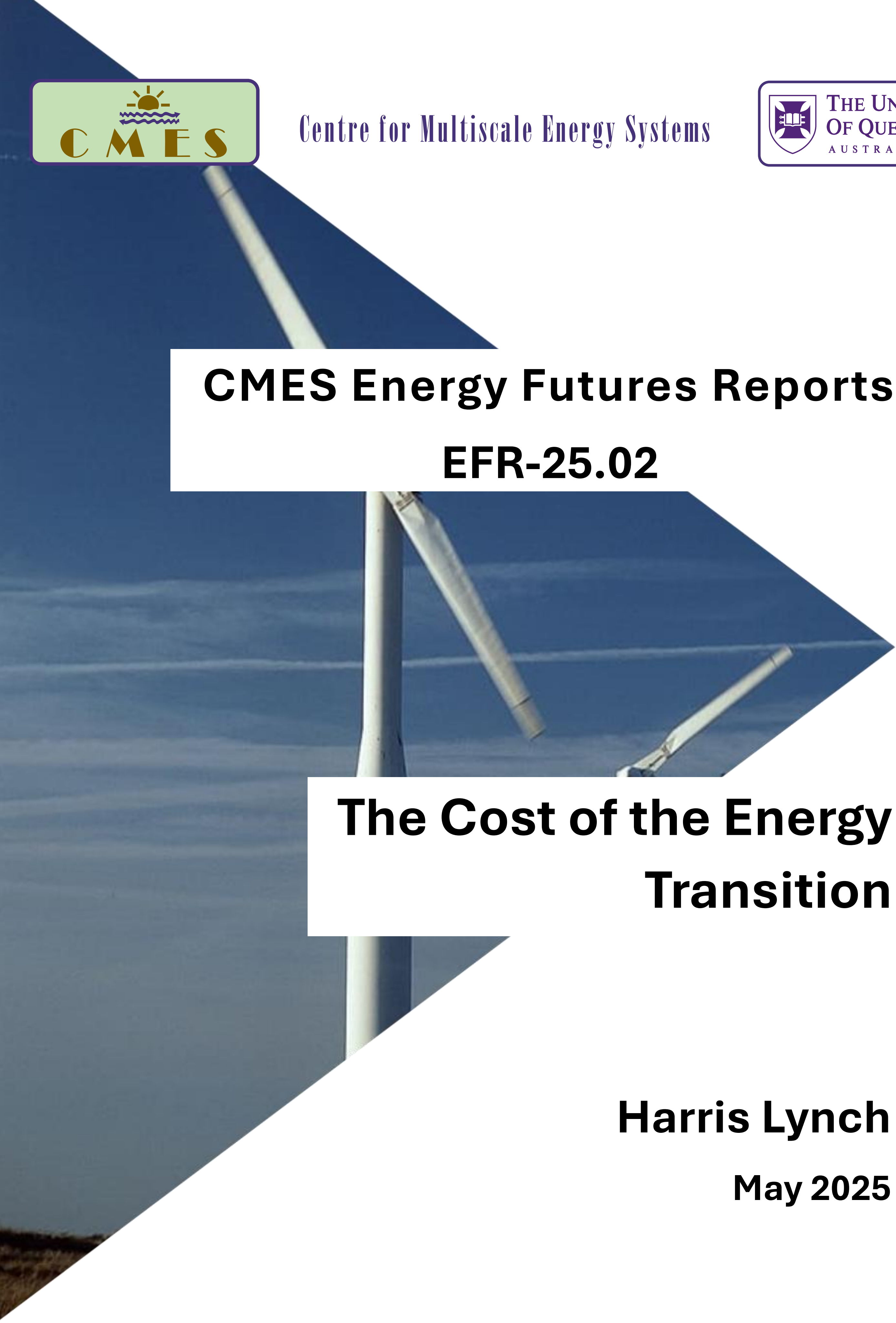
Centre for Multiscale Energy Systems



CMES Energy Futures Reports

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The Cost of the Energy Transition

Harris Lynch

May 2025

Foreword

The cost of the energy transition remains one of the most pressing and debated questions in Australia—particularly in Queensland. Energy transition pathways can include many interacting elements and degrees of flexibility, which determine how technologies and costs are incorporated or excluded from analysis. From an economic standpoint, what matters most is not whether a particular cost component is included or omitted, but whether all scenarios are evaluated consistently—using the same assumptions, boundary conditions, and costing methodology. Only consistent assumptions enable fair comparison of energy options; selective cost treatment risks bias and distortion.

The task of consistent comparing the cost of energy transition across three different scenarios was undertaken by **Harris Lynch**, one of the most diligent and responsible students in his cohort. While such considerations inevitably involve some judgment, this judgment was exercised by Harris himself, with my advice limited to general principles.

All three scenarios assume **complete decarbonisation by 2050**. The future, of course, is not predetermined: varying levels of decarbonisation enforcement through international trade or regulation remain possible. While Australia must be prepared for a range of pathways—from the status quo to strict decarbonisation—comparing the costs of decarbonised and carbon-unrestricted energy production is of limited value, since the latter will always appear less costly than the former.

The three scenarios considered are:

1. **Queensland Energy Gas Scenario (QEGS)** — replacing coal primarily with gas (with carbon capture and storage) and partially with solar and wind, with minimal battery storage (BESS).

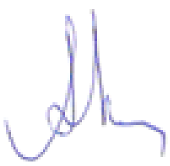
2. **Queensland Energy Renewable Scenario (QERS)** — replacing coal with solar and wind generation supported by extensive BESS and pumped hydro (PHES).

3. **Queensland Energy Nuclear Scenario (QENS)** — replacing coal with nuclear power (two 1.4-GW plants) alongside solar, wind, and the necessary BESS and PHES.

The results of the analysis may seem surprising. Despite very different cost structures, the total expenditure to 2050 is broadly similar for all three scenarios—around **A$400 billion**. However, due to different timing and composition of these expenditures, the **Levelised Cost of Electricity (LCOE)** varies significantly, increasing from Scenario 1 to 2 to 3. This reflects the effect of substantial early investments required in some pathways.

These scenarios were formulated on the basis of the **2022 Queensland Energy Plan**, which has since been replaced by the **2025 Queensland Energy Plan**. The new plan extends the operating life of coal power stations and reduces near-term investment commitments. Such changes would likely lower LCOE even below Scenario 1, but could create risks and potential penalties if international agreements progressively enforce decarbonisation. The 2025 plan retains the official goal of **net-zero emissions from Queensland electricity generation by 2050**.

This report presents an independent, carefully executed study of energy transition economics under full decarbonisation by 2050. It is a valuable and thought-provoking work for anyone in Australia concerned with the future of the nation's energy system.



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The Cost of the Energy Transition

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Abstract

As global pressure and urgency for decarbonisation intensifies, the state of Queensland faces a pivotal and defining moment in its history, transitioning from old fossil fuel industrialization to a practical and reliable decarbonised economy. In-alignment with legislated emission reduction targets, including net-zero emissions by 2050, the Queensland government has committed to a large-scale energy transition. This thesis investigates the cost of the energy transition in Queensland over the next three decades to 2054, focusing on three key areas: 1) New Generation and Storage, 2) Transmission and Stability, and 3) Existing Fossil Fuel Generation.

To evaluate the cost of the energy transition, three scenario models were developed. This included the QEGS, which assumed a system reliant on emission free gas generation utilising carbon capture, along with a minority of renewable generation and limited storage. The second scenario, called the QERS, was modelled upon the current Queensland renewable energy plan. The QENS was the final scenario which considered the implementation of nuclear generation, supported by renewable generation and storage.

Analysis of each research question across each scenario was conducted using data from reliable parties to the energy transition in Queensland, such as Government agencies and primary stakeholders. Both existing and proposed generation and storage projects from the Queensland Government, along with grid transmission infrastructure from the Australian Government, provided an important backbone of which the thesis results are based upon. Costing estimates for each scenario were calculated utilising governmental data sources combined within an excel model which accounted for inflation and critical engineering assumptions. The research investigation across each research question included the identification of assumptions and scope, approach of background research, data collection and methodology, results analysis and discussion, sensitivity analysis, limitations and conclusions.

The key findings from the thesis research investigation for each research question are summarised below:

1. **Research Question 1 – New Generation and Storage**
   Each research scenario maintains the same generation outcomes, with total capacity rising 209% over the investigation timeframe. The combined evaluation of CapEx and OpEx costs to construct and operate the new generation and storage infrastructure for the QEGS, QERS, and QENS are $361 billion, $341 billion, and $359 billion respectively. Although the renewable scenario constructs the largest capacity of assets, it has the lowest CapEx and OpEx costs for this research scenario

2. **Research Question 2 – Grid Transmission and Stability**
   cost estimates were developed to cover new transmission infrastructure, connection cost of new assets, and transmission stability requirements. The QERS incurred the highest cost of $54 billion, follow by the QENS at $43 billion, and the QEGS at $28 billion. The QERS requires more investment due to the inefficiencies of renewable generation, along with the lack of natural inertia available in the generation systems.

3. **Research Question 3 – Existing Fossil Fuel Generation**
   Decommissioning costs considered demolition, material haulage and scrapping, site remediation and a contingency. The cost estimate for the QEGS and QENS was $10 billion, while the cost for the QERS was lower at $7 billion due to the requirement for the repurposing of three older coal power stations for transmission stability requirements

Aggregating the cost across all three research questions, the total system cost varies modestly across the three scenarios, with a maximum difference of $11.5 billion. However, these results were highly sensitive to a range of critical assumptions. For example, the QEGS assumes emission free carbon capture storage is viable at an industrial scale. In-addition to this, the QENS incorporates substantial investment into nuclear, despite the absence of an existing nuclear generation industry. Estimates for the implementation of this industry vary wildly Therefore, this thesis acknowledges the range of uncertainties and critical assumptions made, and considering this, the QERS is the most feasible, appropriate, and cost-effective scenario to transition the Queensland energy grid to net-zero emissions.

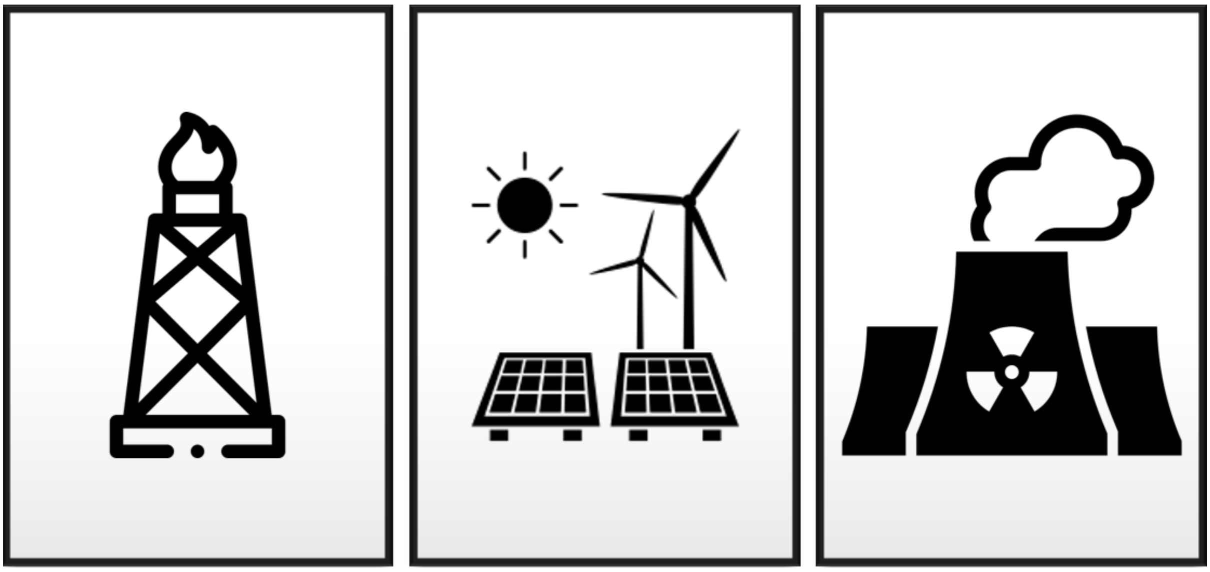

Figure 1 - Fossil Fuel, Renewables, and Nuclear Energy Technologies Adapted from (Flaticon. 2025), (Noun Project. 2025), and (SVGREPO. 2025)

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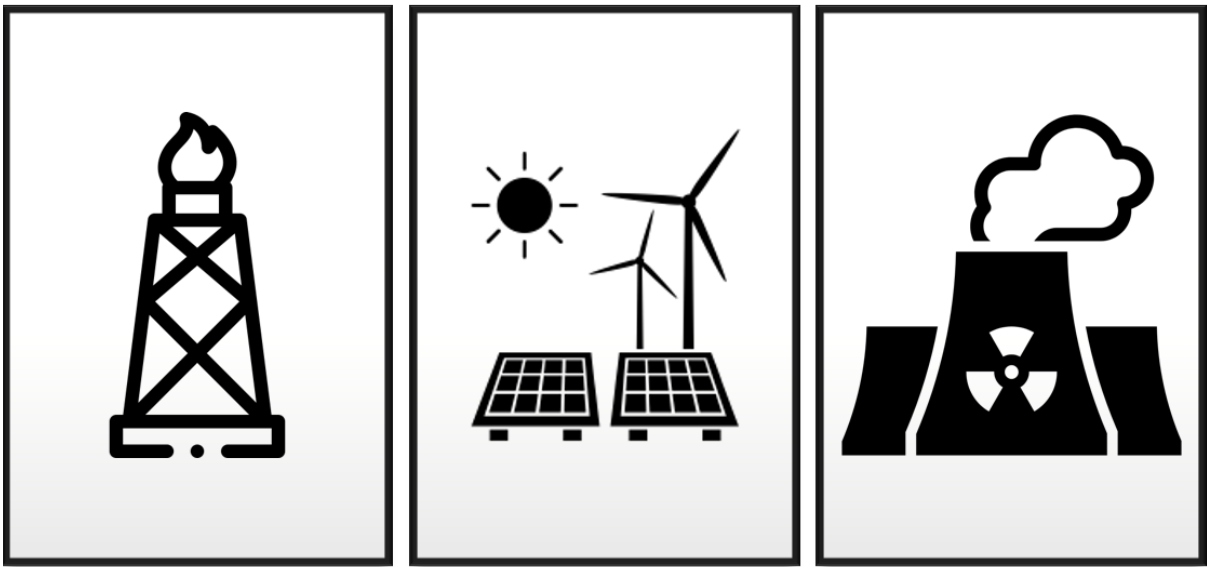
1.0 Introduction



1.1 Background Overview & Context

As the 21st century progresses, it is becoming increasingly apparent that human-induced climate change represents humanities largest obstacle to on-going societal progression. As a result, there has been significant influence worldwide for governing bodies to implement a plan to transition from fossil fuelled industrialisation, to a sustainable and practical renewable energy based decarbonised economy. This influence comes in many forms, including scientific research, diplomatic and international pressure, economic factors, and energy security needs.

In Australia, national government and state governments are implementing and legislating these measures, in the form of emission reduction and net-zero emission policies, to reduce emission carbon intensity. One such example of legislation that the Queensland Government has passed is the '*Clean Economy Jobs Act 2024*', whereby "the 2030, 2035 and 'net zero by 2050' emissions reduction targets" (Queensland Government Department of Energy and Climate. 2024) were enshrined in law. This legislation aims to transition the QLD electricity grid from a predominantly coal and natural gas-based grid to a renewable energy and storage-based grid. In-addition to this, the '*Queensland Energy and Jobs Plan*' was legislated whereby an effective plan to meet these targets was implemented in a cost-effective manner, while also providing economic stimuli to rural communities dependent on fossil fuel generation.

Currently, the state has chosen to apply a 50% reduction of emissions by 2030, 70% by 2032, 80% by 2035 and net-zero by 2050 (AEMO. 2024). To ensure these targets are met, a range of new flagship renewable energy generation and storage projects have been announced and commissioned to increase this desired renewable energy penetration. Some of these projects include the Borumba Downs Pumped Hydro, as well as the SuperGrid transmission grid (Queensland Government. 2022). Primarily, these projects are desired to be constructed and operated around communities which previously had fossil fuel industries operating, which will reduce the burden once the transition occurs.

Initial stages of the energy transition are currently being implemented through the use of technologies such as photovoltaic solar, and wind generation. Due to this form of renewable generation being a variable electricity load, forms of energy storage, such as pumped hydro and battery storage, will need to be implemented to meet consumption demands. However, there have been numerous other plans to approach the energy transition. To maintain baseload generation, there have been calls for the implementation of gas generation with a form of emission free carbon capture. Another approach is the implementation of baseload nuclear generation, which was taken to the 2025 Federal Australian Election as a key policy under the Liberal National Coalition, though this coalition of parties were heavily defeated.

Following the aforementioned legislation in Queensland, significant attention has been concentrated around the feasibility and the timeframe of decarbonisation, resulting from the international pressure. It is, however, important to also cover the various costs which may arise from this pivotal transition. This is especially important when new options, which have not been implemented in Australia before, come into the conversation, such as nuclear generation. It is expected that this transition will better the economy, while ensuring safe and reliable electricity for the decades to come.

