MARSDEN JACOB ASSOCIATES

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Common user transmission and decarbonising Pilbara energy demand

A report for the Clean Energy Finance Corporation

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A Marsden Jacob Report

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Contents

Tables

Figures

1. Executive Summary

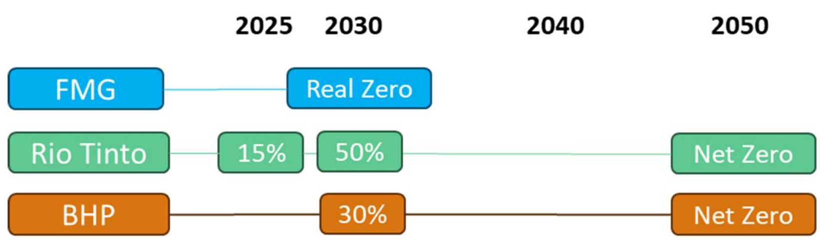
Context

The Pilbara is nationally significant in terms of its contribution to the economy but also to emissions and energy use. Heavy industries, dominated by iron ore mining and liquefied natural gas (LNG) production, contribute a third of national exports and nearly 20% of Western Australia's total economic output.[1]

Pilbara industry accounts for around 23% of the national safeguard facility total greenhouse gas emissions or 40% of that for Western Australia, making it central to Western Australian and Australian decarbonisation ambitions. [2]

The safeguard mechanism is also a key driver for reducing emissions from heavy industry, keeping Australia on track for its emission reduction targets. Pilbara iron ore miners, representing a large portion of key heavy industries in the region, have also made ambitious decarbonisation commitments at the corporate level, shown in Figure 1.

Figure 1: Mining operational decarbonisation ambitions (Scope 1 & 2) of key Pilbara companies



Source: MJA analysis of company reports, see commentary around Figure 4 for details.

Electrification is a key means for achieving the emissions reduction targets in the Pilbara region. The on-site decarbonisation of heavy industries largely relies on the ability to electrify existing practices to displace existing use of fossil fuel primary energy sources. Then the electricity system needs to transform to renewable generation from what is currently a 98% fossil fuel and 2% renewables system under the North West Interconnected System (NWIS).

The Pilbara is rich in solar and wind resources. New transmission infrastructure is needed to unlock this opportunity and the most efficient means of building this infrastructure is on a common user basis. The Pilbara is a key region for growth of new green industries, especially green iron / steel, green ammonia and green hydrogen.

This energy transition delivers two kinds of savings in energy purchase and greenhouse gases (GHG) emissions costs, illustrated by Figure 2 below while maintaining or growing production.

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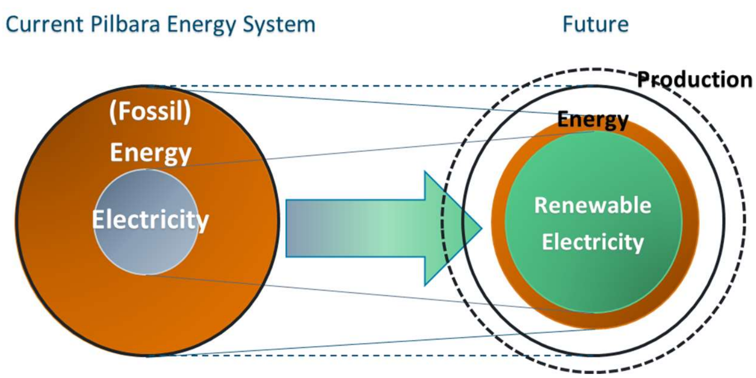
[1] Pilbara Development Commission, Pilbara Economic Snapshot - Edition 6, June 2024 https://www.pdc.wa.gov.au/publications/snapshots.aspx

[2] See https://www.climateaction.wa.gov.au/initiatives/connecting-renewables-in-the-pilbara.

- The costs of primary fuels decreases because the requirement for primary fuel decreases, even for fossil fuel-based electricity, simply because of the higher efficiency of the electrical equipment that puts that energy to its final use.
- The costs of electricity generation decrease as the system transforms to clean energy.

Figure 2: Transformation of the electric and total energy systems for production



Outside of iron ore mining, other significant industries (e.g. lithium mining, ammonia/fertiliser production) benefit from access to the abundant renewable energy resources in the Pilbara. Common User Transmission Infrastructure (CUTI) is a key facilitator of this renewable electricity transition, enabling both existing large industrial energy users and smaller industries to transform their practices to realise savings in costs and emissions through access to a renewable electricity system.

Availability of low-cost renewable energy will also drive new green industries and associated competitive advantage. This represents growth in future production in Figure 2, signifying substantial potential growth in the renewable electricity system.

Since 2022 the WA Government has been building alignment on key challenges amongst stakeholders and facilitating clean energy transition planning in the Pilbara, through CUTI, convening the Pilbara Industry Roundtable (PIR) to bring together key stakeholders (including representatives from heavy industry). In August 2023 its participants reached a consensus that CUTI has "an important role to play in supporting increased levels of renewable energy and decarbonisation in the Pilbara" and the next round of planning priorities. To achieve this CUTI vision traditional energy market players must in turn relinquish some of their independence, however they are the greatest potential winners from a common user system.

Modelling approach

This report has sought to quantify and qualify at a high level the economic, financial, social and emission abatement impacts and benefits of CUTI necessary to decarbonise energy use by the major industrial exporters operating in the Pilbara region of Western Australia. The objectives of the report include identifying and assessing the:

a. **energy efficiency and avoided carbon emissions gains** from the electrification of the current and future energy demand in the Pilbara;
b. **scale of the investment** required to achieve decarbonisation and electrification;
c. **the relative benefits of CUTI** to transfer power from renewable generation hubs (RGHs) to major demand centres at liquefaction facilities, mines, strategic industrial areas, and ports and rail, compared with the miner "go-it-alone" approach, including potential to reduce capital, financing and operating costs, land usage and approvals timelines, and traditional owner implications; and
d. **opportunity for future decarbonised expansion** of major and mid-sized industrial processing industries using CUTI.

The focus on the benefits of CUTI directs our approach to focus on the future of the NWIS electricity system, while understanding the implications for the wider energy system. To achieve this our approach considers three cases combining transmission development and demand scenarios:

1. A Base case combining “fit for system purpose” CUTI transmission development with business as usual (BAU) demand scenario;
2. An Autarky case with "miners go-it-alone" transmission with BAU demand scenario; and
3. A High Demand case with CUTI development enabling higher demand through wider electrification and growth along the coast connected to inland renewable energy sources.

The main objective of the Base and Autarky cases is to examine the differences in generation and transmission investment required due to the choice of transmission development regime. Demand, electrification (and decarbonisation) of end use, transmission technical specification and system emissions reduction targets / constraints and reliability are effectively held constant in modelling, although in reality these will vary.

Table 1: Overview of projected supply cases and demand scenarios

Case	Transmission development	Demand scenario	Key demand feature
Base	CUTI in designated priority corridors	BAU	Electrification of mining primary energy from diesel
Autarky	Miners "go it alone"	BAU	Electrification of mining primary energy from diesel
High demand	CUTI in designated priority corridors	High Demand	Electrification of mining and LNG production primary energy from gas

The third High Demand case seeks to explore how CUTI contributes to the development of substantial new energy intensive industries to take advantage of the region's ample renewable energy resources. MJA do not consider an Autarky development approach for the High Demand case because it is very unlikely that this approach could efficiently meet a High Demand case in the Pilbara.

These cases are used to identify and compare the impact of CUTI on the total costs and benefits of decarbonising existing mining, LNG production, and other major energy demand in the region and future demand growth.

These assumptions are derived from information provided by CEFC and public sources at the time of modelling. In the actively evolving Pilbara context, both the demand and network outlooks may have changed since the time of this modelling.

Key findings

The findings from modelling the above cases, as well as our qualitative findings, include the following:

1. **New transmission infrastructure underpins the energy transition in the Pilbara.** Based on a transmission build program over 2000 kms to 2031, the electricity system rapidly transforms to a variable renewable energy system by the mid-2030s including 4.0 GW solar, 5.0 GW wind and 6.3 GW batteries by 2035 in the Base case.
2. **Significantly more (~19% by nameplate capacity) variable renewable energy (VRE) and storage assets are required in the Autarky case** over 25 years compared to the Base case to meet **the same demand**, because energy can only be shared within the four isolated existing networks.
3. **Electrification** of energy use **delivers end user savings from primary energy that is simply not used** due to displacement of inefficient thermal generation. In mining this averages around **110-140 PJ p.a. or 2.8-3.6 billion litres of diesel** representing **$4.2-5.8 billion p.a. avoided economic costs**.[3] A **further 51 PJ/$500 million p.a**. savings potential from electrifying **LNG production** where CUTI brings renewable energy to the coast.[4]
4. Significantly, in the High Demand case, the construction of CUTI by the early 2030s with sufficient capacity enables larger investment in generation facilities needed for higher demand, with further avoided primary energy and avoided carbon emissions - **62% additional nameplate capacity** is required to enable an **additional 33% of energy demand by 2050**.
5. **Gas powered generation's (GPG) role transforms** in the energy transition into a **backstop** when VRE inter-day energy shortages occur (both direct and stored energy), and it is not possible to recharge batteries. CUTI enables VRE to be optimised to meet wider electrification demand and minimise VRE shortfalls and GPG operation. The reduction in GPG utilisation will lead to an estimated average **$2.2 billion p.a. avoided fuel costs.**[5]
6. **Decarbonisation is a direct result of the avoided primary energy sourced from fossil fuels**: in the Base case an average of **24 Mt CO_2-e p.a. is avoided**. Based on Infrastructure Australia's guidance for valuing emissions, this corresponds to an average value of **$7.6 billion per annum**. The CUTI with the **High Demand** case avoids an **additional 9.6 Mt CO_2-e p.a.**, with an average of **35 Mt CO_2-e avoided emissions each year worth $10.4 billion per annum.** Although the Autarky case targets the same

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3 Range reflects the variation in electrification of demand between cases.
4 In the High Demand case.
5 Annual costs averaged over the period 2031 to 2050.

carbon reductions as the Base case, in practice the transmission planning choice matters. It is less likely in an autarky scenario that other industries (e.g. small and medium miners) would be able to connect to transmission, and more likely infrastructure would be delayed, such that reduced emissions would be overstated.

7. I**nvestment towards decarbonisation is substantial, including annualised $510 million p.a. transmission** and **$5.4 billion p.a. generation** in the Base case calculated over the 25-year study period from 2025 and 2050. The capital expenditure is driven by industry and government commitments to decarbonisation.
8. ***However***, the **Base case delivers the required load** including electrification by miners at **a lower system cost of $126 billion** than the Autarky case that costs **$157 billion over 2025-50**. This investment yields savings in **avoided primary fuel costs** averaging over **$6.6 billion p.a.** over the period 2031 to 2050, combining both end user costs and electricity system costs.
9. **CUTI system planning enables wider participation by both load and generation developers that enables growth of new industries in the Pilbara.** The larger High Demand case calls for proportionately more infrastructure, but with **a system cost of $176 billion** (calculated between 2025-50) this cost is **12% more** than the Autarky case while serving a **load that is 33% higher**.
10. CUTI system planning facilitates a wide range of planning, environmental and social benefits. A "fit for system purpose" approach can **reduce** the infrastructure footprint by **2,845 ha or 21% for transmission** and **9,704 ha or 7% for generation (~12,500 ha or 8% in total)**, requiring fewer approvals and consultations. Although not modelled, fewer land approvals may lead to reduced timeframes for securing land and consequently building transmission infrastructure. This contributes to more timely electrification, decarbonisation of the Pilbara and greater emission savings.
11. The CUTI approach enables co-ordinated engagement with government agencies, industry and Traditional Owners, with a common regulatory framework that reduces risks for developers and users and help to streamline approval processes. Additionally, a single, networked system, as opposed to four, will be easier to operate and manage under normal operating conditions, and be more resilient to outages with the increased frequency and intensity of extreme weather events that are likely to arise with climate change.

What's needed?

The Pilbara energy system is at an inflection point. Decarbonisation provides the opportunity for wholesale system change, as it does across Australia and the world. A product of its history of independent decision making by powerful industrial players, the question is whether that autarkic approach can deliver an efficient decarbonised energy system in a timely manner. This study indicates that independent decision making will be inefficient and risks the social license for achieving emission reductions in the Pilbara.

The option of a common user investment framework approach is well understood and applied in Australia generally. It already exists in the NWIS Pilbara Network Rules. The National Electricity Market (NEM) which delivered huge productivity benefits to the nation, recognised that sharing infrastructure across the states delivered benefits to all users.

The challenge to all stakeholders is to recognise their own roles and bring their capabilities to the common task. This has commenced already through the Pilbara Energy Transition Plan with the leadership by the WA Government, and participation of industry, Traditional Owners and others. To this the Australian Government has made available up to $3 billion concessional finance through the Rewiring the Nation program.

The pace of the change requires all stakeholders to commit and recommit to the challenge and evolve their own role/responsibilities to meet the system needs. The evolution of the energy transition requires the WA Government to continue a leadership role for the duration of that transition, coordinating the planning and actions of all stakeholders through each phase of change. Traditional energy autarkies must in turn relinquish some of their independence and work collaboratively with Government to support the most efficient outcomes.

2. Introduction and background

This report identifies the potential economic, emissions abatement and social benefits from efficient electricity transmission planning and investment necessary to decarbonise energy use by the major energy and mining exporters operating in the Pilbara region of Western Australia.

Decarbonisation means electrifying industry with an expanding renewable electricity system. Electrification delivers significant efficiency dividends to end users. The total energy system in the Pilbara contracts as the losses of inefficient thermal power systems are avoided, saving money and carbon emissions.

CUTI is a key facilitator of this transition, enabling not only existing large industrial energy users to transform their practices to realise savings in costs and emissions, but also to enable decarbonisation of smaller existing loads in the Pilbara as well as support the development of future new green industries in the Pilbara.

2.1 Introduction

This report was commissioned by the CEFC and focuses on the impact of CUTI in the Pilbara region.

The common user investment framework enables physical assets to be shared between multiple users under a defined set of terms. The infrastructure can be owned, operated and delivered by private or public entities and it may include, for example, transport, utilities, port infrastructure and even workers' accommodation. This framework enables investors and developers to 'right size' infrastructure to meet future requirements of the system. This may deliver benefits to all users and stakeholders, for example, in the form of lower overall input costs through reduced duplication, increased competition, more efficient use of land, or reduced carbon emissions. The CEFC can bring finance to support CUTI to achieve this right sizing outcome in the Pilbara.

This report assesses the benefits of CUTI assets for the Pilbara economy and decarbonisation of the iron ore mining and LNG production industries that dominate the region.

This report seeks to articulate and quantify at a high level the economic, financial, emissions abatement and social benefits of decarbonising the Pilbara economy through CUTI. The objectives of the report include exploring the:

a. **energy efficiency and avoided carbon emissions gains** from the electrification of the current and future energy demand in the Pilbara;

b. **scale of the investment** required to achieve decarbonisation and electrification;

c. **the relative benefits of CUTI** to transfer power from RGHs to major demand centres at liquefaction facilities, mines, strategic industrial areas, and ports and rail, compared with the miner "go-it-alone" approach, including potential to reduce capital, financing and operating costs, land usage and approvals timelines, and traditional owner implications; and [6]

d. **opportunity for future decarbonised expansion** of major and mid-sized industrial processing industries using CUTI.

This chapter introduces the background this report, including key concepts in the energy system and the opportunities for decarbonisation in the Pilbara. Section 2.2 is focused on the Pilbara including its national significance to decarbonisation. The characteristics of the NWIS electricity system within the wider Pilbara energy system are described in Section 2.3. Section 2.4 summarises the energy transition in the Pilbara so far and why this report is relevant to the CEFC and other stakeholders now.

Chapter 3 describes the approach to the electricity system modelling, key assumptions regarding network configuration and projected demand and the key technical features of the future renewables based NWIS. This includes both the physical characteristics of this renewables system, and the financial assumptions for the realisation of that renewables system.

Chapter 4 describes the benefits of electrification of the Pilbara energy system, including the benefits of energy efficiency and decarbonisation.

Chapter 5 describes the benefits of investment in CUTI and the relative advantages of the Base and Autarky cases, and the optional potential of CUTI enabling wider electrification, decarbonisation and growth.

Chapter 6 considers the wider benefits of “fit for system purpose” CUTI planning including a range of other planning, environmental and social benefits.

Chapter 7 summarises the key findings from modelling the three transmission cases and the combined benefits of electrification and of CUTI in the preceding chapters.

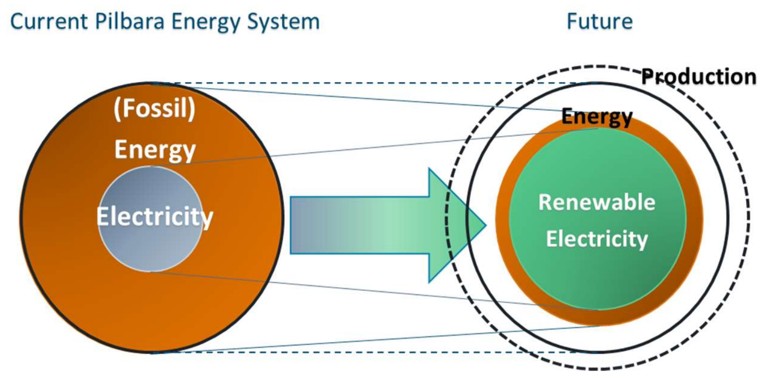
Chapter 8 outlines the enablers that are needed to support a CUTI development path in the Pilbara.

2.2 Decarbonisation opportunities from electrification in the Pilbara

Most generally, the decarbonisation potential of electrification of users' energy demand is based on individual households and companies replacing fossil fuels with renewable electricity in their primary energy use. Consequently, for the same level of final energy use proportional to production or even increased production, the smaller electricity system expands to become coincident with the larger energy system, while total primary energy use reduces because of higher efficiencies associated with equipment electrification, as illustrated by Figure 3.

[6] In economic terms this "go-it-alone" approach of independence is an autarky - a term used in this report in contrast to common user infrastructure.

Figure 3: Transformation of the electric and total energy systems for production



National significance of decarbonisation in the Pilbara

The Pilbara is a powerhouse of Australian export industries with iron ore mining, LNG production and other heavy industries, contributing a third of national exports and nearly 20% of Western Australia's total economic output.[7] This heavy industry also accounts for around 23% of the national safeguard facility total greenhouse gas emissions or 40% of that for Western Australia.[8] Hence decarbonisation in the Pilbara plays a central role in meeting the emissions reductions targets set by the Australian and Western Australian governments.

