-salvageable waste produced under large-scale development scenarios. This is further discussed in **Section 3.4.7**.

Telecommunication

Within the towns and communities of the Sub-basin, Telstra is responsible for providing the full range of telecommunication products, services and solutions (across Mobiles, Fixed and Mobile Broadband, Telephone and Pay TV). The availability of telecommunications infrastructure within townships is not anticipated to limit the development.

As the Sub-basin is in a remote area, the expectation is that the industry infrastructure will be largely self-sufficient for telecommunications with services likely to be provided from satellite connections.

It is assumed that voice and data communications from the well pads will be via fibre option connections that are installed alongside the gathering pipelines. The fibre will connect back to the gas processing, administration and maintenance facilities which will likely have mobile and internet satellite connections.

The baseline assessment of existing essential services within the Sub-basin indicates that it will not be able to support the development of the Sub-basin without significant upgrades to waste water and waste management facilities. The energy requirements of the oil and gas industry will need to be self-sufficient.

3.2.2 Industry Infrastructure

As the existing gas infrastructure consists of gas pipelines, one compressor station and there are no gas gathering networks in the region, there is limited capacity available within the existing gas infrastructure. As a result, for any gas gathering and gas processing requirements, new infrastructure will be required to be constructed within the gas fields.

Industry requirements to support the development of the Sub-basin will likely include:

- Workforce;
- Accommodation;
- Land;
- Equipment and operations;
- Utilities; and
- Export pipelines.

These requirements are discussed in greater detail below. Given the greenfield nature of the development, there is limited discussion on existing capacity, with technical analysis instead focussing on the nature of requirements associated with the proposed development scenarios.

3.2.2.1 Workforce

Workforce requirements will increase over the gas life cycle from exploration through to production, with an estimated doubling of requirements through stages based on number of wells established. The likely direct employment streams will come from earthworks, plant construction, pipeline construction, engineering, drilling operations, drilling services, production operations, plant maintenance, logistics, management, community engagement, training and consulting specialists.

Direct Workforce

Due to the skill mix required not matching the existing skills within the Barkly and Roper Gulf Local Government Areas (LGAs), the direct workforce is likely to consist of fly-in fly-out (FIFO) personnel in the drilling and drilling services industry, and specialist skills within engineering and operations. Local employment opportunities in earthworks, construction / engineering, manufacturing, logistics, training and consulting will emerge and increase across the gas lifecycle.

Table 3-5 provides an estimate of the number of direct personnel required. The number indicates a peak of personnel over a 12-month period during each phase (order of magnitude figure only). The required personnel may only be present in the field for a number of months during the year.

Table 3-5: Direct workforce requirements (infield) – peak annual

Exploration	Appraisal	Development low	Development medium	Development high	Development wet	Operations
130	270	500	3,000	3,000	4,000	1,000

Note, the estimates have been derived from industry estimations of personnel requirements (Origin – In confidence, Pangaea – submission to Fracking Inquiry).

As the personnel required is based on the number of wells, and given that the volumes of gas for the high case will occur over a longer period than the medium case, a material increase in annual peak workforce is not anticipated between the scenarios.

Indirect Workforce

In addition to the direct employment streams, personnel will be required to provide additional services from key supporting industries, such as:

- Freight operations; rail and heavy vehicles;
- Hospitality providers – catering, cleaners;
- Fuel distribution;
- Vehicle and equipment parts;
- Laboratories;
- Waste management; and
- Government regulatory requirements.

It is considered that for the Exploration and Appraisal phase, these services could be provided from existing capacity of supporting industries, however increased capacity could be required from the Development phase onwards.

The location of these personnel will be determined through the individual businesses and organisations' service delivery, business models and industry / government procurement policies.

It is difficult to determine the number of indirect personnel required in supporting industries to service the Sub-basin, however there is substantial potential of employment and business opportunities.

Further determination of indirect workforce requirements is likely to occur under the strategic Social Impact Assessment (SIA) which will be undertaken for the Sub-basin as a region. This information will also be included in the strategic regional environmental and baseline assessment (SREBA). In addition to these studies, individual proponents will detail the workforce requirements for their discrete projects under the Environmental Impact Assessment process.

Transit Options

During the Exploration and Appraisal phase, drilling personnel will be mobile through ground-based transit options, and accommodation will be self-sufficient through temporary field camps.

Use of the nearest airstrip to infield camps and activities and transit on access roads via 4WD will likely be required. Currently, the closest aerodrome to the relevant main exploration permit areas are shown in **Table 3-6**. It is understood that Origin is utilising the Daly Waters aerodrome, whilst Santos is utilising the Tanumbirini aerodrome for their respective exploratory phases.

During the Development phase, it is likely that personnel will rotate in and out through FIFO arrangements and larger aircraft will be required. Upgrades to local airstrips to cater for aircraft, such as an EMB 170 (76 Passengers) or larger, are likely to be required. For example, at Moomba in South Australia, jets seating over 100 passengers are used to provide up to 12 services per week.

Table 3-6: Aerodrome Location

Exploratory permit	Nearest aerodrome
Santos	
EP161	Tanumbirini
Origin	
EP76	Elliot
EP117	Elliot, Beetaloo Station
EP98	Daly Waters
EP76	Elliot
Pangaea	
EP168	Daly Waters, Larrimah, Hidden Valley Station
EP167	Larrimah
EP169	Elliot

3.2.2.2 Accommodation

Accommodation requirements for the majority of personnel servicing the Sub-basin under all development scenarios are likely to be in the field.

Field based personnel will require accommodation within approximately 100 km of the relevant operating field to achieve productivity. During the Exploration and Appraisal phases, field camps will likely be temporary and mobile. The peak requirement for accommodation will be during the Development phase which could typically run for 3-5 years. Accommodation facilities established during the Development phase will have the capacity to cater for ongoing operational personnel requirements.

Potential types of accommodation

Mobile camps

During the Exploration phase, the workforce will be mobilised to undertake seismic surveys, civil works and commence drilling. Temporary camps will be constructed close to well pads and would generally include:

- Accommodation;
- Vehicle maintenance workshop;
- Ablutions and septic(s) waste treatment;
- Kitchen and mess;
- Freezer unit;
- Site office;
- Generator and diesel storage; and
- Water tank.

Permanent field camp

Typically, the gas industry will establish a permanent field camp for FIFO personnel during the Development phase. These camps cater only for workers as there is no long-term commitment to the site. Facilities provided do not include the typical services provided to regional towns. An example of this is Moomba in South Australia, operated by Santos to cater for a population of over 1,000 people. The field camp includes a sealed airstrip, water bores and a reverse osmosis plant, and 20 MW on site power generation.

Industry/Company town

It is unlikely that an industry or company town will be established for accommodation of workers and their families in the Sub-basin. The cost and time to establish a residential town is significantly more than to establish a FIFO workforce and temporary accommodation. The expenditure incurred to cater for the peak period in the establishment of a field camp is unlikely to be increased to provide additional facilities and town-based services for reduced numbers during operations. The establishment of residential towns is not current industry practice in the resources sector and has not been indicated as an expected development option by industry for the Sub-basin.

There may be an increase in businesses offering services to support the oil and gas industry in the existing towns and communities of the Sub-basin.

3.2.2.3 Land

Land availability in the towns and communities of the Sub-basin to support industry may be required to develop regional hub facilities and to cater for:

- Laydown areas;
- Industrial activities;
- Workers accommodation; and
- Upgrades to airstrips.

The baseline assessment of land availability to support the development of the Sub-basin indicates that availability in the towns and communities will be constrained pending location due to land tenure and unresolved native title claims. There is however some Crown land available in Daly Waters and Mataranka, and private land in Larrimah that could be developed to support the expansion of the gas industry.

Further determination of developable land requirements is likely to occur under the strategic SIA which will be undertaken for the Sub-basin as a region. This information will also be included in the SREBA. In addition to these studies, individual proponents will detail the workforce requirements for their discrete projects under the Environmental Impact Assessment process.

A summary of the nearby town suitability has been provided in **Table 3-7**. Refer to **Appendix B** for detailed land assessment.

Table 3-7: Land Assessment

Town	Summary
Katherine	Katherine is the largest nearby town, and provides all basic services associated with a city, including power and water, air services, waste management, and workers' accommodation. The town is serviced by Katherine Airport, which is able to cater for commuter flights. Katherine is zoned under the NT Planning Scheme, with land zoned for General Industry (GI), Light Industry (LI), and future development.

Town	Summary
Mataranka	Mataranka is a small town which provides limited essential services. Waste management facilities in the township are limited, with their current capacity constrained to only being able to support local residents / business. The town lacks sewerage infrastructure, with onsite effluent disposal systems dealing with sewage and wastewater. No airport or rail services exist in the area. Mataranka is not covered under the NT Planning Scheme. Much of the surrounding area is classed as vacant Crown land, under Native Title. Accommodation in the township is heavily constrained, with current arrangements having workers stay at caravan park / motel style accommodation.
Larrimah	Larrimah is small town which provides limited essential services. Waste management facilities are only able to support the local township. Sewerage systems are limited to onsite effluent disposal systems dealing with sewage and wastewater. No airport or rail services are available in the area. Larrimah is not zoned under the NT Planning Scheme. Much of the land in the town is vacant Crown land under Native Title (non-exclusive rights). Current accommodation arrangements are limited to caravan park / pub style accommodation. Due to its proximity to some of the prospective exploration areas, Larrimah is well located to support the oil and gas industry. Development of zoning, planning and essential service infrastructure would be required to establish Larrimah as a service town to the oil and gas industry.
Daly Waters	Daly Waters is a small town which provides limited basic services. Waste management facilities are only able to support the local township. Sewerage systems are limited to onsite effluent disposal systems dealing with sewage and wastewater. The NTG maintains a sealed airstrip. No rail services are provided in the town. Daly Waters is not zoned under the NT Planning Scheme. Much of the land in the town is vacant Crown land under Native Title (non-exclusive rights). Current accommodation arrangements are limited to caravan park / pub style accommodation. The town has flood immunity issues. Due to its proximity to prospective exploration areas, Daly Waters is well located to support the oil and gas industry. Development of zoning, planning and essential service infrastructure would be required to establish Larrimah as a service town to the oil and gas industry.
Elliot	Elliot is small town which provides limited basic services. Waste management facilities are only able to support the local township. Sewerage systems are limited to onsite effluent disposal systems dealing with sewage and wastewater. The NTG maintains a sealed airstrip. No rail services are provided in the town. Elliot is zoned under the NT Planning Scheme, and provides two parcels of land zoned for LI. Much of the township and surrounding land is vacant Crown land under Native Title. Current accommodation arrangements are limited to caravan park / pub style accommodation. Due to its proximity to prospective exploration areas, Elliott is well located to support the oil and gas industry. Development of essential service infrastructure would be required to establish Larrimah as a service town to the oil and gas industry.

Town	Summary
Tennant Creek	Tennant Creek is a regional town which provides all basic services. Current waste management services are expected to be available for another 47 years at current rates, and sewage treated through evaporation ponds. The town is serviced by Tennant Creek Airport, which is able to cater to commuter aircraft. The town has two areas zoned GI, with plans to increase this zoning. Much of the land within the township is under non-exclusive rights Native Title, while much of the adjacent land is under Aboriginal Land Rights. Tennant Creek is located beyond the southern boundary of the Sub-basin. It could be used to support the oil and gas industry through the provision of local personnel and training services.

3.2.2.4 Bulk freight inputs

In the development of an onshore shale gas basin in remote and regional Australia, the bulk freight inputs characterise the logistics and transport infrastructure requirements. The type, quantity and source of materials and equipment have been assessed across the upstream development phases and applied to the supply scenarios.

Bulk Extractive Materials

The bulk extractive requirements (gravel, pad materials, proppant) and materials (tubing, gathering pipe) are the main sources of bulk freight inputs. This provides order of magnitude quantities for freight movements across the supply scenarios.

The detailed calculations for the bulk extractive materials are contained in Appendix A**.**

Gravel

Gravel requirements are primarily for the upgrade and construction of transit routes and access roads for public roads and the gas industry service roads on private properties (pastoral leases) within the exploration leases. Although potential sources of gravel have not been investigated, preliminary consultations indicate that material may be able to be sourced locally within or in the vicinity of the Sub-basin. However, it is expected that sources of gravel within approximately 500 metres either side of the existing public roads will be exhausted due to previous roadworks.

The estimated quantity of gravel required is shown in the following tables. **Table 3-8** details the total gravel requirements estimated for the upgrades to public roads, whilst **Table 3-9** details the estimated total gravel requirements for the internal gas industry service roads by scenario.

It should be noted that the road upgrades are triggered for the low development scenario and are sufficient to support the wet development scenario. No public road upgrades are recommended to support the Exploration and Appraisal phases.

Table 3-8: Estimated Total Gravel Requirements, Public Roads

Road	Volume (m^3)	Tonnage (t/m^3)
Stuart Highway	118,882	258,440
Carpentaria Highway	434,700	945,000
Buchanan Highway	208,035	452,250
Western Creek Road	253,920	552,000
Gorrie Dry River Road	231,840	504,000
Total	**1,247,377**	**2,711,690**

Table 3-9: Estimated Total Gravel Requirements, Internal Service Roads

Scenario	Tonnes per annum (tpa)
Exploratory / Appraisal	40,500
Development Low	409,500
Development Medium	2,047,500
Development High	2,047,500
Development Wet	2,047,500

Well pad and process plant base materials

Well pads will need to be constructed to support the drilling and ongoing operation of the wells. They include the hardstand area for the operation of the wells, temporary buildings, storage and lay down areas.

Table 3-10 details the estimated gravel requirements for well pads and process plant base by scenario. Initial pads will be constructed during the Exploration phase and, as the development progresses through the Appraisal and into the Production phase, more wells will be drilled in each pad. Number of wells per pad could range from four to 10 wells. For the purposes of this assessment, eight wells per pad has been applied for the Development phase scenarios.

Table 3-10: Estimated gravel requirements, well pads and process plant base

Scenario	Well Pads (tpa)	Process Plant Base (tpa)
Exploratory / Appraisal	39,375	0
Development Low	150,000	18,000
Development Medium	750,000	80,000
Development High	750,000	160,000
Development Wet	1,125,000	100,000

Proppant

Proppant is required during hydraulic fracturing to maintain the fracturing. Depending on the formation, hydraulic fluid and water quality different types of proppant will be selected to provide optimal results. Proppants range from silica sands, resin treated sands to ceramic materials. **Table 3-11** details the anticipated volumes of proppant under each scenario.

Table 3-11: Annual proppant quantities

Scenario	Tonnes per annum (tpa)
Exploratory / Appraisal	48,000
Development Low	240,000
Development Medium	1,200,000
Development High	1,200,000
Development Wet	1,800,000

Tubing

In completing a well, it is required to use tubing materials to contain the well fluids that are produced. The process of drilling and completing wells will be in accordance with the requirements of Code of Practice: Onshore Petroleum Activities in the NT. The steel tubing material is installed in a well during the completion process. The tubing is manufactured to international standards for the oil and gas industry.

The volume of tubing is related to the number of wells. It is assumed that each well has 3,000 metres of tubing. Therefore, based on well pads with eight wells each, the tubing required per well pad is 24,000 metres.

Gathering pipe

To connect the well pads to a gas processing facility requires a gathering system. The gathering system predominantly consists of pipe. The pipe is manufactured to international standards for the oil and gas industry. The traditional material for manufacture of pipe for gathering systems is steel; whilst there are other non-steel materials that can be used, for the purpose of this report, it is assumed that the gathering systems are constructed from steel pipe.

The length of gathering line pipe is related to the number of well pads and spacing between the pads. The average diameter of gathering line pipe is related to the number of wells per well pad and the configuration of the gathering system; for the purpose of this report, the average diameter is assumed as DN200 (a pipe diameter of 200mm). Well pads are assumed at 3,000 metre spacing in a grid arrangement, an additional 1,000 metres has been included per pad for connection to the gas processing facility and for ground conditions. Therefore, based on these assumptions, the total gathering line pipe per well pad is 7,000 metres.

Gas Processing Facilities

Gas processing facilities are expected to be required once exploration has occurred and there has been an amount of appraisal activities. The next phase is anticipated to be smaller scale gas processing facilities, likely in the total capacity range of 100 TJ/day to 200 TJ/day. There is potential for several of these smaller scale facilities, depending on the location of discoveries given the geographic extent of the Sub-basin.