1.2 Research Gap and Relevance

Critically, there are many gaps in research related to costing the energy transition which is highly important to understand. The main consideration of this field of study is a lack of a combined approach to cost the energy transition in Queensland, considering multiple factors and scenarios. This is primarily due to the various stakeholders, each operating under a different framework. This leads to wildly different statistics from different stakeholders when it comes to estimating the cost of various projects and policies.

Summarised below, are the main issues with the data available related to this field:

- Variance issues and restricted/misleading data: Databases and figure estimates from the Federal and Queensland Government, along with private investment, can be inconsistent and provide large variances with the proposed figure. There are possibilities of people with influence swaying results for personal gain. Due to this, there are questions regarding the accuracy, reliability, and validity of some of the data ascertained
- Idealised costing without anticipating potential influences: Commonly, engineers are hired to forecast potential costs, of which they are ill-equipped to do so. This commonly results in projects exceeding initial budgetary forecasts. In-particular, government greatly benefit initially from announcing projects with idealised costs, as this increases political benefit
- Omission of essential data required for costing: Occasionally, data bases and figure estimates do not provide the necessary data required for an accurate in-depth analysis in the relevant field. Potentially, results from this may lead to negative consequences where forecasters and government planners' have an inability to find the best plan to transition the grid

1.3 Aims and Scope

The aim of this report is to clearly evaluate the cost of the energy transition in the state of Queensland, considering transitional factors and scenarios relevant to Queensland. A thorough engineering analysis was conducted involving various stakeholders and resources to determine the various costs involved with this. Following this analysis, a true figure was evaluated, inclusive of various factors, assumptions, and issues. Research in this field is required to allow policy makers to understand impacts which may arise from this transition, and how to implement any mitigating policies or procedures to reduce any negative effects derived from these impacts.

Throughout the report, the research scope is clearly defined and outlined throughout the analysis in relation to each sub research question. Though, as outlined in the Research Gap and Relevance, along with Aims and Scope, the overarching scope of this report is to cost the energy transition in Queensland. It is important to consider that this report will not consider the feasibility of such plans outlined by various stakeholders including but not limited to the Queensland Government, the Federal Government, and private investment firms. In-addition to this, regulatory changes, environmental costs, and social costs will not be examined and are out of scope.

1.4 Thesis Research Questions

Important transitional factors to the energy transition in Queensland includes the costs of building new generation and storage projects, developing new stable grid transmission infrastructure, and the decommissioning existing fossil fuel infrastructure. Recognising this, three research questions, which organise the research investigation of this thesis, were developed surrounding these transitional factors. To further structure the research investigation, a range of research sub-questions were developed under these research questions. The format of this research investigation includes:

1. ***New Generation and Storage***

   Following the decommissioning, attention will be focused upon the new generation and storage projects and the associated costs. This is expected to include:

   - RQ1-01 Quantitative analysis of capital expenditure, operational, and maintenance costs required to commission and operate these projects
   - RQ1-02 – Quantitative analysis on the net difference in job numbers required for renewable generation and older fossil fuel generation

2. ***Grid Transmission and Stability***

   Once the renewable generation and storage costs were identified, the next stage draws attention to grid transmission and stability. This includes:

   - RQ2-01 - Quantitative estimation on the requirement of new transmission to interconnect LGAs in Queensland considering the new generation/storage load
   - RQ2-02 – Estimation and analysis of costs to maintain grid stability within the Queensland transmission grid

3. ***Existing Fossil Fuel Generation***

   Initially, an applied engineering analysis will be performed upon decommissioning of the existing fossil fuel generation infrastructure. The following stages will be included:

   - RQ3-01 - Estimation of net costs involved with decommissioning existing fossil fuel generation considering demolition, scrapping and dumping of materials, and site remediation

All tasks have been assigned a code with the structure of RQX-0Y, whereby X refers to Research Question (RQ#), and Y refers to the task number i.e. (1).

1.5 Different Thesis Scenarios

There is a chance that the current Queensland renewable energy plan may not occur, and a different transitional scenario may be implemented instead. This research thesis will identify the key scenarios and cost them accordingly. Thorough analysis identified that there were three potential transition outcomes, which includes gas dominance, the current renewable plan, and the implementation of nuclear in Queensland. Therefore, three transitional scenarios were developed, which best positions this research investigation to analyse these three potential outcomes. These scenarios include:

1.5.1 QEGS – Queensland Energy Gas Scenario

The overarching structure of the QEGS is to maintain and expand fossil fuel base-load generation over the coming years. This scenario expects newer gas generation, in the form of new CCGT (Combined Cycle Gas Turbine) Generation with CCS (Carbon Capture Storage), with older existing generation still expected to be decommissioned in-line with RQ3-01.

Recognising that the Queensland Government has legislated 2050 emission reduction targets, this CCGT with CCS is expected to have negligible emission output so these legislated targets are met. Although theoretical, it is assumed that practical emission free CCS will be commercially viable within the coming years. In-addition to this, renewable generation, supported by storage, will be commissioned in this scenario, though at lower rates.

Although this scenario does have its drawbacks, as the generation technology is theoretical and not commercially viable as of 2024/25 (Monaghan. T, 2024). Uncertain investment has the potential to produce this viability, though investment into fossil fuel generation is decreasing as the world recognises the implications and importance of climate change.

1.5.2 QERS – Queensland Energy Renewable Scenario

The fundamental framework of the QERS is to transition the energy grid in accordance with the current proposed renewable energy plan in Queensland. The Queensland Government has released a detailed report on the plan to transition the energy grid away from the fossil fuel industrialisation to a practical and decarbonised energy grid. This includes the complete phase-out of fossil fuel generation by 2050, with this replaced by a significant expansion of new renewable generation, in the form of new solar & wind, along with BESS & PHES storage.

1.5.3 QENS – Queensland Energy Nuclear Scenario

Finally, the structure of the QENS scenario follows closely to the QERS scenario, while implementing the announced nuclear plan by Liberal National Coalition in the 2025 Australian Election. Altogether, the plan called for two separate nuclear generation plants, each with a capacity of 2GW of nameplate generation. The combined 4GW of nameplate generation will reduce the requirement for renewable generation, along with energy storage. To maintain generation capacity with the other two scenarios, a number of renewable generation and storage projects were removed in a ratio to the addition of nuclear generation.

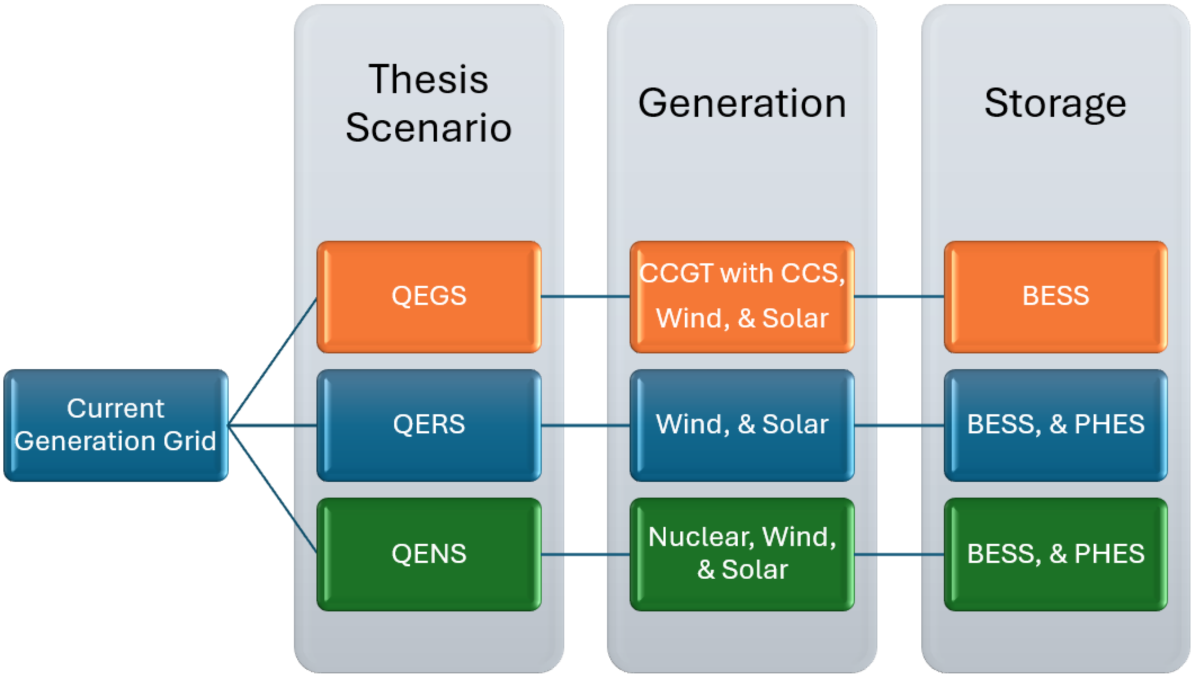
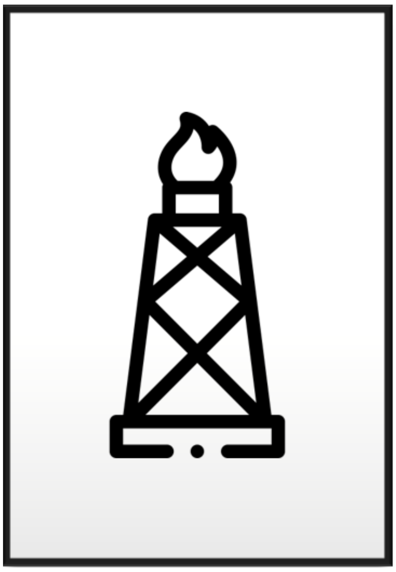
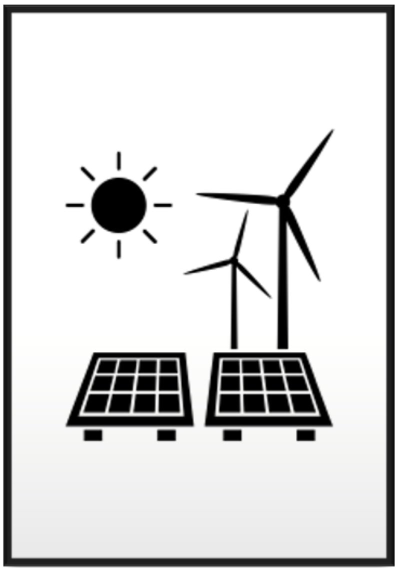


Figure 2 – Process Flow Diagram for the Transitional Thesis Scenarios

2.0 Literature Review


2.1 Primary Stakeholders

2.1.1 Queensland Government Regulatory Bodies

Queensland Department of Energy and Climate (QDEC)

QDEC is responsible for maintaining the transition to a transitioned economy, while maintaining investment and job creation in the energy sector (Queensland Treasury. Accessed 2025).

2.1.2 Federal Government Regulatory and Advisory Bodies

Australian Competition and Consumer Commission (ACCC)

The Australian Competition and Consumer Commission was established to ensure competition in various markets including the energy market. This competition protects consumers from anti-competitive behaviours and practices from providers, and to influence affordability (ACCC. Accessed 2025).

Australian Energy Market Commission (AEMC)

Setup by the Australian Federal Government, the AEMC is responsible with regulating the electricity market. This body includes the regulation of rules including Electricity, National Gas, and National Energy Retail elements of the national grid (AEMC. Accessed 2025).

Australian Energy Market Operator (AEMO)

AEMO is responsible with the management of the electricity and gas markets in the Australian market. This management is in the form of system operation, market operation, management during emergencies, planning, and forecasting. AEMO has released various resources such as the '*2023 Integrated Assessment of System Reliability (IASR) Assumptions Workbook*' (AEMO. 2024) and are important to the execution to the Queensland energy transition. AEMO has developed a strategic roadmap to ensure the National Energy Market (NEM) is capable of reaching future energy requirements in a cost effective, and reliable manner. This roadmap is called the *Integrated Systems Plan (ISP)* (AEMO. 2024)

Australian Energy Regulator (AER)

The Australian Energy Regulator is an independent government body tasked with regulating the electricity and gas markets, set up by the AEMC. This regulation is in the form of network regulation, compliance and enforcement of laws, consumer protection, and observation of markets to ensure fair and efficiency operation (AER. Accessed 2025).

Australian Renewable Energy Agency (ARENA)

Established in 2012, ARENA provides grant funding to promote investment in the renewable energy industry in accordance with government strategy. The goal of this is to reduce cost, and lower financial risk in renewable energy development (ARENA. Accessed 2025).

Clean Energy Finance Corporation (CEFC)

CEFC is a government owned green bank providing finance to renewable energy projects and innovation, much like ARENA (CEFC. Accessed 2025).

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is the national science agency of Australia. In terms of the transition to renewable energy, the CSIRO is pivotal in the assistance of implementation. This is in terms of technological development, research and innovation, cost analysis of technologies and strategies, and energy system modelling (CSIRO. Accessed 2025).

National Energy Market (NEM)

NEM is the electricity grid responsible with supplying consumers on the eastern seaboard of the Australian mainland. Currently, the NEM spans 83,761km of transmission lines (Australian Government, 2025) and acts as a whole electricity market (Figure 3).

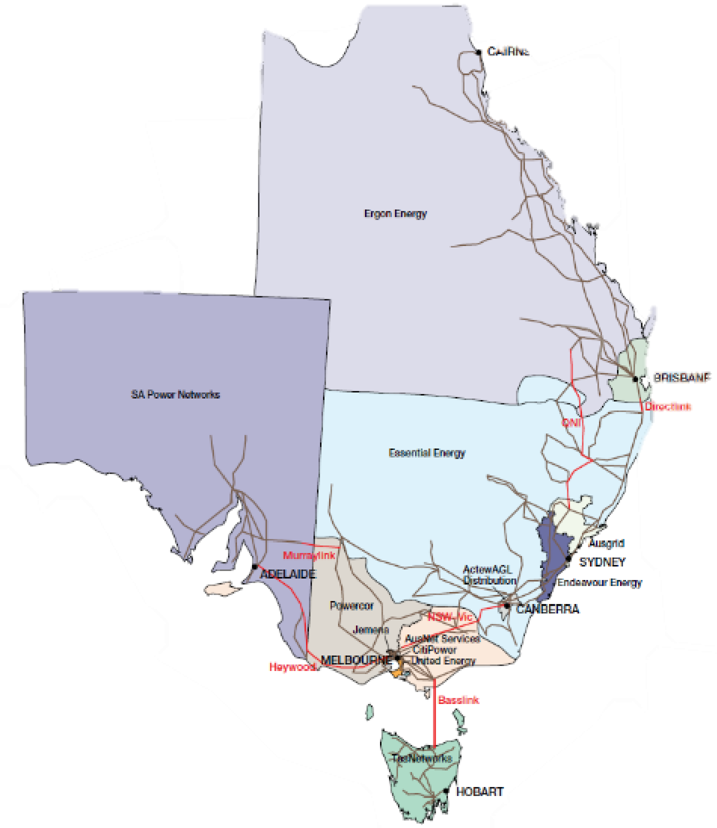


Figure 3 - National Energy Market (Electricity Wizard. 2015)

2.1.3 Industry and Community Stakeholders

Existing Generation Suppliers in Queensland

Various companies, such as Stanwell, CS energy, etc, work with AEMO to ensure that the grid has enough generation, so no blackouts occur. The current assets owned by these companies ranges from fossil fuel power stations to renewable energy generation alternatives. Multitude of these companies are planning to phase out fossil fuel generation to invest in more renewable energy.

National Grid Consumers in Queensland

A diverse group consisting of residential, commercial, and industrial consumers. A variety of these consumers have taken advantage of small scale solar to reduce electricity consuming requirements.

2.2 Relevant Resources

Feasibility Study on the Queensland Energy Plan - Thomas Heath

Thomas Heath conducted a feasibility study on the Queensland energy plan in his 2024 capstone thesis. This literature has used rigorous study and consultation to come to a qualitative conclusion and provide recommendations in the area of study. Relevant fields which were focused on included energy consumption and generation, grid stability, grid energy storage, and grid transmission. The sources used to come to this final conclusion are strong and reliable, primarily coming from government documents and consultations.

IASR Assumptions Workbook 2023 – AEMO

The AEMO created the 2023 Inputs, Assumptions and Scenarios Report (IASR) Workbook and is a quantitative analysis of energy costing for various generation and storage technologies. This includes both existing site-specific generation, as well as the integration of new assets in various energy zones with different site-specific costings. The AEMO works with industry specialists to create reliable and merited metrics for these technologies.

GenCost Report – CSIRO

The GenCost report, created by the CSIRO in collaboration with AEMO, is a report which details the cost of the energy transition in Australia. Various stakeholders were consulted such as engineering firms, and the report is recommended for the "government, industry, the private sector, and economic specialists" (CSIRO. 2024). To calculate the projected costs, GenCost uses capital cost data, along with Levelized Cost of Electricity (LCOE) to make these predictions.