Decarbonisation of heavy industries largely relies on the ability to electrify existing practices to displace existing use of fossil fuel primary energy sources and then transform the electricity system to renewable generation from what is currently a 98% fossil fuel and 2% renewables system.[9] The Pilbara is rich in solar and wind resources. The improved economics of storage to complement solar/wind generation make renewable energy the cheapest option for future energy, making it the preferred approach to electricity system transition.

The safeguard mechanism is a key driver for reducing emissions from heavy industry, keeping Australia on track for its emission reduction targets. Pilbara's heavy industries are covered under the safeguard mechanism and have also made their own decarbonisation commitments. Iron ore and LNG industries dominate total energy demand and their ability to underwrite their own energy infrastructure have shaped the energy system and its decarbonisation ambitions to date. Iron ore miners, representing a large portion of key heavy industries in the region, have made ambitious decarbonisation commitments at the corporate level, summarised in Figure 4 below (noting that briefly summarizing ambitions specific to the Pilbara consistently is difficult as each company describes different scope of operations and employs different language and baselines).[10] While these

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7 Pilbara Development Commission, Pilbara Economic Snapshot - Edition 6, June 2024 https://www.pdc.wa.gov.au/publications/snapshots.aspx

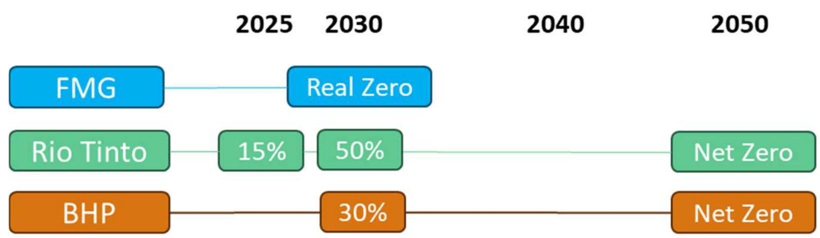
8 See https://www.climateaction.wa.gov.au/initiatives/connecting-renewables-in-the-pilbara. Note totals and proportions may vary based on the facilities included based on geographical scope and the year of comparison. This report restricts the geographical scope excluding Onslow from NWIS, excluding LNG production located there.

9 See https://www.wa.gov.au/organisation/energy-policy-wa/pilbara-energy-transition-plan

10 FMG is the most ambitions with Real Zero targets (i.e. without offsets) by 2030 for Australian terrestrial iron ore operations, 50 per cent reduction by 2030 in emissions intensity levels from iron ore shipping and aiming for Net Zero Scope 3 emissions by

commitments are meaningful, other significant industries (e.g. lithium mining, ammonia/fertiliser production) and future industries need access to a common, renewable electricity system to meet their own decarbonisation commitments.

Figure 4: Mining operational decarbonisation ambitions (Scope 1 & 2) of key Pilbara companies



Source: MJA analysis of company reports – see footnote to text.

CUTI is a key facilitator of this electricity system transition, enabling a fit-for-purpose electricity system that provides all users access to abundant renewable energy resources underpinning the transformation of their practices to realise savings in costs and emissions.

2.3 North-West Interconnected System and the Pilbara energy system

The focus of this report is on transmission infrastructure as an enabler of the transition to a renewable electricity system– a network of relationships between load nodes and generation sources. As illustrated by Figure 3 above, the significance of that transition impacts the broader Pilbara energy system including the use of diesel and gas as primary energy fuels. The following boxes introduce these two systems before we focus on the network's relationships of load nodes and the RGHs identified by Energy Policy WA (EPWA) for the PIR (discussed further below).[11]

Pilbara energy system

The Pilbara is dominated by a small number of very large, mostly islanded, diesel and gas-based energy systems operating outside of or with relatively small physical links to the NWIS. The bulk of current demand is supplied by vertically integrated supply chains within each major demand portfolio of major iron ore and gas resource companies.[12] In economic terms, the Pilbara energy system is currently made up of **several autarkies** - each major resource company makes its own arrangements to supply most of its own energy demand.

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2040 (see FMG Climate Transition Plan, September 2024). On Scope 3, Rio Tinto has a long-term commitment for overall global mining activities to achieving net zero by 2050, with aims to reduce Scope 1 and 2 emissions by 15% by 2025 and 50% by 2030 (2025 Climate Action Plan, September 2024). BHP has a target of 30% reduction by 2030 of global operations (Scope 1 and 2) emissions towards a goal of net zero, together with a long-term goal of net zero Scope 3 emission by 2050 (Climate Transition Action Plan 2024). Roy Hill Iron Ore Mine, not shown, has set regular targets for emissions reduction in line with required environmental planning and legislated Commonwealth Safeguard obligation and West Australian goals. Currently these include a 36% Scope 1 reduction by 2032 over 2022 emissions (see Roy Hill Greenhouse Gas Management Plan Summary Report 2023).

11 EPWA, Pilbara Industry Roundtable Workstream 1: Pilbara Electricity Modelling, 26 July 2023.

12 Depending on the metric, this handful of companies comprise more than 80 or 90% of the Pilbara energy system.

The North-West Interconnected System

The NWIS comprises five Economic Regulatory Authority licensed[13] transmission systems, generation and distribution assets linking the major towns of Port Hedland and Karratha on the northwest coast and extending inland through Rio Tinto's network.

The NWIS transmission assets in four separated networks are owned by five organisations: Horizon Power and Rio Tinto; APA Group; BHP; and Fortescue Metals Group (FMG). The NWIS uses high voltage alternating current, with overhead conductors requiring easements.

Approximately 2,200 MW of installed generation facilities are connected to the NWIS. This capacity largely consists of low efficiency open cycle gas turbines providing dispatchable thermal generation. There are two generators using the more efficient combined cycle gas turbine.

Major electricity customers in the NWIS include the port operations at Port Hedland and Karratha of BHP, Hancock Prospecting, Rio Tinto and the FMG and other miners, their inland mine sites, as well as other mining and chemical production loads, and commercial and residential loads.

Currently, the NWIS electricity system provides less than half the energy used in mining in the Pilbara area. While together iron ore mining and LNG production comprise over 90% of current electricity demand in the Pilbara, the NWIS does not supply any of the energy used to produce LNG for export. For example, the electricity generation used for LNG production in the Burrup Peninsula north of King Bay is islanded from the NWIS node at Karratha. Similarly, Chevron's Gorgon and Wheatstone LNG electricity generators at Onslow are not connected to the NWIS. Also, LNG trains use gas directly from their own gas supply.

The relationships between existing networks, load nodes (blue) and the proposed RGHs are represented in Figure 5 below.

The existing electricity system can be summarised as:

- Horizon Power/Rio Tinto - Port Hedland to Karratha on the coast, extending inland to Rio East;
- Fortescue Metals Group - Fortescue West to Fortescue Coast geographically at Port Hedland but not connected to Horizon Power network;
- BHP – connecting BHP Central to Newman;
- APA Group - connecting Newman to Chichester (and Roy Hill); and
- Isolated load centres at Onslow, Sino and Burrup Peninsula (as opposed to Burrup).

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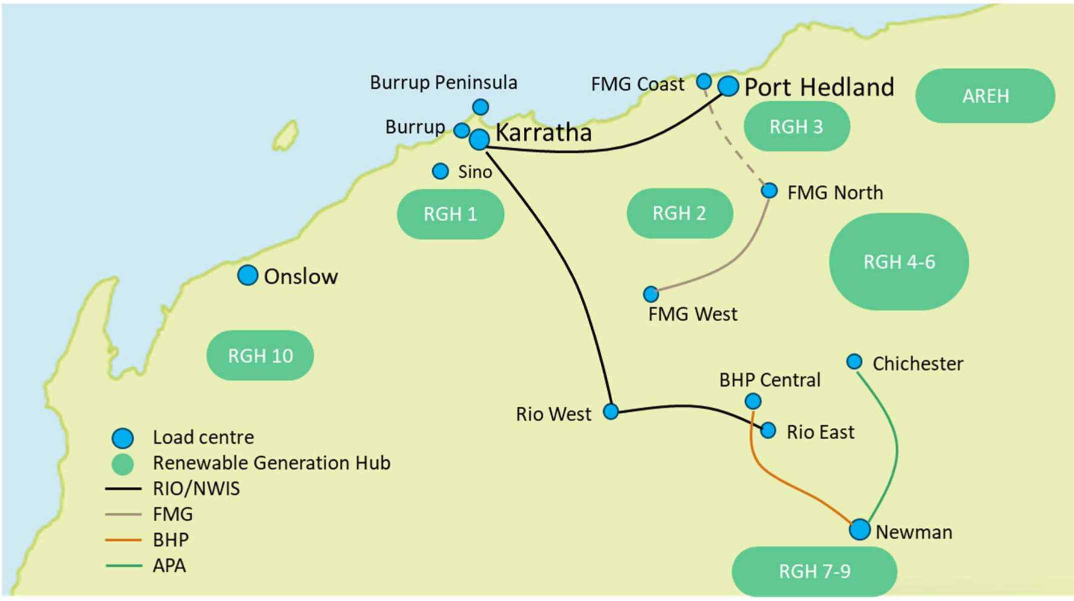
13 See https://www.erawa.com.au/electricity/electricity-licensing/licence-holders

Figure 5: Current Pilbara electricity networks, load nodes and future renewable generation hubs[14]



Source: Horizon Power, Pilbara ISO, EPWA Pilbara Industry Roundtable

2.4 Pilbara Energy Transition Plan

The improved economics of storage to complement solar/wind generation make renewable energy the cheapest option for future energy, making a fit-for-purpose system the preferred approach to electricity system transition.

Currently, the Pilbara industries that dominate ambitions to decarbonise and realise energy efficiencies are those autarkic sectors and companies (predominantly the iron ore mining sector) that have the resources to determine the fates of their own energy infrastructure. These companies have stated decarbonisation ambitions and associated infrastructure planning that are built into the "business as usual" energy demand outlook. Currently there is around 300 MW committed solar to be added to the existing 270 MW solar capacity, about 140 MW committed batteries to be added to the 120 MW existing batteries, and 45 MW committed wind generation. This "miner go-it-alone" planning we will refer to as the **Autarky case**. In the Autarky case the iron ore mining sector realises the benefits of electrification though investing in its own sole-use transmission infrastructure.

CUTI opens a range of opportunities to plan at a network system level rather than a transmission link level, engage stakeholders including Traditional Owners early and systematically, and identify means to streamline processes that collectively contribute to reduced total system costs and accelerate timelines for the energy transition.

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[14] The Australian Renewable Energy Hub (AREH) is a joint venture development integrating renewable generation with load as a low-carbon hydrogen and derivative production centre with access through Port Hedland for exports to Asia and Europe. See https://www.areh.com.au/

EPWA commenced what is now the Pilbara Energy Transition (PET) Plan in 2022 by convening the PIR.[15] The Roundtable facilitated discussion on the challenges of the clean energy transition, reaching a consensus in August 2023 that CUTI has "an important role to play in supporting increased levels of renewable energy and decarbonisation in the Pilbara". The Roundtable identified four planning themes including:

a. continued system modelling to inform CUTI development;

b. evolution of the Pilbara electricity regulatory regime;

c. updating land tenure guidance as a priority; and

d. supporting development that aligns with Aboriginal self-determination and empower Aboriginal people to realise opportunities from the clean energy transformation.[16]

Since then, the work program has evolved, in 2024 convening the PET Aboriginal Working Group providing cultural perspectives, and the Industry Liaison Committee composed of branches of WA Government and industry to understand and, where possible, address the issues facing the resources industry, energy industry and new industries in the region. In alignment with the Roundtable consensus, the Coordinator of Energy approved a scope of work to be undertaken by the evolution of the Pilbara Networks Rules Working Group.

In 2024, EPWA designated and in December awarded preferred developer rights for four priority corridors for development of CUTI in the Pilbara.[17] This CUTI planning is the basis for what we will refer to as the **Base case**.[18]

In August 2023, the Australian Government and the WA Government announced a letter of intent for up to $3 billion in concessional finance to be made available by the CEFC through its Rewiring the Nation program.[19] This investment is intended to leverage private investment to meet the transmission and infrastructure needs that underpin decarbonisation across the Pilbara economy and attract further industry to the region.

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15 Pilbara Industry Roundtable participants included Alinta Energy, ATCO, BHP, bp, The Chamber of Minerals and Energy of Western Australia, FMG, Horizon Power, Macquarie Group, Pilbara Independent System Operator Company, Rio Tinto, Roy Hill and Woodside.

16 Pilbara Industry Roundtable Communique – 26 July 2023, https://www.wa.gov.au/media/40187/download?inline

17 See https://www.wa.gov.au/organisation/energy-policy-wa/designated-priority-corridors

18 While this is a starting point for assumptions in this report, it is emphasised that the modelling here is not intended to duplicate in any sense that by EPWA/Roundtable as our purposes and focus are different, as noted in this report.

19 See https://www.pm.gov.au/media/3-billion-rewiring-nation-deal-power-wa-jobs-and-growth

3. Approach & modelling

This chapter sets out our approach to modelling the transformation of the electricity systems in the Pilbara, and understanding the consequences in terms of energy efficiency, decarbonisation and system costs. Our approach is based on the electrification in the energy system and renewable transition of the electricity system for 3 cases: the relative difference in transmission development between the **Autarky** case and CUTI **Base** case, and the additional electrification and decarbonisation potential of the CUTI approach in **a High Demand** case that provides smaller industrial sectors access to clean electricity.

New transmission infrastructure underpins the expansion of VRE. **Significantly more (19%) VRE/storage assets and (15%) transmission line kilometres** are required in the **Autarky case** compared to the Base case to meet **the same demand** by 2050 because energy can only be shared within the four existing networks.

GPG's role rapidly **transforms** in the energy transition from providing (nearly) all electricity into a **backstop** when VRE inter-day energy shortages occur, and it is not possible to recharge batteries. CUTI enables VRE to be **optimised** to meet wider electrification demand and **minimise** VRE shortfalls (direct and stored energy) and GPG operation.

The different cost of funding is a significant factor in estimates of the whole of system cost. Common access to CUTI dilutes risk attracting cheaper finance. Autarky transmission and generation, with single asset and offtake exposure, focus risk and attract higher weighted average cost of capital (WACC)s for similar assets.

3.1 Approach

The decarbonisation of heavy industries such as those that dominate the Pilbara largely relies on the ability to electrify existing operations and displace fossil fuels, and then transform the electricity system to produce, store and transport VRE generation.

The benefits then come in three categories: avoided direct liquid fuel (diesel) use; avoided direct gas use as fuel or feedstock; and the renewable mix of electricity generation. Together with the economic benefits of carbon abatement, there are avoided costs of primary fuels and operational expenses of a fossil fuel-based electricity system.

The costs come from investment in the electricity system, both to achieve the scale required to substitute for direct fuel use and to decarbonise itself. In this report we consider the capital investment required for decarbonisation of the electricity system, including the cost of new VRE generation facilities, transmission and battery electric storage system (BESS), but do not consider the capital cost to end users of equipment such as electric mining transport or e-drives in LNG trains, as it is assumed they will carry that cost in both Autarkic and CUTI cases.

The purpose of this report is to assess the benefits of CUTI; consequently, the core of our approach is focused on the future of the NWIS electricity system, while understanding the implications for the wider energy system.

Introduction to NWIS cases

Our approach is to define and compare three projected growth and decarbonisation pathways for the NWIS, summarised in Table 2 below. These cases are used to identify and compare the impact of CUTI on the total costs and benefits of decarbonising existing mining, LNG production, and other major energy demand in the region.

Table 2: Overview of projected supply cases and demand scenarios

Case	Transmission development	Demand scenario	Key demand feature
Base	CUTI in designated priority corridors	BAU	Electrification of mining primary energy from diesel
Autarky	Miners "go it alone"	BAU	Electrification of mining primary energy from diesel
High demand	CUTI in designated priority corridors	High Demand	Electrification of mining and LNG production primary energy from gas

The first comparison is between a business-as-usual Base case that includes the CUTI focus of EPWA's designated priority corridors[20], and the Autarky case where iron ore miners "go it alone" in building the transmission infrastructure they individually require. The objective is to examine the different transmission and generation investment required due to the choice of transmission planning approach. Consequently, both cases include the same BAU electricity demand outlook incorporating the same electrification ambitions (and hence end user decarbonisation assumptions), largely confined to iron ore mining operations.

In practice the transmission planning choice matters and other factors would be impacted. The benefits of the CUTI case may be understated, for example from other industries (e.g. small and medium miners) being able to connect to CUTI, access renewable energy and decarbonise their

[20] See https://www.wa.gov.au/organisation/energy-policy-wa/designated-priority-corridors

activities more than implied by this BAU electricity demand outlook. Conversely the electrification/decarbonisation benefits of the Autarky case may be overstated because qualitative factors such as approval timelines and land usage (i.e. getting more parties to agree to a proposed transmission corridor) would adversely impact the progression of the Autarky case.

The third High Demand case seeks to explore how CUTI contributes to the development of substantial new energy intensive industries that are more internationally competitive because they can take advantage of the region's ample renewable energy resources and location near major Asian markets. Under this scenario, CUTI capacity needs to be substantially higher than required under the first two cases, but this additional capacity is an enabler of more renewable generation, more electrification and more decarbonisation.

Modelling

To illustrate changes in the Pilbara energy system demand and carbon emissions, MJA combines detailed electricity system modelling and high-level energy system modelling over a 25-year forecast horizon to 2050.

Electricity system modelling

Least cost planning and simulation modelling supplies the information base for the growth and use of the electricity system.

The key differences between these cases are the approaches to the development of transmission infrastructure, and the demand scenarios enabled by that infrastructure. Otherwise, the electricity system modelling aims to satisfy the same constraints on the electricity system, such as emission constraints and reliability objectives. Sections 3.2 and 3.3 describe the network configurations and demand scenarios for the cases in Table 2 in more detail.

Section 3.4 describes the key technical characteristics of the electricity system transformed by the switch to renewable generation and the differences between the Autarky and High Demand cases from the Base case.

These scenarios focus on the transition in the electricity system, so that the approach to estimating costs and benefits varies between the "benefits of electrification" in chapter 4 and the "benefits of CUTI" in chapter 5.

Benefits of electrification

In chapter 4 we are concerned with the benefits in the Pilbara energy system from making the transition in end use applications, and each case is implicitly compared with the primary energy consumed and associated emissions of a “no decarbonisation” scenario. The avoided primary energy and associated emissions from employing electric powered equipment are implied by the energy efficiency ratio(s) applied to the electricity attributable to electrification of this equipment. The avoided carbon emissions of a renewable electricity system are implied by the current emissions intensity of the NWIS applied to the projected demand to be met. Chapter 4 is indicative of the "size of the prize" for making the transition in the Pilbara electricity system.