As characterisation of the Sub-basin continues over time, it is likely that two large-scale gas processing facilities would be developed. These large-scale facilities are likely to have a total capacity in the range of 1,000 TJ/day to 3,000 TJ/day.

The gas processing facilities are expected to use typical industry practice for configuration with gas processing removing contaminants, and separating stable hydrocarbon liquids and produce water from gas. These processing facilities are assumed to be designed for liquids rich gas. It would be expected that modular construction would be used to a large extent and that this equipment is likely sourced from low cost, global manufacturing locations that specialise in construction of oil and gas equipment and facilities. It is anticipated that the transport of the majority of the equipment for construction of the facilities would be within standard transportation envelopes, with a small percentage of the total tonnage being over size or over weight.

Hydrocarbon liquids separated at a gas processing facility would be held in tanks onsite and transported to market via trucks if the volumes are low and via a dedicated pipeline once the volumes are beyond economic use of trucking. The upper limit of daily volume transported via trucks is likely to be 2,000 to 5,000 barrels per day (~300,000 to 800,000 litres per day) based on an average truck capacity of 60,000L and in consideration of how other developments such as the Cooper Basin operate. Produced water would be treated at the facility and likely re-used in operations. Where trucking is used, it is anticipated that the hydrocarbon liquids would be stabilised and LPGs separated for transport in LPG tankers. Where liquids pipeline is used, it is assumed limited stabilisation occurs at the gas processing facility and that there is a stabilisation facility at the end of the liquids pipeline. This stabilisation facility would likely provide the following product streams: ethane, propane, butane, LPG (a combination of propane and butane), and condensate.

Based on similar scale facilities, the bulk weight of equipment, piping, and supports is expected to be in ranges as follows, excluding bulk earthworks, foundations and pavements:

- Small scale gas processing facilities – 2,000 to 5,000 tonnes; and
- Large scale gas processing facilities – 10,000 to 30,000 tonnes.

3.2.2.5 Utilities

As the Sub-basin is in a remote area, the expectation is that the industry infrastructure will be largely self-sufficient for utilities and direct support facilities. Co-located with the gas processing facilities would be utilities and support facilities. Utilities include power generation, potable and waste water, and telecommunications. Support facilities include accommodation, dining facilities, recreation facilities, first aid, administration, maintenance, and storage facilities. Additionally, there will likely be helipads and / or fixed wing aircraft landing strips depending on the size of the gas processing facility.

Power Supply

In the Exploration phase, the power supply would be mobile systems that are transported within allowable road transport limits. These are likely diesel fuelled, however there is the potential that photovoltaic systems with battery storage could be used. This type of system is also applicable for the construction of permanent facilities and pipelines.

When surface facilities and pipelines are constructed, permanent power supply systems are required.

For well pads, remote gathering system facilities, and cathodic protection systems, it is anticipated that photovoltaic systems with battery storage will be used. This type of power supply system is reasonably common in remote area operations in the oil and gas industry where the power demand is low.

For the gas processing facilities and associated utilities and support facilities, it is expected the electrical power supply would be provided by dedicated power generation facilities located adjacent to the processing facilities. With the rapid development of industrial scale photovoltaic systems, there is potential that powering the gas processing facilities could be a hybrid, gas–powered generation and photovoltaic generation. Such a facility could be provided by a third party owner, with potential for a regional grid connection to multiple gas processing facilities. This power supply to gas processing facilities needs to provide very high reliability. The total potential electrical load could range from modest, in the order of hundreds of kilowatts, to large, in the order 50 to 100 megawatts. This depends on the number and size of gas processing facilities, and the level of electrification used in the facilities.

Telecommunications

As the Sub-basin is in a remote area, the expectation is that the industry infrastructure will be largely self-sufficient for telecommunications services. During the Exploration and Appraisal phases, this is likely to consist of satellite technology services and will be upgraded to include fixed communication masts. It is likely a variety of different technologies will be used, including Global System for Mobile communication (GSM), Very Small Aperture Terminal (VSAT), and surface fibre optic cables.

There may be potential for shared use of the fixed communications infrastructure pending locations and range of installed masts.

Water

Water is required for all phases of development of an onshore shale gas field. Current estimations of the industry's water demand curve follow a ramp-up phase of approximately 4–6 years during exploration and appraisal to peak use for between 5-8 years during the Development phase. Following peak use, the water demand is expected to reduce relatively quickly over a two year period to a point where it reaches a steady to slow decline for the remainder of the expected field life.

To support these development activities, water of both potable and raw / stock quality is needed, as summarised in **Table 3-12**.

Table 3-12: Raw and potable water uses

Raw/stock water/groundwater	Amended or potable water
Drilling and completion	Camp facilities mobile and temporary
Hydraulic Fracturing	Civil construction; roads, well pads
Dust Suppression	
Site maintenance and rehabilitation	

Anticipated water usage for the gas industry in the Sub-basin has been summarised from data provided by the three main operators: Origin, Santos, and Pangaea. Additional data has also been sourced from APPEA based on large-scale shale developments in the United States. **Table 3-13** summarises the anticipated volume of water usage for the Sub-basin.

Table 3-13: Anticipated water use volumes per well

Development phase	Activity	Water volume (ML/well/person)	Water type
Exploration	Civil	1	Potable/Raw
	Drilling and completion	1 - 2	Raw
	Camp facilities	7.5	Potable
Appraisal	Hydraulic Fracturing	16	Raw
	Camp facilities	16	Potable
Development	Hydraulic Fracturing	32	Raw
	Camp facilities	30 to 240	Potable
Operational	Production	<1	Potable/Raw
	Camp facilities	60	Potable

Based on the above volumes and considering a likely 30% recycled water use for hydraulic fracturing, the yearly water use volumes for each scenario are provided in **Table 3-14**.

Table 3-14: Yearly water use volumes calculated from an estimate of 35 ML/well

Development Scenario	Total number of wells	Total number of wells per year	Raw water volume per well (ML)	Annual Potable water per person (ML)	Annual Raw water volume required (ML)	Total annual (ML) required
Exploration	5	5	2	7.5	10	17.5
Appraisal	40	12	16	16	192	208
Development Low	375	45	20	30	900	930
Development Medium	2,200	275	20	180	5,500	5,680
Development High	2,225	280	20	180	5,600	5,780
Development Wet	3,520	440	20	240	8,800	9,040
Operations		40	1	60	40	100

Sources

Given the arid nature of the Sub-basin development areas and the intermittent and unreliable nature of surface water availability, development of water demand will likely be sourced from the known regional groundwater aquifers.

The area is underlain by the Cambrian Limestone Aquifer (CLA), a large system comprising the Tindall Limestone in the Daly Basin, the Montejinni Limestone in the Wiso Basin and the Gum Ridge Formation in the Georgina Basin. The Daly Roper Sub-basin Water Control District was declared on 22 June 2018 to allow for surface and groundwater management purposes. The current understanding on the Sub-basin hydro-stratigraphy discussed in Fulton S and Knapton A (2015)[3] indicates that water of sufficient volume and quality should be available to support the gas industry.

The three main aquifers with supply and water quality viability to meet this demand are:

- Anthony Lagoon Formation;
- Gum Ridge Formation; and
- Bukalara Sandstone.

Current extraction rates from the estimated 800 registered water bores within the development area is approximately 6,000 ML/y[4]. The recharge values for the CLA are currently estimated to be between 100,000 ML/y to 300,000 ML/y.

Water supply options

Given the remote location of the gas developments, water supply will likely be limited to groundwater extractions from the CLA. Depending on the use and quality of the water onsite amendment, blending, or further treatment, may be required to achieve the desired final water quality.

Given the estimated annual recharge values are above 100,000 ML, existing annual use and indicative annual extraction rates (Development Wet) of 15ML estimated water extraction rates are well below recharge.

[3] Fulton S and Knapton A (2015) Beetaloo Basin Hydrogeological Assessment. CloudGMS, Australia
[4] Scientific Enquiry into Hydraulic Fracturing in the Northern Territory - Water

Waste water stream treatment and disposal options

The waste water streams from development activities will be generated through the following processes:

- Drilling and completion;
- Flowback and produced waters;
- Construction water; and
- Grey water and sewage.

Table 3-15 summarises the expected waste stream volumes for the given development scenario on a per well basis.

Drilling and completion fluids, muds and cuttings generated or required during drilling activities typically comprise saline fluids and water based muds. These waste products are stored onsite in appropriately lined sumps and / or tanks as described under the Code of Practice: Onshore Petroleum Activities in the Northern Territory.

Following hydraulic fracturing, flowback water chemically resembles the stimulation fluid. As flowback continues, formation water will begin to dominate and is typically characterised by high total dissolved solids (TDS) depending on the target formation. Flowback fluids are stored onsite in appropriately lined sumps and / or enclosed tanks under the Code of Practice: Onshore Petroleum Activities in the NT. Flowback water can then be treated or amended to allow for recycling of the fluids for additional fracturing operations and for other uses where quality requirements are achieved.

Where recycling of fluids is possible, in-field treatment may entail enhanced solids removal, reverse osmosis, brine concentration and crystallisation, ammonia removal, dechlorination and pH adjustment. Water amendment and adjustment could also be utilised to bring the sodium absorption ratio (SAR) into an acceptable level to allow reuse of the water for applications, such as dust suppression or construction water.

Brines generated from the treatment process would be stored on site and are expected to be evaporated down in volume to a size which allows for transport and final disposal to an appropriately licensed waste handling facility. It is also assumed that residual volumes in tanks are also disposed of in a similar manner. There is potential for a licensed waste handling facility to be constructed close to the Sub-basin to minimise the transport of these waste streams.

Greywater and sewage is expected to be treated onsite through sewage treatment processes. Following treatment, this water is generally disposed of through local irrigation.

Table 3-15: Annual waste water volumes for development scenarios

Development Scenario	Total number of wells	Total number of wells per year	Drilling and completion - Wastewater generated (ML/yr)	Flowback and Produced water (ML/yr)	Grey water and sewerage (ML/yr)	Total wastewater (ML/yr)
Exploration	5	5	5	40	6	56
Appraisal	40	12	12	96	12.8	132.8
Development low	375	45	45	360	24	474
Development Medium	2,200	275	275	2,200	144	2,894
Development High	2,225	280	280	2,240	144	2,944
Development Wet	3,520	440	440	3,520	192	4,592
Operations		40	40	320	48	448

Waste Management

A range of solid and liquid wastes will be generated throughout the Exploration, Appraisal Development and Operational phases. The vast majority of waste generation would be classified under Northern Territory Environment Protection Authority (NTEPA) landfill guidelines[5] as either inert waste, municipal solid waste or industrial waste, with a small quantity of waste classified as listed waste (i.e. wastes specified in Schedule 2 of the Waste Management and Pollution Control (Administration) Regulations 1998). For the purposes of this report, inert waste, municipal solid waste and industrial waste are collectively referred to as 'general waste'. Listed wastes pose a threat or risk to public health, safety or the environment and include substances which are toxic, infectious, mutagenic, carcinogenic, teratogenic, explosive, flammable, corrosive, oxidising and radioactive. They are sometimes referred to as 'hazardous wastes'.

The types and quantities of waste generated will change throughout the life of the project reflecting the changing nature of the main activities performed and workforce size requirements. The volume and make-up of these wastes will be detailed through individual proponent's Environmental Impact Assessments.

General construction and operational waste expected to be generated includes the following:

- Construction and demolition waste, including concrete, asphalt, bricks, plasterboard, timber, vegetation, metals, plastic wrapping, asbestos and contaminated soils;
- Domestic garbage arising from the kitchens, messes and accommodation facilities of mobile camps or permanent field camps, including food scraps, paper and cardboard, glass, metals and grease trap waste;
- Office waste, including food scraps, paper and cardboard, spent printer cartridges, batteries and broken electrical equipment;
- Clinical or health care wastes, including sharps, bandages, dressings, swabs and expired medicines; and

[5] Guidelines for the Siting, Design and Management of Solid Waste Disposal Sites in the Northern Territory, NTEPA, January 2013

- Industrial waste, including mineral oils, lubricants, oily waters or emulsions, petrol, acids, solvents, paints, materials contaminated with oils, lubricants, paints and/or cleaning solvents such as spent oil filters and cleaning rags, fuels, containers that are contaminated with residues of a listed waste such as lubricants, paints and solvents, tyres and batteries.

Most construction and demolition wastes, domestic garbage and office wastes generated would be classified as 'general waste'. Most clinical wastes and workshop wastes generated would be classified as 'listed waste'.

General waste, or the individual materials comprising these broad waste classifications, can often be reused, recycled or reprocessed. Such opportunities for listed waste are usually quite limited, especially in a remote setting such as the Sub-basin region.

The Santos GLNG Gas Field Development Project Environmental Impact Statement provides estimated waste quantities produced through the development of 6,100 wells over 30 years. Based on these published quantities, the waste quantities provided in tonnes per annum (tpa) in Table 21 are provided as high-level, conservative estimates of waste production for the Sub-basin development scenarios.

Table 3-16 High level waste quantity estimations in tonnes per annum

Development Scenario	Total number of wells per year	General Waste tpa	Recylables tpa	Oils tpa	Tyres tpa	Plastics tpa	Scrap metal tpa	Waste chemicals tpa	Electrical and batteries tpa
Exploration	5	225	50	5	1	0.01	1	0.5	0.3
Appraisal	12	540	120	12	2.4	0.024	2.4	1.2	0.72
Development low	45	810	45	29.7	4.5	0.225	4.5	2.25	0.27
Development Medium	275	4950	275	181.5	27.5	1.375	27.5	13.75	1.65
Development High	280	5040	280	184.8	28	1.4	28	14	1.68
Development Wet	440	7920	440	290.4	44	2.2	44	22	2.64
Operations	40	1800	10	1	0.2	0.002	0.2	0.1	0.06

Disposal options

Waste disposal is challenging given the limits of existing waste management infrastructure and the remoteness of the Sub-basin. The options are as follows:

- Waste Transfer Station, with resource recovery and transport of waste to existing facilities at Katherine and / or Darwin;
- New landfill constructed to meet the requirements of the Sub-basin (note that some listed wastes may still require transport to other disposal sites); and
- New technologies such as waste incineration or waste to energy (note that there will still be a disposal requirement for some components of the waste stream and by-products of the process).

Selecting a waste disposal option will be based on detailed feasibility planning and cost benefit analysis. In planning for waste infrastructure, the steps are to document projected waste quantities and characteristics, then develop concepts along with preliminary investment and operational costings for each option. With the increasing stringency of waste management and environmental regulatory requirements, waste management planning is integral to the infrastructure planning process. Inclusive community engagement should be integral in developing a local solution. Both a waste transfer station and a landfill facility require suitable siting, and the community needs to understand costs, benefits and risks with either model. Making these issues clear at the outset reduces the risk of local discord.

3.2.2.6 Export Pipelines

Export pipelines are required to transport gas and hydrocarbon liquids (above the economic volume for trucking) from the Sub-basin to market locations as per the scenarios in Table 3 Gas and liquids transit options. These pipelines need to be designed, constructed and operated in accordance with the relevant NT legislation and to Australian Standard AS2885 Pipelines – Gas and liquid petroleum. Additionally, the gas export pipelines will be covered under the National Gas Law which regulates the commercial operation of pipelines in participating jurisdictions, which includes the NT.

These pipelines transport the gas and hydrocarbons liquids at high pressure due to the significant distances involved. The pipeline flow rates required, based on the cases developed, range from moderate flows to very high flows with respect to typical gas transmission pipeline systems within Australia.

It is probable that for the low cases, augmentation of the capacity of the existing pipelines would be sufficient to enable gas to be transported to market. For the medium and high cases, new pipelines would need to be constructed to deliver the gas flow rates.

For the cases where liquids pipelines are required, new liquids pipelines would need to be constructed as there are none in the region.

The level of sharing of export pipelines will ultimately depend on the scale and timing of the projects developed. For some of the cases, the gas volumes exceed that capable of being transported in one pipeline and will require multiple pipelines. With multiple pipelines, it could be one owner or several owners. It is common practice where several pipelines are expected from a basin to a common market location, that the government nominate a pipeline corridor that must be used for pipelines. It is assumed at this stage that new export pipelines from the Sub-basin would be developed, owned and operated by a third party to the Sub-basin gas development proponents.

Consideration should be given by the NTG to the concept of an infrastructure corridor for pipelines and other linear infrastructure, from the Sub-basin to Darwin and to the Queensland border.