Integrated Systems Plan – AEMO

Created by AEMO and from a range of resources such as the 2023 IASR Assumptions Workbook, the Integrated Systems Plan is an important document regarding the implementation of the energy transition. The ISP displays a range of scenarios regarding the speed of closure of current fossil fuel infrastructure, along with the renewable penetration increase. These relevant scenarios are:

- Green Energy Exports Scenario (Ambitious renewable energy transition which sees faster adoption of renewables)
- Step Change Scenario (Transition speed with current legislation)
- Progressive Change Scenario (Reduced economic growth leading to slower renewable penetration)

In-addition to this, the ISP factors in a range of additional factors which will affect the speed of renewable energy penetration. These include but are not limited to residential solar generation, Electric Vehicle (EV) ownership expectation, and small-scale commercial generation.

2.3 Transitional Stages for Renewable Implementation.

The process where fossil fuel energy generation, such as coal and gas fired power stations, is gradually phased out favouring increased renewable energy penetration is a complex and multi-stage process. For simplicity in this engineering analysis, the energy transition within Australia, and more specifically Queensland, is a four-stage process. Each stage occurs whereby specific milestones are met. In Queensland, the main driver for the implementation of this four-stage energy transition are the legislated energy emission reduction targets. These stages are:

2.3.1 Stage 1 – Initiation

This initial stage refers to the commencement of the renewable energy implementation and phase out of fossil fuel generation. It is expected that coal generation assets begin planning for closure, or initiate decommissioning and demolition. Coinciding with this decommissioning, it is expected that renewable energy penetration meets a 25% threshold. As of 2024, Queensland is expected to be within this stage right now with all coal assets planning to close, in-addition to the creation of an energy transition roadmap.

2.3.2 Stage 2 – Implementation

In this phase, a dramatic increase in renewable energy penetration leads to renewable energy becoming a dominant power source in the grid generation makeup, surpassing gas-powered generation. Simultaneously, coal-powered generation is completely removed from the grid as all generation stations are decommissioned. Initial stages for planning begin to decommission gas power stations or reconfigure these stations to a hydrogen mix generation. This hydrogen mix is

2.3.3 Stage 3 – Renewable Energy Dominance

This stage of the energy transition relates to the closure of all fossil fuel power stations and a 100% renewable energy generation penetration within the electricity grid. Coinciding with this, hydrogen infrastructure development has initiated, and hydrogen generation penetration begins.

2.3.4 Stage 4 – Hydrogen Economy

Finally, seen as the final stage of the renewable energy economy, a mature hydrogen economy develops whereby hydrogen is produced from excess renewable energy generation. This hydrogen is stored and used in generation to ensure supply meets demand. In-addition to this, the economy transitions from supplying international markets with coal and natural gas, to hydrogen exports.

2.4 Relevant Grid Technologies

In Queensland, the electricity grid operates both direct current (DC) and alternating current (AC) electricity. Electricity generation, and most often consumption, is in the form of DC electricity. DC electricity is primarily used for transmission and distribution over long distances due to low energy losses. Facilities known as inverters are used to convert DC to AC, and rectifiers are used to convert from AC to DC.

The 2024 QLD Energy and Jobs Plan, along with the AEMO ISP and various other sources call for a range of technologies to be utilised to ensure the QLD renewable energy transition successfully occurs. These technologies discussed are considered in this engineering analysis and can be classified as generation, storage, transmission, and grid stability assets in the NEM.

2.4.1 Generation and Storage Technologies

Battery Energy Storage - BES

BES systems utilise chemical potential between two electrodes, an anode and cathode, to store electricity. Battery systems can respond quickly, typically within a fraction of a second, to fluctuations in demand. This makes them well suited to additionally maintain grid stability. Large-Scale Battery Storage (LSBS) contains a large number of batteries in a facility, and various projects of this nature have been announced in QLD. There is an expectation for the number of proposed and constructed projects to significantly rise due to “the technologies versatility and falling costs" (ARENA. 2024). BES systems have a technical lifespan of 20 years (AEMO. 2024).

Distributed Energy Resources - DER

Typically referring to small scale generation and storage units, the use of DER systems is expected to significantly grow over the coming years, to 45% of generation capacity by 2050. DER changes the concept of how the energy grid is perceived, by shifting from large, centralised power stations, to more small scale and dispersed generation assets in various homes and businesses (ARENA. 2024). Examples of DER includes residential and commercial solar, battery, and other generation methods.

Coal Powered Generation - CPG

CPG is known as an old technology, operated in the form of base-load electricity generation for residential and commercial consumers. This is achieved by burning coal to heat water which passes through a turbine, driving a generating and creating work and electricity (TVA. Accessed 2024). Although CPG is known as a mainstay in old energy generaiton, a major consequence of such technology is the high degree of environmental damage. This is primarily in the form of emissions intensity, as well as land pollution and scarring from mining. Due to this, various countries are making plans and considerable efforts to transition away to reduce the impacts of global warming.

Gas Powered Generation – GPG

A cheap and reliable generation method, GPG is also considered a high-density base-load generation method to assist with the energy transition, primarily due to the low emission released during operations. In Australia, GPG is designed in the form of Combined Cycle Gas Turbine (CCGT) generation, whereby a gas is combusted to generate work and electricity. Exhaust gas from this combustion reaction are directed to a Heat Recovery Steam Generator (HRSG) to extract further thermal energy (Engie. Accessed 2024). With this duo of turbines, CCGT plants can expect thermal efficiencies of 60%. Various transition plans, including Queensland's, plan for CCGT turbines to be retrofitted with hydrogen turbines using a hydrogen-natural gas fuel mix. CCS can be combined with CCGT plants to theoretically reduce emissions to a negligible amount. The CCS considered and utilised in this investigation is Oxyfuel combustion with CCS (Oxy-CCS), and works by burning fuel in pure oxygen. Resultant flue gases mostly consists of water and CO_2, whereby the CO_2 is captured and stored (Talei S. 2024)

Pumped Hydro Energy Storage – PHES

A form of long-term energy storage, PHES schemes involve a configuration of two reservoirs at differing elevations, whereby water is transferred using a tunnel between them in the form of energy transfers. An increase in energy storage (potential energy) in the system is facilitated by pumping water to the Higher Elevated Reservoir (HER) from the LER, using a pump. Energy is released from the system through a water transfer to the LER from the HER , whereby potential energy is transferred to kinetic energy which spins a turbine. This turbine is connected to a generator which generates electricity. The pumps and turbines are stored in a pump house at the LER (ARENA. 2024). PHES systems are well suited as a form of long-term energy storage, and can be considered through the following metrics:

- Medium duration: 4-12 hour facilities with a capacity of 300-1000MW
- Long duration: >24 hour facilities, with a capacity of more than 1000MW

Schemes of this nature have a technical lifespan of 50 years, and an economically productive lifespan of 40 years (AEMO. 2024).

PV – Photovoltaic Generation

PV generation is regarded as a crucial renewable and clean technology to assist the energy transition. DC electricity is generated from sunlight incident upon a solar panel, resulting in significantly lowered operational costs due to no fuel costs required. Initial capital costs can be high due to a large, required area to be covered by solar panels for meaningful generation. This is due to solar radiation being measured in a unit per area, with a typical commercial generation per unit area around 200-350kW/m^2 (Roderick A. August 2021). In-addition to this, PV generation systems have a technical life and economically productive lifespan of 30 years (AEMO. 2023). Other technologies such as dual axis, or multijunctional cells can increase the effectivity of electricity generation over a unit time than more traditional single axis panel systems. However, these systems can have increased maintenance costs due to the presence of mechanical components.

Figure 4 - Typical PV Solar Generation Plant (PVcase. 2023)

In QLD, Solar is seen as a necessary technology for implementation, and therefore the number of solar generation sites will increase. Across all three thesis scenarios, this remains true, as it provides a cheap and practical form of energy generation which can be quickly scaled up.

Concentrated Solar Thermal - CST

Harnessing the use of solar, CST is an energy storage using solar incident radiation to store energy. CST facilities use large heliostats (mirrors) which reflect solar radiation into a target area to heat water. Energy is released through a steam turbine and generator. “Most CST plants used for electricity production incorporate 3-15 hours of thermal energy storage” (ARENA. 2024). These schemes have an operational lifespan of 20 years.

Wind Generation

Wind turbine generation generates DC electricity by converting wind incident force, which acts upon turbine blades, into electricity using a generator. This technology is implemented either onshore, or offshore, however projects in QLD are on-shore. The location of wind turbine farms is important for the viability of a project, as specific geographical areas have more consistent wind than others (Energy.Gov. Accessed 2024). Wind turbines typically have an economically productive life of 25 years, and a technical lifespan of 30 years (AEMO. 2024). Much like solar generation, wind is a unit per area generation, resulting in more generation from more turbines installed at a site. Wind is seen as a necessary technology in the energy transition, and the number of operating sites is expected to increase as the transition occurs.

Nuclear Generation

Nuclear Generation is a baseload generation technology, which utilises the same principles as CPG and GPG whereby water is super-heated, and work is produced via a steam turbine. The technique to heat this water though is significantly different compared CPG and GPG. Nuclear generation utilises atomic fission to convert the water to steam to drive the steam turbine. This atomic fission comes from the core and is made up primarily of uranium-235, or plutonium-239, though these elements do produce significant and harmful nuclear waste. However, there are new designs of this generation technology which can utilise thorium in the form of uranium-233, producing similar electricity generation and significantly less nuclear waste (IAEA, 2023).

2.4.2 Transmission and Grid Stability Technologies

Transmission Lines

Transmission lines facilitate the transport of electricity from a generation source to a consumption source. The QLD electricity transmission grid is operated by Powerlink and is responsible for a 1,700km expanse of region from the New South Wales (NSW) border to Cairns. In-total there is 23,672km of transmission lines and 147 substations. Various new projects such as the SuperGrid, and subset grids such as CopperGrid, have been announced in QLD to upgrade existing transmission infrastructure (QLD Government. 2024).

Synchronised Condensers

A solution to maintain grid frequency stability, synchronised condensers have been developed to be used in conjunction with long-distance transmission lines, as well as high demand networks. This device uses a DC-excited synchronous machine whereby both shafts are freely rotating and do not attach. The frequency stability immigrates from the synchronous inertia from these shafts, while voltage regulation comes from "continuously generating/absorbing adjustable reactive power as well as improve short-circuit strength" (Entsoe. Accessed 2024). Old CPG can be repurposed to synchronised condenser facilities as a cheaper alternative. The AER estimates a 30-year technical lifespan of these facilities before the requirement of maintenance and works to prolong the service and technical lifespan (AER. 2017).

2.5 Renewable Energy Zones – REZ

REZ's are a key aspect to significantly reduce emissions during the renewable energy transition within Queensland. These zones are located in areas of high renewable resource abundance, such as sunlight or wind, whereby investment into renewable energy projects are encouraged. REZ's development occurs in four stages, of which these include consultation and planning of REZ's with communities, further consultation and declaration of an REZ, construction and operation, and commissioning. As of 2024, there are 9 areas of interest for the commissioning of REZ's ranging from the Darling Downs Local Government Area (LGA), to up to Far North Queensland (Figure 5) (Powerlink, 2024). This scheme increases the coordination and acceleration of the energy transition.

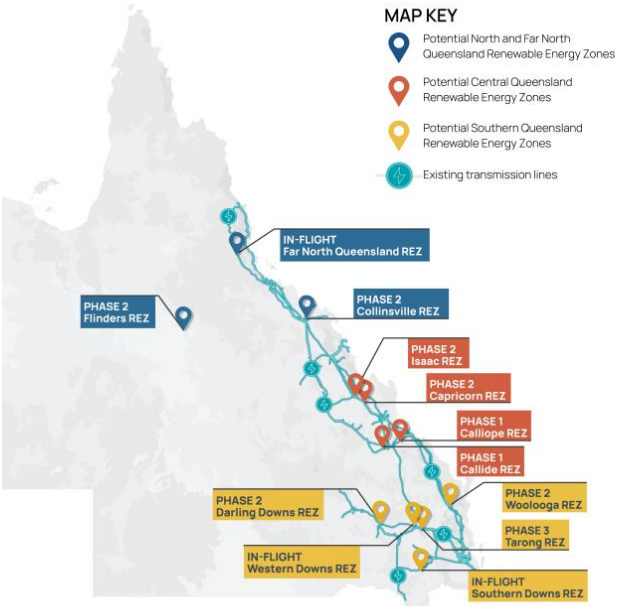
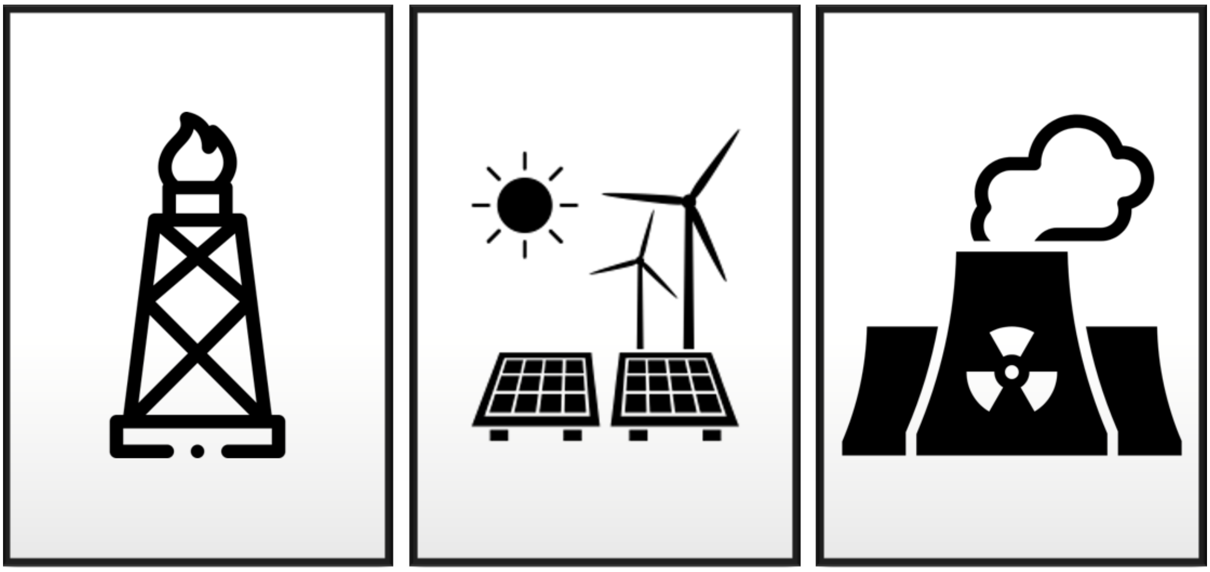


Figure 5 - REZ zones map in QLD (Powerlink. 2024)

2.6 General Approach of Analysis

To ensure this engineering research analysis is coordinated and realistic, the areas of research have been divided into three research questions which best answer the cost of the energy transition. These comprise of new generation and storage, grid transmission and stability, and finally decommissioning of existing fossil fuel infrastructure. The approach to research questions involves scope and assumptions, relevant theory, data collection methods and result methodologies, result analysis and discussion, sensitivity analysis, and limitations and conclusions. Furthermore, a mean approach was followed where an estimate was provided for costings to ensure unbiased and accurate data collection and analysis.

3.0 Research Question 1 – New Generation and Storage



3.1 RQ2-01 Financial Requirements for Construction and Operation

3.1.1 Scope and Assumptions

Reference	Scope/Assumptions	Explanation
AS111	All costs are inclusive of inflation at a rate of 2.5% per annum	The Reserve Bank of Australia (RBA) expects the Consumer Price Index (CPI) to increase between 2-3% per annum long term, which is within its inflation targets. This affects all areas of the economy, and more specifically build cost and operational costs for power stations, which is more relevant to this investigation.
AS112	Unknown project commissioning dates were assigned a commissioning date at random between 2029 to 2039	AEMO predicts that the greatest consumption rise will occur between 2029 to 2039/40. Along with this, a substantial degree of capacity generated by fossil fuel generation will be decommissioned from the grid during this time. To ensure grid demand will be met, renewable projects without a start date will be commissioned between 2029 to 2039.
AS113	All fossil fuel power stations are to close by 30th of June, 2050	Due to the legislated Net Zero Emissions by 30th of June 2050, all fossil fuel power stations with a retirement date after this legislated date will have a new retirement date of 30th of June 2050
AS114	New generation and storage projects, along with current renewable generation and storage will not be considered for decommissioning	The Queensland Government have legislated net zero emissions by 2050. This only affects existing Coal, Gas, and Waste Coal Mine Gas Generation. In-addition to this, a detailed and sophisticated plan has not been released to detail projects which will come after this current influx of new generation and storage projects. Considering the decommissioning date will break the nature of the investigation, meaning grid generation will decrease when in actual fact, it should increase with the proposal of future projects.
AS115	Generation and storage sites were altered or removed specific to each scenario	To ensure that each scenario had the correct generation or scenario specific requirements, the currently proposed projects were altered to best fit this.
AS116	The capacity factor of CCGT with CCS able to remove 90% of emission, is the same as emission free generation	As outlined in the introduction, this feasibility of the technology is theoretical as of 2024/25. This assumption was required to be made as the QEGS is built upon this technology, and it is the only fossil fuel generation technology which will meet the 2050 emission reduction targets.