Section 3.5 describes the principles underlying the energy efficiency ratios employed in modelling the primary energy savings from electrification of these end-uses in the Pilbara.

Benefits of CUTI

In chapter 5 we focus on the Pilbara electricity system and the relative costs of CUTI and Autarky transmission development approaches to implementing the decarbonisation transition that is itself a fundamental assumption. As noted above, this report is limited to equating the electrification benefits of the Base and Autarky cases, so that the benefits of one approach is the avoided costs from one approach over another.

Section 3.6 outlines the differences in the financial assumptions employed in modelling the long-term costs of these renewable transformations between the CUTI and Autarky planning approaches.

Assumptions and limitations

The analysis involves both high level energy system analysis and detailed electricity system modelling of the Pilbara electricity system.

The electricity system modelling draws on the techno-economic assumptions used in the two EPWA PET reports.[21] The system configuration required assumptions to be made regarding high-level network configuration and transfer capacity, the number of major supply and demand centres. The allocation of industrial demand was inferred from public information in sources such as Annual Reports that do not necessarily distinguish Pilbara operations in wider portfolios. In the actively evolving Pilbara context, both the demand and network outlooks may have changed since the time of this modelling.

The electricity system modelling identifies the system requirement, which is the quantum of renewable generation resources required to meet system demand given parameters such as reliability at least cost. It does not model (gas) plant exits, which would be an exogenous constraint on the dispatch simulation. Nor does it not account for wider economic influences in the Pilbara that may help or hinder deployment of that infrastructure.

The analysis is focused on a scenario study of different transmission planning approaches. It considers the direct capital cost of Pilbara electricity system decarbonisation, excluding the cost of associated industry plant and equipment, and infers the avoided costs of avoided primary fuel and carbon emissions. It is not a technical or techno-economic optimisation of the transmission system within a particular planning approach.[22]

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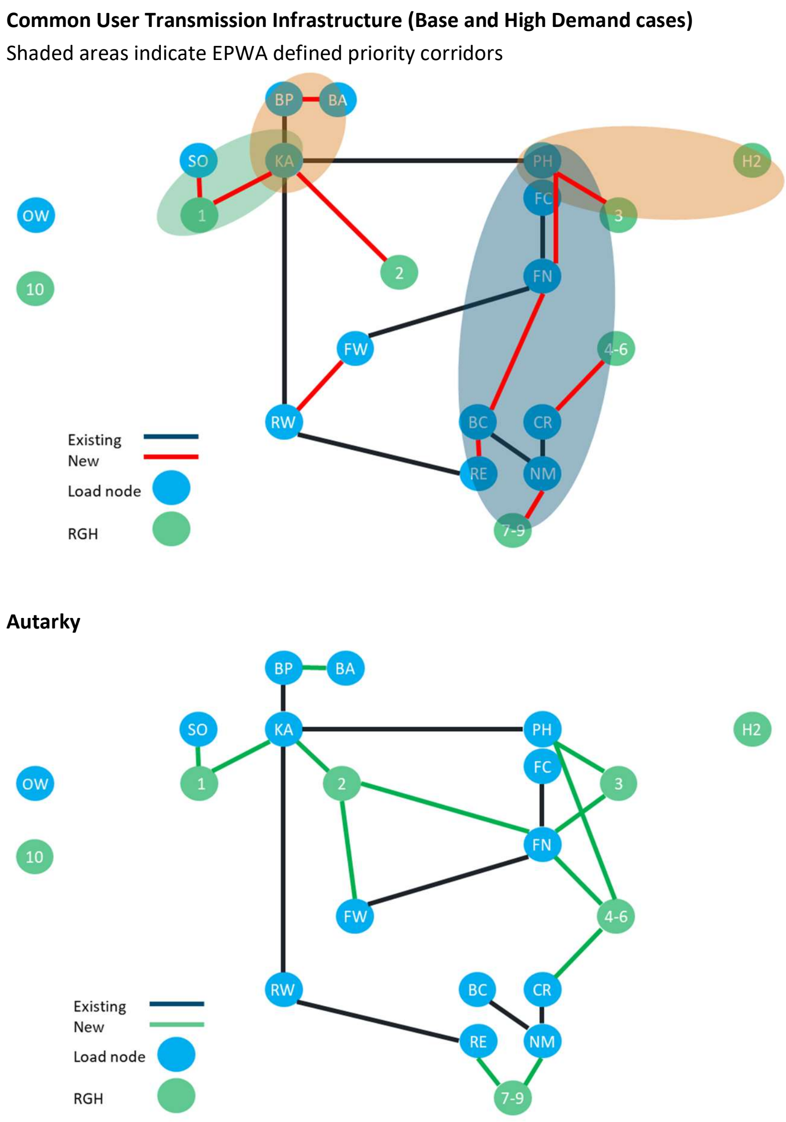
21 Pilbara Industry Roundtable, Workstream 1: Pilbara Electricity Modelling, Preliminary findings and next steps, 26 July 2023, Energy Policy WA; EPNR Working Group, Evolution of Pilbara Network Rules Working Group, EPWA, 22 August 2024. Note the objective here is to assess two transmission development approaches, so together with varying assumptions the modelling outcomes will differ from EPWA goals focused towards techno-economic optimisation.

22 Note these differences in objectives, together with varying assumptions, will guide the modelling towards outcomes that differ from EPWA resources drawn on to complete this work. Therefore, this does not infer anything about EPWA's own modelling outcomes.

3.2 Network configurations

The two network configurations employed in the three cases are described by the topological maps in Figure 6 below. These topological maps extract just the network relationships of links between nodes, omitting extraneous information from the geographical map in Figure 5 above. For brevity, the load node names are replaced by abbreviations and the RGH are represented just by their identification number as indicated by the legend.

Figure 6: CUTI and Autarky network topologies



Load Nodes

H2 AREH
BA Burrup Peninsula
BC BHP Central
BP Burrup
CR Chichester
FC FMG Coast
FN FMG North
FW FMG West
KA Karratha
NM Newman
OW Onslow
PH Port Hedland
RE Rio East
RW Rio West
SO Sino

RGH

1 RGH1
2 RGH2
3 RGH3
4 RGH4
5 RGH5
6 RGH6
7 RGH7
8 RGH8
9 RGH9
10 RGH10

The proposed CUTI network is illustrated by the top map, showing the proposed transmission links between 12 networked nodes for load and towards RGHs. The existing links will be upgraded, and the proposed new links are primarily in the EPWA defined priority corridors for the Burrup Peninsula, Chichester Range south of Burrup, Hammersley Range south of Port Hedland and Great Sandy Desert east of Port Hedland. This configuration is used in the Base case as a 220kV network and High Demand case as a 500kV network links between load nodes and 220kV links to RGHs.[23]

The bottom map shows the transmission links in the Autarky case. In this case there are no extensions of the four existing networks, only independent 220kV links from these networks to RGHs. It is assumed each existing network will have to upgrade.

While shown in Figure 6 for completeness, two load nodes have been excluded from the current analysis. The load node at Onslow has been excluded from this study as there is no current proposal to link Onslow. The Australian Renewable Energy Hub (AREH) load node is also shown, but similarly with no proposed linkage to the CUTI network. In general, the AREH site is considered self-sufficient for the purposes of the modelling here- generation is constructed to meet electrolyser loads and load is flexible to variable renewable generation and batteries installed. These two sites do not contribute to the network load - discussed further in the demand analysis below.

Both the Base case and Autarky case represent over 2000 kilometres of transmission line construction. Table 3 shows there is a trade-off between the new/upgraded transmission links between load nodes and rationalised RGH links in the Base case versus the duplication of links to RGHs from different load nodes in the Autarky case. **The net difference in line length is of the order of 17% higher in the Autarky case**.

Table 3: Estimated total new and upgraded transmission line lengths (km), 2025-50

Scenario	New node links	Link upgrades	RGH links	Total
Base	511	1072	779	2,362
Autarky	0	957	1,812	2,769
Difference	-511	-115	1,033	407
Increase		-11%	133%	17%
High Demand	511	1072	779	2,362

3.3 Projected electricity demand

For the three cases considered we use two projections of electricity demand in the Pilbara following the approach by EPWA for the PIR: a "business as usual" scenario where decarbonisation proceeds based on announced plans, used for the Base and Autarky cases, and an "ambitious decarbonisation" scenario used for the High Demand case.[24]

The figures below decompose these projections into the key components of electricity demand growth. Industrial demand has been separated into two components industry by industry:

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23 The 500kV transmission in is an assumption based on Pilbara Industry Roundtable reports cited, including reliability recommendations. These are consistent with the levels of energy flows in MJA modelling. However, this is not technical advice - a lower level (say 330kV) with lower costs may suffice, as noted techno-economic optimisation is out of scope for this study.

24 EPWA, Pilbara Industry Roundtable Workstream 1: Pilbara Electricity Modelling, 26 July 2023

- The **base demand of an industry BAU growth** is based on forecasts of industry production, based on the Australian Industry Energy Transitions Initiative forecasts, except for LNG Exports that are based on International Energy Agency (IEA) World Energy Outlook.[25] This is estimated as the electricity demand required to meet expected production. Iron ore mining and LNG export already comprise over 90% of NWIS load; and
- Sector **demand above BAU growth** is attributable to the electrification of industrial processes. This is productive energy that would otherwise be sourced from fossil fuel primary energy and hence producing carbon emissions.

The NWIS total system load is decomposed into load nodes from public sources - this is dominated by assumptions about the location and production capacity of iron ore mining and LNG export.

Figure 7: Composition of NWIS electricity demand growth in Base case projection

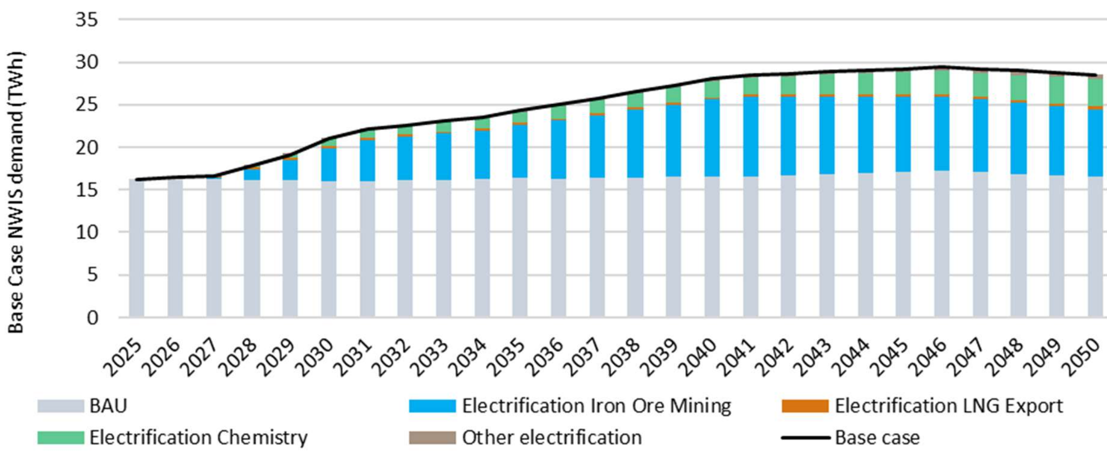

Figure 7 illustrates the Base case BAU demand projection, showing that there is minor growth in BAU demand and the major components of demand growth come from electrification of iron ore mining and the electrification of industrial chemical production (e.g. ammonia). There is a small amount of electrification in LNG exports, but no significant change to energy-intensive mechanical compression and liquefaction trains that are the main source of the industry's energy demand. There is some other electrification of industry (i.e., lithium mining and residential/commercial) but this is only minor given that energy use in these sectors is small relative to Iron ore and LNG.

Onslow and AREH are excluded from this study, as noted above. The proportion of BAU and new demand attributable to Onslow is deducted from these projections. Future hydrogen loads are assumed to be located at the AREH consistent with BP's announcements and EPWA's assumptions. While demand for green hydrogen/ammonia is reasonably certain in principle, AREH is expected to

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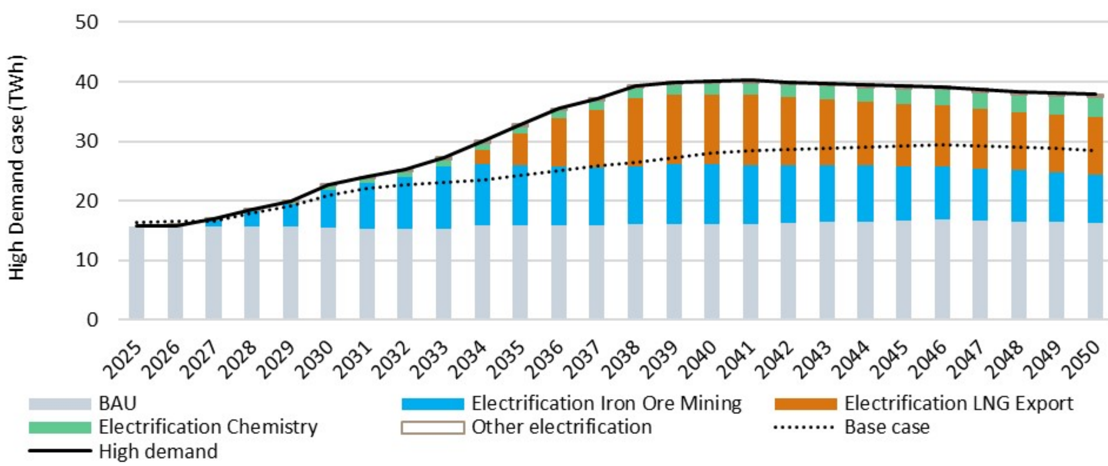
[25] See Climateworks Centre and Climate-KIC Australia, 'Pathways to industrial decarbonisation: Positioning Australian industry to prosper in a net zero global economy', Phase 3, Australian Industry Energy Transitions Initiative, 2023
Note that BAU production growth for chemical production in these forecasts is incremental. However, Perdaman Chemicals and Fertilisers has invested in a 2Mtpa capacity Pilbara urea plant that will be a step change in production for Pilbara and Australia when completed. This is not included in this modelling.

be self-supplying, scaling generation facilities to actual contracted demand.[26] These exclusions do not materially impact the modelling that is focused on the relative benefits of the CUTI versus Autarky approach to developing transmission infrastructure.

A core benefit of CUTI beyond the Base case is that the construction of CUTI by the early 2030s with sufficient capacity enables electrification and access to renewable energy beyond the demand of current interested parties, primarily the iron ore miners. This includes mid-tier and small miners and other nascent industries in the Pilbara that could not otherwise support their own transmission infrastructure.

The High Demand forecast demand case is premised on new demand, notionally from LNG producers as shown in Figure 8 below, where gas powered mechanical trains are replaced with electric drive trains to facilitate decarbonisation through avoided gas combustion and VRE power. But effectively the High Demand case encompasses any new source of demand where CUTI supports the transmission of electricity to the coastal demand centres. This results in a final demand that is a third higher than the Base case.

Figure 8: Composition of NWIS demand growth in High Demand projection



3.4 Modelling electricity generation mix

This section reports on key features of the transformation of the Pilbara electricity system that underpin the findings on decarbonisation and system costs in the following chapters 4 and 5.

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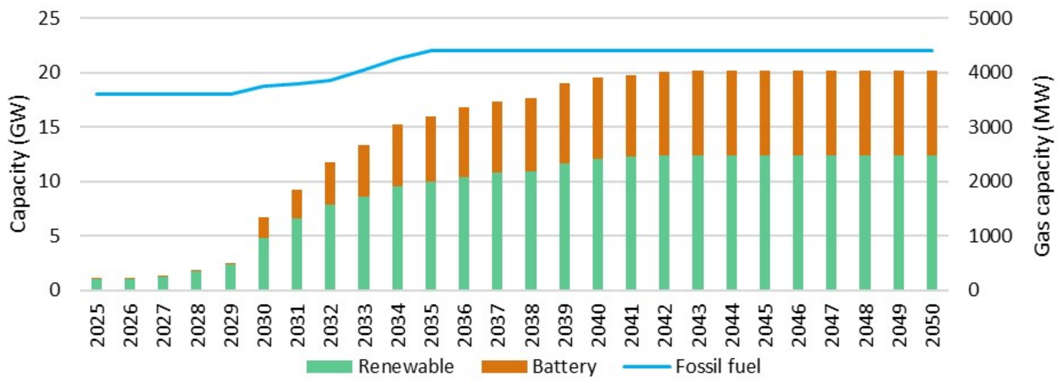
[26] Pilbara is envisioned as a major source of maritime bunker fuels in adjacent markets in South East Asia, for example: RMI, Oceans of Opportunity Supplying Green Methanol and Ammonia at Ports, Zero-Emission Shipping Mission, April 2024; DNV, Energy Transition Outlook 2024 Maritime Forecast to 2050, 2024: and DITRDCA, Singapore and Australia Green and Digital Shipping Corridor, March 2024.

Base case

The system transformation in the Base case is characterised in the following charts, illustrating the growth of total VRE generation and storage capacity (Figure 9) and the displacement of fossil fuel energy production and the eclipsing of fossil fuel as dispatchable energy by batteries (Figure 10).

The transformation of the NWIS occurs relatively rapidly to put in place the facilities and infrastructure necessary to decarbonise most electricity demand by 2040 (see Figure 9). The lower capacity factors of renewable energy are reflected in the 3.5X size of renewable capacity compared to the 2X demand growth (see Figure 7).

Figure 9: Total generation capacity - Base case



A system dominated by large industrial loads has a largely flat load profile, although this may change to some degree in future as electrification diversifies end loads. In general *variable* renewable generation profiles do not align with such loads, even when there is some variation between VRE generation sites. Consequently, extensive storage of VRE generation is required to intraday time-shift generation to demand, particularly overnight demand. Large quantities of 8-hour battery storage are constructed to run sequentially through the night, with sufficient VRE to charge the batteries each day.