Table 3-17 Gas and liquids transit options

Play	Case	Total Gas Production Levels (TJ/day)	Gas Export Pipeline Diameter	Liquids transit options	Gas Export Pipeline Compressor Station
Middle Velkerri Dry gas	Low	100	DN300 (12")	N/A	No
	Mid	1,700	DN1050 (42")	N/A	Yes
	High	3,300	2 x DN1050 (2 x 42")	N/A	Yes
Kyalla Liquids-rich gas	Low	200	DN400 (16")	~ 8,500 bbl/day = trucking	No
	Mid	800	DN900 (36")	~56,000 bbl/day – a 12" pipe is reasonable for this flow.	No
	High	1,700	DN1050 (42")	~ 120,000 bbl/day – a 20" pipe is reasonable for this flow.	Yes

3.3 Modelling Infrastructure Requirements

Modelling the potential choices that will guide the development of the Sub-basin is critical to understand the likely impacts on the freight network. Equally, the anticipated freight movements from these choices will inform the infrastructure requirements from the development of the Sub-basin. Key findings from GHD's analysis of these choices and freight movements are summarised below.

3.3.1 Preferred Product Mode Choice

The choice of transport mode is a critical consideration for wider freight-related projects as part of the feasibility and funding decision process. Transport can be a significant proportion of the overall costs for a remote project and is a key influencing factor.

Transport freight logistic modelling analysed freight options to determine the most cost effective and efficient modes for the transport of the bulk, break bulk and unitised freight for the gas industry development scenarios. A summary of the supply chains for a liquids rich gas basin is depicted in **Figure 3-2**.

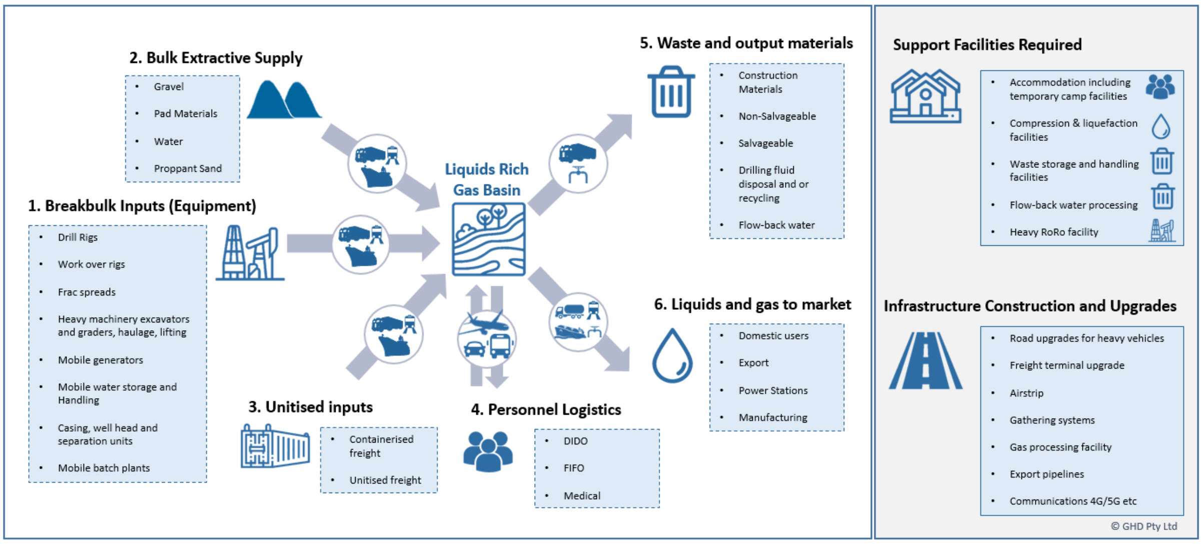


Figure 3-2 Liquids rich gas basin development supply chain

Key considerations of the analysis included:

- The requirements for each of the low / medium, high and wet scenarios to determine the on mode traffic / trips;
- Darwin, Port Roper and Bing Bong Port were analysed for importation of freight, in particular the bulk freight such as pipes to determine preferred option;
- Rail versus road transport from port to Sub-basin; and
- Road options for development of the western province (Pangaea, Origin and INPEX leases) of the Sub-basin, such as industry requirements to use of Western Creek Road, Buchanan Highway or Gorrie Dry Creek Road.

Refer to **Appendix E** for the full results of the transport freight logistic modelling.

Despite cost being a primary consideration for projects, there are a range of other important factors that influence the choice of transport mode, such as:

- **Distance** – between origin and destination is a key driver of the comparative cost of alternative modes of transport;
- **Volume and/or mass** – where regulatory constraints and infrastructure capability influence achievable payload;
- **Handling requirements** – where specialist equipment is required for efficient and / or safe handling (at either end of the supply chain);
- **Speed** – where freight is time sensitive (time cost of freight and spoilage considerations), and influences cycle times (achievable capacity);
- **Service frequency** – with respect to inventorycarrying costs and storage requirements;
- **Reliability** – with respect to meeting contract obligations and critical timelines;

- **Availability** – with respect to access to fleet and / or terminals for the handling and transport of product (at either end of the supply chain); and
- **Flexibility** – with respect to the ability to increase or decrease capacity, and the ability to recover through 'sprint' capacity.

Considering the above factors, **Table 3-16** identifies the preferred transport mode by product type.

Table 3-18: Preferred transport mode, product type

Mode	Preferred product origin (or destination)	Preferred mode
Bulk extractive		
Gravel	Local area	Road
Pad material	Local area	Road
Proppant	International – Port of Darwin	Rail
Base material (process plant)	Local area	Road
Break-bulk		
Gathering pipes (8")	International – Port of Darwin	Rail
Tubing (5")	International – Port of Darwin	Rail
Process plant steel	International – Port of Darwin	Rail
Drill rigs / Equipment	International – Port of Darwin	Road
Export pipeline	International – Port of Darwin	Road
Unitised		
Containerised freight	Domestic - Darwin	Road*
Liquids and gas		
Gas	International – Port of Darwin	Pipeline
Condensate	International – Port of Darwin	Pipeline
LPG	International – Port of Darwin	Pipeline

* Containerised freight will predominantly be sourced from the city of Darwin and will include perishable products delivered direct to camp. Containerised product may also be transported by rail.

Note that the preferred transport mode may change subject to product supply availability geographically and in the event the assumed transport parameters for the ports, road and rail change in the future.

3.3.2 Freight Requirements

Freight demand for the onshore oil and gas industry will vary throughout the project life cycle and is dependent on the scale of uptake within the industry. Our approach to modelling these requirements is summarised below.

1. **Development scenario definition**

   The exploration and appraisal and low, medium, high and wet development scenarios were defined.

   The order of magnitude freight task was forecast for bulk, breakbulk and containerised products for each development scenario.

   - Bulk extractive;
   - Break-bulk;
   - Unitised freight; and
   - Liquids and gas.

   Table 3-17 below outlines the freight demand requirement forecast over the project life cycle stages of exploration / appraisal, development and operations for each development scenario. Details on how the order of magnitude freight forecasts were calculated are included in **Appendix D.** These forecasts have been prepared for the purpose of assessing the infrastructure requirements only and should not be used by industry for commercial purposes.

2. **Transport option definition**

   The potential enabling ports, roads and railway lines to support freight transport were defined.

   The potential different modal route options (road, rail, pipeline, air and sea) were then defined for each product.

3. **Mode selection**

   The transport network limitations were captured for each of the potential route options.

   Transport cost modelling was completed taking into account the transport network limitations.

   The preferred mode / route was assigned for each product type based on the transport cost modelling and product specific considerations.

4. **Determining freight movements by infrastructure asset**

   The freight volume by infrastructure asset was calculated based on the preferred mode / route assigned for each product.

   The freight movements were calculated based on the freight volume estimates and assumed average payload per trip for each route and mode.

Table 3-19 Annual freight demand by development scenario

Product	Units	Exploration/ appraisal	Development - low	Development - medium	Development - high	Development - Wet	Operations
Bulk extractive							
Gravel	tpa	-	58,866	294,328	294,328	441,492	-
Pad material	tpa	155,250	172,500	862,500	862,500	1,293,750	-
Proppant	tpa	-	240,000	1,200,000	1,200,000	1,800,000	-
Process plant base	tpa	-	18,000	80,000	160,000	100,000	-
Break-bulk							
Gathering pipes (8")	tpa	-	360	1,800	1,800	2,700	-
Tubing (5")	tpa	-	3,600	18,000	18,000	27,000	-
Process plant steel	tpa	-	1,600	5,000	10,000	3,750	-
Drill rigs / Equipment	tpa	TBC	TBC	TBC	TBC	TBC	TBC
Export pipeline	tpa	-	3,750	308,000	616,000	283,500	-
Unitised							
Containerised freight	TEU / annum	30	80	460	760	460	150
Liquids and gas (outbound)							
Gas	PJ / year	3.6	36.5	620.5	1,204.5	620.5	
LNG	Mmtpa	0.0	0.0	9.0	18.0	9.0	
Condensate	mmbbl / annum	-	-	-	-	6.9	
LPG	mmbbl / annum	-	-	-	-	13.8	

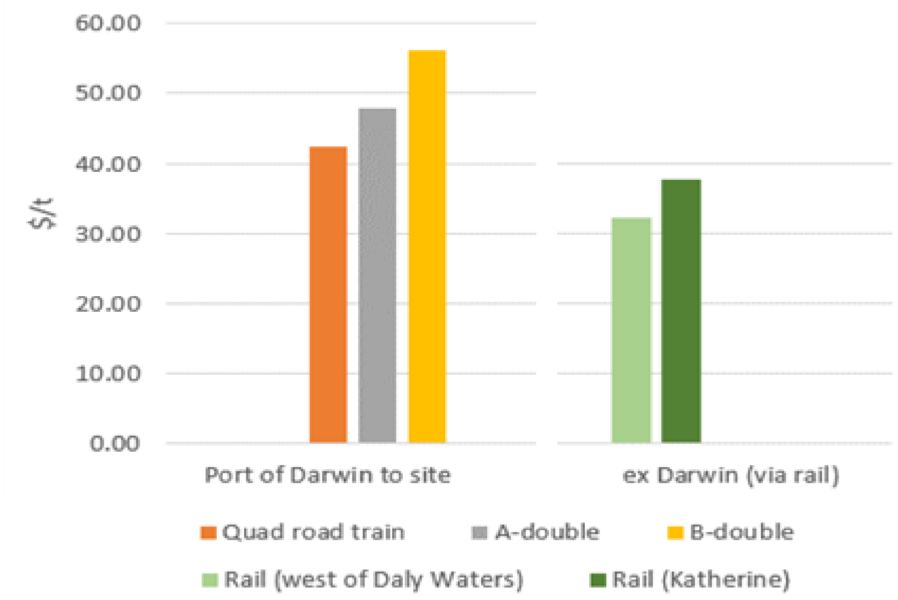
3.3.3 Freight Demand

Freight demand forecasts have been prepared by GHD and RISC as part of this study using a bottom-up approach to provide an indication of the potential increased transport load and required upgrades or works required.

3.3.3.1 Annual freight demand

The inbound freight task to support the onshore oil and gas industry can be broken up into bulk extractive, break-bulk and unitised product groupings, which will be sourced either domestically or imported internationally. All internationally sourced inbound freight can be imported via the Port of Darwin, with the unitised or bulk extractive import of proppant likely to be transported from the port via rail to a rail siding near the Sub-basin due to the cost efficiencies achieved, as shown in **Figure 3-3**.

Figure 3-3 Freight cost comparison for proppant (ex Darwin Port) road versus rail



The transport of break-bulk product to site will be split across rail and road depending on the product / equipment characteristics (i.e. mass and dimensions), and unitised freight (containers) may need to be transported by road due to time sensitive / perishable freight products.

Table 3-18 provides a sample output of annual freight demand by infrastructure asset for the low case scenario based on the preferred transport routes defined as part of this study.

The estimated annual freight demand by infrastructure asset for the other demand scenarios are provided in **Appendix D**.

Table 3-20: Potential freight demand by infrastructure asset (Low Case)

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	**tpa**	**tpa**	**TEU / annum**
Port of Darwin	240,000	9,310	-
Bing Bong	-	-	-
Port Roper*	-	-	-
Key Roads			
Stuart Highway (ex Darwin)	-	3,750	80
Stuart Highway (ex rail siding)	240,000	5,560	-
Carpentaria Highway	240,000	9,310	80
Buchanan Highway	240,000	9,310	80
Western Creek Road	240,000	9,310	80
Roper Highway / Nathan River Road	-	-	-
Existing Beetaloo Sub- Basin Access Roads**	208,967	3,750	80
New Access Roads to production wells**	208,967	3,750	80
Rail			
Adelaide to Darwin Line	240,000	5,560	-

* Break-bulk volumes transported by road exclude drill rigs and equipment tonnages, which have not been calculated as part of the study.

** The transport volumes represent the total volume spread across all access roads. Actual volumes will vary by individual access road.

3.3.3.2 Annual freight movements

Table 3-21 details the forecast annual freight movements for each infrastructure asset based on the forecast freight demand above and the adopted payloads per trip as identified in **Table 3-19**. The assumed capacity takes into consideration the comparative limitations of the ports and road and railway networks supporting the development of the Sub-basin.

Table 3-21: Assumed transport payloads by product and infrastructure asset

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
	Payload/trip (tonnes)		
Ports	45,000	20,000	50 TEU*****
Key Roads	89.4	54	3 TEU
Rail	2,729	2,729	2,729

*The vessel payload total of 50 TEU is not representative of containerised shipping capacity at the listed ports, rather, it reflects that imported containerised freight will only be delivered in small quantities using a liner shipping service due to the small annual freight task.

The forecast heavy vehicle increase on roads is material during the Development phase, particularly for the medium, high and wet scenarios. For these three scenarios, the increase will impact Carpentaria and Buchanan Highways and Western Creek Road mostly due to current road standards. For example, for the high development scenario, the section of the Stuart Highway servicing the rail transport option will attract approximately 110 vehicle movements per day, as compared to about over 60 vehicles per day for the sections north of Mataranka. As detailed in **Table 3-20**, heavy vehicles are already prevalent on each of the roads.

The freight movement calculations to individual roads also include all three exploration sites managed by Santos, Origin and Pangaea. The actual transport load on the roads post Stuart Highway will be driven by the development location and road once the service centre is established (e.g. Pangaea freight movements may be via either Western Creek Road or Buchanan Highway).

Table 3-22 Existing Percentage of Heavy Vehicles

Relevant road	Heavy Vehicle %	Peak annual average daily traffic (AADT)
Stuart Highway (North Carpentaria Highway)	28.7	841
Stuart Highway (South Carpentaria Highway)	23.5	808
Carpentaria Highway	35.9	108
Buchanan Highway	54.6	60
Western Creek Road	Not recorded	Low

Table 3-23: Annual freight movements by infrastructure asset

Infrastructure asset	Exploration/ appraisal	Development - low	Development - medium	Development - high	Development – wet	Operations
Ports (vessel calls/annum)						
Port of Darwin	2	7	47	63	61	0
Bing Bong	0	0	0	0	0	0
Port Roper*	0	0	0	0	0	0
Major Roads (AADT)						
Stuart Highway (ex Darwin)	2	2	34	64	30	2
Stuart Highway (ex rail siding)	4	16	78	78	114	0
Carpentaria Highway (ex Stuart Highway intersection)	4	16	94	96	110	2
Buchanan Highway	4	16	48	48	56	2
Western Creek Road	4	16	48	48	56	2
Roper Highway	0	0	0	0	0	0
Existing Beetaloo Sub-basin Access Roads	4	14	94	130	120	2
New Access Roads to production wells	4	14	94	130	120	2

Infrastructure asset	Exploration/ appraisal	Development - low	Development - medium	Development - high	Development – wet	Operations
Rail (trips/annum)						
From Darwin on Adelaide to Darwin Line	18	90	449	451	672	0

3.4 Infrastructure and Industry Options

Considering the form and standard of the existing infrastructure within the Sub-basin, a broad range of potential options were developed to support the development of the Sub-basin.

3.4.1 Roads

The key consideration for the need for road upgrade works to support the development of the Sub-basin was freight mode choice. Based on the freight demand and freight logistics modelling, the preferred transport modes are:

- Low scenario – all freight via road transport from the Port of Darwin; and
- Medium, high and wet scenarios – freight via road and rail, including the construction of a new siding in the vicinity of the Sub-basin.