3.1.2 Relevant Background Information and Context

Current Fossil Fuel Generation Infrastructure

As of 2024, there are a total of 19 fossil fuel generation assets operating in Queensland, consisting of 8 CPG stations, and 11 GPG stations. These sites are expected to start closing within the coming years, starting from 2028, lasting to 2051 (Table 1, Table 2).

Table 1 - Existing CPG stations in QLD (AEMO. 2024)

Name	Generator Type	Capacity (MW)	LGA	Commissioning	Expected Retirement
Callide B	Steam Sub Critical	700	Banana Shire Council	1988	2028
Callide C	Steam Super Critical	844	Banana Shire Council	2001	2050*
Gladstone	Steam Sub Critical	1680	Gladstone Regional	1976	2035
Kogan Creek	Steam Super Critical	744	Western Downs Regional Council	2007	2042
Millmerran	Steam Super Critical	852	Toowoomba Regional Council	2003	2050*
Stanwell	Steam Sub Critical	1460	Rockhampton Regional Council	1993	2043
Tarong	Steam Sub Critical	1400	South Burnett Regional	1986	2036
Tarong North	Steam Super Critical	450	South Burnett Regional	2003	2037

Table 2 - Existing GPG stations in QLD (AEMO. 2024)

Name	Generator Type	Capacity (MW)	LG A	Commissioning	Expected Retirement
Condamine A	CCGT	144	Western Downs Regional Council	2009	2039
Darling Downs	CCGT	645	Western Downs Regional Council	2010	2045
Swanbank E GT	CCGT	385	Ipswich City	2002	2036
Townsville Power Station	CCGT	244	Townsville City	2004	2046
Yarwun Cogen	CCGT	180	Gladstone Regional	2010	2050*
Barcaldine Power Station	OCGT	37	Barcaldine Regional Council	1996	2034
Braemar	OCGT	564	Western Downs Regional Council	2006	2046
Braemar 2 Power Station	OCGT	519	Western Downs Regional Council	2009	2049
Mt Stuart	OCGT	424	Townsville City		2033
Oakey Power Station	OCGT	346	Toowoomba Regional Council	2000	2050*
Roma	OCGT	80	Maranoa Regional	1999	2034

'*' – please refer to AS112

The ISP indicates that there is potential for closure of these sites within a faster timeframe than initially estimated and planned. The '*Step Change*' scenario forecast by the ISP, of which factors in Australia's committed policies, predicts that the decommissioning of these generation assets will occur at 2-3 times quicker. It is expected that all coal generation assets will decommission by 2034/35, with GPG generation continuing for some years afterwards (AEMO. 2024). This faster retirement date would affect the Callide C, Kogan Creek, Millmerran, Stanwell, Tarong, and Tarong North power stations. However, this is only a prediction. The combined capacity of these assets makes up 70.73% of the coal capacity production of the Queensland grid.

It is important to mention that significant generation operators, such as CS Energy, are required to file a 'notice of closure' to the Queensland Government and AEMO at least 3.5 years from the expected closure. The trends which may be pushing this significant change in ownership prospects are:

1. Higher operating and maintenance costs
2. Reduced fuel security due to the closure of coal mines
3. Greater competition from renewables
4. Less attractive ownership of coal assets

AEMO Modelling Scenarios

The various modelling scenarios AEMO considers in their ISP are the:

- Progressive Change – A low renewable uptake scenario where a reflection of slower economic growth leads to a more conservative renewable energy grid penetration uptake. It is expected that there is a 42% chance of this scenario occurring through to 2054.
- Step Change – A medium renewable uptake scenario where Australia's current commitments to emission reduction is adhered to in a growing economy. The Step-Change Scenario is expected to have a 43% chance of occurring.
- Green Energy Exports – A high renewable uptake scenario whereby a strong push towards fossil fuel industrial decarbonisation leads to a high degree of investments into renewable infrastructure and green energy exports. Due to the ambitious nature of this scenario, AEMO estimates that there is a 15% chance of this scenario occurring

Costs Considered

Primarily, there are two genres of costs relevant to this research investigation. These include:

- CapEx (Capital Expenditure) Costs - Initial upfront investment
- OpEx (Operational Expenditure) Costs – Ongoing operational investment

An operating power station has a wide variety of costs which need to be taken into account for an accurate analysis. Unforeseen costs were omitted from consideration as it is impossible to account for these. The two genres of considered costs were displayed below:

- Fixed Operational and Maintenance (FOM) Costs: The costs associated with operations and maintenance which does not change with energy generation or supply levels. This typically includes permanent staff, scheduled regular maintenance, property taxes, insurance, and more.
- Variable Operational and Maintenance (VOM) Costs: The costs associated with operations and maintenance which do change with energy generation or supply levels. This typically includes fuel usage, wear and tear on equipment, consumables, and more.

The FOM costs are typically attributed to the nameplate capacity of the power station, for example the total MW of the facility. Whereas the VOM costs are derived from the actual generation produced, such as the MWh produced.

In their 2023 IASR Assumptions Workbook, the AEMO lists the various costs for each generation and storage type for each region in Queensland. These exclude nuclear, however the CSIRO, who works closely with AEMO, has accessible information on cost metrics for nuclear generation.

Capacity Factors by Generation

Although a power generation station is rated to a specific maximum nameplate capacity, they are unable to operate consistently at that generation capacity outside of ideal generation scenarios. Factors such as maintenance, grid load requirements, environmental conditions, and unplanned grid instability can reduce the operational capacity for each power plant. Therefore, a value is multiplied to the maximum nameplate capacity which results in the actual capacity, as seen below.

$$Actual\ Capacity\ = Cf \cdot Nameplate\ Capacity$$

This value is called the Capacity Factor, which is a measure of the actual energy output compared to the maximum energy output over a given time period. The capacity factor for each generation type is influenced by various factors. For example, grid load requirements primarily affect the capacity factor for fossil fuel generation, while environmental conditions such as sunlight availability or wind speed affect the capacity factor for renewable energy generation. For Queensland, the expected capacity factors for each generation are below (Table 3):

Table 3 – Capacity Factors by Generation Source (Thomas Heath. 2024)

Generation Type	Capacity Factor
Coal	0.645
Gas	0.32
CCGT with CCS	0.46
Hydro	0.33
Bioenergy	0.55
Solar Thermal	0.45
Solar	0.275
Wind	0.325
Nuclear	0.92

3.1.3 Data Collection Methods, and Result Methodology

To carry out an in-depth analysis and to formulate an estimate for costing the three transitional scenarios, a large-scale excel model was formulated.

This model consists of multiple sub-models which includes the consumption, along with the three-cost estimation for each thesis transitional scenario. Projected costs are estimated from 2025 to 2054.

Consumption Sub-model

The AEMO provides a consumption energy forecast in TWh for Queensland between 2025 to 2054. This data was exported directly to the model for grid consumption analysis. A separate sub-model was created called the ‘RQ1-01 Consumption’

Calculation of Generation Capacity and Storage

Three separate sub-models were created called the ‘RQ1-01 QEGS’, ‘RQ1-01 QERS’, and ‘RQ1-01 QENS’.

The year-on-year generation capacity estimates were calculated from a direct export of data, provided by the Queensland Government, which included key specifications existing and proposed generation and storage facilities through to 2054. These key specifications included nameplate capacity, location, commissioning and decommissioning date, technology type, and plant owners. To ensure accurate results were procured, a range of steps were established:

- Power stations were only considered in the model if their associated status included either ‘Proposed’, ‘Under Construction’, or ‘Existing’. Power stations with the status ‘Decommissioned’, or ‘Cancelled’ were not included
- Proposed power stations with an unconfirmed commissioning date had a randomised allocated commissioning date between 2029 to 2039 (AS112). This was completed with the ‘**rand'** excel function
- Existing sites were checked on Open Electricity to understand whether they produce electricity for the grid or are used to power closed off systems.

Maximum annual generation capacity was calculated for each generation site by applying a capacity factor (cf) to nameplate capacity (P) multiplied by the number of hours in a year. Capacity factor values for each fuel generation type were extracted from CMES-EFR-24-02

$$Energy\ Generation\ (MWh) = P \cdot cf \cdot 8766$$

From there combined active generation for each year was combined and presented.

Alterations to facilities for the Three Scenarios

The alterations to generation and storage facilities for each scenario are as follows:

- QEGS: All generation and storage sites which with the status ‘proposed’, were removed. Subsequently, the total year-on-year generation change was identified, and the year-on-year generation gain for each technology type was calculated by applying a ratio based upon current % makeup in the grid. Utilising the energy generation formula shown previously, the nameplate capacity for each generation type for each year was calculated. The required BESS capacity increased by applying the year-on-year generation increases.
- QERS: No change required as this scenario is built upon the present-day energy transition plan. The generation prediction was also made using this scenario
- QENS: This scenario is similar to the QERS scenario, although there was an addition of 4GW of nuclear, more specifically a 2GW nuclear plant built in 2036, and another built in 2040. To compensate for this, the total solar and wind generation required to be removed for these dates were calculated using the above formula and the correct ratios. In-addition to this, the prior step was completed for BESS and PHES sites as nuclear is a base-load generation

To adhere to AS111, all values were required to be inclusive of inflation at a rate of 2.5% per annum. Using the below formula, inflation was accounted for:

$$Adjustment = value \cdot 1.025^{Year\ of\ Interest - Year\ of\ Figure}$$

For each of the scenarios, the total build and operational costs were calculated. The build cost for any power station with the status 'Existing', or 'Under Construction' was calculated by multiplying the nameplate capacity (kW) by the cost to build, a metric provided by AEMO. As this data was released in 2023, inflation was required to be adjusted.

$$Build\ Cost = P(kW)\ \cdot\ (\$/kW)\ \cdot 1.025^{(Commissioning\ Date-2023)}$$

Following this, the operational cost was estimated, by considering the FOM ($/kW/Annum) and the VOM ($/MWh) for each power station during its operational lifetime. The FOM was calculated by multiplying the nameplate capacity in (kW) by the respective FOM, and by multiplying the VOM by the energy production. This was conducted for each power station between 2025 to 2054.

$$Operational\ Cost\ = (FOM\ \cdot\ P\ +\ VOM\ \ \cdot\ Generation) \cdot 1.025^{(Year-2023)}$$

All these values were combined by generation type and year utilising excel functions for further analysis. Below in Table 4 are a range of functions used in the model and their intended use:

Table 4 - Sample Functions for RQ1-01 (Sample 'RQ1-01 QERS)

Function name	**Function**	**Description**	**Sample Cell**
Storage Capacity	==[@[Discharge Time]]*[@[Maximum Capacity]]	This function is used to calculate storage capacity (MWh) for storage facilities, from nameplate capacity (MW) and discharge time (h)	N2
CapEx Cost ($B)	=IF([@Satus]="Existing","",(([@[Build Cost ($/kW)]]*[@[Maximum Capacity]]*1000)/1000000)*1.025^([@Commissioning]-2023))	This function calculates the build cost ($B) for each generation and storage facility considering cost per MW ($/kW), nameplate capacity (MW), and inflationary aspects	Q3
OpeX Costs ($M)	=IF($D2<=Z$1,IF(Z$1<$E2,($T2*$F2+ IF($M2="",$M2*$U2,0))*1000,""),"")	This function calculates the VOM costs for each asset each year, without considering inflation (this was calculated at a later stage). For each year, it checks if the facility is still operating, and if the if statement is true, then a VOM cost value is calculated	Z2
Available Nameplate Capacity	=SUMIFS($F$2:$F$344, $B$2:$B$344, $Y350, $D$2:$D$344, "<=" & Z$349, $E$2:$E$344, ">=" & Z$349)	This function sums all available operating nameplate generation for each generation type for each year	Z350
Total OpEx costs	=SUMIFS(Z$2:Z$344,$B$2:$B$344,$Y381) *1.025^(Z$395-2023)	This function sums all operating costs for each generation type for each year	Z396
LCOE	=Z406/(Z372*1000000)	This function is used to calculate the total operational costs over compared to the available generation capacity	Z411

3.1.4 Results Analysis and Discussion

Future Electricity Consumption

An annual forecast consumption of electricity for Queensland between 2025 to 2054, was conducted by AEMO for the Step-Change scenario. Over the period, total annual energy consumption increased by over 100% from 47.5TWh to TWh (Figure 6).

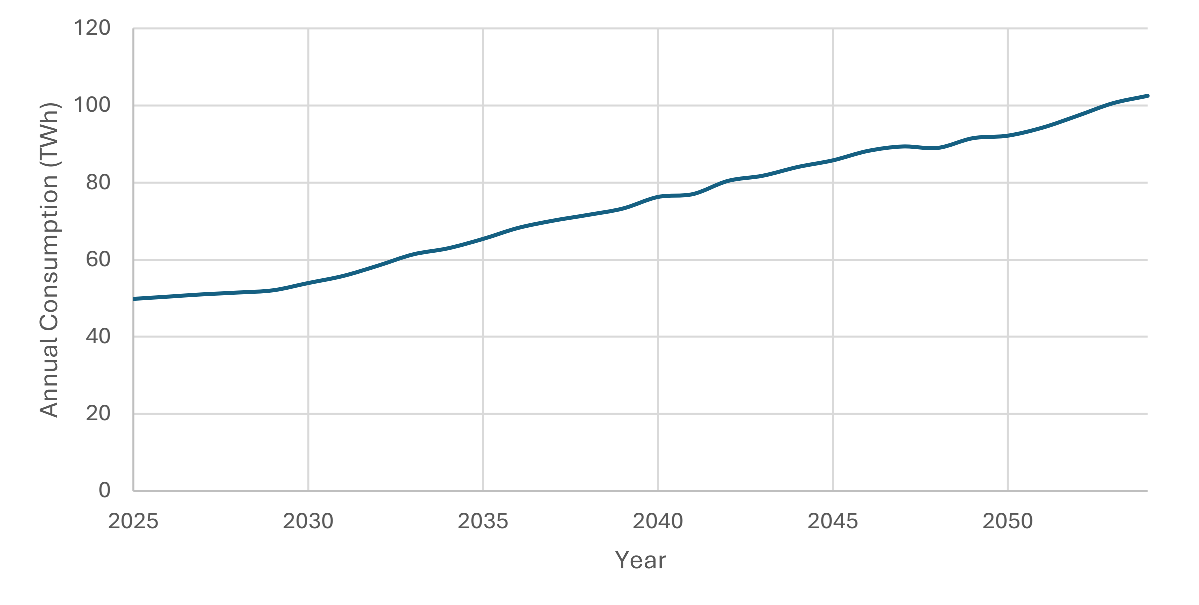


Figure 6 – Annual QLD Grid Consumption by Source (excluding Rooftop PV) (AEMO. 2025)

The main reason of for this dramatic increase in annual grid consumption is attributed to electrification, electric vehicles, and hydrogen production. Hydrogen production is predicted to initiate in 2030, increasing to 27TWh of electricity consumption per annum. In-addition to this, the rise in annual consumption was also attributed to electrification, and electric vehicles, with rises in 15TWh, and 19TWh respectively. The breakdown of electricity consumption requirements can be seen in Figure 7.

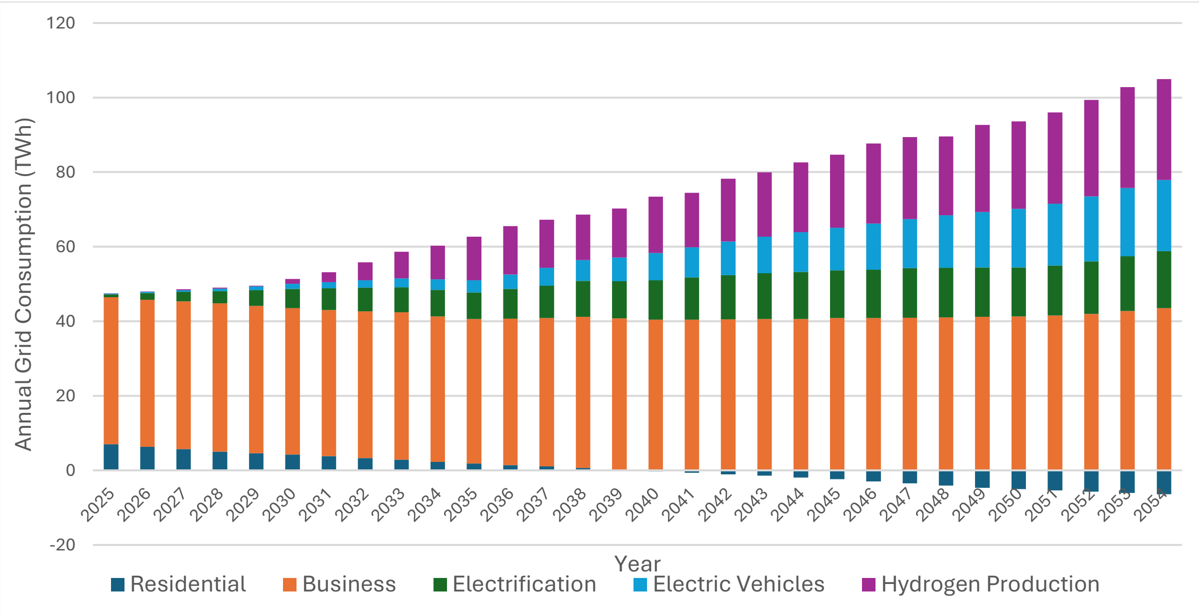


Figure 7 – Annual QLD Grid Consumption by Source (excluding Rooftop PV) (AEMO. 2025)

Current Generation

Figure 8 depicts the predicted grid energy production capacity (TWh) against predicted grid consumption (TWh) in Queensland from 2025 to 2054. As expected, annual generation rises to meet consumption to ensure that there is a suitable supply of electricity to the grid. This data can be found in the 'Important Information' sub-sheet in the provided excel spreadsheet (Appendices 1 – Thesis Data Spreadsheet).