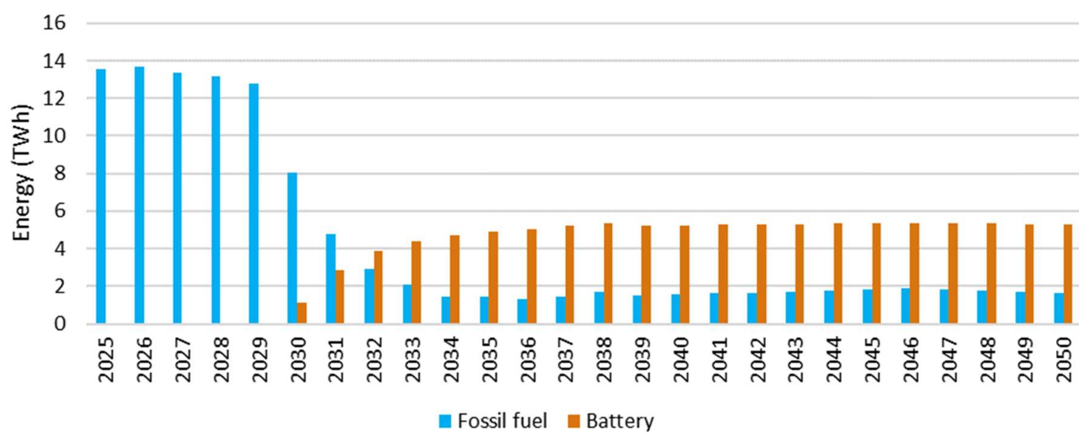
However, at times cloudy, low wind weather patterns mean that daily generation is insufficient to meet concurrent load and charge batteries. This inter-day VRE (both direct and stored) energy shortage means that the existing GPG facilities are used to meet this demand. This altered role retains GPG in the system as shown in Figure 10 following the system transition between 2029 and 2035. Following 2035, GPG use remains at around 4% of energy consumption each year.

Our electricity system modelling assumes limited industrial load flexibility - during the system transition the Base and Autarky cases require incrementally more GPG capacity (350 MW at Chichester\FMG West, 450 MW at Karratha\Port Hedland) to maintain system reliability while VRE/storage are being built. Were it the preferred approach, rapid deployment is one of the adaptable features of gas turbines.[27] Similarly, it is not yet entirely clear how fossil fuelled generation

[27] South Australia installed 276 OCGT in 2017 capacity for emergency power generation outside the market following the power system event in 2016. The units have subsequently been sold on and shifted to other sites by their new owners. Alternatively with system planning larger single OCGT can be constructed in 2–4-year schedules including planning approvals in other markets.

will be reduced from 4% beyond 2035 although market and regulatory conditions are likely to be different in a decade.

Figure 10: Dispatchable energy as generated per annum in Base case

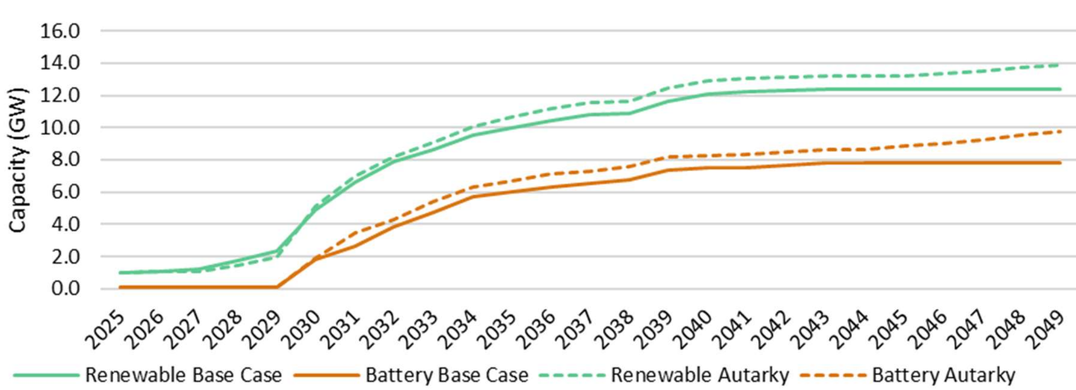


Autarky compared to the Base case

The difference in generation capacity in the Autarky case from the Base case is shown in Figure 11 In general Autarky follows a similar deployment path, driven by the same load and similar parameters, while optimises the system to meet the same requirements for system reliability and carbon emissions.

The key difference is the restriction of load and RGH connections to transfer energy only within each of the four existing networks shown in Figure 5. This creates the requirement to overbuild both generation and battery capacity relative to the Base case so that each of the four networks is self-reliant in energy. In the Base case the demand of a node anywhere on the entire network can be met from shared generation facilities anywhere on the network.

Figure 11: VRE generation and battery capacity - Base and Autarky cases



In the Autarky case an additional 19% by nameplate capacity (compared to the Base case) is built over 25 years in a system of four separate networks, which includes:

- 28% more solar;

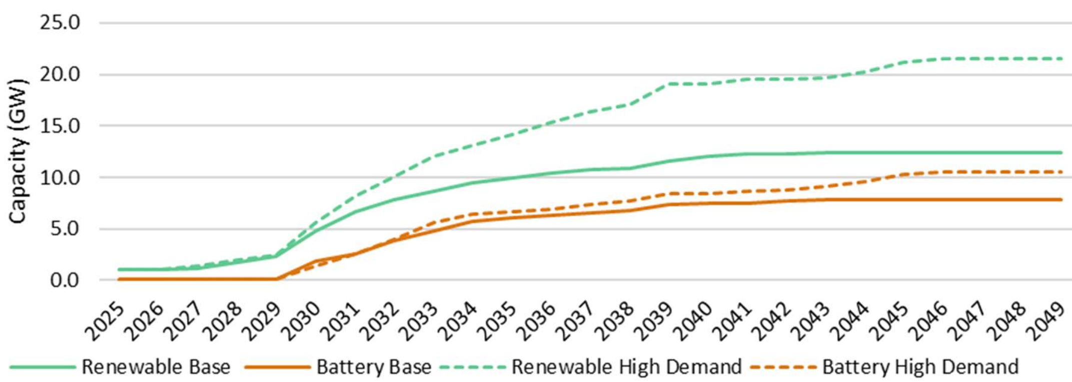
- 5% more wind; and
- 37% more 8hr storage.

High Demand compared to the Base case

The High Demand case describes the "option value" of the Base case, with investment in CUTI providing the capacity to meet higher demand. The investment in renewables in the High Demand case is scaled up to meet the additional 33% of energy demand to be delivered by 2050. In total the additional 62% build of generation capacity in a CUTI network includes (relative to the Base case):

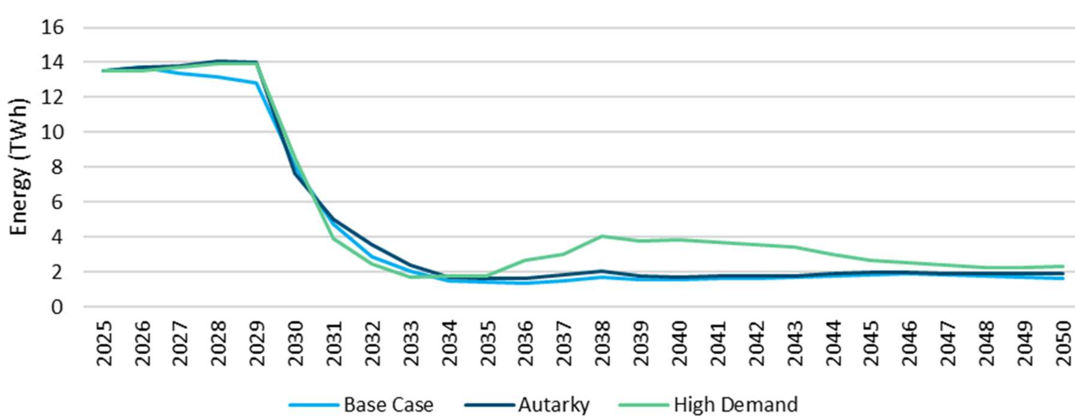
- 68% more solar;
- 90% more wind;
- 99% more 4hr storage; and
- 11% more 8hr storage.

Figure 12: VRE generation and battery capacity - Base and High Demand cases



However, in the High Demand case the steeper demand growth through the 2030s stimulates the use of gas facilities, as illustrated in Figure 13 below, while still deploying more renewables and batteries.

Figure 13: Gas generation - all cases



Like the Base and Autarky cases, the expansion of VRE generation quickly displaces energy produced by gas facilities through the first half of the 2030s. Like the Base and Autarky cases, the role of gas transforms to meet inter-day VRE energy shortfalls (both direct and stored). However, from 2035 gas facilities are used more often than in the Base and Autarky cases, reflecting a need for generation to keep up with demand growth and more frequent inter-day VRE energy shortfalls despite the steeper growth in VRE and storage capacity investment. This eases back through the 2040s to 2 TWh by 2050 (similar to the Base case).

3.5 Energy efficiency opportunities from electrification

Figure 3 above indicates that a key benefit of the energy transition is the contraction of total energy system as a whole that comes about from the *energy efficiency* of electric machines relative to thermal powered machines.

The energy and carbon savings from energy efficiency are independent of the generation mix of the electricity system as they derive from energy that is *just not used*. These savings are estimated by the Energy Efficiency Ratios (EERs) between thermal and electrically powered equipment, as demonstrated by the light automotive drivetrain example in Table 4.

Table 4: Energy Efficiency Ratio of light electric vehicle

Vehicle	Diesel	Electric	Energy Efficiency Ratio
Input energy	Diesel	Grid connection	
Engine efficiency	Engine 32.6%	Battery/motor 90%	2.8
Drivetrain efficiency	96%	82%	
Power train cooling/steering	95%	97%	
Auxiliary	98%	98%	
Regenerative braking	Nil	-22%	
Motive usable energy	22%	89%	4.1

Source: US Dept of Energy, Fuel Economy Guide, Where the energy goes, https://www.fueleconomy.gov/

Electrically powered equipment requires less input energy to operate as the transformation from primary energy to useable power does not involve direct heat loss, friction between moving surfaces, the transformation of linear power to rotational power, and further motor and drive train transmission losses. For vehicle motors and similar equipment, electrification can improve efficiency by EERs between 2.8 and 4.1, as shown in Table 4 above.

In the Pilbara, the two primary sources of efficiency gains in the current consumption of primary energy are the electrification of diesel fuelled haulage and equipment in iron ore and other mining, and the electrification of gas fuelled LNG mechanical compression and liquefaction trains.

The decarbonisation of electricity used is derived separately from the changing renewable generation mix over time.

Estimating mining EERs

Most of the diesel consumption in surface mine mining is for material movement, estimated by Advisian as 83% for a typical mix of excavators, dozers, haulage trucks and light/auxiliary vehicles.[28]

The EERs of electric vehicles changes depending on vehicle weight and duty cycle. Heavier vehicles consume more energy in general and significantly more under acceleration and are more likely to have stop/start duty cycles, represented as average speed in Table 5 below. Electric trucks benefit with zero fuel consumption when idle, more efficient energy transfer under acceleration, and regenerative charging when braking.

Consequently, electrical equipment is usually 2 to 6 times more energy efficient, depending on the application. A weighted EER in surface mine mining based on Advisian's mix of haul trucks, excavator loader, dozers and light vehicles is 4.9.

Table 5: Energy Efficiency Ratio estimates in heavy vehicle use cases

Heavy vehicle use cycle	Average speed (km/h)	Energy Efficiency Ratio
Arterial	25	3.9
Bus CBD	20	5.4
Drayage Local/waste	15	5.1
Drayage Near Dock	10	5.5
Mining	10	6.1

Source: California Air Resources Board, Battery Electric Truck and Bus Energy Efficiency Compared to Conventional Diesel Vehicles, May 2018, and Somnath Gain, Sudipta De, Satadru Ghosh, Decarbonizing Mining: Diesel vs Electric Haul Trucks on Cost and Efficiency, SRK Consulting, October 2024

Estimating LNG EERs

An LNG mechanical compression and liquefaction train has a direct drive shaft connection between the gas turbine and the compressor. Hence the primary source of efficiency for an electric drive train (e-drive) is the relative efficiency of the turbine and the electric motor system that replaces it, as shown in Table 6 below. Consequently, for LNG trains, electric drives have EERs of 2.6.

Table 6: Example of LNG train efficiency

LNG train	Mechanical	Electric	Gain
Input energy	Gas	Grid connection	
Gas turbine	36%		
Transformer		99%	
Inverter		99%	
Motor		97%	
Compressor	82%	82%	
Usable energy	29%	77%	2.6

Source: Håvard Devold, Tom Nestli & John Hurter, All electric LNG plants, ABB Process Automation Oil and Gas, 2006; MJA analysis of GT efficiency of NWS and Pluto 1&2 LNG trains.

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[28] Advisian, Stationary energy (excluding electricity) - mining and energy technology and efficiency opportunities, Department of Climate Change, Energy, the Environment and Water, 2022

Electrolysis impact on industrial chemical production in the Pilbara

The industrial ammonia/fertiliser sector is a major contributor of GHG emissions because carbon dioxide as a byproduct of the conventional ammonia production process based on natural gas as both the feedstock and the energy source for producing hydrogen through steam methane reforming. Hydrogen electrolysis replaces water as the feedstock and electricity as the power source, enabling the elimination of nearly all emissions.[29]

Currently the Pilbara produces about 40% of Australia's ammonia due to the availability of gas as a feedstock for production, and the industrial chemical production sector accounts for around 5-7% of GHG emissions in the Pilbara. [30,31]

Yara Pilbara Fertilisers (YPF) has joined with energy company Engie to explore decarbonising the hydrogen supply to the YPF ammonia plant by the development of large-scale hydrogen via electrolysis powered by renewable electricity. The first demonstration phase includes building a 10 MW hydrogen electrolyser with solar and 30-35% capacity factor to demonstrate the operationality of renewable powered hydrogen supply, expected to be operational in 2025.[32]

YPF has estimated the plant is expected to avoid GHG at a rate approximately 0.194 t/MWh electricity consumed by the electrolysis process.[33]

Other paths to decarbonisation

An alternative to electrification of mining haul trucks is the use of low-carbon liquid fuels (LCLF). LCLFs such as sustainable aviation fuel, renewable diesel and e-fuels can be produced using biomass, waste deposits or zero-carbon feedstocks like green hydrogen. LCLFs, specifically renewable diesel in the mining context, offers a pathway to abatement as a drop-in fuel, as it is compatible with existing assets including fuel infrastructure, mining haul trucks and other ancillary equipment. LCLFs have been trialled in the Pilbara over the last few years, and may be expected to play an important role in reaching net zero emissions for Australia and the Pilbara region, where they could be used when full electrification is not possible or impractical in planning timeframes, e.g. in some remote locations and as a transition solution. Detailed consideration of LCLFs role is out of scope for this report.

3.6 Expenditure and financing investment

The costs of the electricity system include the capital expenditure (CAPEX) to construct new transmission and generation infrastructure, and the operational expenditure (OPEX). The network, generation and storage capital costs are derived from the AEMO ISP report (including a 30% Pilbara

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29 See for example, Climateworks Centre and Climate-KIC Australia, 'Pathways to industrial decarbonisation: Positioning Australian industry to prosper in a net zero global economy', Phase 3, Australian Industry Energy Transitions Initiative, 2023.

30 Climateworks Centre and Climate-KIC Australia, 'Pathways to industrial decarbonisation: Positioning Australian industry to prosper in a net zero global economy', Phase 3, Australian Industry Energy Transitions Initiative, 2023; carbon data drawn from EPWA Pilbara Industry Roundtable, Workstream 1: Pilbara Electricity Modelling, 26 July 2023.

31 Note that this is correct at the time of writing. However, Perdaman Chemicals and Fertilisers has invested in a urea plant near Karratha. The plant will be one of the largest in the world with a nominal production capacity of 2Mtpa that will double Australia's grey ammonia production and substantially increase this sector's contributions to emissions in the Pilbara.

32 See https://research.csiro.au/hyresource/yuri-renewable-hydrogen-to-ammonia-project/

33 Engie-Yara Renewable, Hydrogen and Ammonia Deployment in Pilbara, October 2020, Feasibility Study Public Report https://research.csiro.au/hyresource/yuri-renewable-hydrogen-to-ammonia-project/

factor) and its sources including the Commonwealth Scientific and Industrial Research Organisation (CSIRO) GenCost 2024, Aurecon Cost and Technical Parameters Review and AEMO Transmission Cost Database and MJA's own forecast of gas fuel costs in Western Australia.

The CAPEX has been annualised using a simplified building block financial model, accounting for the required return on capital financed by equity and debt, asset depreciation, OPEX and tax.[34] OPEX is a pass-through cost in the building block revenue method, so it can be examined separately from CAPEX. Generation OPEX is largely driven by its variable component (fuel costs) in proportion to energy production. Generation OPEX is examined employing the information on generation utilisation provided by the system modelling.

A significant benefit of the case for a common user infrastructure approach in the electricity system is the access to cheaper forms of finance for investment in transmission and generation. Table 7 below shows the assumptions used in a standard capital asset pricing model calculation of the pre-tax rates of return employed in the annualisation of CAPEX derived from the system modelling.

Commonly developers of infrastructure such as electricity transmission are able to obtain a lower cost of capital from financial markets because of their long-term stable revenue. Infrastructure ventures may be further able to access lower cost government backed financing provided as an incentive to help achieve decarbonisation (e.g. CEFC).

The access rights to CUTI of different generation and demand parties broadens the pool of contract parties for the sale of electricity, and investors can align development with expected optimum system requirements. This reduces the risks to private sector developers of generation facilities and the corresponding risk premium for investors, which potentially lower the unit cost of use of the CUTI.

In comparison, in the Autarky approach, individual firms or joint venturers develop individual assets largely at their own rates of return on capital. Resource companies are exposed to market volatility in price and other factors that increase their cost of capital. In addition, private investors in generation facilities potentially take volume and stranded asset risk for sole offtake arrangements in the limited Autarky case where network areas remain independent. In these circumstances developers may be less capable of leveraging equity.

Consequently, the calculations of WACC vary between cases. Based on the above we have assumed the following:

- market risk premium 6.5% in Autarky case compared with 6.0% in CUTI;
- private sector equity beta 1.2 (Autarky transmission and all generation) compared with 0.83 CUTI;
- private sector debt risk premium 2.04% (Autarky transmission and all generation) versus 1.83% CUTI; and
- while the debt/equity ratio is the same for either transmission investment approach, for generation the ratio changes from 55/45 for CUTI to 35/65 for Autarky.

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34 See for example the AER post tax revenue model (PTRM) for transmission networks, or ERAWA Benchmark Reserve Capacity Price determinations.