Table 3-22 details the upgrade options for the key roads supporting the development of the Sub-basin. The road upgrades are triggered for the low development scenario and are sufficient to support the wet development scenario, however, upgrades will be ultimately dependent on the location and scale of development and uptake of rail transport. No road upgrades are recommended to support the Exploration and Appraisal phases.

Table 3-24: Key roads: upgrade requirements – All scenarios

Road	Identified upgrade requirements
Stuart Highway	Pavement strengthening through rehabilitation including widening to achieve the National Highway Standard, potential capacity improvements such as overtaking lanes, and intersection upgrades to lower order transport roads.
Carpentaria Highway	Upgrade to two lane seal standard for 140 km (Santos proposed development areas).
Western Creek Road	Upgrade to two lane seal standard for 56 km (Pangaea proposed development area). Improvements to the gravel road (36 km) to connect with Gorrie Dry Creek to connect servicing loop road.
Buchanan Highway	Upgrade to two lane seal standard to the Adelaide to Darwin railway, approximately 67 km.
Gorrie Dry Creek Road.	Upgrade to good gravel road standard to the Western Creek Road turnoff approximately 84km on the basis that Western Creek Road will be the main gas industry servicing road in the west.

3.4.2 Rail

The transport freight modelling identified that, to service the wet development scenario (worst case) for the Sub-basin, an estimated increase of over 13 return train trips per week is required, which more than doubles the current six return train trips per week. The additional train movements will require scheduling of train movements to manage the additional train movements generated by the gas industry and may require the Katherine Rail Terminal to be used as an additional passing opportunity between Darwin and Daly Waters.

The transport cost modelling suggested that the rail freight task will be most cost effective with the construction of a rail siding, with freight facilities in the vicinity of the Sub-basin (e.g. west of Daly Waters). Options to construct a new siding on the Adelaide to Darwin Rail Line includes:

- Western extension of the Daly Waters Road and Sunday Creek Road to the Adelaide to Darwin Rail Line across a flood prone area for a distance of approximately 65 km from the Stuart Highway. This will require construction of a new road for a distance of approximately 65 km across poor terrain (high cost) and includes upgrading of Daly Waters Road, Kalala Road and Sunday Creek Road.
- In their submission to the Inquiry, Pangaea proposed a rail siding off the Western Creek Road at a distance of 46 km from the Stuart Highway. The Western Creek Road would require upgrading and would involve the increased haul distance of 91 km from the Carpentaria Highway to Western Creek Road along the Stuart Highway.
- Establish a siding at the intersection of the Adelaide to Darwin Rail Line and Buchanan Highway which would require the upgrading of the Buchanan Highway for a distance of 67 km and would involve an additional haul distance from the Buchanan Highway to the Carpentaria Highway of 36 km, along the Stuart Highway.

3.4.3 Ports

The port facilities at East Arm Wharf (EAW) and the available existing capacity make the Darwin Port the most attractive sea freight option. Darwin Port Operations estimated the current utilisation of the EAP at 25% and has considerable spare capacity with proven performance on large scale projects such as Inpex, Northern Australian Gas Pipeline. Currently, there are no facilities in place to load directly to rail and equipment, and storage facilities would have to be established to load to rail. Consequently, loading facilities from ship to rail is listed as a requirement.

The capability for exporting bulk liquids will require further investigation, but preliminary investigations suggest that storage facilities could be required in the VOPAC Fuel Terminal and piped from there to bulk fuel tankers at the EAW for a low case scenario. There are existing pipes from VOPAC to the Bulk Loading Berth at EAW. For a high case liquids scenario, additional capacity in storage facilities, pipework and export facilities would be required.

At this point in time, both Port Roper and Bing Bong Port are not considered feasible due to shipping costs and infrastructure upgrades required to support a medium to large scale oil and gas operation when compared to Darwin Port.

3.4.4 Aerodromes

It is anticipated that the gas industry will be required to upgrade existing local and regional airports or construct new aerodromes in the vicinity of gas processing facilities for FIFO workers.

Upgrades to local airstrips will likely be required to cater for aircraft similar to the EMB 170 (76 passengers) or larger and are likely to be required in the Appraisal and Development phases, on a case-by-case basis depending on individual financial investment decisions.

A shared user airport could be considered for the Development and Operational phases and would require consideration of distance to productive fields, land availability / suitability and provision of supporting services.

3.4.5 Pipelines

Augmentation of the capacity of the Amadeus Gas Pipeline is anticipated to be sufficient for the low development scenario to enable gas to be transported to market. If the gas is to be delivered to the eastern Australian states, there may be a level of augmentation required of the Northern Gas Pipeline and other pipelines in the eastern gas market, depending on the flow rates and ultimate gas delivery location.

For the medium and high development cases, new large-capacity pipelines would need to be constructed to deliver the gas flow rates.

A separate liquids pipeline would be required for transportation north to Darwin for export or use in downstream industry and processing.

3.4.6 Accommodation

An industry town is unlikely to be developed.

Permanent field camps will be developed for each field and will largely be self-sufficient for power, water, wastewater and telecommunications facilities.

3.4.7 Waste management

The current waste management infrastructure is inadequate for the waste likely to be generated from the Exploration, Development and Production phases proposed for the Sub-basin.

The first requirement is to determine the most cost effective disposal solution, analysing the costs, benefits and risks with constructing and operating a local landfill, compared to a waste transfer station which would transfer waste for disposal at Katherine or Darwin disposal sites (after on-site resource recovery activities). A focus on resource recovery will potentially reduce transport and disposal costs, and will need to be prioritised in the cost / benefit analysis and detailed design process. For listed wastes likely to be generated, analysis will be required to ensure the final end use or disposal meets NTEPA regulations and site licence conditions for the proposed disposal site, potentially triggering a permit upgrade process for existing disposal sites operating licences at the Katherine and / or Darwin facilities. In considering long-term use of either of these sites, it is worth noting that both of these facilities are nearing capacity.

Construction of a local landfill site to service the Sub-basin would require a rigorous site selection process to mitigate environmental risk. Alternatively, siting a waste transfer station would be more straight-forward, based on siting criteria and transport economics. One likely site for a transfer station facility could be at Mataranka, Daly Waters, Elliott or Larrimah, depending on where key work sites and support facilities are developed. A key component of infrastructure development for resource recovery and final disposal will be transport vehicles and equipment to maximise cost efficiencies.

3.5 Recommended Approach

The findings of the infrastructure analysis have highlighted a series of recommendations relevant to common user infrastructure requirements for each of the resource development scenarios. These findings are summarised in **Table 3-23** below, highlighting both the lead time for planning works as well as the delivery timeframes for key infrastructure investments. Opinion of probable cost estimates have been prepared based on a brief description of the infrastructure required, without sites being nominated, site conditions unknown and without design, therefore these estimates should be regarded as being indicative of the cost as many factors will influence the cost.

Table 3-25 Common user infrastructure requirements

Infrastructure Type	Production development scenario	Requirement	Timing	Probable capital cost estimate
Infrastructure Type - Roads				
Stuart Highway - Pavement rehabilitation program	Medium & High (Dry Gas), High (Liquids)	Business case development Program of works Procurement Construction	2024	$2M/km
Stuart Highway - Intersection upgrades	Medium & High (Dry Gas), High (Liquids)	Business case development Survey Confirm easement / title Design Approvals Procurement Construction	2023	$270K
Stuart Highway - Capacity Upgrades - Upgrade widening of carriageway (60km)	Medium & High (Dry Gas), High (Liquids)		2023	$60M
Carpentaria Highway - Upgrade to two lane sealed (140km)	All		2022	$150M
Western Creek Road (Ch 0 to 56) - Upgrade to two lane sealed (56km)	All		2024	$58M
Western Creek Road (Ch 56 to 92) - Upgrade to good gravel standard (36km)	All		2026	$27M
Buchanan Highway - Upgrade to two lane sealed (67km)	Medium & High (Dry Gas), High (Liquids)		2024	$70M
Gorrie Dry Creek Road - Upgrade to good gravel standard (84km)	Medium & High (Dry Gas), High (Liquids)		2026	$62M
Infrastructure Type - Airports				
Shared user airport would require consideration of distance to productive fields, land	Medium & High (Dry Gas), High (Liquids)	Business case development	2024	$38M

Infrastructure Type	Production development scenario	Requirement	Timing	Probable capital cost estimate
availability / suitability and provision of supporting services. Assume located at Larrimah, Daly Waters or Newcastle Waters				
Infrastructure Type - Waste Management				
Upgrades to existing landfills	Medium & High (Dry Gas), High (Liquids)	Capacity assessment	2024	$227 per m^2
Wastewater treatment facilities – cost based on PWC Katherine WTP	Medium & High (Dry Gas), High (Liquids)	Wastewater characterisation Treatment selection Design Construction	2024	$28M
Waste transfer station	Medium & High (Dry Gas), High (Liquids)	Land suitability assessment Concept design Approvals Detailed design Construction Approvals	2024	$710K
New landfill	Medium & High (Dry Gas), High (Liquids)		2026	$3.2M
Infrastructure Type - Export Pipelines				
New gas pipeline	Medium & High (Dry Gas), High (Liquids)	Survey Confirm easement / title Design Approvals Procurement Construction	2024	$45K to $65Kper inch / km
Liquids pipeline	Liquids		2025	$45K to $65Kper inch / km
Infrastructure Type - Port				
Bulk liquids storage and loading gantry	Liquids	Design Approvals Procurement Construction	2024	Cost to be determined at business case phase.
Upgrade to facilities to load proppant to load rail cars	Medium & High (Dry Gas), High (Liquids)	Design Procurement Construction	2025	Cost to be determined at business case phase.
Infrastructure Type - Rail				
Siding	Medium & High (Dry Gas), High (Liquids)	Survey Confirm easement / title Design Approvals Procurement Construction	2024	$16.2M

Notes to costing: Probable capital cost estimates include; Quantities, preliminaries, margin, design / construction contingency escalation to quarter 1 2021, escalation construction, consultants fees, NT build levy and GST.

For the purposes of this estimate, it is assumed that commencement would be the first quarter of 2021, allowing for design regulatory and planning approvals, with various construction periods. The individual proponent's project delivery cost for each project are excluded.

In addition to these identified works, it is recommended that the following early priority actions occur:

- **Industry engagement:** Convene a working group with industry and government to confirm common user infrastructure requirements, align program schedules and determine approach for a Gas Community Benefit Fund to achieve the provision of works as outlined in **Table 3-23**.
- **Pipelines:** Progress a pipeline easement study to secure a corridor to dry and liquid gas transmission from the Sub-basin north to Darwin.
- **Roads:** Commence planning and business case activities for the Carpentaria Highway upgrade.
- **Gravel:** Confirm the quantities of bulk extractive supply required for identified upgrades and model sources capacity. This includes analysing condition data for the Stuart Highway to confirm pavement rehabilitation requirements.
- **Waste:** Prepare landfill capacity assessments for listed waste at Katherine and Shoal Bay landfill sites, undertake land suitability assessments for waste management sites and transfer stations at Elliott, Daly Waters and Mataranka.
- **Cumulative impacts:** Consider the cumulative infrastructure requirements of other regional developments including those associated with gas development in the McArthur Basin, and the broader resources, agricultural and tourism sectors.
- **Supporting services:** Continue to identify opportunities to grow the local service and supply industry through a supporting services opportunity and needs assessment.
- **Regulation:** Confirm the approach to provision of resourcing and associated requirements for regulation activities.

The location of key assets identified in the recommendations in Table 3-23 have been mapped in Figure 3-4 below. The staging of key works required for key assets is also detailed further in a gantt chart for each of the scenarios.

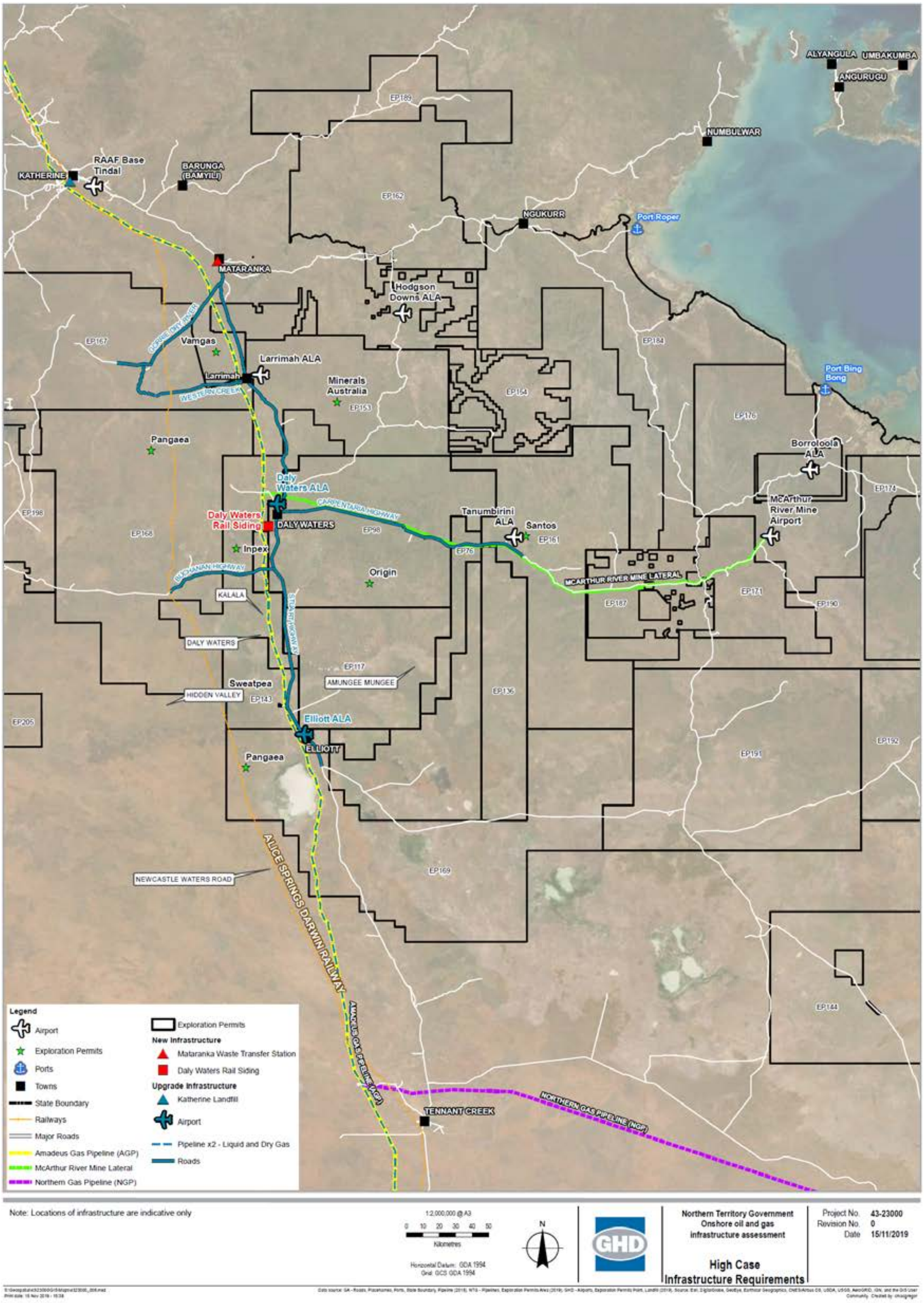
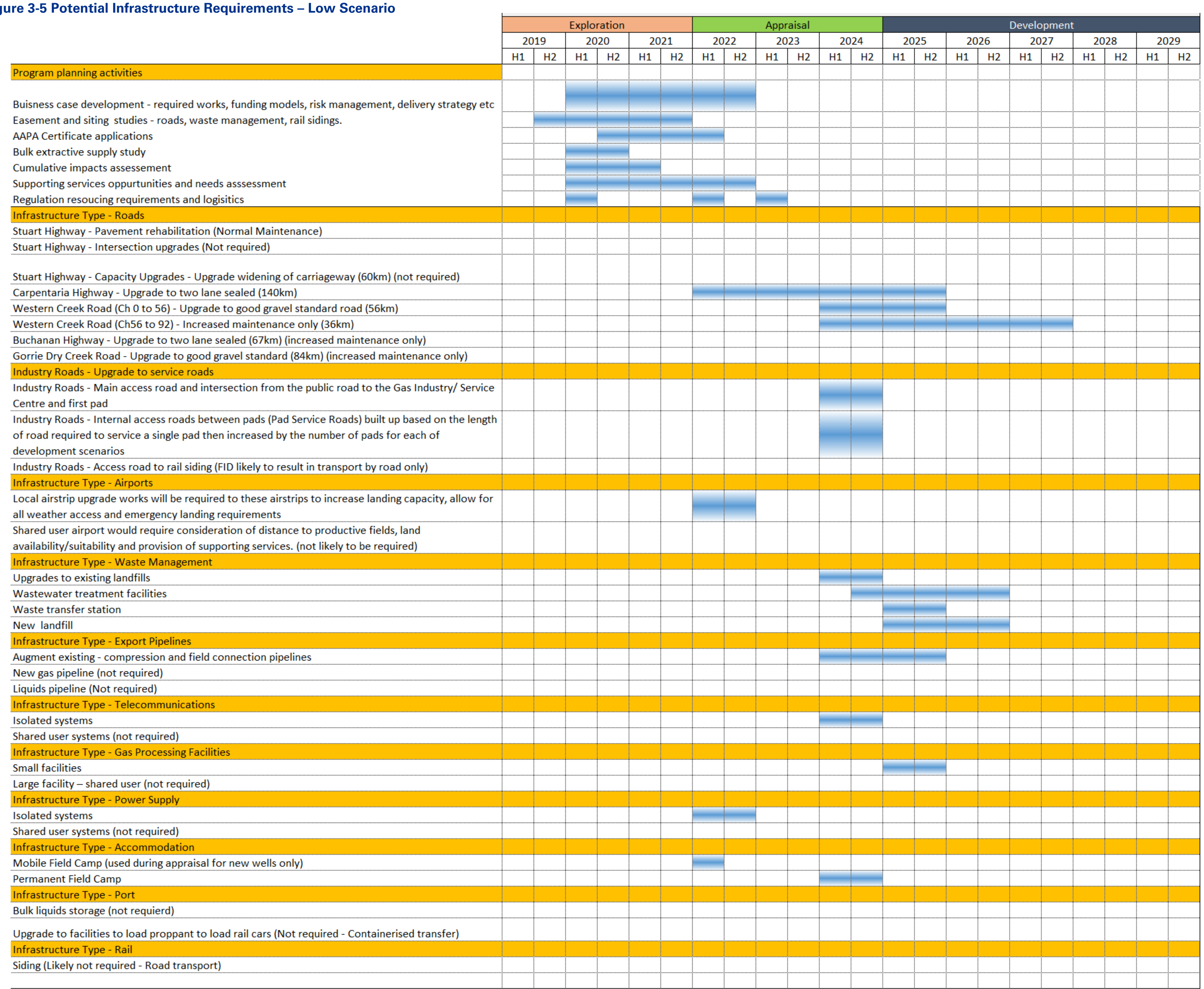