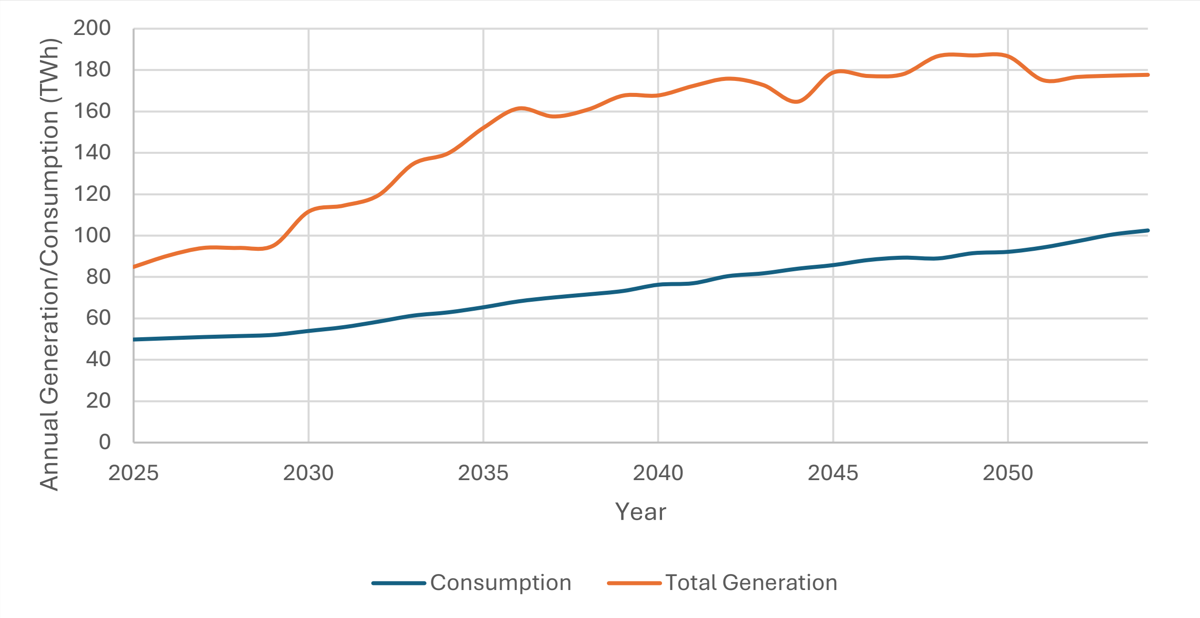


Figure 8 - Queensland Electricity Generation Capacity and Consumption (AEMO. 2025)

Between 2025 to 2054, the estimated electricity generation capacity in the Queensland Grid rose from 84.92TWh to 177.71TWh, peaking at 187.09TWh in 2049. This represents a 202.3% increase, whereby consumption rises 205.8%. Across all of these years, there is a minimum ratio of consumption to generation capacity of 170.5% in 2025, to a maximum ratio of 232.59%. In realistic sense, the generation capacity estimation is an overvaluation of what is going to be actual levels in the future, as base-load generation can reduce production. It is possible that electricity trading can occur with other states and territories, however additional transmission infrastructure will need to be costed and procured. This is explored in Research Question 1 – New Generation and Storage in detail.

In-regards to the current energy infrastructure generation in 2025, the vast majority of the nameplate capacity (MW) comes from fossil fuel generation, representing 53.93%. On the other hand, renewables make up 46.07% of nameplate generation. This can be seen in Figure 9. It should be mentioned that nameplate capacity of fossil fuel generation is significantly higher than renewables, therefore the ratio of fossil fuel electricity generation in TWh to all generated electricity is greater. In Figure 10, the ratio of fossil fuel generation is 67.78% of all generation capacity.

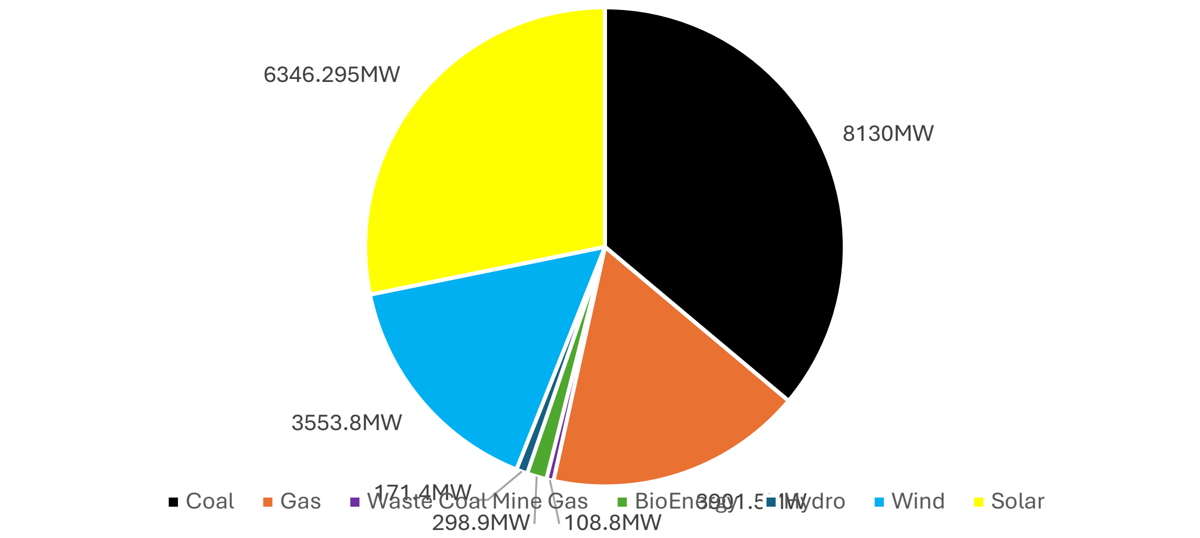


Figure 9 - Current Nameplate Capacity (MW) by Generation Type in Queensland 2025

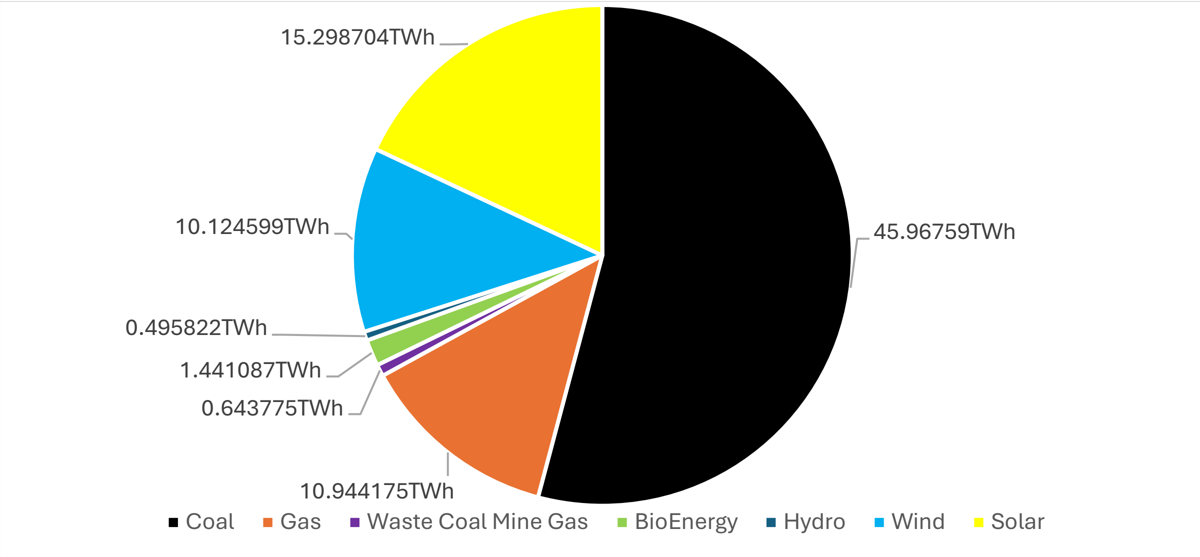


Figure 10 – Current Generation Production in TWh by Generation Type in Queensland in 2025

Utilising the AEMO IASR assumptions workbook, the total OpEx costs for the grid was expected to cost $939.27 Million in 2025. This figure represents both the OpEx costs for generation assets in-addition to storage assets operating in Queensland. It is clear that the most expensive form of meaningful generation (<5% of total generation) is coal, costing $11.23 million per TWh produced, for a total cost of $545.22 million in OpEx costs. Gas is considered cheaper than all other forms of generation, costing $5.45 million per TWh produced. Solar and wind costs $7.79 million per TWh and $10.10 million per TWh produced, or $232.71 million in total (Figure 11). The expected phase out of coal generation is expected to reduce costs to produce electricity.

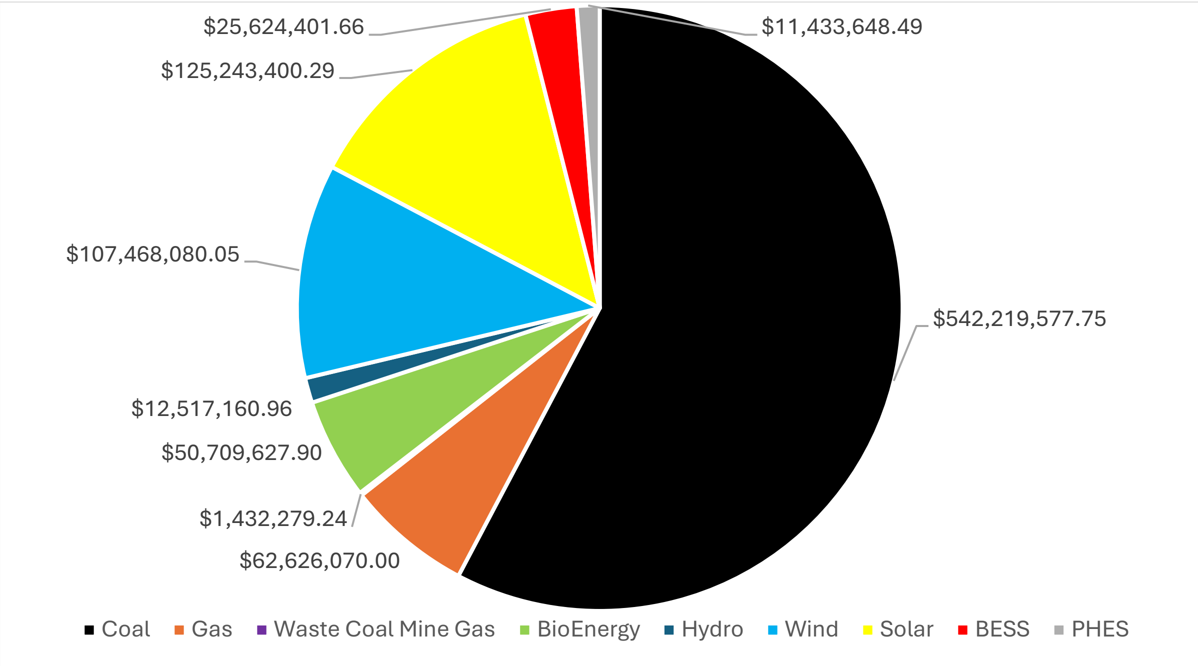


Figure 11 – Operational Costs of Current Generation/Storage Infrastructure in 2025

From here, multiple scenarios were investigated. These include:

1. QEGS – Queensland Energy Gas Scenario: The ratio of fossil fuel to renewables remains constant through to 2054. Current fossil fuel generation is phased out for more advanced CCGT Gas Generation with Carbon Capture Storage (CCS)
2. QERS – Queensland Energy Renewables Scenario: The current plan is followed whereby every announced energy project for Queensland is built. Net-zero emissions is achieved by 2050, and renewable energy backed-up by storage forms the electricity grid
3. QENS – Queensland Energy Nuclear Scenario: Similar to QERS, the net-zero emissions by 2050 are achieved through the implementation of renewable generation and storage in-combination with nuclear generation. This plan has been announced recently and is popular in politics with certain political parties.

Table 5 – Total Generation Capacity (GW) Change between 2025 to 2054 all Scenarios

	2025 Mix	**2054-QEGS**	**2054-QERS**	**2054-QENS**
Coal	8.13	0	0	0
Gas	3.90	13.46	0	0
Solar	6.35	7.54	6.57	5.17
Solar Thermal	0	0	0.11	0.11
Wind	3.55	3.97	11.82	9.70
Nuclear	0	0	0	3.68
BESS	2.53	7.28	16.94	13.81
PHES	0.57	0.57	6	4.85
TOTAL	**25.03**	**32.24**	**41.43**	**37.33**

QEGS Scenario

In the QEGS Scenario, the ratio of fossil fuel to renewables remains constant through to 2054. CCGT paired with CCS replaces older fossil fuel generation, and capacity is added year on year to meet the expected generation. Figure 12 displays the nameplate generation of each generation type from 2025 to 2054.

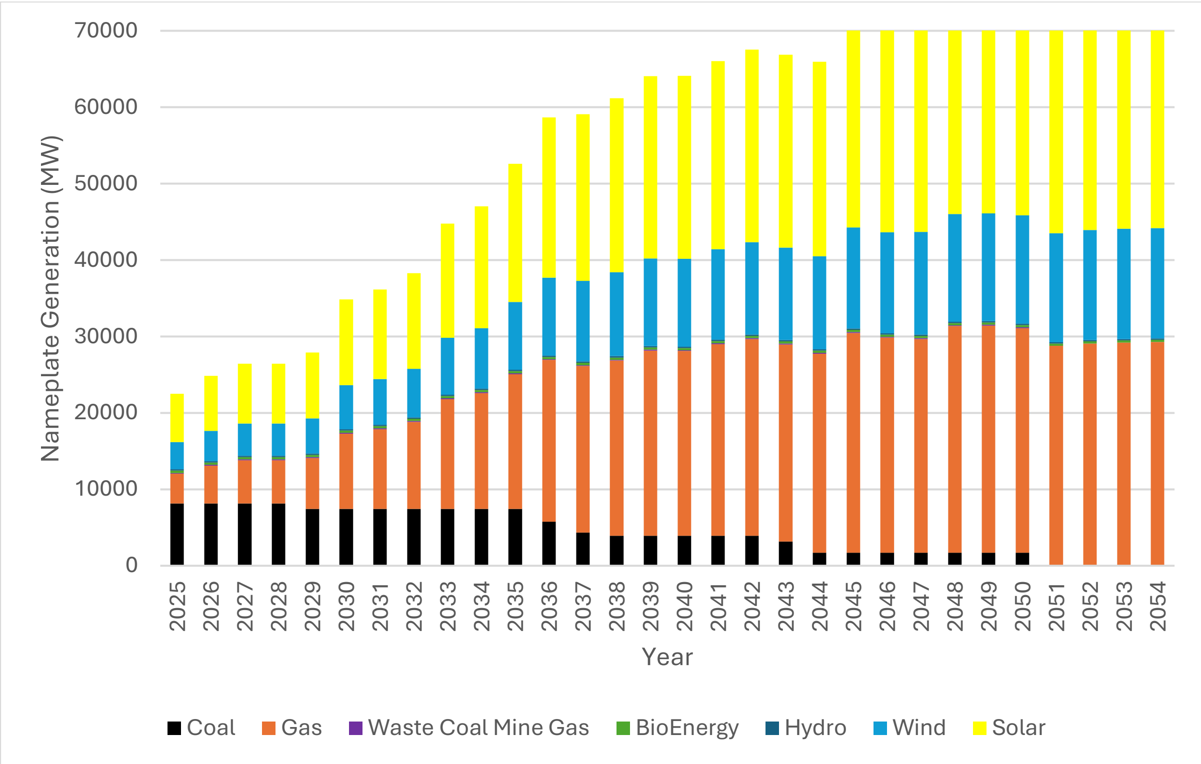


Figure 12- QEGS Scenario Annual Nameplate Generation (MW)

Additional capacity for solar, wind, and gas generation was added based upon a year-on-year ratio of total generation increase. As expected, older fossil fuel generation such as coal and older gas generation begins to decommission, from 2028 to 2050. This generation is replaced with newer CCGT with CCS gas generation. Nameplate gas generation rises to 29.27GW of capacity, while solar and wind generation rise to 30.39GW and 14.45GW respectively. In-addition to this, the capacity of energy storage rises in-line with current storage values. BESS capacity rises from 11MWh to 28.3MWh by 2054. PHES was not considered for this scenario AS115.