Table 7: Calculation of Real pre-tax rates of return of transmission and generation

Capital asset pricing model parameter	CUTI (Base, High)	Autarky Transmission	Private Sector Generation (Base, High)	Autarky Generation
Nominal Risk Free Rate of Return (%)			4.00%	
Expected Inflation (%)			2.57%	
Real risk free rate of return (%)			1.43%	
Market Risk Premium (%)	6.00%	6.50%	6.00%	6.50%
Asset beta			50.00%	
Equity beta	0.83	1.20	1.20	1.20
Debt risk premium (%)	1.83%	2.04%	2.04%	2.04%
Debt Issuance Costs (%)			0.10%	
Corporate tax rate (%)	30.00%			
Franking credit value	50.00%			
Debt to total assets ratio (%)	55.00%		45.00%	35.00%
Equity to total assets ratio (%)	45.00%		55.00%	65.00%
Pre-Tax WACC	8.01%	9.62%	10.01%	11.17%
Real WACC	**5.31%**	**6.88%**	**7.26%**	**8.39%**
Real Cost of Debt	***3.27%***	***3.48%***	***3.48%***	***3.48%***
Real Cost of Equity	***6.25%***	***9.00%***	***8.42%***	***9.00%***

Source: MJA analysis; Economic Regulation Authority WA, 2025 Benchmark Reserve Capacity Price determinations, various years

4. Case for CUTI - Benefits of electrification

This chapter examines the benefits of investment in the energy transition in the Pilbara. This includes the energy and carbon savings to end-users from electrification, and the avoided carbon emissions of a renewable electricity system.

Electrification delivers significant savings from primary energy that is simply not used due to displacement of inefficient thermal generation in end uses. Comparing the demand cases, around **110-140 PJ p.a**. or **2.8-3.6 billion litres** of diesel for **mining** can be saved, representing **$4.2-5.3 billion p.a. economic savings in diesel fuel costs**.[35] A potential further **51 PJ/$500 million p.a**. savings are available from electrifying LNG production.[36]

Decarbonisation is a direct result of the avoided primary energy sourced from fossil fuels. Based on the same electrification assumptions the Base/Autarky cases target the same carbon reductions: **an average of 24 Mt CO_2-e p.a. avoided each year with an average value of $7.6 billion per annum**. [37] This may overstate Autarky savings where, for example, multiple land approvals delay construction. The more ambitious High Demand (with CUTI) case avoids an additional **9.6 Mt CO_2-e p.a**., with an average of **34 Mt CO_2-e** avoided each year with an average value of **$10.4 billion** per annum.

4.1 Economic value of energy efficiency

The key benefit of electrification is the savings in primary energy avoided through the energy efficiency of electrical equipment as discussed in Section 3.4, with EERs of 2 to 6 times compared with heat engine powered equipment. Figure 14 below illustrates the estimated avoided primary energy under the Base cases where electrification potential is focused on current interested parties, primarily the iron ore miners, where the 4.9 EER is estimated for surface mining.[38] These savings are independent from the energy sources for electricity.

After initial ramping up to 2031, in the long-term iron and other mining together with other industries can save an average of 113 PJ per annum from energy efficiencies in the Base case,

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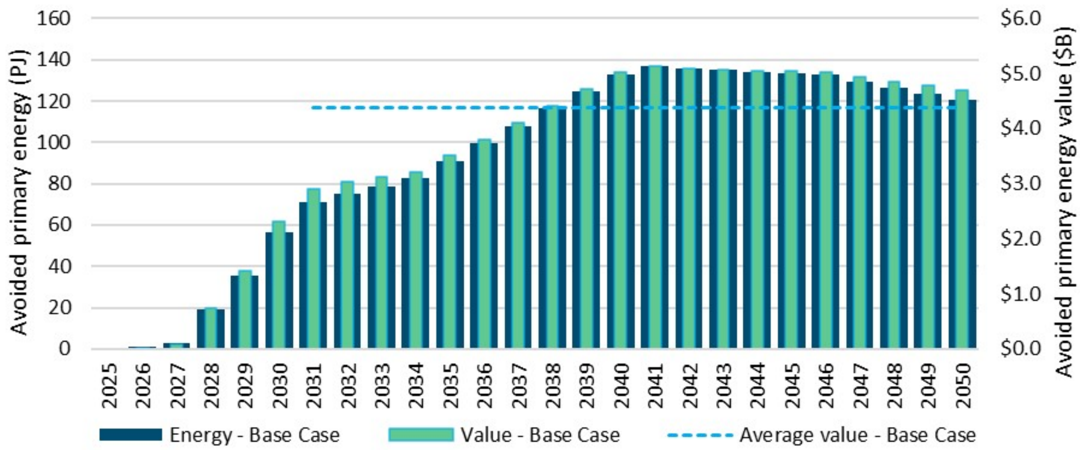
35 Economic value, not financial value to users. Range reflects the variation in electrification of demand between cases.
36 In the High Demand case.
37 Annual costs averaged over the period 2031 to 2050.
38 In the current modelling the size and rate of electrification is the same in both the Base and Autarky cases as an assumption, although it is probable to be different (larger for Base case) in practice.

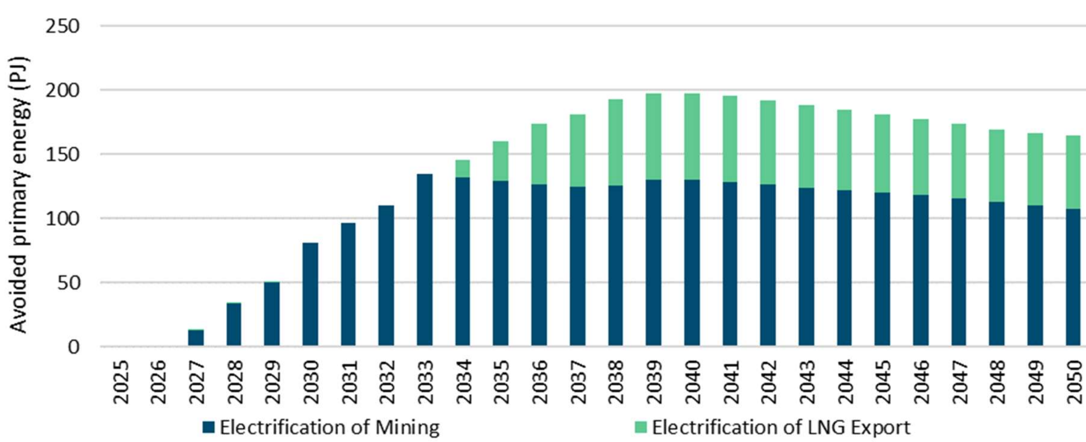
illustrated in Figure 14 below. The estimated avoided economic cost of avoided primary energy consumption, based on projected diesel and gas prices, is an average economic saving of $4.4 billion per annum in this Base case.[39]

Figure 14: Potential avoided primary energy - Base case



The construction of CUTI by the early 2030s with sufficient capacity enables new demand, notionally from LNG producers as shown in Figure 15 below for the High Demand case, but effectively any new source of demand where CUTI supports the transmission of electricity to the coastal demand centres. Indicatively, assuming replacement e-drives in LNG trains with on 2.6 EER, as well as a higher 138 PJ per annum savings in mining, energy efficiency in LNG production can save a further 48 PJ per annum.[40] Figure 16 shows this economic value of avoided primary energy consumption in the High Demand case. The higher cost of diesel fuel per gigajoule (~$40/GJ) compared to gas (~$9-10/GJ) amplifies the savings to miners, averaging $5.3 billion per annum compared with $0.56 billion per annum for LNG producers.

Figure 15: Potential avoided primary energy - High Demand case



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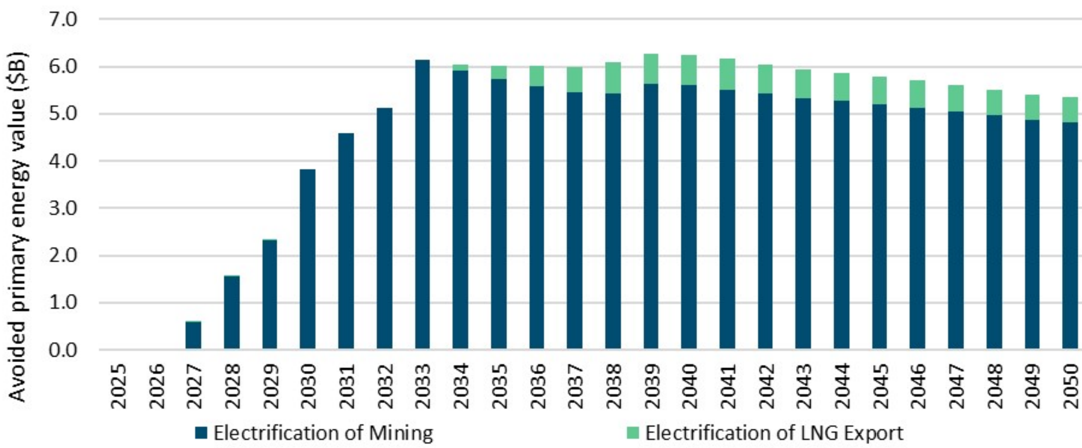
[39] These economic saving represents the value to the state that may be otherwise utilised for production. It may vary from actual financial costs to users (in this case miners) depending on other financial instruments, such as fuel rebates etc...

[40] Electrification of LNG e-drives is used as a quantifiable example – LNG producers may not be willing to invest in such assets or may find viable alternatives to decarbonise LNG train emissions resulting in more or less savings.

Figure 16: Estimated economic value of avoided primary energy - High Demand case



The range of the electrification potential for diesel fuel savings from iron ore and other mining is summarised in Table 8 with the variation between all three cases, including the estimated volume of diesel fuel for the avoided energy.[41] CUTI expands the potential to electrify mining beyond the autarkic companies, adding a further 200-800 million diesel that can be avoided. Around 110-140 PJ p.a. or 2.8-3.6 billion litres p.a. in diesel for mining can be saved by electrification. This represents economic savings in diesel fuel costs in the range of $4.2-5.3 billion p.a. economic savings.

Table 8: Estimated average annual diesel savings in mining, 2031-2050 – all cases

	Base case	Autarky	High Demand
Energy (PJ)	113	109	138
Volume (GL, billion litres)	3.0	2.8	3.6
Economic value ($billion)	$4.4	$4.2	$5.3

4.2 Emissions reduction opportunity is substantial and valuable

The following charts show the quantum of avoided GHG emissions. As discussed in Chapter 2, there are three sources of emissions abatement in the Pilbara energy system:

- the **primary (diesel) fuel that simply is not used** by end-use equipment (energy efficiency) that is electrically powered equipment rather than thermal powered (referred to in the following charts as "Electrification of …");
- the **change in the electricity system generation mix** providing energy to that electrically powered equipment from renewable electricity generation compared to fossil fuel-based generation at the current level of emissions intensity (referred to in charts as "Renewable generation in NWIS"); and
- **industrial chemical production by electrolysis**, where the avoided emissions are estimated by the electricity powering the electrolysers (referred to as "Electrification of NH4").

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41 Note that the calorific value (energy per unit volume) of diesel varies depending on composition and conditions such as ambient temperature.

Figure 17: Emissions avoided - Base case

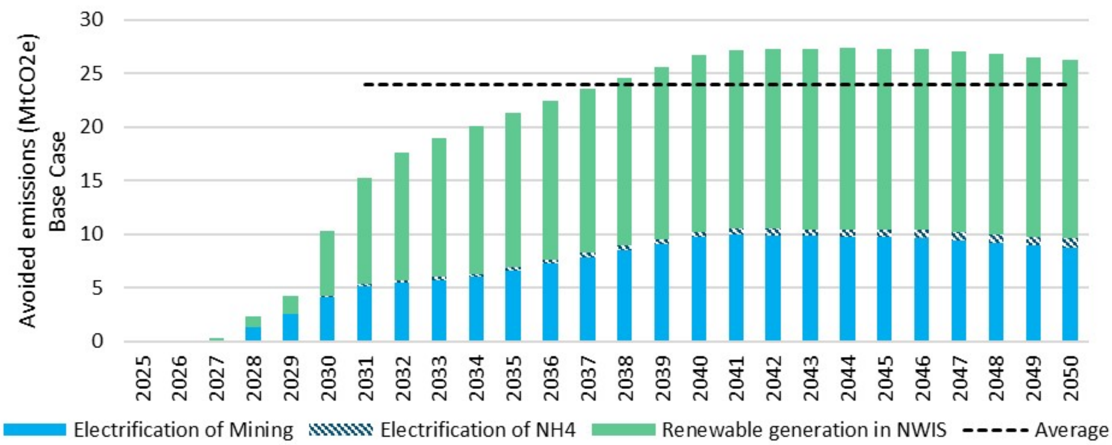
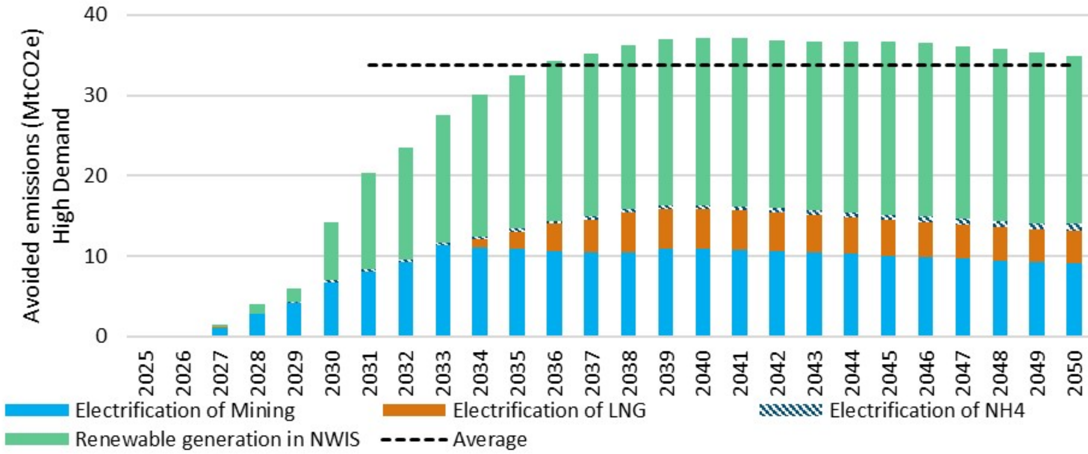


Figure 17 illustrates the reduction in annual emissions in the Base case. Following the early 2030s infrastructure build, an average 24 Mt CO_2-e are avoided each year. About a third of the emissions reduction arises from avoided primary energy from electrification in mining (including mining other than iron ore enabled by CUTI) and 2-3% from electrifying of industrial chemical production. **The bulk of the emissions reduction (66%) is the replacement of gas or diesel fired electricity generation** in a growing electricity system that integrates the new demand from electrification of end uses into its existing load as shown in Figure 7.

The emission reductions for the Autarky case are essentially assumed to be the same as the Base case as a modelling constraint as discussed in Section 3.1. As noted above, in practice delays in the Autarky case and opportunities for smaller industry to electrify through open access CUTI, MJA would expect the Base case to achieve higher decarbonisation outcomes. While the Autarky case overbuilds renewable generation relative to the Base case, this is required to achieve the same reliability target (amount of unmet load) given the same demand and carbon reduction within a set of networks that cannot share energy, and the difference between the two cases is marginal. This overbuild cannot contribute to significant emissions savings.

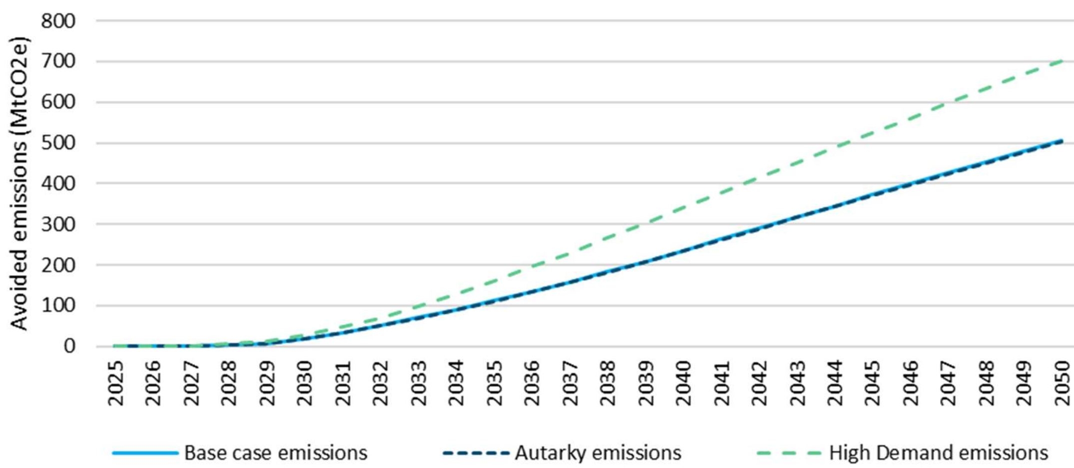
Figure 18 below shows the further reduction in emissions from the more ambitious High Demand case with an average 34 Mt CO_2-e avoided each year, 9.9 Mt CO_2-e p.a. higher than the Base case. The avoided emissions additional to the Base case include both the high avoided primary energy in Figure 15 above with the electrification of LNG production, and the larger renewable generation system serving this larger demand for electricity. Hence avoided energy in LNG production now comprises 10% of avoided emissions.

Figure 18: Emissions avoided - Base case



The cumulative growth of avoided emissions is shown in Figure 19 below for the three cases. The Base/Autarky optimise towards the same carbon reduction, achieving **506 Mt CO_2-e over the 25 years to 2050**. The more ambitious **High Demand case achieves 40% more abatement, reaching 702 Mt CO_2-e over 25 years**.

Figure 19: Cumulative emissions abatement - three cases



Valuing Pilbara emissions that are avoided

Figure 20 compares the economic value of the avoided emissions in each of the cases above, based on the central carbon value calculated by Infrastructure Australia.[42] As above the difference between the Base and Autarky cases is marginal as the **annual value of emissions climbs to $10.2 billion p.a. by 2050 and cumulative $148 billion over 25 years**. The larger growth of the electricity system in the High Demand case means following the construction of CUTI in the early 2030s, the value of avoided

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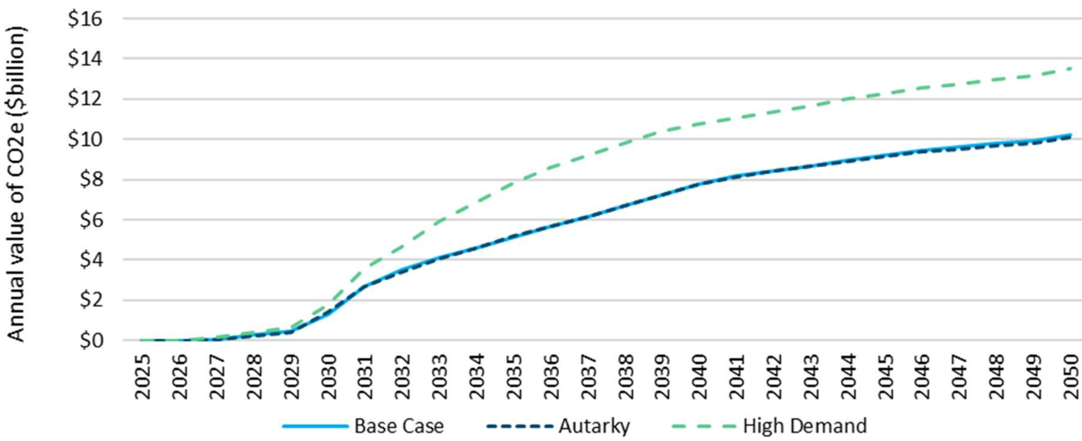
42 Infrastructure Australia, Valuing emissions for economic analysis Guidance note, 2024

emissions is an average $2.8 billion p.a. higher than the Base case, climbing to $13.5 billion in 2050 and cumulative $204 billion over 25 years.