Figure 3-4 High Scenario Infrastructure Requirements

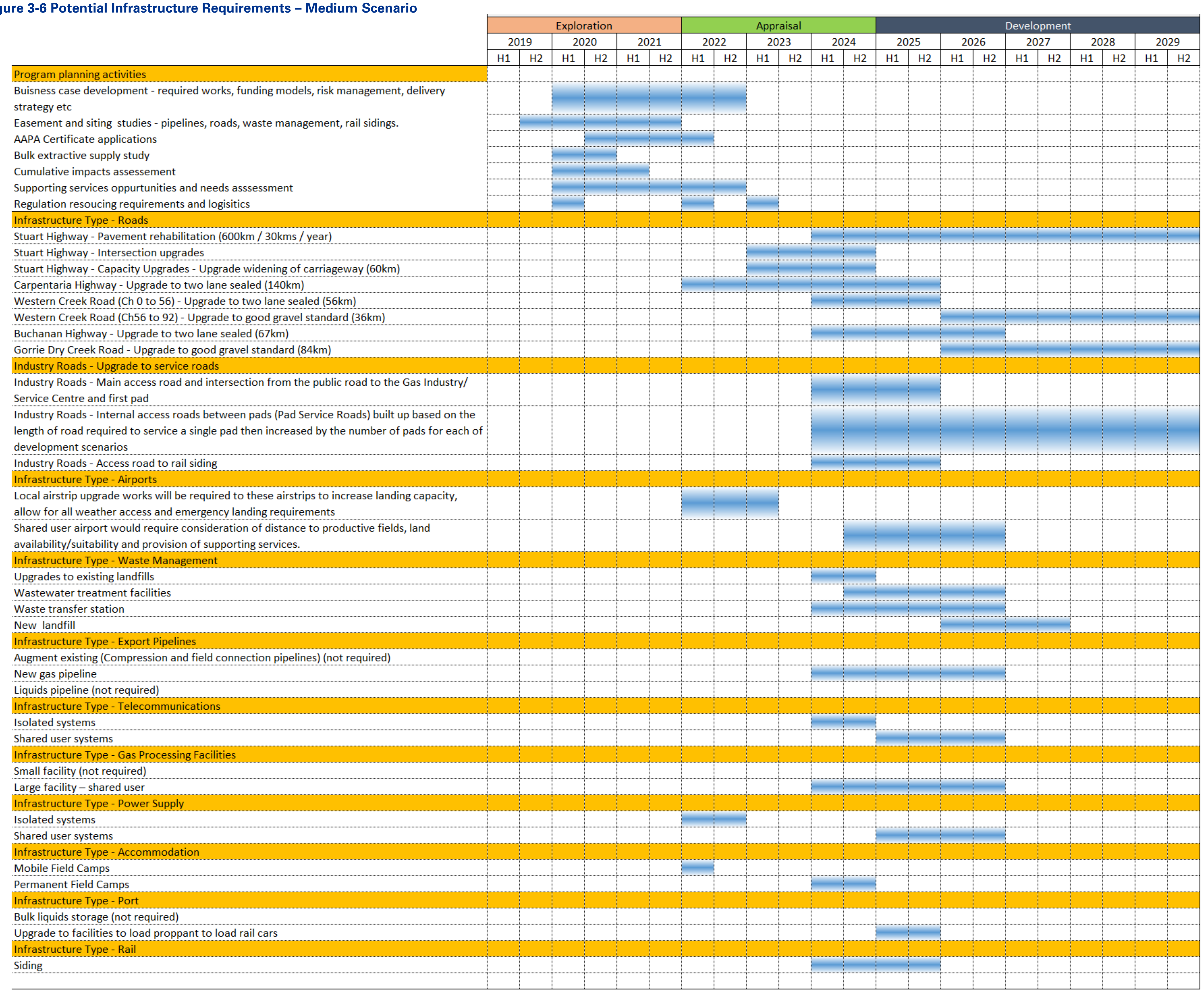
Figure 3-5 Potential Infrastructure Requirements – Low Scenario



Notes:
1. Assume FID in 2024 to allow design to commence
2. Buchanan Highway upgrade will not be required should Western Creek Road development take priority and rail siding is constructed on another road alignment. It may still require a gravel road upgrade.

Implementation duration, including approvals, design and construction

Figure 3-6 Potential Infrastructure Requirements – Medium Scenario



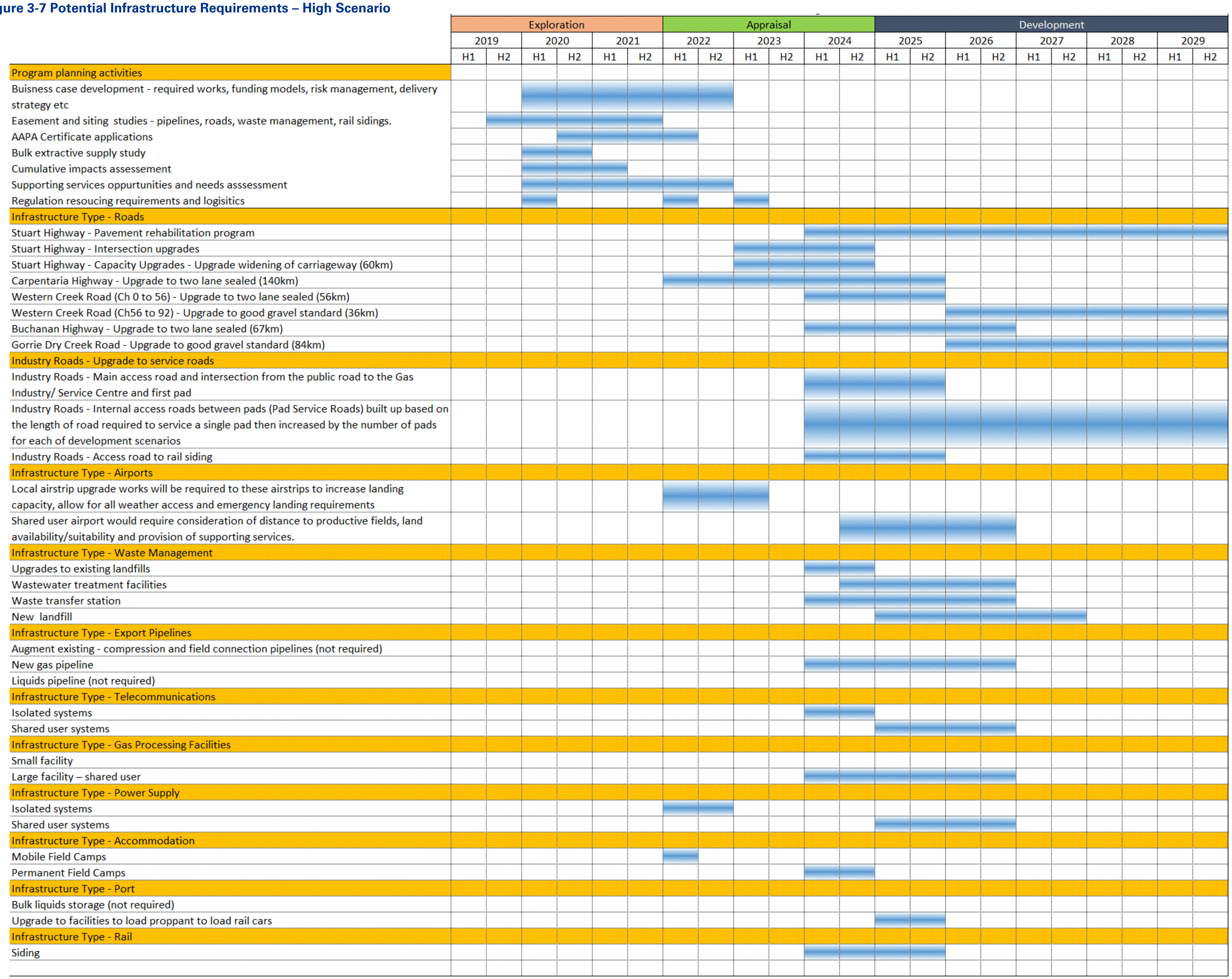
rved.

Notes:

1. Assume FID in 2024 to allow design to commence
2. Buchanan Highway upgrade will not be required should Western Creek Road development take priority and rail siding is constructed on another road alignment. It may still require a gravel road upgrade.

Implementation duration, including approvals, design and construction

Figure 3-7 Potential Infrastructure Requirements – High Scenario

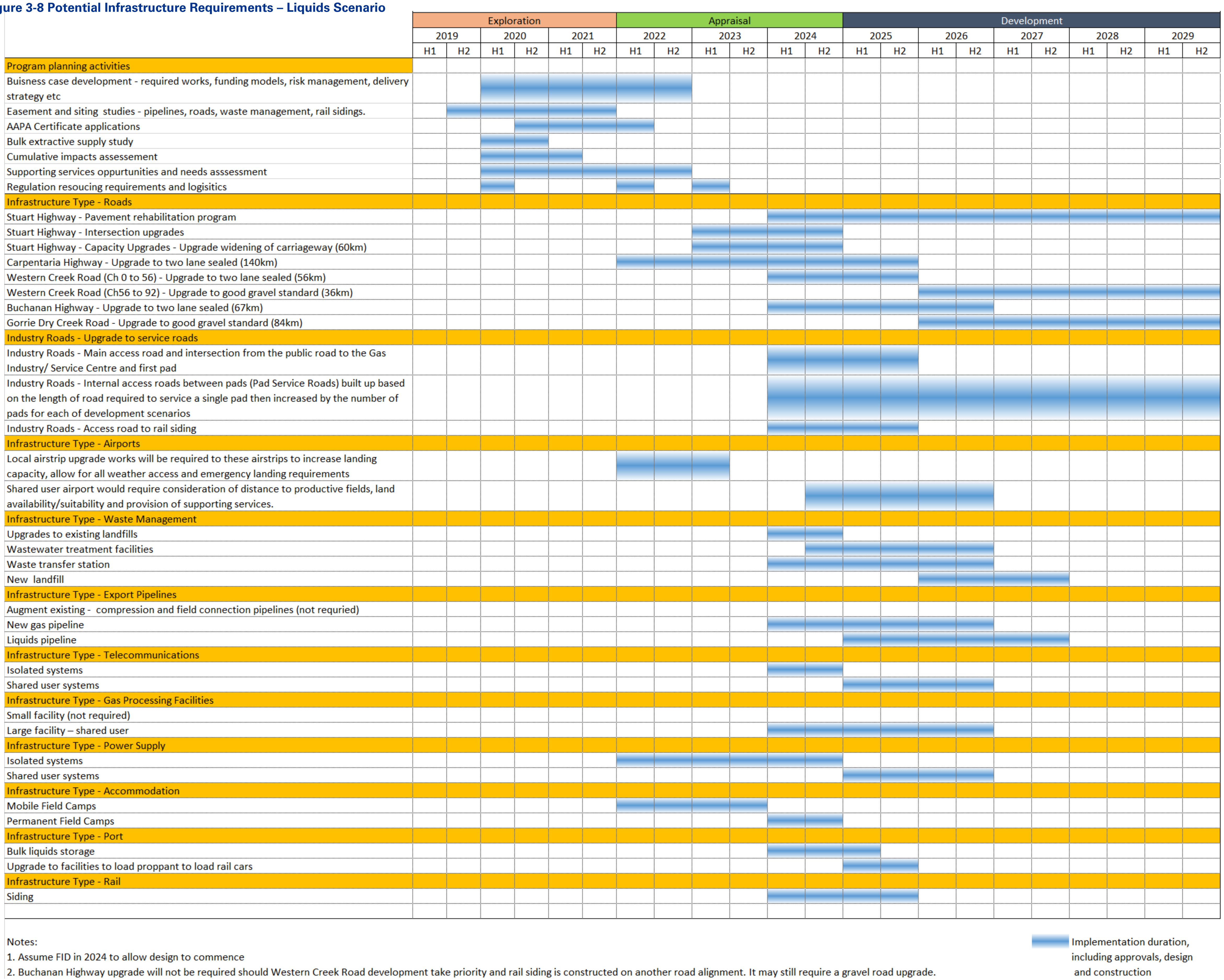


Notes:

1. Assume FID in 2024 to allow design to commence
2. Buchanan Highway upgrade will not be required should Western Creek Road development take priority and rail siding is constructed on another road alignment. It may still require a gravel road upgrade.

Implementation duration, including approvals, design and construction

Figure 3-8 Potential Infrastructure Requirements – Liquids Scenario



Notes:
1. Assume FID in 2024 to allow design to commence
2. Buchanan Highway upgrade will not be required should Western Creek Road development take priority and rail siding is constructed on another road alignment. It may still require a gravel road upgrade.

3.6 Approval Requirements

Table 3-24 below lists the potential legislative requirements triggered by works to support the development of the Sub-basin.

Table 3-26: Legislative Requirements

Legislative Requirement	Relevant Legislation	Administrator
Exploration Permit	Petroleum Act 2016 and Petroleum (Environment) Regulations	DPIR
Approved Environmental Management Plan	Petroleum (Environment) Regulations	DENR
Minister's Approval	Environment Protection and Biodiversity Conservation Act 1999	DOEE
Notice of Intent and Formal Environmental Assessment	Environmental Assessment Act 2013 and Administrative Procedures	NTEPA
Must not enter, damage or interfere with a Sacred Site (even if not registered)	Northern Territory Aboriginal Sacred Sites Act 2013	CLC
AAPA Authority Certificate	Northern Territory Aboriginal Sacred Sites Act 2013	AAPA
Work approval (for removal or damage of archaeological sites)	Heritage Act 2011	DENR
Groundwater Extraction Licence	Water Legislation Amendment Act 2018	DENR
Reporting under National Greenhouse and Energy Reporting Scheme)	National Greenhouse and Energy Reporting Act	Commonwealth Government – Clean Energy Regulatory
Dangerous Goods Business Licence	Dangerous Goods Act	NT Worksafe
Dangerous Goods Vehicle Licence	Transport of Dangerous Goods by Road and Rail (National Uniform Legislation) Act	NT Worksafe
Land Access and Compensation Agreement	Petroleum Act 2016 and Petroleum Act Stakeholder Engagement Guidelines Land Access (Land Access Guidelines)	DPIR

The NTG is already considering necessary legislative changes as a component of the implementation of the recommendations from the independent inquiry. This program will need to continue as a component of providing the industry the certainty it needs to progress investment.