It is evident that with the large amount of new generation capacity coming online in the coming years and considering inflation, the OpEx costs required to operate these assets will rise dramatically. OpEx costs in 2025 are expected to be $939.27 million and are expected to rise to $3.51 billion. Total OpEx costs adjusted for inflation between 2025 to 2054 are expected to cost $55.14 billion. Progressing towards 2054, it is clear that CCGT with CCS OpEx costs becomes the most expensive form of generation, costing 31.6%% of total OpEx costs.

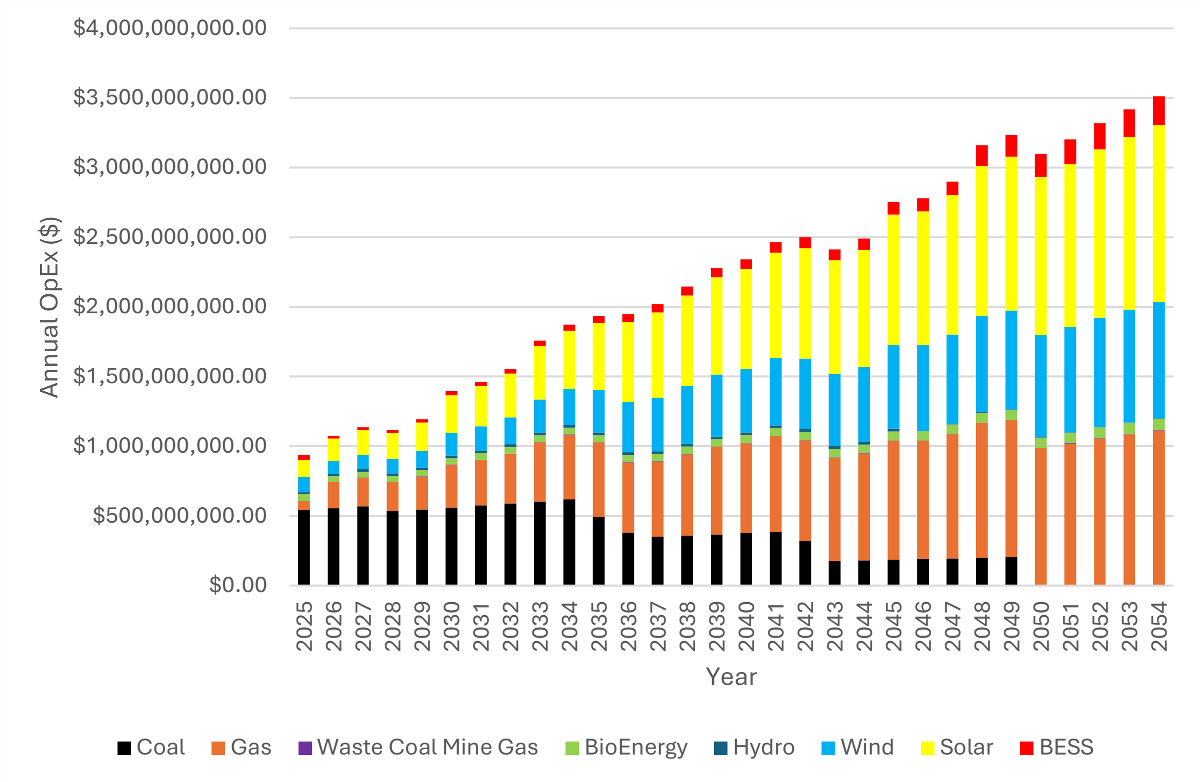


Figure 13 - QEGS Annual Inflated OpEx by Type

An analysis on CapEx costs surrounding building the anticipated 32.24GW of nameplate generation in the QEGS scenario is expected to cost $306.08 billion (Table 6Table 6). The vast majority of these CapEx costs comes from the new CCGT with CCS generation, costing an estimated $142.67 Billion, for $10.8 billion per installed GW of generation. Total OpEx costs for these facilities is expected to cost $55.14 billion over the same time. Considering this, the total cost per GW considering CapEx and OpEx costs was $11.68 billion per GW of nameplate generation for this scenario. The most expensive form of generation in the scenario was wind, costing $15.4 billion per GW, while CCGT with CCS costs $16.14 billion per GW.

Table 6 – CapEx and OpEx Costs for QEGS Scenario

	Total Installed Capacity	**CapEx ($ Billions)**	**OpEx (2025-2054) ($ Billions)**
CCGT with CCS	13.46	193.85	18.93
Solar	7.54	59.66	20.57
Wind	3.97	44.74	13.11
BESS	7.28	7.83	2.5
Total	32.25	306.8	55.14

QERS Scenario

In the QERS scenario, the fossil fuel generation is progressively replaced by renewable generation, in the form of solar and wind. These projects have been proposed or are already under construction in Queensland and have been provided by the Queensland Government and were imported into the model. It is clear that wind generation becomes the most dominant generation source increasing from 3553.8MW in 2025 to 38395MW, in 2054, of nameplate generation. This is followed closely by solar generation which increases from 6346.3MW into 26896.6MW of nameplate generation during the same period. Fossil fuel generation decreases from around 50% of nameplate generation to being completely decommissioned by 2050. This is in-line with the legislated net-zero emissions reduction targets by 2050.

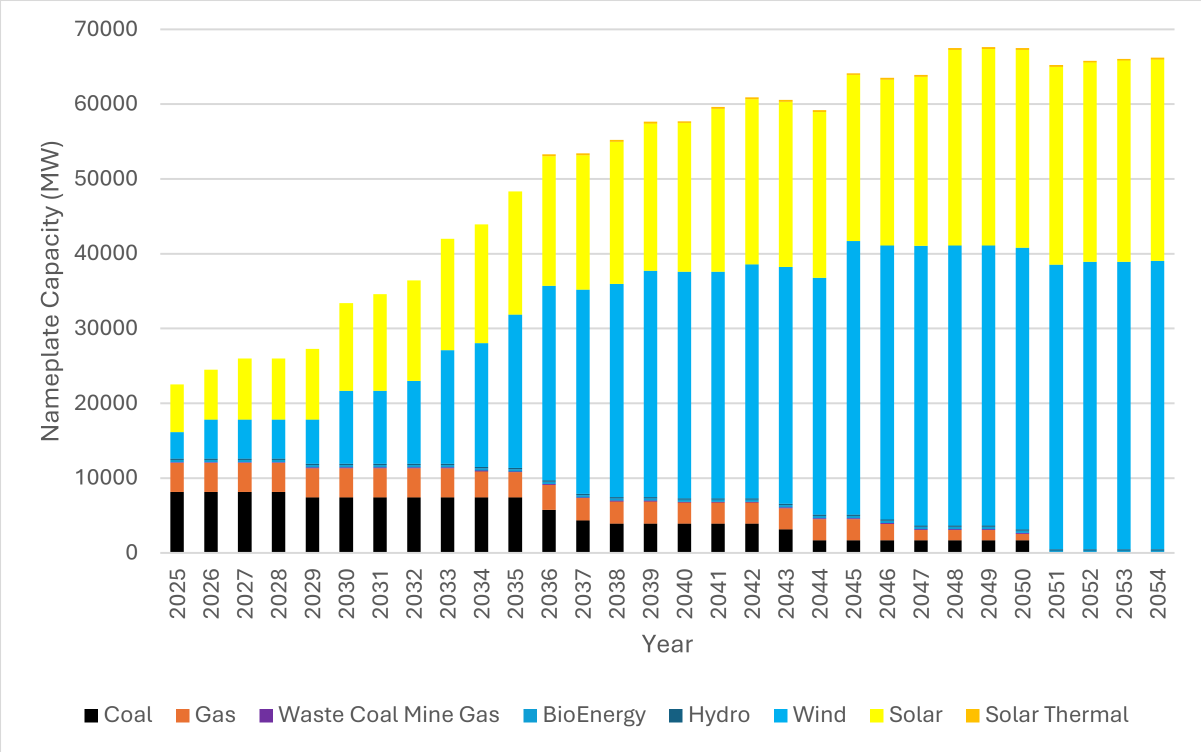


Figure 14 - QERS Scenario Annual Nameplate Generation (MW)

The total storage is expected to increase dramatically, especially in the form of new PHES implementation. Total storage will increase from 11220.6MWh in 2025 to 15334.6MWh in 2054, representing a 13.67x increase in this period. From 2031 onwards to 2054, PHES represents 70-80% of total storage capacity, while the rest of the storage capacity is in the form of BESS.

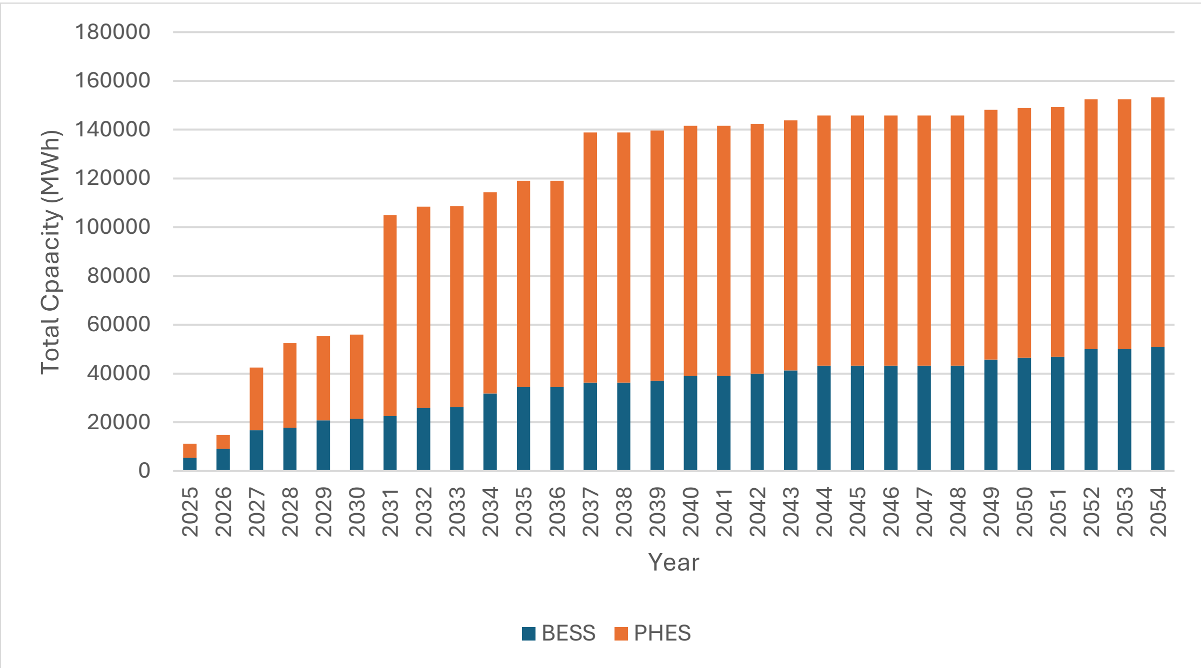


Figure 15 - QERS Scenario Total Storage (MWh) by Storage Type

OpEx costs of the QERS scenario rise from $939.3 million in 2025 to $4.4 billion in 2054, representing a 4.68x increase between this time. The largest proportion of growth for this scenario is wind generation, OpEx costs surrounding wind generation, growing at an average rate of 1.12x each year from $107.5 million in 2025 to $2.3 billion in 2054. Solar on the other hand rises at an average rate of 1.08x each year from $125.2 million to $1.08 billion within the same period.

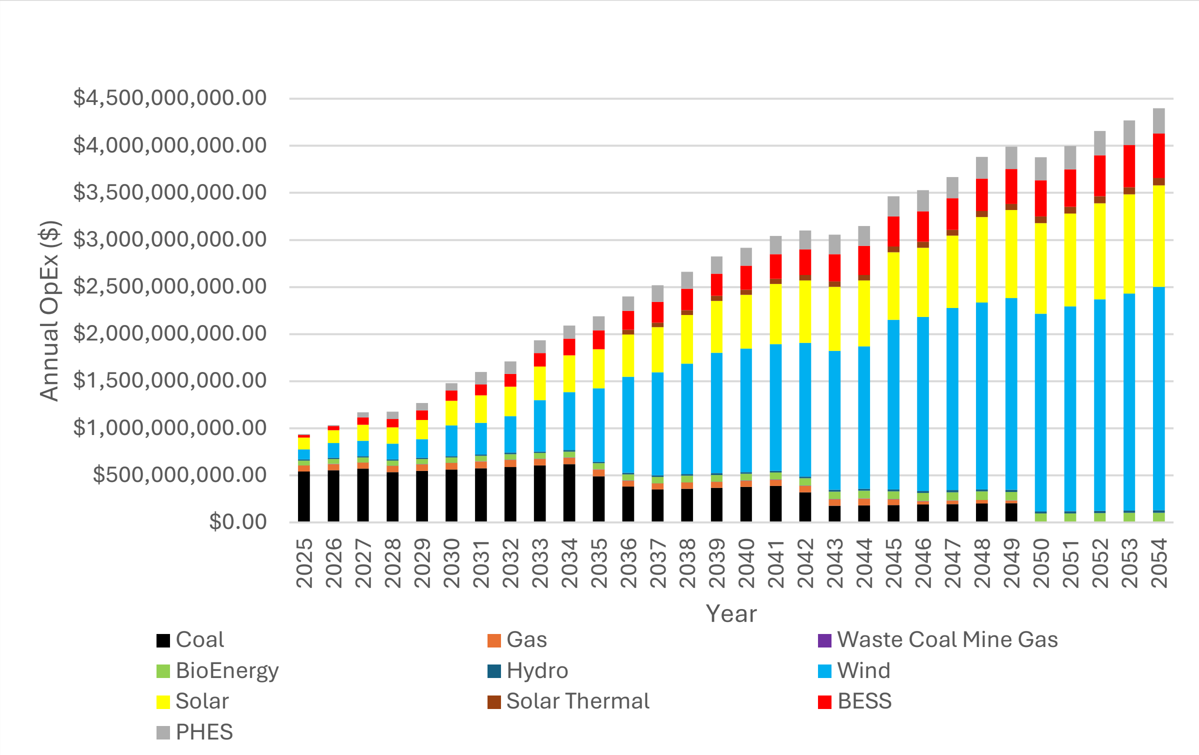


Figure 16 - QERS Annual Inflated OpEx by Type

Finally, CapEx costs for the QERS scenario are expected to cost $273.62 billion in total to build these generation and storage assets. This is predominately made up of wind generation, which is expected to cost $147.6 billion, while solar is expected to cost $56.6 billion. Total storage costs are expected to cost $70.0 billion. The 30-year OpEx maintenance costs are expected to cost $67.1 billion over this time frame. Therefore, the cost per GW for generation/storage in this project is expected to cost $8.71 billion per GW.

Table 7 – CapEx and OpEx Costs for QERS Scenario

	Total Installed Capacity	**CapEx ($ Billions)**	**OpEx (2025-2054) ($ Billions)**
Solar	6.57	56.62	17.25
Wind	11.85	147.62	36.22
Solar Thermal	0.11	2.4	1.16
BESS	16.94	38.14	7.31
PHES	6	28.84	5.12
Total	41.45	273.62	67.06

QENS Scenario

The QENS scenario is similar to the QERS scenario, whereby net-zero emissions by 2050 is achieved through the implementation of renewable generation and storage in-combination with nuclear generation. In total, 4GW of nuclear generation is implemented before 2040. To counter this additional baseload generation, a ratio for solar, wind, BESS, and PHES was applied whereby in total 32.25TWh of generation is removed annually from 2040 onwards. This resulted in the removal of 6500GW of wind and 5100MW of solar projects to maintain generation in-line with the other two scenarios. This can be seen in Figure 17.