Figure 20: Annual value of avoided emissions - all cases



5. Case for CUTI – Benefits of CUTI investment

This chapter examines the investment costs in transforming the Pilbara electricity system, including the new transmission and generation CAPEX costs and OPEX benefits.

Investment towards decarbonisation is substantial, including total annualised cost over **$510 million p.a.** in transmission and **$5.4 billion p.a**. in generation in the Base case.

However, the Base case delivers the required load including electrification by miners at substantial cost savings to the Autarky case. Over 25 years to 2050 the **annualised cost of transmission** in the **$14.7 billion Autarky case** is approximately $4 billion or **40% higher** than the **$10.5 billion Base case,** and the **annualised cost of generation** is **25% higher** in the **$131.6 billion Autarky case** than the **$105.4 billion Base case**. This investment reaps savings in **avoided primary fuel costs** averaging **$6.6 billion p.a.** combining both end user costs and electricity system costs.[43]

CUTI system planning enables wider participation by both load and generation developers. The larger High Demand case calls for proportionately more infrastructure, but at **$176 billion** 2025-50 this cost is **just 12% more** than the **Autarky** case while serving a load that is **33% higher,** ***illustrating the system optionality delivered by the CUTI Base case***.

5.1 Electricity system expenditure

Decarbonisation involves substantial investment for the generation and transport of energy to service new electrified loads. This section details the expenditure required to realise the decarbonised electricity system described in section 3.4. The focus is on the benefits (avoided costs) of the Base case with CUTI relative to the Autarky case without CUTI, and the relative costs of investing in CUTI to achieve further benefits identified in Chapter 4 of the High Demand case. [44]

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[43] Annual costs averaged over the period 2031 to 2050.

[44] Chapter 3 highlighted that decarbonisation is a fundamental assumption of these scenarios, and we do not consider the different CAPEX of, for example, a non-decarbonisation BAU scenario where significant GPG CAPEX would occur to meet growing demand. That said, there is interest in the implicit comparison of the avoided fuel costs of a renewable, non-gas-based electricity system and the accompanying avoided greenhouse gases.

CAPEX schedule

The column chart in Figure 21 below shows the schedule of CAPEX in the electricity system, its inherent lumpiness and the sequencing challenge that sufficient transmission must be available before new generation can be utilised.

For transmission in particular, there is limited scope to increase capacity incrementally, so that capacity will be overbuilt at first, in the period up to 2031. However, this transmission capacity enables both a large program of new generation facilities in the early 2030s and a continuing program of new generation over the following decade at a reduced scale. (Note that the *Rewiring the Nation* fund is proposed to play a key role in facilitating the financing of the "right-sizing" of transmission in the Pilbara).

Figure 21: Schedule of transmission and generation CAPEX deployment

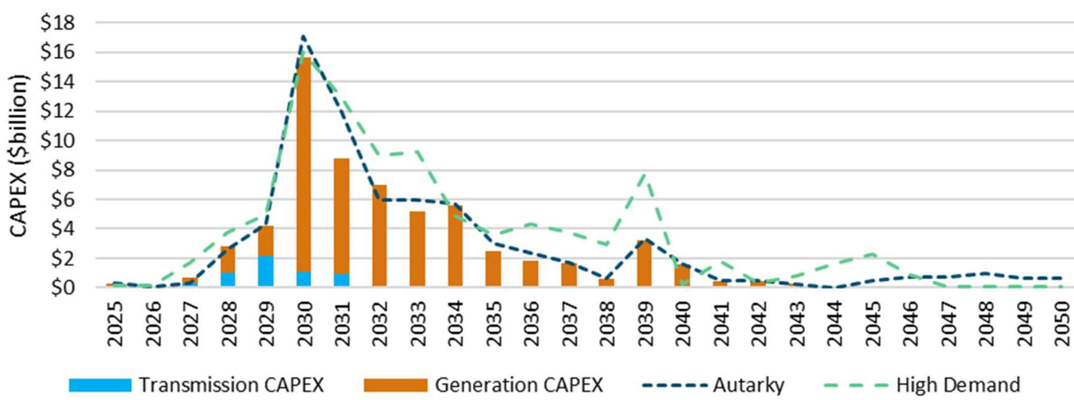


Figure 21 also shows the timing of the total CAPEX for the Autarky and High Demand cases. While both cases indicate more expenditure in every decade to 2050, broadly the scheduling of the three cases is similar, driven by the demand to meet the new and growing loads in the 2030s with decarbonised electricity. Significantly, in the High Demand case, the construction of CUTI by the early 2030s with sufficient capacity enables the larger investment in generation facilities needed for higher demand, further avoided primary energy and avoided carbon emissions.

Cost stack

This section builds the stack of costs for comparison of the three cases, including transmission and generation CAPEX and generation OPEX. The CAPEX has been annualised using a simplified building block financial model, discussed in Section 3.6 above, smoothing CAPEX out with finance at the varying rates of return between scenarios in Table 7, with key inputs including:

- depreciation based on 50-year life for transmission assets and 30-year for generation;
- transmission OPEX estimated at a rate of 0.2% of capital base; generation OPEX calculated separately (see below); and
- AER/ERAWA default values employed for tax/imputation.

We do not consider the ongoing capital cost of existing gas facilities. Partly this is because it is a sunk cost, partly because we do not model the timing of gas plant exits such that plant would be written off from the existing capital base. All costs are in real $2024. Net Present Costs (NPC) are calculated with low/central/high 4%/7%/10% discount rates.

Transmission costs (annualised CAPEX and OPEX)

Figure 22 compares the annualised cost of transmission expenditure (CAPEX and OPEX) for the industry "go it alone" scenario Autarky case versus the Base case. After 2032, the annualised cost is on average $712 million/year in the Autarky case, or $202 million/year (40%) more than the $510 million p.a. in the Base case.

The total network construction costs of the Base case and Autarky case are relatively similar - the total length of new line (as shown in Table 3 above) is relatively similar as there is a trade-off between the new transmission links and rationalised RGH links in the Base case and the duplication of links to RGH in the Autarky case. While the direct costs are 14% higher, a key factor in the difference in Figure 22 is the higher financing cost for miner’s corporate investments compared with infrastructure finance and government backed investments, as discussed in Section 3.6. Over 25 years from 2025 this adds up - the **total annualised costs in the Autarky case are over $4 billion or 40% higher than the Base case**, as shown in Table 9 below.

Figure 22: Annualised transmission cost - all cases

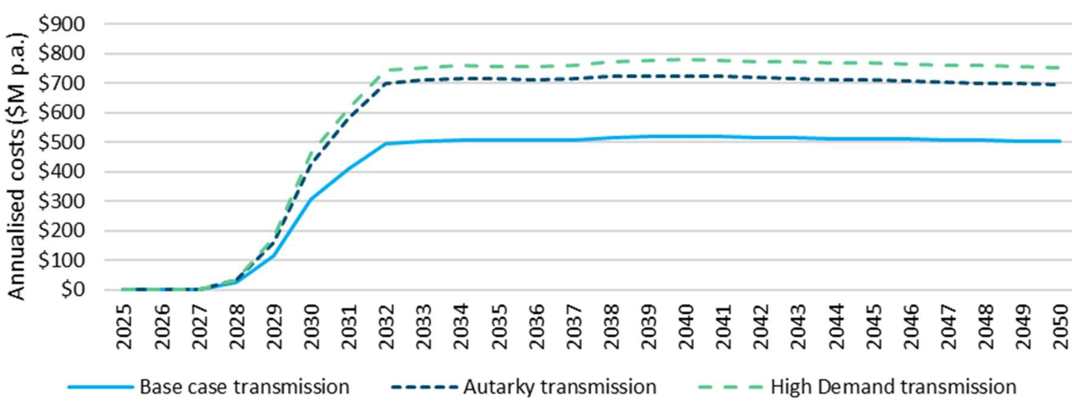


Figure 22 also indicates that the additional transmission investment required to enable the High Demand case is a relatively minor increase on the Autarky case at $765 million per annum. The total transmission annualised CAPEX costs and their NPC for the three cases are given in Table 9 below Over 25 years the total costs to enable the High Demand case are 7% higher than the Autarky case, or $380 million more at the central NPC rate.

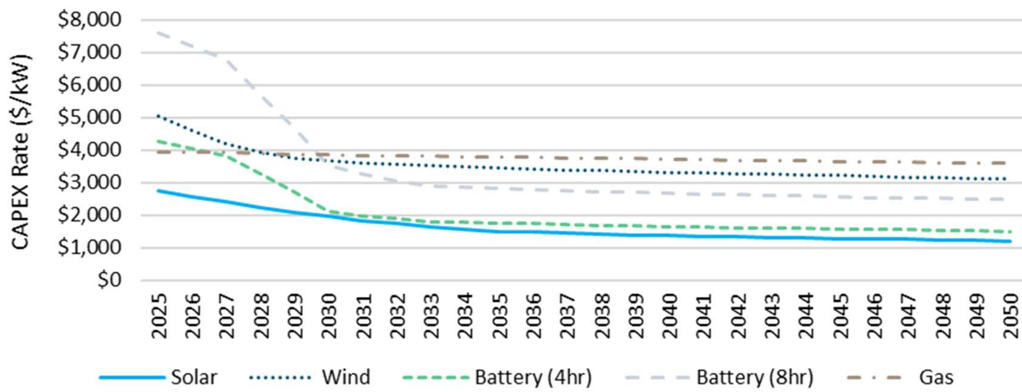
Table 9: Total annualised transmission cost over 2025-50 years ($million)

Case	25y cumulative cost	NPC (low)	NPC (central)	NPC (high)
Base	$10,537	$5,752	$3,836	$2,655
Autarky	$14,726	$8,051	$5,375	$3,722
High Demand	$15,805	$8,628	$5,754	$3,982

Generation and storage CAPEX

The generation CAPEX for the generation build described in section 3.4 is calculated using the CAPEX rates illustrated in Figure 23, based on CSIRO's 2024 GenCost report adjusted with regional and cyclone factors.

Figure 23: Generation CAPEX rates, including Pilbara cost factors ($/kW)



Source: CSIRO GenCost 2024, Aurecon Cost and Technical Parameters Review

Figure 24 below shows the Base case breakdown of CAPEX between VRE generation and storage facilities. The domination of demand by industrial loads means that the system load profile is essentially flat, meaning that extensive storage of VRE generation is required to meet demand, particularly overnight. Consequently, large quantities of 8-hour battery storage are constructed to run sequentially through the night, with sufficient VRE to charge the batteries each day.

Figure 24: Generation CAPEX - Base case

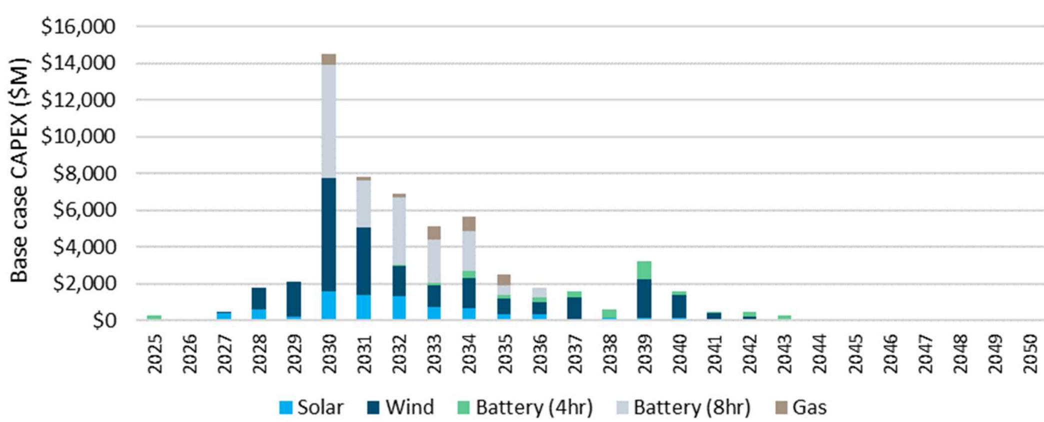
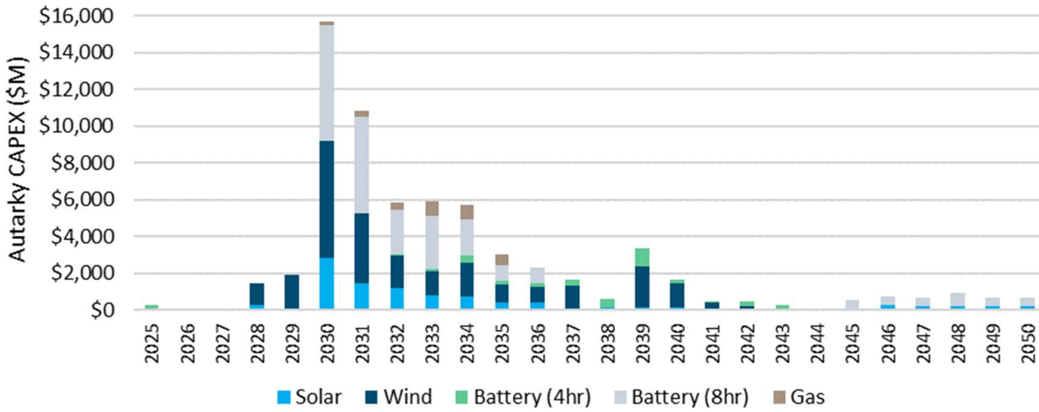


Figure 24 features some GPG investment - Section 3.4 discussed this is a product of our modelling assumptions requiring load to be met at all times (i.e. no load flexibility) and may be substituted by other load and supply options that may emerge in the near future.

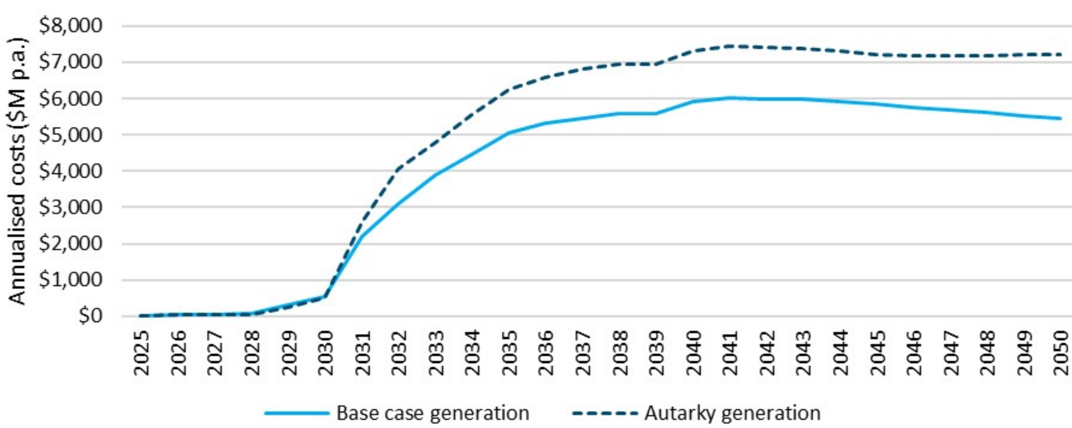
Figure 25: Generation CAPEX - Autarky case



The same CAPEX breakdown for the Autarky case is shown in Figure 25 above. As discussed in Section 3.4 above, generation/storage assets are overbuilt in the early 2030s (see Figure 11) to deliver the same energy to loads through a system of four separate networks. These extra VRE resources do not deliver more carbon savings; the additional assets are required to make each individual network self-sufficient and less reliant on gas generation support, whereas CUTI in the Base case requires the *system* is self-sufficient, a condition met with less VRE and storage. In the Autarky case more excess energy is spilt - while the energy is clean, it is not employed to produce anything and does not lower the emissions intensity of what is produced by the system.

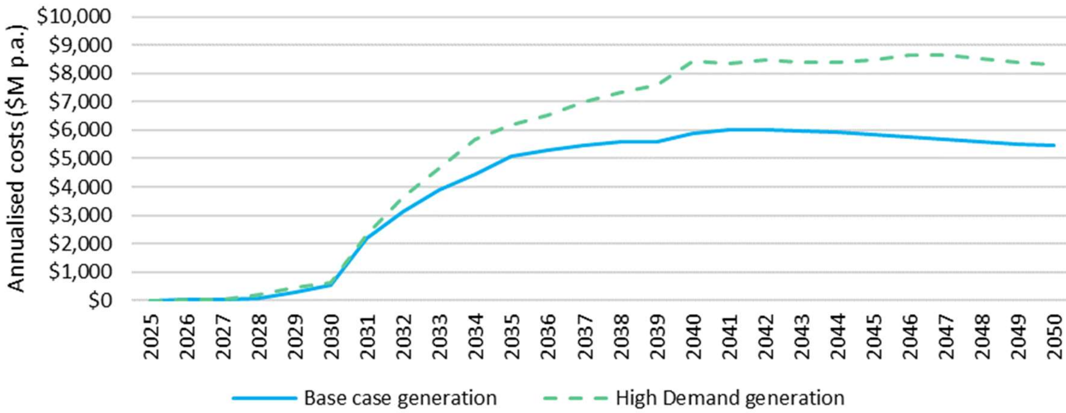
Figure 26 shows the annualised cost of generation facilities CAPEX for the Base and Autarky cases. **After the initial construction period the annualised cost in the Autarky case is on average $6.7 billion per annum, or $1.3 billion p.a. (24%) more than the $5.4 billion p.a. in the Base case**. In both cases generation assets are privately developed and incur the same financing costs, so this difference is due to the larger generation build as discussed in Section 3.4.