Appendix A: Bulk Freight Inputs

This appendix considers the bulk extractive requirements (gravel, pad materials, proppant) and materials (tubing, gathering pipe) that are the main sources of bulk freight inputs. This provides order of magnitude quantities for freight movements across the supply scenarios.

A.1 Extractive Requirements

Gravel

Requirement

Gravel requirements are primarily for the upgrade and construction of transit routes, access roads for public roads and the gas industry service roads on private properties (pastoral leases) within the exploration leases. The gravel requirements for road pavement construction has been estimated based on the following assumptions:

- Fill and select fill material will be won through "cut to fill" operations in forming of roads. Additional fill will be required for raising the formation through low lying areas subject to flooding and this will be obtained from borrow areas close to the works. For the purposes of this study, it will be assumed that fill material will be available either through cut to fill or borrow to fill operations as it is difficult to estimate and will need to be addressed on a case-by-case basis.
- The quality of the fill material and gravel should be in accordance with the Department of Infrastructure Planning and Logistics (DIPL) Standard Specification for Roadworks V 4.0 (July 2019).

The sealing aggregate requirements for roadworks are not covered in this study.

Potential source of material

Although potential sources of gravel have not been investigated, preliminary consultations indicate they may be able to be sourced locally within or in the vicinity of the Sub-basin; however, a detailed investigation will be required to confirm that this is the case. It is understood the NTG is working with the Extractive Industries on this issue. For sections of the National Highways outside of the Sub-basin, the gravel quantities have not be quantified for this study.

It is expected that sources of gravel within, say, 500 metres either side of the existing public roads will be exhausted due to previous roadworks.

Transport routes on public roads

From a review of recent road construction projects provided by DIPL, the likely pavement depths and widths for upgrading the different road classifications for the public roads are:

- National Highways – Pavement depth of 400 mm (200 mm sub base and 200 mm base course) and 11 m wide pavement including shoulders.
- Other Public Roads - Pavement depth of 300 mm (150 mm sub base and 150 mm base course) and 9 m wide pavement including shoulders.

Using the above standards, the volume for each of the following road upgrading works has been determined as described in the following sections.

Stuart Highway

Pavement rehabilitation works

From data provided by DIPL, pavement age, roughness and rutting was investigated to arrive at a high level, best estimate percentage for rehabilitation of the road over the length of road under assessment within the Sub-basin; hence the volume of gravel is based on width and depth above this length. The basis of the estimate is as follows:

- Pavement Age – Pavement design life is 30 years, but 40 years pavement life is generally adopted for asset management planning purposes as the life of the pavement is dependent on maintenance practises and traffic growth. Based on the estimated pavement life of 40 years for the section from Roper Highway to Barkly Stock Route, 22% of the highway is older than 40 years.
- A 40 year cycle suggests 2.5% as a theoretical rehabilitation rate per year.
- Roughness – Based on the roughness IRI (International Roughness Index) criteria >4.2 <5.3 and ≥ 5.3, the percentage of this section exceeding 4.2 IRI is approximately 1%.
- Rutting – Based on the rut depth of exceeding the lower moderate rating of 10 mm, the percentage determined was 3%.
- On forecasted heavy vehicle increases due to the high development scenarios out of Darwin and for the section of the highway servicing the rail siding ranges from 66 to 114 vehicles per day. This represents a percentage increase of 32% and 89% over the existing heavy vehicles AADTs. There will also be additional traffic locally from the activities associated with construction of public roads and the commuter traffic generated by the workforce transport task. The increase in traffic on the old pavements will accelerate pavement deterioration and result in safety issues.

For high level estimation of gravel requirements for the length of the Stuart Highway between the Roper Highway and Barkly Stock Route, 5% of the road may need to be rehabilitated given the forecasted increase in heavy vehicles traffic, ageing pavements and road rutting. DIPL advised that pavement strength testing has recently been undertaken which will enable a detailed pavement assessment to be undertaken for better estimation of pavement rehabilitation requirements in determining the contribution of the gas industry to pavement wear and tear.

Carriageway widening

The Baseline Assessment indicated that 18% of the Stuart Highway between Roper Highway and Barkly Stock Route (324 km) is required to be upgraded to meet the National Highway Standard; hence, gravel volume is calculated based on the length and depth above, as well as an additional two metres widening to achieve the 11 metres carriageway width.

Capacity improvements – overtaking lanes

A preliminary assessment of the increase in heavy traffic estimated that an increase in heavy vehicle traffic will range from 66 to 114 vehicle per day on the Stuart Highway. This may require investigation in the need for passing lanes based on criteria set down in Austroads' Road Design Guide Part 3 Table 9.1 – Traffic Volume Guidelines for Providing Overtaking Lanes (i.e. traffic will be "very restricted" when the traffic volume of 670 AADT is made up of 20% or more of slow traffic). However, consideration could be given to managing the traffic through a Construction Traffic Management Plan to minimise traffic delays.

The quantities of gravel required for passing lanes have not been determined separately, but there should be adequate coverage by the gravel quantities estimated in the items above for high level planning purposes.

Intersection improvements

Intersection improvements may be required at Western Creek Road, Daly Waters Access Road (if Airport upgraded for FIFO), Buchanan Highway and Gorrie Dry River Road. Again, intersection improvements have not been determined separately, but there should be adequate provision in the items above for high level planning purposes.

Carpentaria Highway

For the high level scenarios, the increase in heavy vehicles is forecast to be 110 vehicles per day as compared to the current count of 26.

From the baseline infrastructure assessment, it is clear that the Carpentaria Highway does not meet an appropriate standard for the estimated increase in both light and heavy vehicle traffic. The road will require upgrading to two lane sealed standard from the Stuart Highway to Santos's development proposed at 140 km along the highway. The volume of gravel required for the upgrade was determined based on the depth and width for "Other Roads" above this length. It is likely the intersection of the Stuart Highway and Carpentaria Highway already meets triple road train standard but checking will be required through a detailed Traffic Impact Assessment (TIA).

Western Creek Road

From Pangaea's submission to the Inquiry, they proposed the upgrading of the Western Creek Road and have had some design work undertaken to upgrade to a two lane sealed standard which received support from the local community. This is consistent with GHD findings that the road will require upgrading.

The length proposed for upgrading is 56 km, the distance from the Stuart Highway to the proposed site in Pangaea's submission. The volume of pavement gravel is determined based on this length, depth, and width for "Other Roads" set out above.

Due to the potential for development of the gas field north of Western Creek Road, extending the road to connect with Gorrie Dry Creek Road, a distance of 36 km, at a good gravel standard has been allowed.

Buchanan Highway

The Buchanan Highway traverses the exploration leases of Inpex, Origin and Pangaea and may have future importance apart from exploration. If required for the Development phase, the proposed upgrading is to two lane sealed standard from the Stuart Highway to the Adelaide to Darwin to Railway a distance of 67 km. The volume of pavement gravel is determined based on this length, depth, and width for "Other Roads" set out above.

The upgrading of the Buchanan Highway will compete for priority against the Western Creek Road which seems to be the most attractive road for development at this time.

Gorrie Dry Creek Road

The Gorrie Dry Creek Road has potential to service Pangaea's development and minor players in the gas industry and included at the request of DIPL. The length proposed for upgrading to a good gravel road standard is 84 km, in order to connect to the Western Creek Road. The volume of pavement gravel is determined based on this length, depth, and width for "Other Roads" above.

Table A - 1 Total gravel requirements – public roads

Road	Volume (m^3)	Tonnage (t/m^3)
Stuart Highway	118,882	258,440
Carpentaria Highway	434,700	945,000
Western Creek Road	253,920	552,000
Gorrie Dry River	231,840	504,000
Buchanan Highway	208,035	452,250
Total	*1,247,377*	*2,711,690*

Roads outside of the Sub-basin

The gravel requirements for upgrading the public roads outside of the Sub-basin has not been determined. It is assumed there will be gravel available in reasonable haul distances to the proposed upgrading works or other arrangements and that provision of gravel will be made, such as manufacturing pavement materials on the Stuart Highway and Barkly Highway where good, naturally occurring gravels have been exhausted or are scarce. The roads that fall into this category include:

- Stuart Highway from Cox Peninsular Road to Roper Highway;
- Stuart Highway from Barkly Stock Route to the Barkly Highway; and
- Barkly Highway from Stuart Highway to NT/Queensland Border.

Gas Industry Service Roads

This section covers the gravel requirements for the gas industry service roads off the public road network. The standard of road used for Exploration and the Appraisal phases is generally basic, with existing pastoral roads utilised and, where required, new tracks to 6 to 8 m wide running surface with gravelling as required; however, a higher road standard is required for the Development and Operation phases.

The Inquiry submissions from Pangaea, Origin and Santos provided guidance to identify the road requirements and the general standard for the internal road networks for each of the gas developments. The internal roads assessed were as follows:

- Main access road and intersection from the public road to the gas industry / service centre and processing plant. The main access road will be as per the dimensions of "Other Roads" for a length of five kilometres.
- Internal access roads between pads (pad roads) built up based on the length of road required to service a single pad then increased by the number of pads for each of the development scenarios. GHD has estimated the gravel requirements for pad roads adopting a length of three kilometres, single lane gravel 4 m wide with passing opportunities provided every third pad for a 100 m section 6 m wide 200 mm thick gravel.

Table A - 2 Total gravel requirements - gas industry service roads

Scenario	Tonnes per annum (tpa)
Exploratory / Appraisal	40,500
Development Low	409,500
Development Medium	2,047,500
Development High	2,047,500
Development Wet	2,047,500

Pad materials

Requirement

Well pads will need to be constructed to support the drilling and ongoing operation of the wells. Initial pads will be constructed during the Exploration phase and, as the development progresses through the Appraisal and into the Production phases, more wells will be drilled in each pad. Number of wells per pad could range from four to 10 wells. For the purposes of this assessment, eight wells per pad has been applied for the Development phase scenarios.

Well pads include the hardstand area for the operation of the wells, temporary buildings, storage and lay down areas.

The construction of the well pads will involve clearing, stripping of top soil, earthworks to construct the formation / foundation with fill material to support the pavement and to ensure the pad will not be impacted by stormwater (i.e. flooded), and then construction of the gravel pavement to the hard standing areas of 200 mm by 200 mm. The well pads will be bundled and treated with a geomembrane or clay liner.

Similar to the road construction, the fill and gravel materials should meet the quality requirements of the DIPL Standard Specification for Roadworks V 4.0 (July 2019).

The well pads should comply with the requirements of the Code of Practice: Onshore Petroleum Activities in the Northern Territory - Clause A.3 Surface activities mandatory requirements.

Potential source of material

Well pads will generally be constructed using fill and gravel materials from the development area. Gravel for the pads will require investigation as described above.

Volume

The quantities of gravel for the pad construction activity for each of the scenarios has been built up from the volume calculated for a single pad based over a 200 m x 200 m surface area by the depth of 300 mm of gravel. Indicative gravel quantities for well pads are shown in **Table A - 3,** whilst **Table A - 4** details the indicative gravel quantities for the process plan base. The process plant pads are similar to the well pads with a pavement thickness of 400 mm.

Table A - 3 Gravel quantity requirement for well pads

Scenario	Tonnes per annum (tpa)
Exploratory / Appraisal	39,375
Development Low	150,000
Development Medium	750,000
Development High	750,000
Development Wet	1,125,000

Table A - 4 Gravel quantities for process plant base

Scenario	Tonnes per annum (tpa)
Exploratory / Appraisal	0
Development Low	18,000
Development Medium	80,000
Development High	160,000
Development Wet	100,000

Proppant

Requirement

Proppant is required during hydraulic fracturing to maintain the fracturing. Depending on the formation, hydraulic fluid and water quality different types of proppant will be selected to provide optimal results. Proppants range from silica sands, resin treated sands or ceramic materials.

Potential source of material

For the purposes on this study, it has been assumed that the proppant will be sourced internationally and imported through the Port of Darwin

Volume

The estimated annual proppant volumes are detailed in **Table A - 5**. The volume of proppant was determined based on annual proppant tonnage as determined by RISC. Exploratory and appraisal volume is an estimate of 20% of the low case scenario, calculated from a proportion of wells compared to the low case scenario.

Table A - 5 Annual proppant quantities

Scenario	Tonnes per annum (tpa)
Exploratory / Appraisal	48,000
Development - Low	240,000
Development -Medium	1,200,000
Development -High	1,200,000
Development --Wet	1,800,000

Transport route

The potential port facilities that could be used for the import of proppant include the Port of Darwin and regional Ports Roper and Bing Bong.

The Port of Darwin would allow the proppant to be imported via import vessels and loaded via existing cranes, either directly onto road trains or moved to a storage facility for movement via the train network.

Both Port Roper and Bing Bong Port would require import via transhipment vessels and / or barges only. At the wharf, facilities would need to be constructed to transfer the materials onto road trains.

Tubing

Requirement

In completing a well, it is required to use tubing materials to contain the well fluids that are produced. The process of drilling and completing wells will be in accordance with the requirements of Code of Practice: Onshore Petroleum Activities in the Northern Territory. The steel tubing material is installed in a well during the completion process. The tubing is manufactured to international standards for the oil and gas industry.

Potential source of material

Well tubing will be sourced from specialist vendors that provide tubing for the oil and gas industry. Given the anticipated quantities, it is expected that the majority of the tubing required would be sourced from international manufacturing locations rather than Australian-based suppliers.

Volume

The volume of tubing is related to the number of wells. It is assumed that each well has 3,000 m of tubing. Therefore, based on well pads with eight wells each, the tubing required per well pad is 24,000 m.

Transport route

The transport route for all tubular products will be the same, given the likely sourcing of these items directly from international manufacturers. For the purpose of this report, tubular products consist of tubing and line pipe.

The transport route for tubular products is expected to be via ship from international manufacturers to Darwin. From Darwin, the tubular products are expected to be transported via rail to a location as close to the productive fields as possible, where it would be transferred onto road transport for delivery to the construction locations in the Sub-basin. The tubular products are anticipated to be in the order of 12 m to 18 m in length. For the longer tubular products, extended trailers are required for road transport.

Gathering pipe

Requirement

To connect the well pads to a gas processing facility requires a gathering system. The gathering system predominantly consists of pipe. The pipe is manufactured to international standards for the oil and gas industry. The traditional material for manufacture of pipe for gathering systems is steel. Whilst there are other non-steel material that can be used, for the purpose of this report, it is assumed that the gathering system are constructed from steel pipe.

Potential source of material

Pipe will be sourced from specialist vendors that provide pipe to the oil and gas industry. Given the anticipated quantities, it is expected that the pipe would be sourced from international manufacturing locations rather than Australian-based suppliers.

Volume

The length of gathering line pipe is related to the number of well pads, and spacing between the pads. The average diameter of gathering line pipe is related to the number of wells per well pad and the configuration of the gathering system. For the purpose of this report, the average diameter is assumed as DN200. Well pads are assumed at 3,000 m spacing in a grid arrangement. Therefore, based on these assumptions, the total gathering line pipe per well pad is 7,000 m.

Transport route

The transport route for all tubular products will be the same as the current route, given the likely sourcing of these items directly from the international manufacturers. For the purpose of this report, tubular products consist of tubing and line pipe.

The transport route for tubular products is expected to be via ship from international manufacturers to Darwin. From Darwin, the tubular products are expected to be transported via rail to a location near to Daily Waters, where it would be transferred onto road transport for delivery to the construction locations in the Sub-basin. The tubular products are anticipated to be in the order of 12 m to 18 m in length. For the longer tubular products, extended trailers are required for road transport.

Appendix B: Land Tenure and Services

The land tenure status and services availability of the towns considered to be potential regional hubs is summarised in the following sections.