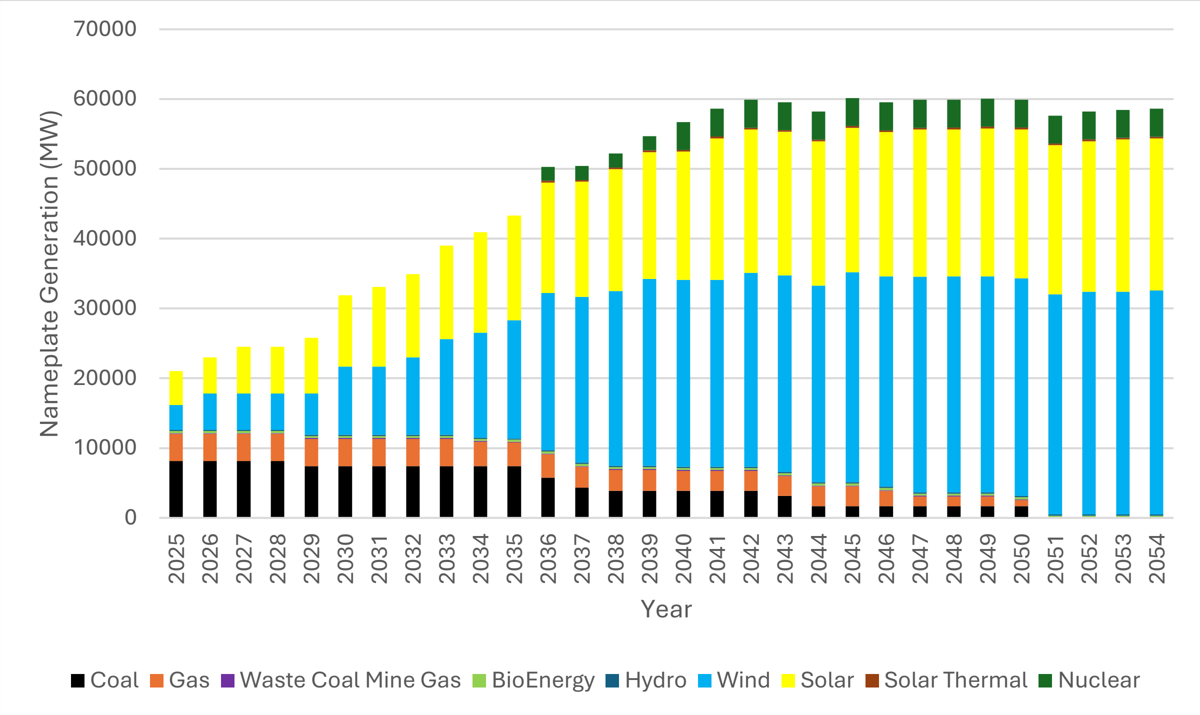


Figure 17 - QENS Scenario Annual Nameplate Generation (MW)

Figure 17 displays the total storage size by storage type in the QENS scenario. 29480MWh of generation storage was removed from this scenario in-line with AS11. Ratios between PHES and remain similar compared to the QERS scenario.

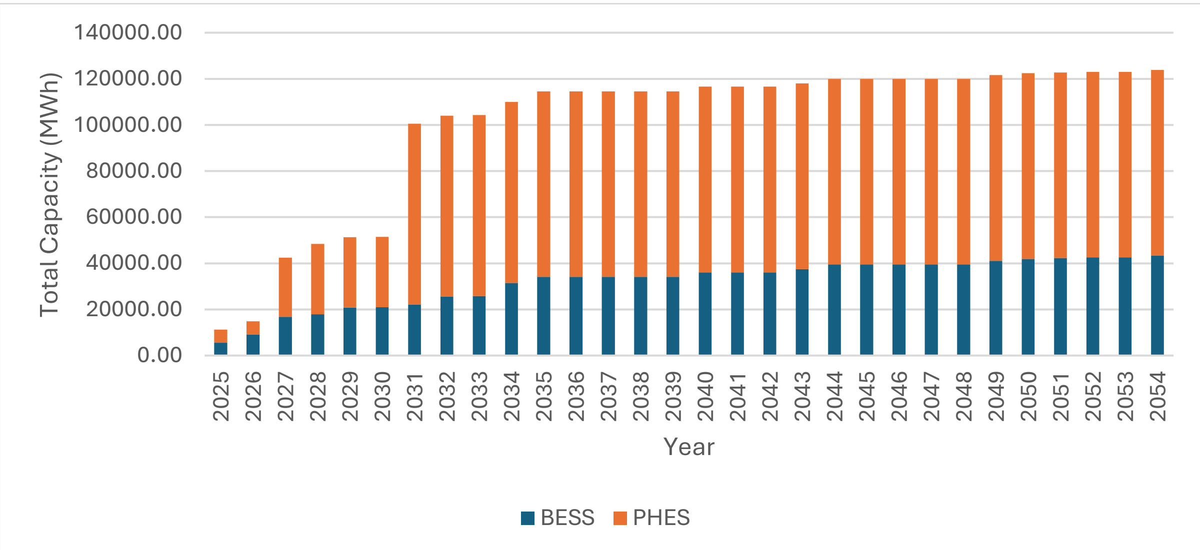


Figure 18 - QENS Scenario Total Storage (MWh) by Storage Type

Total annual OpEx costs in the QENS scenario rise from $939.3 million in 2025 to $5.79 billion in 2054. Although nuclear generation only represents 6.8% of nameplate generation, the generation type represents 38% of total OpEx costs, or $2.2 billion by 2054. This is primarily due to nuclear generation having a significantly higher capacity factor, along with high operational costs. Operational costs for wind generation is the second highest, costing $2.26 billion and solar costs $549.5 million by 2054. Total costs for energy storage is expected to cost $627.2 million in the same period. A breakdown of the costs by generation type can be seen in Figure 19.

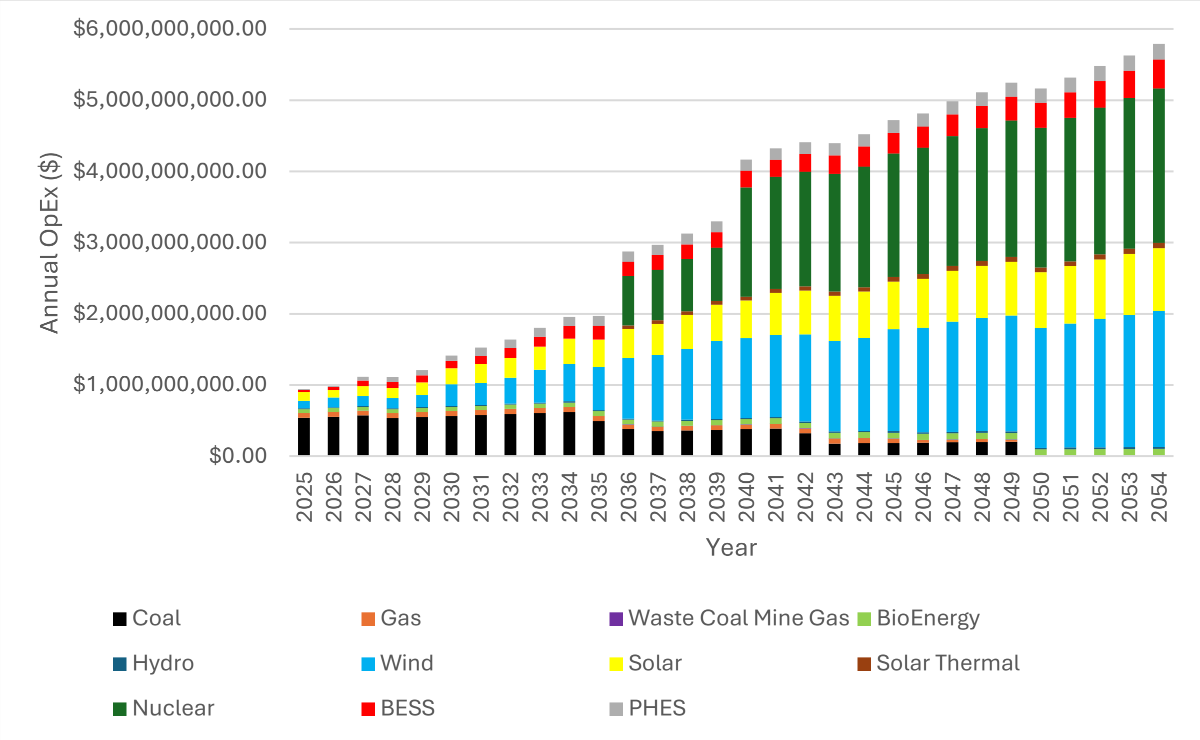


Figure 19 - QENS Annual Inflated OpEx by Operation Type

In-total CapEx costs for the QENS scenario is estimated at $270.95 billion in total to build and connect these generation and storage assets. In-addition to this, total maintenance costs are expected to cost an estimated $87.55 billion in this time period. The total cost per GW of generation/storage is expected to cost $10.05 billion per GW. The largest cost by generation is wind, with a CapEx and OpEx cost of $118.56 billion, followed by nuclear with $53.46 billion. It is clear that nuclear is a not an effective source as it is more than double the cost per GW compared to solar or wind.

Table 8 – CapEx and OpEx Costs for QENS Scenario

	Total Installed Capacity	**CapEx ($ Billions)**	**OpEx (2025-2054) ($ Billions)**
Solar	5.17	42.7	15.1
Wind	9.70	118.56	29.86
Solar Thermal	0.11	2.4	1.16
Nuclear	3.68	53.46	30.39
BESS	13.82	31.08	6.7
PHES	4.85	22.75	4.34
Total	37.33	270.95	87.55

Evaluation of the Different Generation/Storage Scenarios

The three model scenarios present notable differences in terms of generation and storage infrastructure. The QERS scenario has an installed capacity of 41GW, which is more than the QEGS and QENS scenario, each havening 32GW and 37GW respectively. However, the differences in storage are more pronounced, as the QENS and QERS scenario require more storage compared to the QEGS.

Due to the inherent nature of renewables having a lower capacity factor compared to fossil fuel generation and nuclear, there is a greater amount of nameplate capacity required. In-addition to this, as the technology is a non-baseload generation type, a renewable only generation grid must be substantially supported with BESS and PHES storage. Consequences of these requirements can be seen in Table 9, where the QERS scenario has significantly more generation and storage compared to the QEGS and QENS scenario.

In-terms of the capital and operational expenditure required for each plan, the gas scenario requires the most upfront investment, with a total generation and storage cost of $361.22 billion. The renewable generation scenario costs the least at $340.68 billion, while the nuclear scenario is expected to cost $358.5 billion.

Table 9 – Overall findings and costs for the three scenarios

	QEGS	**QERS**	**QENS**
Installed Capacity (GW)	32.25	41.44	37.33
Installed Storage (MWh)	28346.9	153324.6	123844.6
CapEx ($B)	306.08	273.62	270.95
OpEx ($B)	55.14	67.06	87.55
Total Costs	361.22	340.68	358.5

The overarching reason that the gas scenario is the most expensive is due to the lower capacity factor of CCGT with CCS compared to regular gas generation, and the higher costings. Although not as expensive compared to nuclear, CCGT with CCS is 4x more expensive than regular gas and solar generation per MW of nameplate capacity. Furthermore, this scenario delivers the least new capacity, therefore reducing the effective cost per GW of nameplate capacity.

In-addition to this, the maintenance costs of nuclear generation propel the overall cost to become the 2nd most expensive scenario. This can be seen in Figure 20, whereby the OpEx costs for the nuclear generation dramatically rises in 2036, and 2040, which is when the two 2GW nuclear generation sites are commissioned and start to produce electricity for the grid. If these nuclear sites were commissioned earlier, the maintenance costs for the nuclear scenario would be significantly greater.

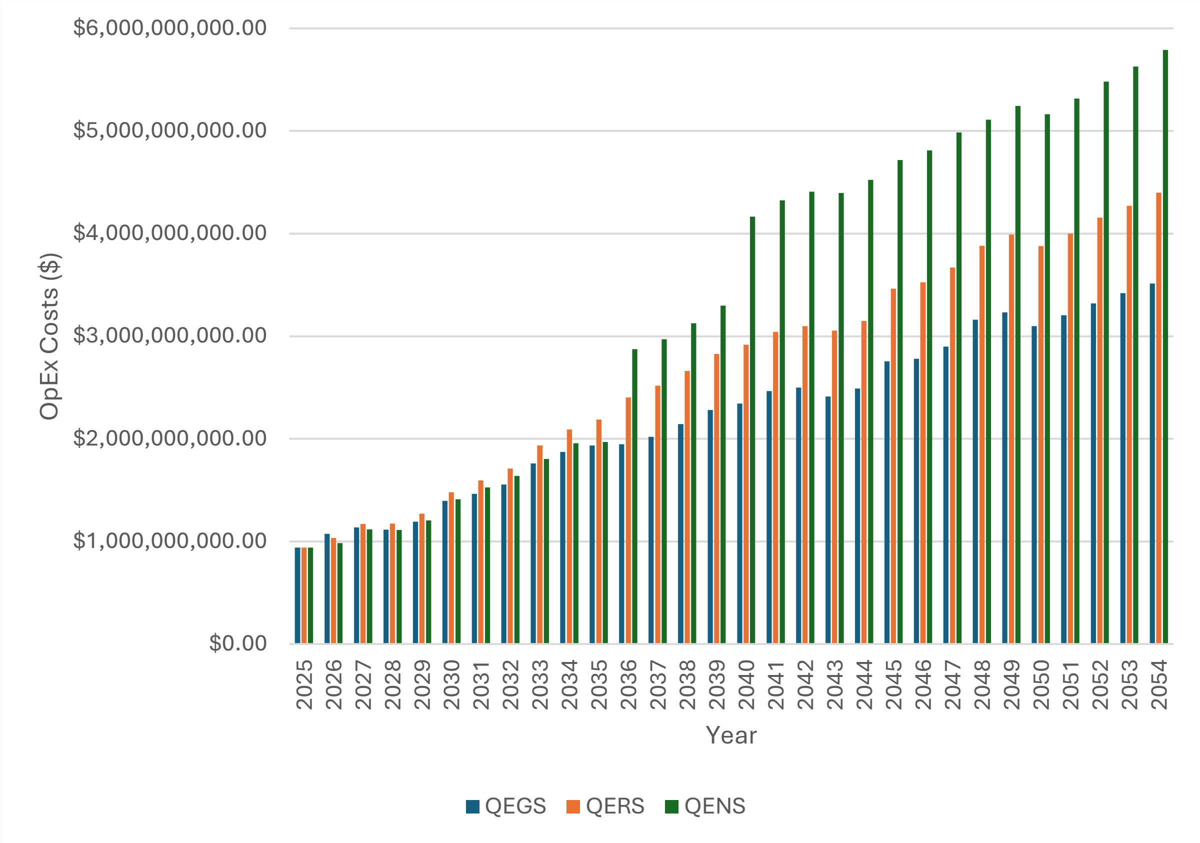


Figure 20 - OpEx Costs for Each Scenario

In-addition to this, Figure 21, which displays the LCOE ($/MWh) sent out considering both generation and storage costs, further supports that nuclear is extraordinarily costly to operate compared to gas and renewable generation. There are dramatic rises in the cost per unit energy in 2036 and 2040.

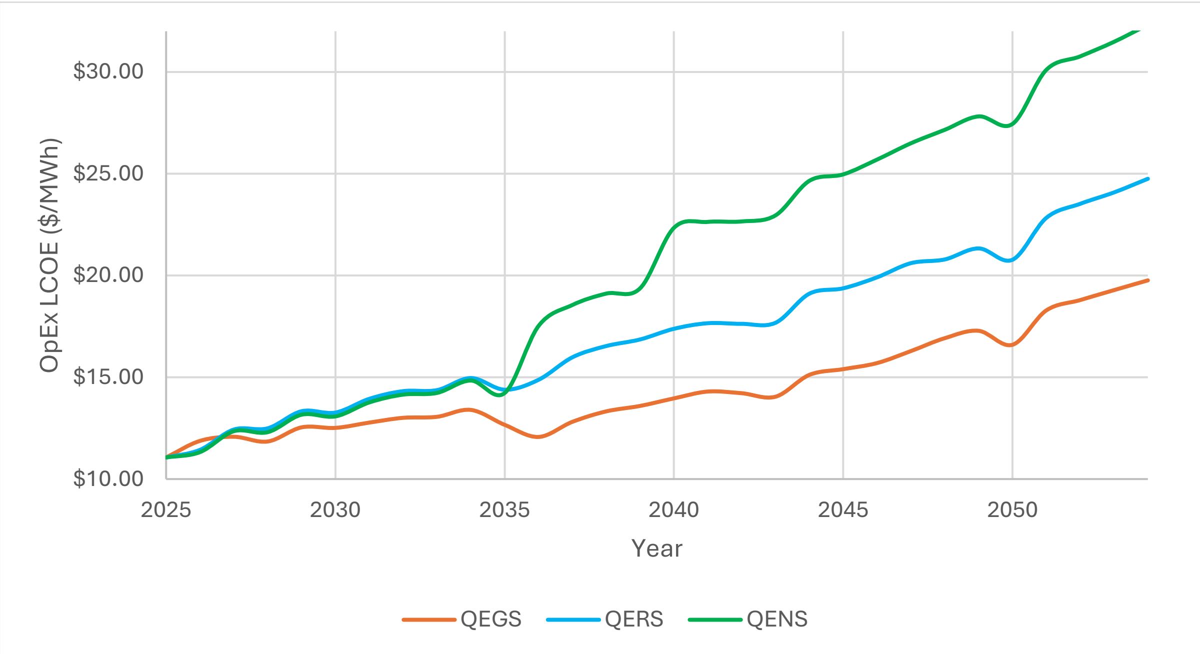


Figure 21 - OpEx LCOE including Inflation for each Transitional Scenario

3.2 RQ1-02 Net Change in Jobs

3.2.1 Scope and Assumptions

In-order to cost job losses of existing personnel in the industry and affects on communities, it is important to refine the scope and state assumptions:

Reference	**Scope/Assumptions**	**Explanation**
AS121	2.5% per annum increase in wage costs	The Reserve Bank of Australia (RBA) expects the Consumer Price Index (CPI) to increase between 2-3% per annum long term, which is within its inflation targets. This affects the cost of wages to workers of the power stations, and it is expected that wages will increase at 2.5% as a result of this
AS122	Employee totals for Callide B&C are split between each power station by the ratio of nameplate capacity	CS energy, the owners of Callide B&C, supply combined employee totals for the Callide power stations. For the calculation of various metrics, employee totals are split between one another and rounded to the nearest number based upon rated capacity
AS123	Estimated occupational breakdown for power station	Due to a lack of information, an estimation will be produced upon this breakdown. Research shows that there is a higher proportion of professionals in power plants compared to industry trades.
AS124	Relevant occupations for the occupational breakdown has been grouped into five categories	This simplifies the research investigation and presents the data in a digestible and understandable format for the reader.
AS125	The Stanwell, Tarong, and Tarong North CPG will not be decommissioned in the QERS	These facilities are required for the grid system inertia plan for the QERS system; therefore these jobs will not be lost as the plant remains operational in a different capacity

3.2.2 Relevant Theory

The relevant occupations can be broken down to specific trades/professions. The relevant occupations include machinery operators/drivers (only considered for coal mining), technicians and trades workers, professionals (engineers, geologists, etc), managers, and clerical/administrative personnel. From this, employment within coal mines and power stations can be classified into two groups: Direct and Indirect Labour.