Figure 26: Annualised generation CAPEX - Autarky versus Base case



The additional generation investment enabled by CUTI to meet the High Demand case is shown in Figure 27 below. The average annualised cost after 2032 is $7.5 billion p.a. or $2.1 billion p.a. above the Base case. Although the total High Demand cost of $145 billion over 25 years is 38% higher than the Base case (see Table 10 below), this is driven by the need to meet a load that is 43% higher than the Base case in 2040 and 33% higher in 2050 (see Figure 8 above). **The 25-year generation CAPEX meeting this additional load, with the additional avoided emissions from electrification of industry, is only 10% more than the 25-year generation CAPEX required to meet the lower demand of the Autarky case**.

Figure 27: Annualised generation CAPEX - High Demand versus Base case



The total generation annualised CAPEX costs and their NPC for the three cases are given in Table 10.

Table 10: Total annualised generation CAPEX over 2025-50 years ($million)

Case	25y cumulative cost	NPC (low)	NPC (central)	NPC (high)
Base	$105,360	$54,988	$35,322	$23,495
Autarky	$131,590	$68,414	$43,821	$29,065
High Demand	$145,208	$74,456	$47,210	$31,017

Generation and storage OPEX

Base case

Figure 28 below illustrates the generation OPEX for the Base case. The OPEX for solar, wind and battery plant are largely fixed; the OPEX for gas/diesel plant is dominated by variable OPEX mostly related to fuel consumption, in turn proportional to energy production.[45] This results in generation OPEX in all cases (see Figure 29 below) that follows the trends in Figure 13 for energy production.

Figure 28 demonstrates two characteristics:

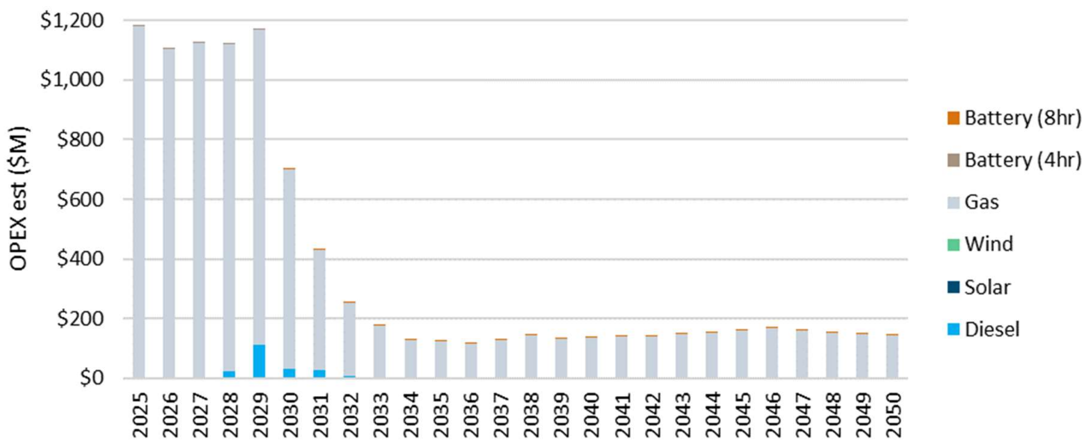
- Comparing future GPG OPEX to current levels, the cost of GPG in the decarbonisation/renewable generation Base case significantly reduces from $1.1 billion from 2025 to 2029, to an average of $142

[45] Note that high fuel cost diesel generation is utilised as final source of energy. As noted elsewhere, in between 2028 and 2032 the system as modelled experiences energy shortages that, without flexible load or other treatment, invokes the use of available backup diesel generation and installation of new gas generation. Before and after this period generation is sufficient that diesel generation utilised at a rate less than 1-2% of the maximum visible in Figure 28.

million post 2032, following the pattern of falling utilisation of gas facilities in Figure 13; and

- Post 2032, the fixed OPEX of renewable generation are outweighed 99 to 1 by the OPEX of gas/diesel plant dominated by fuel costs.

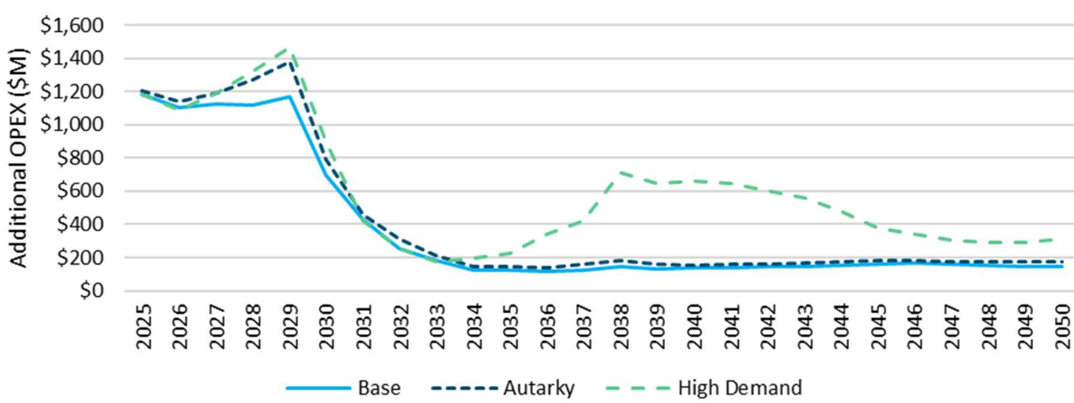
Figure 28: NWIS generation OPEX by generation type - Base case



Autarky and High Demand cases versus Base case

Generation OPEX for all three cases is summarised by Figure 29 and Table 11 below.

Figure 29: Generation OPEX – All cases

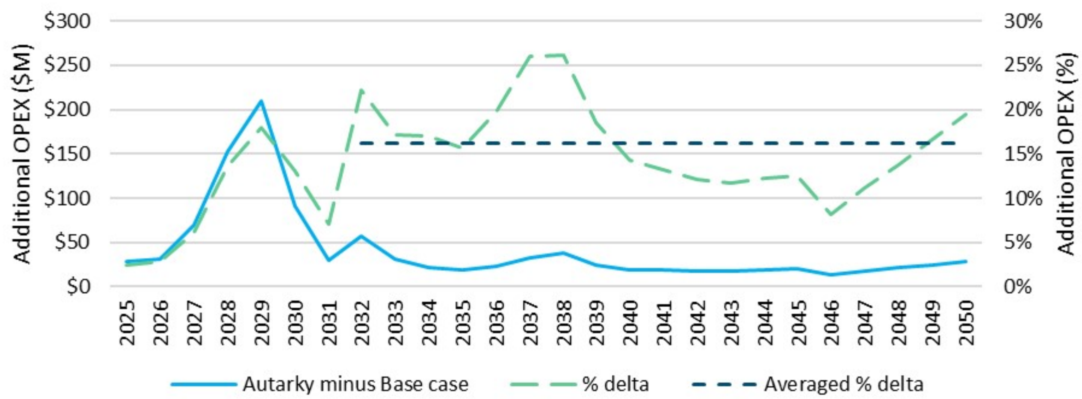


In the key comparison of the development approach to transmission infrastructure, Figure 13 above showed that gas generation in the Autarky case, driven by same drivers as Base case, was similar but particularly higher during the transition period and generally higher thereafter. The key issue is the inability to share energy between the four networks in the Autarky case. When energy is short at a node in one network there is no ability to share VRE generation, but a gas facility within the network must meet the shortfall.

This requires the additional OPEX in the Autarky case illustrated in Figure 30. Once the transformation of gas into its balancing role is complete, after a peak difference of $210 million p.a.

in 2029, this additional cost is on average an extra $23 million p.a. or 16% higher than in the Base case. **Over 25 years the Autarky case accumulates over $1 billion or 11% more OPEX than the Base case** as enumerated in Table 11 below.

Figure 30: Generation OPEX Difference (Autarky minus Base case)



Gas generation in the High Demand case is significantly higher again, as shown in Figure 29, consistent with the additional use of fossil fuels, especially mid-2030s to mid-2040s, so total OPEX over this period is $5.7 billion more than the Base case as seen in Table 11.

Table 11: Total generation OPEX over 25 years ($million)

Case	25y cumulative cost	NPC (low)	NPC (central)	NPC (high)
Base	$9,693	$7,472	$6,396	$5,603
Autarky	$10,768	$8,241	$7,021	$6,125
High Demand	$15,396	$10,622	$8,510	$7,078

Total annualised costs

The total costs of transforming the Pilbara energy system into a renewable electricity-based system are summarised in the tables and charts below for each of the three cases, summing the cost components above.

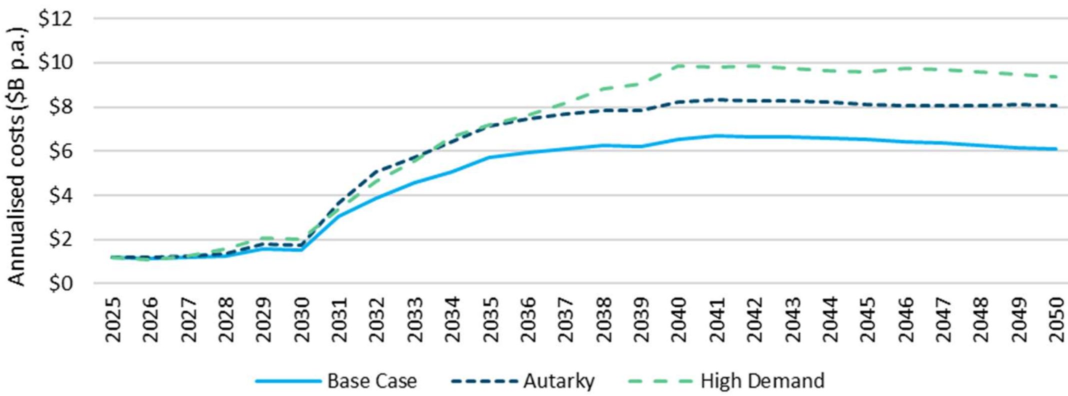
Table 12: Basic cost comparisons 2025-50 ($billion)

Case	CAPEX + OPEX	Annualised CAPEX + OPEX
Base	$72.7	$125.6
Autarky	$83.3	$157.1
High Demand	$108.9	$176.4

The annualised cost is summarised in Figure 31 with NWIS CAPEX and OPEX adding to around $8.0 billion p.a. from 2035 in the Autarky case compared to $6.3 billion p.a. in the Base case or 27%

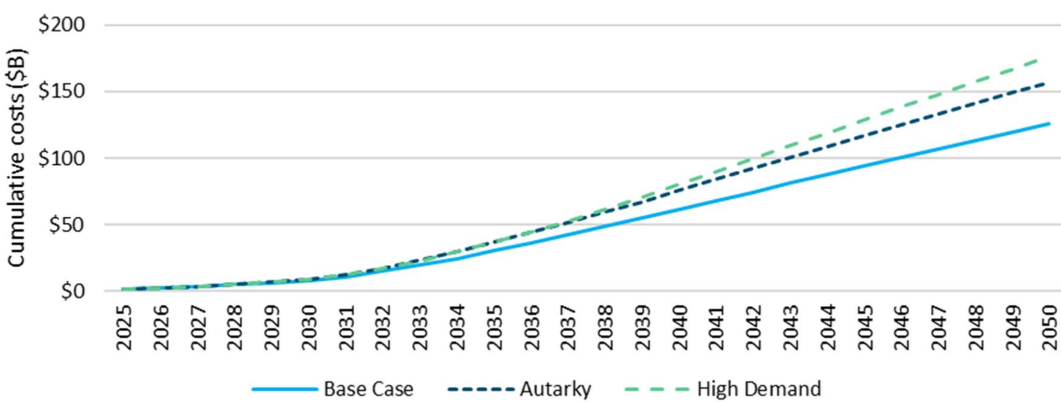
higher. The more ambitious High Demand case continues to invest at the same pace through to 2040, slowing thereafter allowing the annualised cost to stabilise around $9.7 billion per annum.

Figure 31: Annualised NWIS CAPEX and OPEX - three cases



The cumulative capital investment for the three cases is shown in Figure 32. **Over the 25 years to 2050 the Autarky case involves a total cost of $157 billion compared to $126 billion in the Base case (25% higher**). The ambitious High Demand case is realised for $176 billion or 12% more than the Autarky case.

Figure 32: Cumulative NWIS CAPEX and OPEX - three cases



The net present value of these costs is shown in Table 13 below, with a 7% discount rate providing NPC value of $45.6, $50.4 and $61.5 billion respectively for the Base, Autarky and High Demand cases.

Table 13: Total annualised costs over 25 years ($billion)

Case	Cumulative cost	NPC (low)	NPC (central)	NPC (high)
Base	$126	$68.2	$45.6	$31.8
Autarky	$157	$84.7	$56.2	$38.9
High Demand	$176	$93.7	$61.5	$42.1

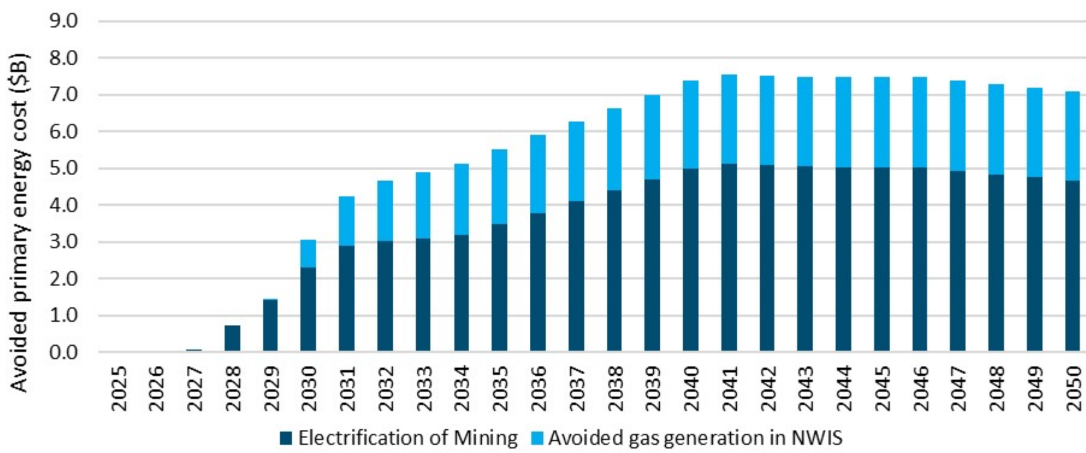
5.2 Total energy operational costs

In Section 2.2 it was noted that the primary energy that is avoided and the resulting costs avoided from an electrified and renewable energy system has two components:

1. energy that is *just not used* by electrical equipment that replaces inefficient thermal engine equipment (energy efficiency), irrespective of the energy source for electricity generation; and
2. renewable generation displacement of thermal generation that would otherwise be required to generate electricity.

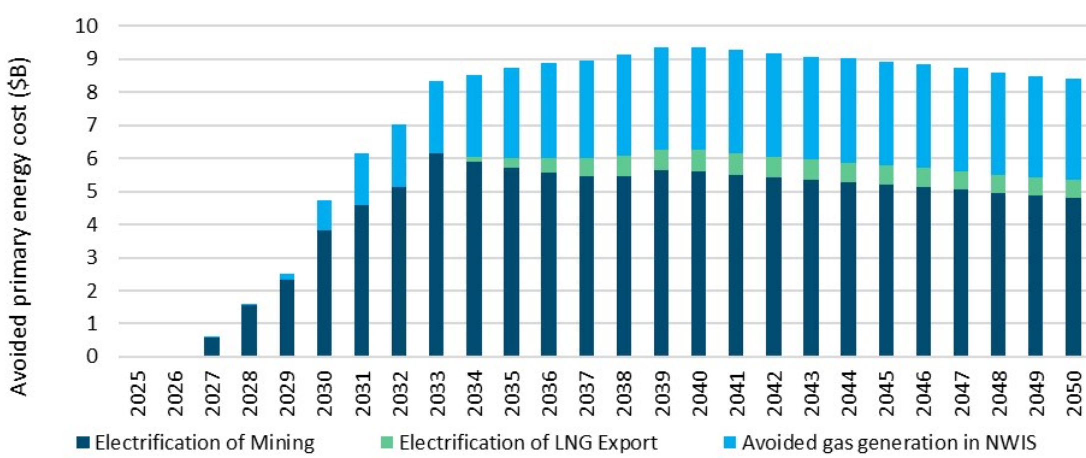
This combined total value of avoided energy costs is illustrated in Figure 33 for the Base case. **After ramping up, from 2031**, **this averages over $6.6 billion per annum**.

Figure 33: Avoided annual OPEX by electrification and renewable generation - Base case



The vertical axis in Figure 33 is fixed to be comparable with the axis in Figure 34 below that provides the same estimate for the High Demand case. This case includes faster and higher savings in mining electrification, savings in LNG production, and larger savings in electricity generation in what is a larger electricity system. **After ramping up, from 2031 this averages over $8.7 billion per annum**.

Figure 34: Avoided annual OPEX by electrification and renewable generation - High Demand case



6. Other benefits of CUTI

CUTI planning that is "fit for system purpose" also permits a wide range of other planning, environmental and social benefits.

CUTI provides a framework for a wider range of parties providing and accessing transmission and generation, distributing risk across a wider set of developers and users. A system approach enables early and streamlined engagement with government agencies, industry and Traditional Owners. The focus on the system encourages a view to identify the potential to streamline processes.

A "fit for system purpose" CUTI approach can **reduce the infrastructure footprint with estimated land use for transmission 2,845 ha (21%) lower** than Autarky case, leading to 9,704 ha (7%) less land use for VRE generation. Less land use can be expected to require fewer approvals and, together with collective and streamlined processes, require fewer consultations.

CUTI presents an opportunity to achieve a broader range of benefits, facilitated by a Pilbara CUTI system planning approach.

Open third-party access

CUTI provides a recognised framework for open, third-party access to the network under the current and future Pilbara Network Rules (PNR) and broader national laws regarding third party access to critical infrastructure. ***Open access CUTI provides the opportunity for a wider range of generation and loads to engage in the task of decarbonising industry in the Pilbara***, including entities that are not yet recognised in the Base case modelling.

On the energy demand side this includes both enabling the other half of existing Pilbara energy demand to electrify, such as Tier 2 iron ore, gold and lithium miners and LNG producers, and encouraging prospective new electrified 'green' industries to develop in the Strategic Industrial Areas.[46]

On the supply side this enables a wider range of VRE developers not contracted to iron ore miners to invest, diversifying the supply market with the associated market competition and spreading of development risks.

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46 As noted in background, the scale of energy use in the Pilbara is gigantic and dominated by iron ore mining and LNG production in roughly equal proportions, so decarbonisation of LNG production is important. All forecasts are assumption driven: those underpinning the High Demand case depicted in Figure 8 result in a 38%/45% split between iron ore/LNG with 17% made up from other sectors.