B.1 Katherine

Katherine (estimated population 9,800) has land suitable to support industrial development. The existing land zoning provides area for GI (General Industry) and LI (Light Industry) uses. Most GI and LI zoned land is outside of the 1% AEP Flood Level. Large parcels of vacant Crown land also exist within the township, however the overwhelming majority of this land is under a scheduled Native Title application as shown below in **Figure B - 1.**

There is capacity in the power (Darwin to Katherine grid connected), sewer treatment and disposal networks. The access to a potable water supply is limited due to PFAS contamination.

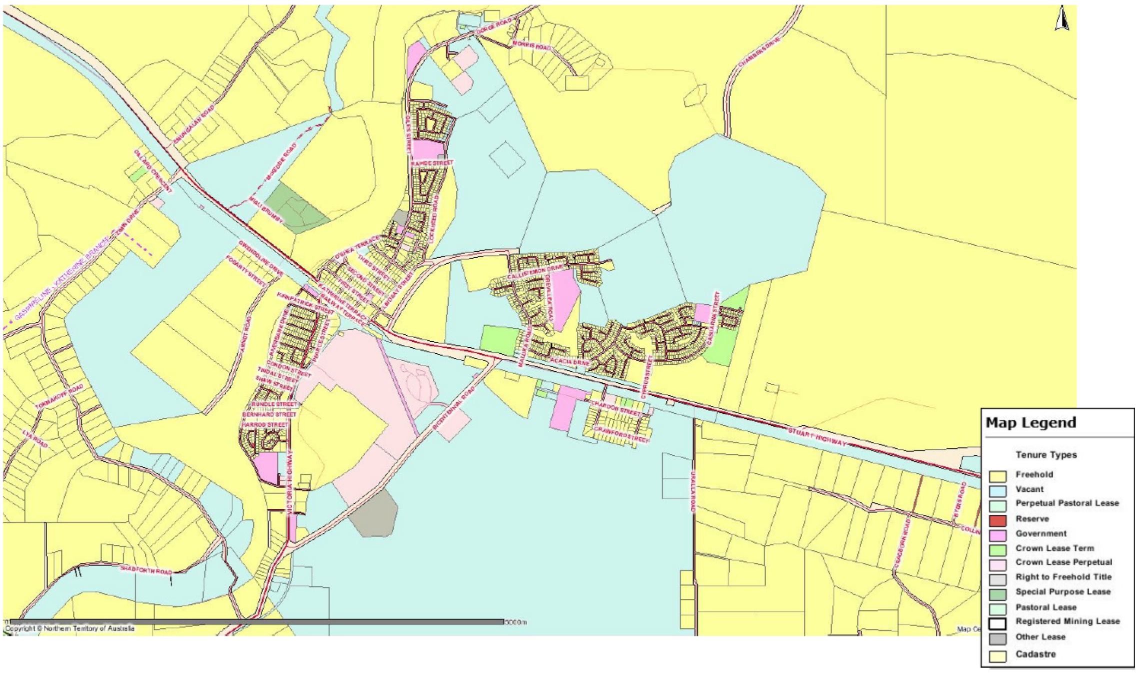


Figure B - 1 Katherine inner land tenure

B.2 Mataranka

Mataranka (estimated population 350) has some suitable land to support industrial development. The land tenure within Mataranka provides vacant Crown land. However, the overwhelming majority of vacant Crown land within the township is under Native Title exclusive rights. Large areas of Crown Lease in Perpetuity that are not under Native Title are located directly north of Mataranka as shown in **Figure B - 2**.

There is capacity in the power supply (Darwin to Katherine grid connected) and water supply is 63% utilised. The sewer treatment and disposal is an on-site effluent disposal system and is not suitable for industrial development.

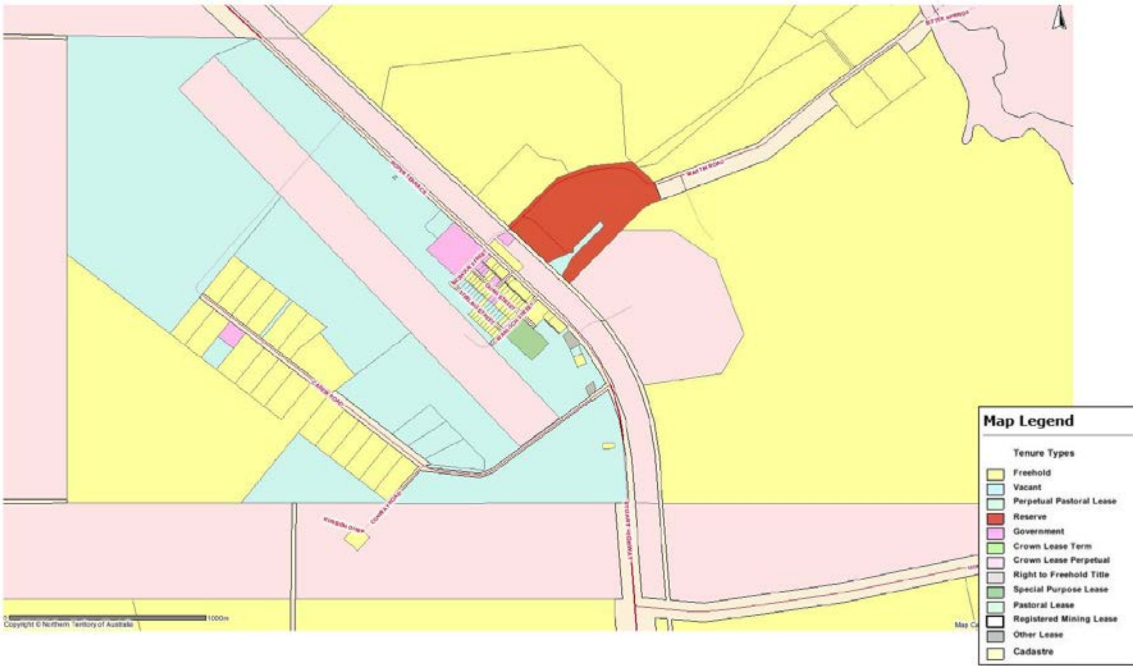


Figure B - 2 Mataranka inner land tenure

B.3 Larrimah

Larrimah (estimated population 47) has land tenure directly outside the township as Crown Lease in Perpetuity, with a large part of this land to the east under Heritage Listing and to the west it is owned by Northern Territory Land Corporation as shown in **Figure B - 3**.

Power supply is limited at Larrimah to a diesel run power station. Sewage and waste water is disposed of through on-site effluent disposal systems. There is some capacity in the water supply, however upgrades to water storage tanks may be required.

Figure B - 3 Larrimah inner land tenure

B.4 Daly Waters

There exists large amounts of vacant Crown land within the township of Daly Waters (estimated population 9) under Native Title non-exclusive rights that could potentially accommodate industry and accommodation type activities as shown in **Figure B - 4**. Land tenure outside the township is Perpetual Pastoral Lease under Native Title non-exclusive rights.

The township area of Daly Waters is also impacted by flooding, and the flooding immunity levels will require further investigation in order to determine land availability.

Power supply is limited at Daly Waters to diesel generators. Sewage and waste water is disposed of through on-site effluent disposal systems and, as such, is not suitable for industrial development. There is capacity in the water supply, however upgrades to storage tanks may be required.

Figure B - 4 Daly Waters inner land tenure

B.5 Elliott

The land zoning within Elliott (estimated population 300) provides for LI as mentioned and FD (Future Development). The land tenure within Elliot also provides much vacant Crown land as shown in **Figure B - 5**. However, the overwhelming majority of vacant Crown land within the township and Freehold land immediately outside of the township is under Native Title exclusive rights and under Aboriginal Land Rights respectively. Some land tenure further from the township is under Perpetual Pastoral Lease, Native Title non-exclusive rights.

Power supply is limited at Daly Waters to diesel generators. Sewage and waste water is disposed of through on-site effluent disposal systems and, as such, is not suitable for industrial development. There is capacity in the water supply.

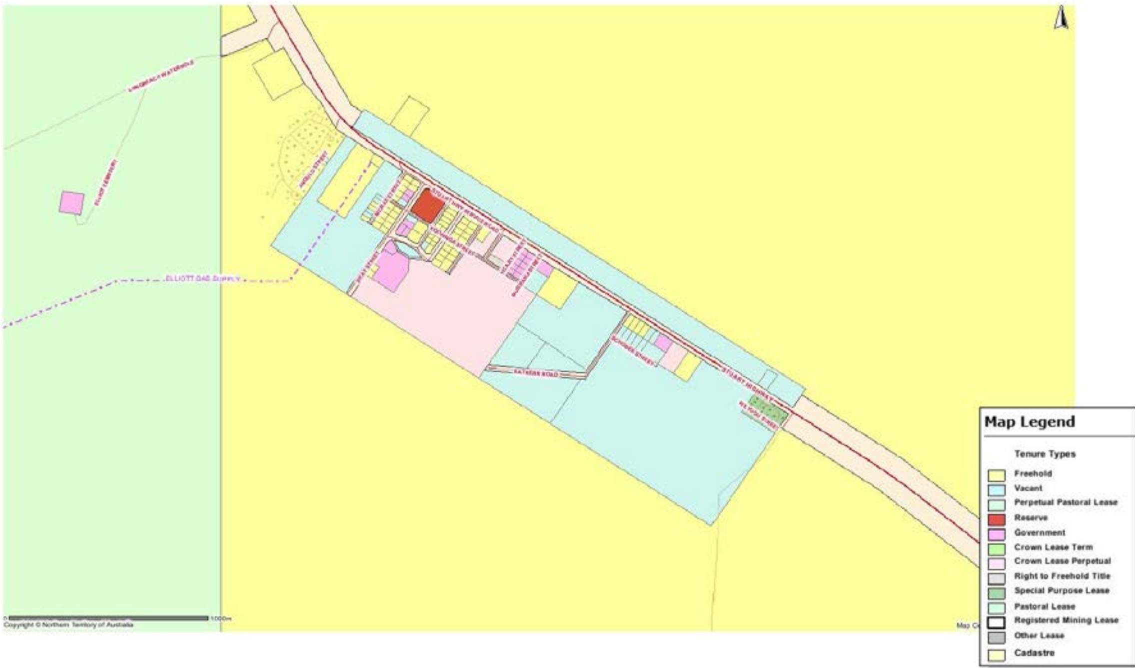


Figure B - 5 Elliott inner land tenure

B.6 Tennant Creek

Tennant Creek (estimated population 3,000) has suitable land zoning and tenure within areas of the township. The existing and a proposed expansion of GI (General Industry) zoned land under the Draft Tennant Creek Land Use Plan, provide much area to support the establishment of construction and industry related business activity. Large parcels of vacant Crown land exist under Native Title non-exclusive rights that provide potential for development as shown in **Figure B - 6**.

The power station at Tennant Creek has limited capacity, however it could require augmentation. The water supply and wastewater treatment facilities have capacity.

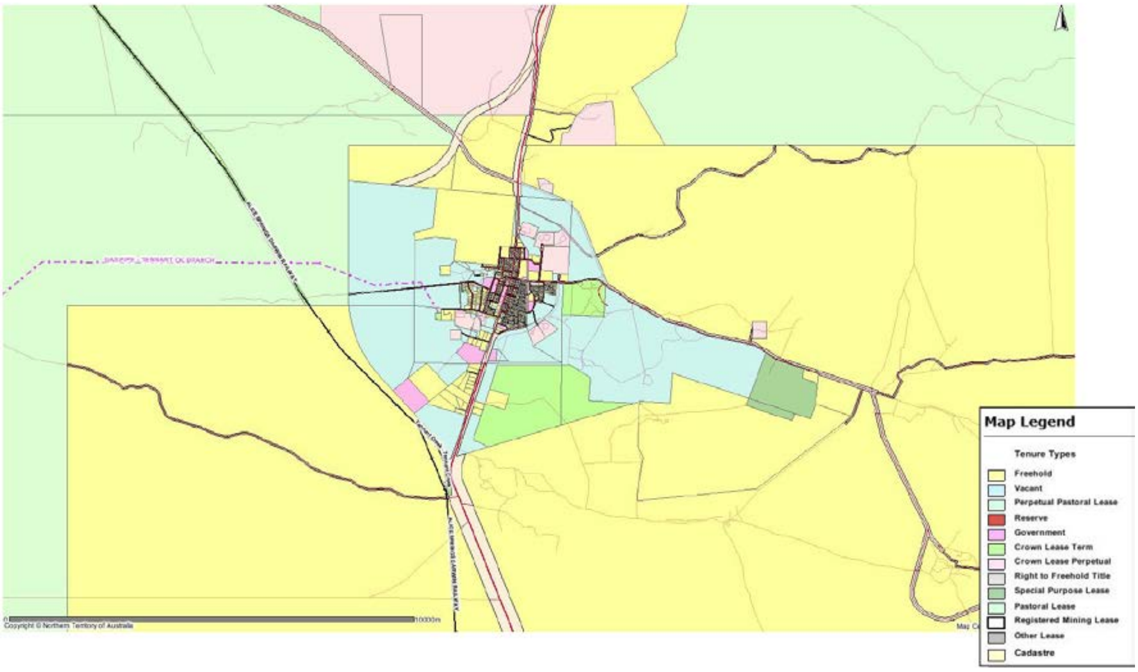


Figure B - 6 Tennant Creek inner land tenure

Appendix C: Waste Management Options

C.1 Waste Transfer Station and Disposal at Existing landfills

Using existing landfill infrastructure is only an option for the sites located in Katherine and Darwin. Given the significant haulage distances, a local Waste Transfer Station would be necessary to improve transport efficiencies.

Using the local landfills at the closest regional towns – Mataranka and Elliott – is not a viable option. Both towns operate small landfills to serve the local community, but neither have an NTEPA Environment Protection Licence as they serve less than 1,000 people and only accept municipal solid waste. The degree of compliance with the NTEPA landfill guidelines and the NTEPA's *Waste Management Guidelines for Small Communities in the Northern Territory* is unknown. However, it is unlikely they have environmental controls, such as an engineered base liner, a leachate collection system and environmental monitoring infrastructure. The sites are not designed or operated to receive and dispose of potentially large quantities of waste arising from development of the Sub-basin.

The closest existing landfills to the Sub-basin region, which holds an Environment Protection Licence and which are of a suitable scale and development to possibly accept waste generated by the project, are Katherine Town Council's Katherine Landfill, and the City of Darwin's Shoal Bay Waste Disposal Facility. Alice Springs Town Council also operates a licensed landfill, however, haulage distances for waste would be considerably further than Katherine and Darwin. The Tennant Creek Landfill does not currently hold a licence.

Both the Katherine Landfill and the Shoal Bay Waste Disposal Facility are licensed to handle a range of listed wastes, and have a resource recovery facility capable of receiving a range of recyclable materials. Given the significant haulage distance to Katherine and Darwin, a waste transfer station would need to be developed to make either of these disposal locations economically viable. This enables waste, and in particular general waste, collected by typically small waste collection vehicles, to be transferred to large containers or trailers for bulk haulage. Back-loading of waste to Katherine or Darwin for disposal may be possible and is worthy of evaluation. In developing waste haulage solutions, the focus is on achieving transport cost effectiveness whilst ensuring waste and associated leachate does not impact on the environment and communities along the travel route.

Mataranka has been identified as a potential site for a waste transfer station given existing facilities, location, land availability and suitability. In designing a waste transfer station, there is an opportunity to reduce operational costs through a focus on maximising resource recovery. The more resources that are recovered, the lower transport and disposal costs. This underlying premise may strengthen the viability of a range of on-site options such as organics recycling.

A number of listed wastes likely to be generated will require final disposal solutions to be developed in collaboration with NTEPA and the landfill facility and / or waste processing facility owners. The list below outlines some examples and considerations.

Clinical waste Paints Contaminated soils	Katherine landfill is not licenced to accept these materials. Can be transported to Darwin facility which is licenced to dispose of these wastes.
Grease trap waste Solvents Materials contaminated with oils, lubricants, paints and/or cleaning solvents Containers that are contaminated with residues of a listed waste	Both Kathrine and Darwin landfills are not licenced to accept these wastes. Transporting them would require an amendment to the existing landfill licence. Global resource Recovery in Darwin can process solvents, and may be able to accept some of the other listed wastes.

Depending on the level and type of contamination, on-site options can be also considered, such as contaminated soil remediation, or grease trap waste treatment technologies. Co-location with the waste transfer station would be ideal, ensuring all aspects of the waste system are closely managed.

Global Resource Recovery, a private sector waste processing and resource recovery company specialising in solutions for challenging waste streams, have recently opened a plant in Darwin. This provides an alternative destination for potential waste products, as well as a technical resource for developing optimal solutions for listed wastes.