Optimise electricity infrastructure development

CUTI can optimise electricity infrastructure building with a network system fit-for-purpose approach rather than a network link fit-for-purpose approach. This means that a system can be designed and operated at an optimal size to deliver renewable energy across the system.

The analysis here suggests ***this "right-sizing" is likely to require less transmission infrastructure than the Autarky case, avoiding duplication of transmission links to generation sources, and combining the existing networks into a single system*** able to transfer energy from multiple sources to multiple loads.

In particular, ***a system approach including open access for users and generators can better anticipate the future system needs*** where users are predominantly located on the coast accessing energy from VRE sites mostly located inland.

System reliability and resilience

While the "fit for system purpose" CUTI development approach focuses on resource adequacy, the systems-based approach is the basis for better reliability for all users. **A single integrated and looped network is better placed to provide N-1 reliability than four individual networks where additional redundancy must be built into each network, and one system has to be held in a "secure operating state" instead of four.**

Electricity systems are recognised as essential to the resilience of communities to the shock of major disruptions, particularly extreme weather conditions that could occur more frequently due to climate change. Network systems (and corresponding network regulations) are being increasingly "hardened" to better support this resilience.[47] The Pilbara is already a cyclone zone, adding to CAPEX to harden transmission. Again, an integrated and looped network supports the resilience of the electricity system when one or more components are inoperable for longer periods of time.

Environmental and social impacts

System planning that optimises CUTI development should have lower environmental and social impacts. Multiple and unnecessary duplication of infrastructure footprints within the same corridor is **a key concern of traditional owners in the Pilbara, impacting their approvals and timelines**.

Table 14 provides an estimate of the land use for transmission and generation in the modelled cases. This includes transmission easements for the estimated line lengths in Table 3 at widths standard for Australian transmission companies for given transmission voltages, and generation based on EPWA/AEMO (ha/MW) land use factors applied to the generation capacities identified by the modelling in section 3.4.

[47] For example, the Australian Energy Market Commission recently completed developing a Rule change for electricity network expenditure that includes a definition of resilience (as opposed to reliability) and resilience expenditure factors. See ERC0400 - Including distribution network resilience in the National Electricity Rules. https://www.aemc.gov.au/rule-changes/including-distribution-network-resilience-national-electricity-rules

Each autarkic company must seek planning approvals from the state and negotiate with traditional owners for their own (smaller) transmission asset, with possibly overlapping or contiguous transmission easements. As noted in Section 3.2, there is a trade-off in the Autarky case between no new links between load nodes requiring transmission easements and the separate development of renewable generation requiring separate corridors to those hubs. This results in an **additional 2,845 hectares or 27% transmission easements** in the Autarky case compared to the Base case (CUTI). The corresponding overbuild of generation capacity results in **an additional 9,704 hectares or 7% land** required for solar and wind farms in the Autarky case compared to the Base case.

Table 14: Estimated land area use (hectares)

	Transmission	Solar	Wind	Generation (a)	Total
Autarky	13,265	14,608	129,344	144,129	157,393
Base	10,420	11,413	122,877	134,425	144,845
Difference	2,845	3,195	6,467	9,704	12,549
Saving	21%	22%	5%	7%	8%
High Demand	10,420	19,186	232,855	252,211	264,993
Difference	0	7,773	109,978	117,786	120,148

(a) Generation also includes batteries, but these are not listed separately as constituting 0.1-0.4% of land use

CUTI supports the development of larger transmission assets in the proposed designated priority transmission corridors, including rationalising transmission connecting RGHs. This results in lower land impact and requires fewer planning approvals and accompanying consultations.

Facilitated planning opens the opportunity to engage stakeholders earlier in the system development process. This approach is more likely to identify priority issues early, bypass dead-ends and build social licence for the energy transition. In this respect, EPWA has:

- modelled the Pilbara and NWIS and devised a commercial model for the development of key CUTI corridors;
- engaged industry in CUTI development through the PIR;
- as at the date of this report, allocated preferred developers for four key Pilbara corridors; and
- created the PET Aboriginal Working Group to engage 32 Native Title holders/claimants in planning a clean energy future with sensitivity to their unique cultural heritage and respect and protection of Country.

CUTI system planning provides further opportunity to minimise environmental and social impacts by integrating infrastructure planning beyond just CUTI. Public information and discussion allows for better coordination within the State's regional planning strategies and for other developers to coordinate and align planning for other infrastructure such as multiuser rail and ports. Other developers may identify opportunities to share easements with a potential to both reduce land use and expedite planning approval for what would otherwise be separate developments.

Streamlining planning processes

The CUTI system planning approach better supports the rapid transition of a decarbonised Pilbara energy system. The collective vision of parties provides opportunities to meet the schedules for rapid development of a connected, renewable electricity system. The collective parties are better able to recognise opportunities to consider classes of approvals so that planning processes may be streamlined. Improved planning processes are then able to decide applications faster while still satisfying the stakeholders engaged with planning and thus accelerate development cycles.

As a result of such efficiencies, **system planning is more likely to achieve shorter schedules for the planning and construction of individual units** (e.g. an inter-node transmission links) and associated infrastructure (e.g. RGHs and associated transmission links). This has advantages both for achieving the energy savings and decarbonisation targets for those already committed parties, but also to create the opportunity for wider industries to claim opportunities for energy and emissions savings.

7. Summary of modelling results

This section summarises the key findings from modelling the three transmission cases and considering benefits of electrification and of CUTI in the previous sections.

The focus of this report is the relative advantages of a "fit for system purpose" CUTI development approach. The CUTI Base case exhibits significant advantages, where a system planning approach can facilitate development of a transmission system open to a wide range of both loads and generation developers to build an efficient system at a lower cost for the **CUTI system of $10.5 billion (cumulative cost over 2025-50), compared to the Autarky case of $14.7 billion.**

Two thirds of the **$6.6 billion p.a. avoided economic fuel costs** is attributable to the electrification of **iron ore miners**, with a combined 26.4 Mt CO_2-e of avoided carbon emissions in 2050 (per annum).[48]

The CUTI approach in the Base case opens the door to further load growth, more electrification and decarbonisation. The High Demand case represents **33% more demand**, **81% more electrification** and **33% more decarbonisation than the Autarky case with only 12% more electricity system expenditure** between 2025-50.

The following tables summarises the differences between the three cases for:

- transmission infrastructure in Table 15;
- generation infrastructure in Table 16; and
- combined properties of the electric system and energy system as a whole in Table 17.

[48] Note these savings refer to the 2031 to 2050 average, see for example section 5.2.

Table 15: Transmission infrastructure

Metric	Base	Autarky	High Demand
Network topology	Single connected network between load centres and RGH	4 existing networks between loads, independent extensions to RGH	Single connected network between load centres and RGH
Est. new line length by 2050 (km)	1,290	1812	1290
Est. upgrade line length by 2050 (km)	1,072	957	1,072
Est. additional land use by 2050 (ha)[49]	10,420	13,265	12,782
Total annualised cost by 2050 ($B)	$10.5	$14.7	$15.8
Net Present Cost of total annualised cost by 2050 ($B)	$3.8	$5.4	$5.8
Legal/regulatory framework	Open access, new load opportunity, wider range of developers	Autarkic networks, load contracted developers	Based on realisation of opportunity in Base case
Environmental impacts/ planning	Smaller footprint, fewer approvals, consultations, shorter timelines	Potential duplication, larger footprint, separate approvals	Based on realisation of opportunity in Base case
Stakeholder, Traditional Owner engagement	WA state-coordinated system focus, early engagement, consistent, sustained approach	Separate consultations with multiple developers, duplicated consultations with traditional owners	Based on realisation of opportunity in Base case
Planning processes	Potential to streamline	Status quo	Potential to streamline

[49] Includes both new and widened corridors.

Table 16: Generation infrastructure

Metric	Base	Autarky	High Demand
Load in 2050 (TWh)	28.5	28.5	37.9
Planning – right sizing:	System	Network link	System
Solar capacity new/total by 2050 (GW)	4.6/5.1	5.8/6.4	7.7/8.3
Wind capacity new/total by 2050 (GW)	6.8/7.2	7.1/7.6	12.9/13.3
4hr Battery capacity new/total by 2050 (GW)	2.1/2.1	2.1/2.1	4.3/4.3
8hr Battery capacity new/total by 2050 (GW)	5.7/5.7	7.8/7.8	6.3/6.3
Est. additional land use by 2050 (ha)	134,425	144,129	252,211
Generation CAPEX, 2025-50 ($B)	$105.4	$131.6	$145.2
Generation CAPEX NPC (central) ($B)	$35.3	$43.8	$47.2
Generation OPEX, 2025-50 ($B)	$9.7	$10.8	$15.4
Generation OPEX NPC (central) ($B)	$6.4	$7.0	$8.5
Stakeholder, Traditional Owner engagement	Early engagement, system focus	Separate consultations	Early engagement, system focus
Planning processes	Potential to streamline	Status quo	Potential to streamline

Table 17: Whole of system

Transmission	Base	Autarky	High Demand
Electrification in 2050 (TWh p.a.)	11.9	11.9	21.6
Avoided primary fuel by end users in 2050 (PJ p.a.)	120.6	120.6	179.2
Value avoided primary fuel to end users in 2050 ($B p.a.)	$4.4	$4.4	$5.4
Value avoided gas for GPG in 2050 ($B p.a.)	$2.4	$2.4	$3.0
Total transmission & generation annualised cost by 2050 ($B)	$125.6	$157.1	$176.4
NPC combined annualised cost (central) ($B)	$45.6	$56.2	$61.5
Avoided carbon emissions in 2050 (Mt CO_2-e p.a.)	24.9	24.8	34.5
Est. value of avoided GHG in 2050 ($B p.a.)	$10.2	$10.1	$13.5
Aggregate avoided carbon emissions by 2050 (Mt CO_2-e)	506.6	503.4	702.2
Aggregate est. value of avoided GHG 2025-50 ($B)	$148.2	$147.3	$204.0

8. What is needed for CUTI in the Pilbara?

The Pilbara energy system is at an inflection point. Electrification and decarbonisation provide the opportunity for wholesale system change, as it does across Australia and the world. A product of its history of independent decision making by powerful industrial players, the question is whether that autarkic approach can deliver an efficient decarbonised energy system in a timely manner. **This study indicates that independent decision making will be inefficient and risks the social license required for achieving emission reductions in the Pilbara.**

The option of a common user investment framework approach is well understood and applied in Australia generally. It already exists in the NWIS Pilbara Network Rules. The National Electricity Market (NEM) which delivered huge productivity benefits to the nation, recognised that sharing infrastructure across the states delivered benefits to all users.

The challenge to all stakeholders is to recognise their own roles and bring their capabilities to the common task. This has commenced already through the Pilbara Energy Transition Plan with the leadership by the WA Government, and participation of industry, Traditional Owners and others. To this the Australian Government has made available up to $3 billion concessional finance through the Rewiring the Nation program.

The pace of the change requires all stakeholders to commit to the challenge and evolve their own role/responsibilities to meet the system needs. The evolution of the energy transition requires the WA Government to continue a leadership role for the duration of that transition, coordinating the planning, regulatory evolution and actions of all stakeholders through each phase of change. Traditional energy autarkies must in turn relinquish some of their independence and work collaboratively with Government to support the most efficient outcomes. All parties need to work urgently to meet 2030 timelines.

This chapter considers what is needed to progress CUTI as it is described by the analysis in this report. It is a high-level view of key issues to support the scope of the energy transition, which has a duration measured in decades. It is not intended to be a comprehensive description of the work programs that have been completed or are currently underway. Nor is it intended to be prescriptive towards those involved in the work programs, which have their terms of reference and are delivering results, including within the period of development of this report.

It is a validation of the opportunity stakeholders are already taking steps to seize, and of the common goal for which stakeholders have already publicly declared support.

Multifaceted approach

System change means a multifaceted approach to the complexities of the system, indicated in this case by the participation and perspectives not only of energy stakeholders, but also government stakeholders for planning, environmental regulation, infrastructure, jobs, Treasury and Premier and Cabinet, infrastructure industry and investor representatives, and Traditional Owners and other community representatives. Each stakeholder has roles and responsibilities in the existing system.

System change means new roles and responsibilities, and the openness of stakeholders to change to better fit those roles/responsibilities and invite new parties to join the endeavour where gaps appear. CUTI means, for example, expanding the roles of third-party infrastructure providers, a single independent system operator, independent generation developers and regulators. Traditional autarkies must in turn relinquish some of their independence.

System change needs to be managed with as much clarity about roles and responsibilities as possible so that all parties understand the change process, while accepting degrees of uncertainty in a process that will involve shifts and modifications. Broadly these roles include:

- System planner, maintaining an up to date understanding of the requirements of the future Pilbara electricity system to deliver secure, reliable and affordable electricity to all users.
- Transmission planner & developers, to construct the "fit for system purpose" transmission and generation required to enable the renewable energy transition.
- Industry, as both the primary source of demand of the future system and as the experienced developers of the existing system. They also understand many of the challenges to be overcome to achieve the energy transition in the timeframe required.
- Investors, to bring the capital required for the energy transition, including potential commercial models appropriate to the nature of industry as the primary users of the Pilbara system, including the role of government finance such as Rewiring the Nation to help facilitate system change.
- Traditional Owners, with whom the magnitude of system change must be managed while minimising the impact on land and heritage.
- Government, both
  - in traditional roles such as oversight of land, environment, planning and the electricity system

regulatory framework to deliver secure, reliable and affordable electricity, modified in ways that accelerate system change while satisfying legislative and community purpose, and

– as the leader of the system change process.

Leadership

Leadership is critical to marshalling the resources of all stakeholders for the decades of the energy transition required. This leadership naturally sits with the West Australian Government, given the need to ensure a representation for the Pilbara communities affected and given their understanding and legislative authority over many facets of the system.

The WA Government has recognised and assumed this role, with Ministerial leadership and coordination by EPWA to convene stakeholders and commence working on the Pilbara Energy Transition Plan. The Plan has successfully worked through the first phase to identify the objectives and challenges of the energy transition and has now started the second phase to begin to implement the Plan (see section 2.4).

This leadership and orchestration of the parties involved in the Pilbara energy transition is vital, and the WA Government needs to make, communicate and maintain commitment to the plan. Looking ahead over the time scale of the transition, this leadership role will need to be renewed and refreshed as the transition moves phases. The core of the role will remain the same:

- maintaining industry alignment, coordination and action with the Plan's objectives, and
- coordinating development and action within those parts of the WA Government that are essential to industry being able to act on the ground at the speed required.

Currently focus and support is directed towards CUTI development required to underpin the energy transformation. Very soon this focus and support will need to expand to include the energy developers that will deliver the required renewable energy generation.

Regulatory confidence

The CUTI approach amalgamates all infrastructure providers and users with a single regulatory regime. This is recognised in the Pilbara Energy Transition Plan with the objective to support greater access to high-quality renewable resources under a fit-for-purpose open access framework. This is not a new framework but an evolution of the Pilbara electricity regulatory regime in the Pilbara Network Rules, with work commencing early in 2024.

This is likely to include a wide range of regulations needing urgent resolution reflecting the multifaceted approach required. For example, MJA understand that miner State Agreement terms restrict purchase and sale of energy, and limit the ability to use existing generation assets for grid support. Such Agreement terms and the PNR will need to be reconciled with each other.

Confidence and certainty in the regulatory system is critical to unlocking private capital from third parties, rather than the industrial mining users of the Pilbara. Investing parties need to know they will be treated fairly under a consistent and transparent set of rules.

Third party capital is available and looking for opportunities to invest in the energy transition. With such a low level of renewable penetration and the decarbonisation imperatives of the users the Pilbara is a standout investment opportunity. This report identifies a CUTI framework that would enable this capital to be unlocked for the benefit of the users and the broader community. Such a framework helps unlock public funding by supporting the development of competitive markets that leverage private investment.

There is an urgency to these regulatory reforms, both to establish the terms of the basic framework and the processes for wider engagement in its evolution. The basic fact is that the construction of more than 2000 kilometres new and upgraded transmission by 2031/2032, together with substantial quantities of solar and wind generation prior to 2030 means that developers and investors need confidence in the regulatory framework under which those assets will operate.

A clear and logical path forward

Given the quality of VRE resources in the Pilbara, there are significant decarbonisation opportunities for industry in a region that represents a substantial part of the nation's total carbon emissions. The industrial demand in the Pilbara (effectively baseload or flat demand) can be met by a mix of solar and wind, firmed up by GPG and increasingly battery energy storage systems. Its users and the future demand for the products produced in the region (i.e. iron ore, ammonia nitrate, LNG etc) and the long-term investments (i.e. mining infrastructure, rail, port facilities) required to supply those products, provide certainty for investment in long duration assets such as transmission, storage and generation assets. Decarbonisation starts from a low base, and yet the payoff from decarbonisation in cost and environmental term is enormous. Public and private investors are ready to act. They just need the framework within which they can invest.

This report, by demonstrating the scale of benefits and savings in cost and emission reductions that arise from a common user framework, aims to catalyse Australia's greatest untapped transition opportunity. What is good for the country is also beneficial for the community. The users that have been the basis of the autarkical system that exists in the Pilbara today are however the greatest potential winners from a Common User Transmission Infrastructure system. Now is the time to act.

Appendix 1. Acronyms and abbreviations

Abbreviation	Definition
AEMO	Australian Energy Market Operator
AREH	Australian Renewable Energy Hub
BAU	Business as usual
BESS	Battery electric storage system
CAPEX	Capital expenditure
CEFC	Clean Energy Finance Corporation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CUTI	Common user transmission infrastructure
EER	Energy efficiency ratios
EPWA	Energy Policy WA
FMG	Fortescue Metals Group
GHG	Greenhouse gases
GJ	gigajoule
GPG	gas powered generation
ha	hectares
IEA	International Energy Agency
ISP	Integrated System Plan
km	kilometre
kV	kilovolt
kW, MW, GW	kilowatt, megawatt, gigawatt
kWh, MWh, GWh, TWh	kilowatt hour, mega, giga, terawatt hour
LCLF	low carbon liquid fuels
LNG	liquefied natural gas
NEM	National Electricity Market
NPC	Net Present Costs
NWIS	North-West Interconnected System
OCGT	open-cycle gas turbine
OPEX	operational expenditure
PET	Pilbara Energy Transition
PIR	Pilbara industry roundtable

Abbreviation	Definition
PJ	Petajoule
PNR	Pilbara Network Rules
RGH	Renewable generation hub
VRE	Variable renewable energy
WACC	weighted average cost of capital
YPF	Yara Pilbara Fertilisers

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