Regardless of end destination, the waste transfer station will require separation and secure storage facilities for listed wastes. Sound environmental management processes are required in source separation, waste identification, receiving, storage, labelling and site safety.

C.2 Development of a new landfill

Rather than rely upon distant existing landfills for the disposal of waste, an alternative disposal strategy is to establish and operate a new landfill to specifically service the Sub-basin. A resource recovery facility and listed waste reception and storage compound (for listed wastes which cannot be disposed of to local landfill) would also be required.

The NTEPA provides environment protection approvals and licences for activities listed in Schedule 2 of the *Waste Management and Pollution Control Act 1998*. The activities of relevance to the development of a new landfill as part of the project are associated with the:

- Disposal of waste by burial; and
- Collection, transport, storage, recycling, treatment or disposal of listed waste.

Environment protection approvals are granted for works associated with the Construction phase of these activities, and environment protection licences are granted for the Operational phase of the activity.

A new landfill will need to be sited, designed, developed, operated, maintained and monitored in accordance with the NTEPA's Landfill Guideline. Consideration will need to be given to a range of factors in site selection, including geology, hydrogeology, hydrology, the location of environmentally sensitive areas and adjacent land use and zoning. Many of these factors, and others, will also need to be taken into consideration in the design of a new landfill site to ensure the natural environment and nearby communities are suitably protected from potential offsite impacts.

The NTEPA's Landfill Guideline states that new landfills must provide an appropriate level of retention to protect the environment from the adverse effects of leachate entering the groundwater and surface waters. This would generally comprise a leachate retention or liner system and a leachate collection system. The Guideline also states that all medium and large landfills (which, presumably, the new landfill would fall under) should, as a minimum, have a composite liner system consisting of a compacted clay liner, a HDPE geomembrane and a drainage layer / leachate collection system. The provision of a leachate collection system means that a leachate treatment or disposal system would also need to be provided. A landfill gas management system may also be required.

The NTEPA's Landfill Guideline outlines extensive operational and management requirements for landfills including controlled receipt, placement, compaction and covering of waste. Further, upon completion when the landfill is no longer required or has reached its capacity, the landfill will need to be closed, rehabilitated and then maintained in accordance with the Guideline. Ongoing monitoring and management may continue several decades post-closure.

It is apparent that developing a new landfill to serve the Sub-basin is dependent upon finding a suitable site, obtaining regulatory approval from NTEPA, and potentially other statutory bodies, and will incur significant capex and opex.

C.3 Development of alternative waste treatment or disposal technologies

Alternative waste treatment or disposal technologies employed for general waste include incinerators, waste to energy plants and composting plants. Such technologies are unlikely to be able to accept the full range of listed wastes expected to be generated, and therefore the use of distant treatment, processing or disposal facilities will likely form part of the overall waste management strategy.

The technical and financial viability of these technologies is dependent upon a range of factors, including the quantity and composition of waste requiring treatment, the demand for facility end products, the availability of suitable land on which to establish the facility, and the availability of a skilled workforce to operate, maintain and repair the technology. Such technologies typically have higher capital and operating costs than landfilling. In all likelihood, these technologies are likely to complement, rather than remove the need for, a landfill.

Waste reduction and resource recovery

The NTEPA released the publication *Waste Management Strategy for the Northern Territory 2015-2022* in July 2015. A key management action of this strategy is to improve waste management through promotion of waste reduction and resource recovery in the NT. The strategy identifies actions to be implemented by the NTEPA, however, it is apparent that engagement with industry and their subsequent participation is critical to successful implementation of the actions and the broader objectives of improving waste reduction and resource recovery.

Implementing resource recovery in remote locations such as the Sub-basin can be challenging and often may not be financially viable for many potentially recyclable materials. However, the alternative transport and / or disposal costs of the mixed waste stream may tip the balance in favour of a resource recovery option for some waste streams. The resource recovery industry is undergoing an intensified research and development phase to explore opportunities for production of materials for local use, such as aggregates in roads or end products for the construction sector. As cost effective technologies develop in the future, this may broaden opportunities to divert resources from the waste disposal route.

The broader environmental benefits of resource recovery need to be weighed up against greenhouse gas emissions associated with long distance haulage, especially if back loading of segregated recyclables is not possible.

Possible waste reduction / resource recovery initiatives worthy of consideration include the following:

- Providing suitable bins or skips during the Construction phase for scrap metal. The material collected could be sold to the scrap metal merchant in Katherine.

- Providing suitable bins or skips for beverage containers covered by the Container Deposit Scheme generated from accommodation quarters, offices, kitchens and messes. The containers collected could be sold to the NTEPA approved collection depot in Katherine.
- Providing suitable bins or skips and a paper baler for paper and cardboard waste generated from accommodation quarters, offices, kitchens and messes.
- Providing a small scale organics composting unit (e.g. Orca) to receive food scraps generated from accommodation quarters, offices, kitchens and messes. The compost produced could be used on garden beds around offices or accommodation quarters.

In summary, the proponents should investigate waste reduction and resource recovery opportunities during all project phases. Whilst opportunities may be limited due to large distances to markets, they may become viable when compared to the high costs of transport and disposal costs for waste.

Appendix D: Freight Model Outputs

D.1 Estimated annual freight demand by product type:

Estimated annual freight demand by product type - Exploration / Appraisal phase

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	**tpa**	**tpa**	**TEU / annum**
Port of Darwin	48,000	0	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads			
Stuart Highway (ex Darwin)	0	0	30
Stuart Highway (ex rail siding)	48,000	0	0
Carpentaria Highway	48,000	0	30
Buchanan Highway	48,000	0	30
Western Creek Road	48,000	0	30
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	39,375	0	30
New Access Roads to production wells	39,375	0	30
Rail			
Adelaide to Darwin Line	48,000	0	0

Estimated annual freight demand by product type - Development Low Scenario

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	tpa	tpa	TEU / annum
Port of Darwin	240,000	9,310	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads			
Stuart Highway (ex Darwin)	0	3,750	80
Stuart Highway (ex rail siding)	240,000	5,560	0
Carpentaria Highway	240,000	9,310	80
Buchanan Highway	240,000	9,310	80
Western Creek Road	240,000	9,310	80
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	208,967	3,750	80
New Access Roads to production wells	208,967	3,750	80
Rail			
Adelaide to Darwin Line	240,000	5,560	0

Estimated annual freight demand by product type – Development medium scenario

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	**tpa**	**tpa**	**TEU / annum**
Port of Darwin	1,200,000	332,800	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads			
Stuart Highway (ex Darwin)	0	308,000	460
Stuart Highway (ex rail siding)	1,200,000	24,800	0
Carpentaria Highway	1,200,000	332,800	460
Buchanan Highway	600,000	166,400	230
Western Creek Road	600,000	166,400	230
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	990,038	308,000	460
New Access Roads to production wells	990,038	308,000	460
Rail			
Adelaide to Darwin Line	1,200,000	24,800	0

Estimated annual freight demand by product type – Development high scenario

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	**tpa**	**tpa**	**TEU / annum**
Port of Darwin	1,200,000	645,800	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads			
Stuart Highway (ex Darwin)	0	616,000	760
Stuart Highway (ex rail siding)	1,200,000	29,800	0
Carpentaria Highway	800,000	430,533	507
Buchanan Highway	400,000	215,267	253
Western Creek Road	400,000	215,267	253
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	1,069,934	616,000	760
New Access Roads to production wells	1,069,934	616,000	760
Railway lines			
Adelaide to Darwin Line	1,200,000	29,800	0

Estimated annual freight demand by product type – Development Wet scenario

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	**tpa**	**tpa**	**TEU / annum**
Port of Darwin	1,800,000	316,950	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads			
Stuart Highway (ex Darwin)	0	283,500	460
Stuart Highway (ex rail siding)	1,800,000	33,450	0
Carpentaria Highway	1,200,000	211,300	307
Buchanan Highway	600,000	105,650	153
Western Creek Road	600,000	105,650	153
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	1,459,879	283,500	460
New Access Roads to production wells	1,459,879	283,500	460
Rail			
Adelaide to Darwin Line	1,800,000	33,450	0

Estimated annual freight demand by product type – Operations scenario

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	**tpa**	**tpa**	**TEU / annum**
Port of Darwin	0	0	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads			
Stuart Highway (ex Darwin)	0	0	150
Stuart Highway (ex rail siding)	0	0	0
Carpentaria Highway	0	0	150
Buchanan Highway	0	0	150
Western Creek Road	0	0	150
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	0	0	150
New Access Roads to production wells	0	0	150
Rail			
Adelaide to Darwin Line	0	0	0

D.2 Annual trip uplift by product type:

Annual trip uplift - Exploration / Appraisal phase

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	Vessel calls	Vessel calls	Vessel calls
Port of Darwin	2	0	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads	HV trips (one-way)	HV trips (one-way)	HV trips (one-way)
Stuart Highway (ex Darwin)	0	0	10
Stuart Highway (ex rail siding)	537	0	0
Carpentaria Highway	537	0	10
Buchanan Highway	537	0	10
Western Creek Road	537	0	10
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	440	0	10
New Access Roads to production wells	440	0	10
Rail	Trains (one-way)	Trains (one-way)	Trains (one-way)
Adelaide to Darwin Line	18	0	0

Annual trip uplift – Development Low Scenario

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	Vessel calls	Vessel calls	Vessel calls
Port of Darwin	6	1	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads	HV trips (one-way)	HV trips (one-way)	HV trips (one-way)
Stuart Highway (ex Darwin)	0	69	27
Stuart Highway (ex rail siding)	2,685	103	0
Carpentaria Highway	2,685	172	27
Buchanan Highway	2,685	172	27
Western Creek Road	2,685	172	27
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	2,337	69	27
New Access Roads to production wells	2,337	69	27
Rail	Trains (one-way)	Trains (one-way)	Trains (one-way)
Adelaide to Darwin Line	88	2	0

Annual trip uplift – Development medium scenario

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	Vessel calls	Vessel calls	Vessel calls
Port of Darwin	30	17	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads	HV trips (one-way)	HV trips (one-way)	HV trips (one-way)
Stuart Highway (ex Darwin)	0	5,704	153
Stuart Highway (ex rail siding)	13,423	459	0
Carpentaria Highway	13,423	6,163	153
Buchanan Highway	6,711	3,081	77
Western Creek Road	6,711	3,081	77
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	11,074	5,704	153
New Access Roads to production wells	11,074	5,704	153
Rail	Trains (one-way)	Trains (one-way)	Trains (one-way)
Adelaide to Darwin Line	440	9	0

Annual trip uplift – Development high scenario

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	Vessel calls	Vessel calls	Vessel calls
Port of Darwin	30	33	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads	HV trips (one-way)	HV trips (one-way)	HV trips (one-way)
Stuart Highway (ex Darwin)	0	11,407	253
Stuart Highway (ex rail siding)	13,423	552	0
Carpentaria Highway	8,949	7,973	169
Buchanan Highway	4,474	3,986	84
Western Creek Road	4,474	3,986	84
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	11,968	11,407	253
New Access Roads to production wells	11,968	11,407	253
Rail	Trains (one-way)	Trains (one-way)	Trains (one-way)
Adelaide to Darwin Line	440	11	0

Annual trip uplift – Development Wet scenario

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	Vessel calls	Vessel calls	Vessel calls
Port of Darwin	45	16	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads	HV trips (one-way)	HV trips (one-way)	HV trips (one-way)
Stuart Highway (ex Darwin)	0	5,250	153
Stuart Highway (ex rail siding)	20,134	619	0
Carpentaria Highway	13,423	3,913	102
Buchanan Highway	6,711	1,956	51
Western Creek Road	6,711	1,956	51
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	16,330	5,250	153
New Access Roads to production wells	16,330	5,250	153
Rail	Trains (one-way)	Trains (one-way)	Trains (one-way)
Adelaide to Darwin Line	660	12	0

Annual trip uplift – Operations scenario

Infrastructure asset	Bulk extractive	Break-bulk	Unitised
Ports	Vessel calls	Vessel calls	Vessel calls
Port of Darwin	0	0	0
Bing Bong	0	0	0
Port Roper*	0	0	0
Major Roads	HV trips (one-way)	HV trips (one-way)	HV trips (one-way)
Stuart Highway (ex Darwin)	0	0	50
Stuart Highway (ex rail siding)	0	0	0
Carpentaria Highway	0	0	50
Buchanan Highway	0	0	50
Western Creek Road	0	0	50
Roper Highway / Nathan River Road	0	0	0
Existing Beetaloo Sub-basin Access Roads	0	0	50
New Access Roads to production wells	0	0	50
Railway lines	Trains (one-way)	Trains (one-way)	Trains (one-way)
Adelaide to Darwin Line	0	0	0

Appendix E: Transport Cost Modelling

Using GHD's Transport Logistics Cost model, indicative costs were prepared to compare freight transport by road from Port of Darwin, Port Roper and Bing Bong Port versus rail transport from Darwin. The cost estimates were developed based on a first principles cost build up, and actual rates may vary subject to commercial negotiation.

As illustrated in **Figure 3-9,** the results show that Bing Bong Port possesses the lowest land transport costs due to its proximity to the Sub-basin followed by rail transport with a siding located west of Daly Waters. However, rail transport from Darwin is deemed preferable to road transport from Bing Bong Port due to the fact that shipping costs will be higher via Bing Bong Port shown in Figure 20, and there is likely insufficient latent throughput capacity at the port to support a medium to large scale oil and gas operation.

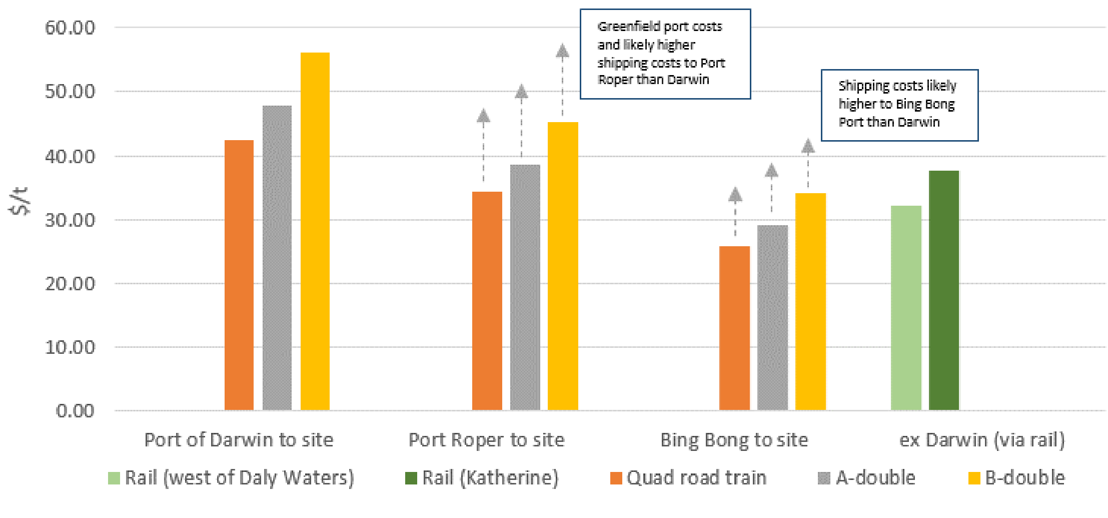


Figure E - 1 Indicative land transport costs to site (modal comparison)

Table E- 1 Shipping costs (dry bulk or containerised extractive)

Shipping (dry bulk)	Port of Darwin	Bing Bong (trans.)	Bind Bond (direct)
Vessel size	40,000t (direct)	40,000t (with trans-shipment)	5,000t (direct)
Shipping duration (example only)	15 day cycle	22 day cycle	20 day cycle
Indicative daily rate	$20,000/day	$20,000/day	$12,000/day
Shipping cost	$300,000	$440,000	$240,000
Transhipment cost allowance per call **	-	$160,000	-
TOTAL COST	$300,000	$600,000	$240,000
$/T	**7.5**	**$15.0**	**$48.0**

* Assumes extra 1,000 km each way to reach Bing Bond (+5 days at 10 knots) and extra 2 days to tranship product onto barges

** Transhipment cost allowance assumes two self propelled trans-shipper barges are located permanently at Bing Bong at $10,000 per day or $3.65 M per year each (i.e. $7.3 M per annum). This cost is spread across 45 calls based on a demand of $1.8 Mtpa for proppant sand.

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