- Direct labour is the labour directly responsible for the generation of the product, such as resources extracted/produced. The occupations considered to be direct are machinery operators/drivers, power plant workers, technicians, and trades workers
- Indirect labour assists the direct labour to complete their tasks. Occupations within this classification include professionals (engineers, geologists, etc), managers, clerical, and administrative employees.

Occupational Breakdown by Generation Type

In-line with AS123, a ratio for the number expected jobs per MW of nameplate generation by generation type will be used. Table 10displays this ratio for all relevant generation and storage technologies for both construction and maintenance/operational phases of the project. The most demanding in regard to required jobs during maintenance is nuclear generation, while the least demanding is PHES.

Table 10 – Ratio of Expected jobs per MW of Nameplate Generation (J Rutovitz. 2025)

	GPG	Solar	Wind	Hydro	Solar Thermal	Nuclear	BESS	PHES
Construction	1.27	1.61	2.65	7.36	1.61	16	4.44	7.18
Maintenance	0.14	0.09	0.21	0.14	0.09	0.33	0.23	0.08

To understand the occupational breakdown changes from 2025 to 2054 for all three scenarios, the occupational breakdown by each generation and storage technology must be understood. Table 11presents this occupational breakdown by generation and storage.

Table 11 - Occupational Breakdown for Generation and Storage (APH. 2023) (J Rutovitz. 2025)

Professional % Breakdown	CPG	GPG	Solar	Wind	Hydro	BESS	PHES	Solar Thermal	Nuclear
Machinery Operators / Drivers / Laborers	12.30%	12.30%	0.60%	0.00%	1.70%	0.60%	1.70%	0.00%	15.00%
Trades and Technicians	46.80%	46.80%	49.80%	64.90%	28.60%	49.80%	28.60%	64.90%	42.50%
Professionals	17.00%	17.00%	4.70%	15.50%	35.10%	4.70%	35.10%	15.50%	27.50%
Managers	12.30%	12.30%	36.00%	13.00%	19.70%	36.00%	19.70%	13.00%	7.50%
Clerical / Admin	11.60%	11.60%	8.90%	6.60%	14.90%	8.90%	14.90%	6.60%	7.50%

The different professional positions considered are:

- **Machinery Operators / Drivers / Laborers**: Responsible for operating heavy machinery and transport of materials, components and fuels. Also perform manual tasks and support maintenance activities

- **Trades and Technicians**: Includes a range of specialised direct labour, however the most relevant includes electricians, mechanical fitters and instrumentation. Responsible for installing specialised equipment and maintaining this equipment

- **Professionals**: Occupation classified by a tertiary degree, such as engineering, environmental scientist, and specialists. Accountable for design, oversight, and specialised expertise

- **Managers**: Includes a range of management such as operations, project, asset, HSE, and maintenance managers. Responsible for high-level operations, compliance, overseeing of teams and budgets.

- **Clerical / Admin**: This occupation is responsible for record keeping, organisation, and communication. Relevant fields include HR, document control, site administration, and inventory.

3.2.3 Data Collection Methods, and Result Methodology

Expected Job Losses

Using the AEMO IASR Assumptions Workbook 2023, all fossil fuel generation sites were identified with additional information such as Capacity, Local Government Area (LGA) location, and expected retirement year. To further add to this information, the total number of workers were identified using the National Pollutant Inventory (NPI) service from the Australian Government Department of Climate Change, Energy, the Environment, and Water.

The ratio (R) of expected jobs by the capacity (P) in MW of generation and storage was identified and applied to generation and storage capacities identified in RQ1-01 for each scenario. Therefore, the total number of jobs (NoJ) required for both construction and maintenance were calculated utilising the formula:

$$NoJ = P \cdot R$$

Occupational breakdowns (OB) were identified and grouped into the relevant categories listed above for each generation and storage technology. This data was applied to calculated number of jobs. Therefore, the categorised jobs (CJ) by occupation was found using:

$$CJ = NoJ \cdot OB$$

Below in Table 12 are the sample functions used in RQ1-02.

Table 12 - Sample Functions used for RQ1-02

Function name	**Function**	**Description**	**Sample Function**
Construction / Operational Jobs	=ROUND(XLOOKUP (C20, $N$3:$T$3, $N$4:$T$4) *C21,0)	This function calculates the number of construction and operational jobs required for each scenario by generation type. This considers nameplate generation, and job ratios	C22
Occupational Breakdown	=ROUND(XLOOKUP (C$20, $N$7:$V$7, $N8:$V8)*C$23,0)	This function calculates the number of expected operational jobs required by occupation	C24
Total Number of Jobs	=SUM(C22:F22)	This function sums all jobs in either the construction, or operational field	K20

3.2.4 Results Analysis and Discussion

Expected Job Losses

The QEGS and QENS models see 19 fossil fuel generation stations decommissioning by 2050, which employ a total of 1238 personnel. The QERS only requires 16 fossil fuel generation stations to decommission, employing a total of 888. Table 13 presents the number of works at each power station expected to decommission.

Table 13 - Number of site workers employed at each fossil fuel power station (NPI. 2024)

CPG Stations		**GPG Stations**	
Power Station	**Number of Site Workers**	**Power Station**	**Number of Site Workers**
Callide B*	112	Condamine A	20
Callide C*	134	Darling Downs	33
Gladstone	191	Swanbank E GT	37
Kogan Creek	103	Townsville Power Station	11
Millmerran	70	Yarwun Cogen	6
Stanwell**	135	Barcaldine Power Station	4
Tarong**	300	Braemar	7
Tarong North**	40	Braemar 2 Power Station	19
		Mt Stuart	5
		Oakey Power Station	7
		Roma	4
TOTAL	610/1085	**TOTAL**	153

'*' – Please refer to AS122 for clarification

'**' – Please refer to AS125 for clarification

Table 14 provides an insight into the jobs which are expected to be lost in the current fossil fuel generation sites. The overwhelming majority of jobs lost for both CPG and GPG is trades and technicians, which contribute to nearly 50% of total jobs.

Table 14 - Occupational Breakdown of jobs in Existing Fossil Fuel Infrastructure

Type of Job	**CPG (QEGS + QENS)**	**CPG (QERS)**	**GPG**
Machinery Operators / Drivers / Labourers	75	133	19
Trades and Technicians	285	508	72
Professionals	104	184	26
Managers	75	133	19
Clerical / Admin	71	126	18
Total	610	1085	153

Forecast Renewable Energy Jobs

In total, there is expected to be a total of 145,972 jobs required to construct 68.41GW of nameplate generation and storage for the QEGS. To support these projects during operations once commissioning has occurred, there is expected to be a requirement of 10802 jobs. The overwhelming majority of these jobs are in the Trades and Technicians occupation, consisting of 53% of all jobs, or 5644 positions. The technology with the most required jobs is the CCGT with CCS, requiring 4097 jobs.

Table 15 – Required Jobs for the QEGS Model

Type of Generation	CCGT with CCS	Solar	Wind	BESS	TOTAL
Nameplate Capacity (MW)	29267	27404	12213	7279	
Construction	37169	2466	2565	1674	145972
O&M	4097	2466	2565	1674	10802
Machinery Operators / Drivers / Labourers	504	15	0	10	529
Trades and Technicians	1917	1228	1665	834	5644
Professionals	696	116	398	79	1289
Managers	504	888	333	603	2328
Clerical / Admin	475	219	169	149	1012

The QERS model, with 83.44GW of nameplate generation, requires 253,491 construction and 14,183 operational jobs to support these generation and storage projects. This scenario sees a reduced number of unskilled direct labour jobs, with an increase in trades and technicians, rising to 58% of all jobs. Total number and makeup of total workforce for managers and professions increases. The largest employer for this scenario is clearly wind generation, employing 7,634 jobs, which makes up 54% of all jobs (Table 16).

Table 16 – Required Jobs for the QERS Model

Type of Generation	Solar	Wind	Solar Thermal	BESS	PHES	TOTAL
Nameplate Capacity (MW)	23902	36353	250	16935	6000	
Construction	38482	96335	403	75191	43080	253491
O&M	2151	7634	23	3895	480	14183
Machinery Operators / Drivers / Labourers	13	0	0	23	8	44
Trades and Technicians	1071	4954	15	1940	137	8117
Professionals	101	1183	4	183	168	1639
Managers	774	992	3	1402	95	3266
Clerical / Admin		504	2	347	72	925

There is expected to be 269,946 construction and 14,183 operational jobs required for the QENS model to construct 71.57GW of nameplate generation and storage. The ratio of professionals increases significantly compared to other scenarios, with decreases in the ratio of trades and technicians.

Table 17 – Required Jobs for the QENS Model

Type of Generation	**Solar**	**Wind**	**Solar Thermal**	**Nuclear**	**BESS**	**PHES**	**TOTAL**
Nameplate Capacity (MW)	18802	29853	250	4000	13815	4850	
Construction	30271	79110	403	64000	61339	34823	269946
O&M	1692	6269	23	1320	3177	388	12869
Machinery Operators / Drivers / Labourers	10	0	0	198	19	7	234
Trades and Technicians	843	4069	15	561	1582	111	7181
Professionals	80	972	4	363	149	136	1704
Managers	609	815	3	99	1144	76	2746
Clerical / Admin	151	414	2	99	283	58	1007

Table 18 provides total construction and operation jobs for each scenario, along with generation expected to be decommissioned. The largest employer of construction jobs is the QERS at 269,946, which is over 100,000 more than the QEGS, which is 145,972. This trend carries over to the operational jobs, with QERS requiring 14,183 jobs and the QEGS requiring 10,802 jobs. The QENS requires 90% of the jobs employed by the QERS. The QERS requires significantly more jobs compared to other scenarios as it has the most nameplate capacity for generation and storage. The QEGS has the least capacity, hence it has the least number of required jobs by a significant margin. Due to the QENS having a nameplate capacity between the two other scenarios, the required number of jobs are also between these two scenarios.

Table 18 – Required Jobs across all three Scenarios for Construction and Operations

Scenario	**Construction**	**Operation**
New Generation - QEGS	145,972	10,802
New Generation - QERS	253,491	14,183
New Generation - QENS	269,946	12,869

3.3 Sensitivity Analysis

Parameter	Current Standard	Variance	Impact on Results
Current area specific cost codes	Facilities added in the QEGS model were assigned a location at random from LGAs which already have that generation	Random LGAs with no prior generation in them could be listed.	LGAs added are located in high-cost zones of Queensland. The variance listed increased the price of renewables by 3% overall
Capacity factor	An average capacity factor for each generation technology was utilised	A low or high range of capacity factors could be utilised	This would drastically affect the generation capacity, with a deviation on 17%.
Facilities with unknown commissioning date	Facilities of this nature were assigned a random commissioning between 2029 to 2039 for renewables, and 2030 for hydrogen generation	Some of these facilities may be commissioned before or after the selected dates, for instance, the dates are changed from 2025 to 2044	The only change this would bring is inflationary costs. The application of these dates only deviated the model less than 1% of total costs for each scenario
Facilities with unknown decommission date	Fossil fuel power stations with no clear decommissioning date were assigned a decommissioning date of 2050, in line with net-zero emission reduction targets.	The decommissioning date for these facilities could be assigned at random for between 2040 to 2050	This reduces the OpEx and CapEx for these facilities by 10% over the 30 year period
Large variance in nuclear generation cost estimates	The CSIRO GenCost report result was utilised for this research investigation	For example, the cost per kW to build nuclear varies greatly, with estimates ranging around 50% of the used benchmark	The CapEx and OpEx of RQ1 surrounding nuclear would change drastically. This technology has not been utilised in Australia prior, so there is a large range of variance on costs. Estimations predict the CapEx and OpEx would change by over 100% due to the drastic deviation in predicted costings
BESS facilities with no listed discharge capacity time	A capacity discharge time of 1, 2, 4, or 8 was assigned to BESS with no listed discharge capacity time	An average capacity, found by averaging existing BESS capacities, could be assigned to each BESS	This would increase the accuracy of the cost estimations for the BESS systems, along with increasing costs by 3%

3.4 Limitations and Recommendations

A range of limitations and recommendations were identified to further improve an accurate engineering estimation. A primary limitation of this investigation is the futuristic nature of the source. These include:

1. Due to a lack of coordination between government departments on both and between Queensland State and Australian Federal Departments, there are projects announced under different names or project specifications. In-addition, there was a serious issue with accessible information provided by these entities for power station specifications and information. This made the investigation unreliable at times, and costly assumptions were made to ensure the investigation could continue. It is recommended that there should be more interconnectivity between these government departments, along with more transparent information sharing to the general public.

2. A potential for proposed facilities not to finish construction. The two primary reasons for this occurring are the current political climate, along with the costly nature of building these projects. An example of this occurring is the cancellation of the 5GW Pioneer Burdekin PHES system by the newly elected Queensland State LNP Government, along with a freeze in funding for the Central Queensland Hydrogen Project, making its future uncertain. The LNP government have promised to scrap the legislated renewable energy targets excluding net zero by 2050. This significantly increases the difficulty to provide a cost estimation on the renewable energy transition, when core pillars for this transition are cancelled, resulting in the path to net-zero unclear. This leads to cost over runs as a clear and detailed plan is not developed and committed to, leading to a disorganised and unreliable transition

3. As the nuclear plan is only a proposal, these facilities are realistically expected to come on-line in the 10-15 years, with potential for significant delays. A fairer comparison of operational and build costs is recommended, however the implementation in the real-world is unrealistic. To gather a fair comparison, nuclear generation should be commissioned from 2025 onwards. However, this is not realistic as the nuclear plan is not a proposal, and the party taking this proposal to the election lost to the incumbent government who is against it. In-addition to this, Australia has practically no experience dealing with nuclear generation, and the generation technology requires significant lead times to build and commission these facilities.

4. This analysis only considered the total maximum generation available. In-realistic terms, generation may be lower. This large excess generation has the potential to be used for interstate energy export. Although generation capacity can be reduced to lower VOM costs

3.5 Summary and Conclusions

This first research question has the overarching aim of determining the costs of building and operating new generation and storage across three different scenarios. These scenarios included the gas, renewable, and nuclear scenarios. Current and proposed generation and storage facilities were exported from the Queensland Government and alterations were made for each of the scenarios, in-addition to being supported by information direct from the project developers and operators. Additionally, location-based costs were used for each generation and storage type across all three scenarios, which increases the accuracy of the estimate basis. Combining all this data, an excel model was produced which analysed direct export data, and formulated results between 2025 to 2054. All cost figures estimated were inclusive of inflation at a rate of 2.5%/annum. Finally, the number of jobs by occupational breakdown were calculated for each model by finding a ratio of jobs and % occupational breakdown, then combing that with nameplate capacity for each generation/storage type. The major items and direct results from the model, across all three scenarios, are:

- Predicted grid consumption growth by consumption type
- Estimated CapEx to build new grid generation and storage capacity
- Expected OpEx to operate these projects
- New number of jobs required by occupation

Aligning with the aims and scope of RQ1, the conclusions below were identified:

- **Consumption and Generation**: Although there is a predicted increase in grid consumption of 206%, rising from 50TWh in 2025 to 103TWh in 2054. In comparison, the grid generation is expected to rise from 85TWh in 2025, to 178TWh by 2054, representing an increase of 210%. At all times, the generation capacity, inclusive of power station maintenance and downtime, exceeds the consumption. As there is such a large difference between the two, the model is considered viable.

- **Capital Costs**: The addition of multiple new generation and storage facilities for each scenario was costed in an estimate basis. The total capital costs for the QEGS, QERS, and QENS is $306.08 billion, $273.6 billion, and $270.9 billion respectively. The QEGS is the cheapest while considering the capital costs

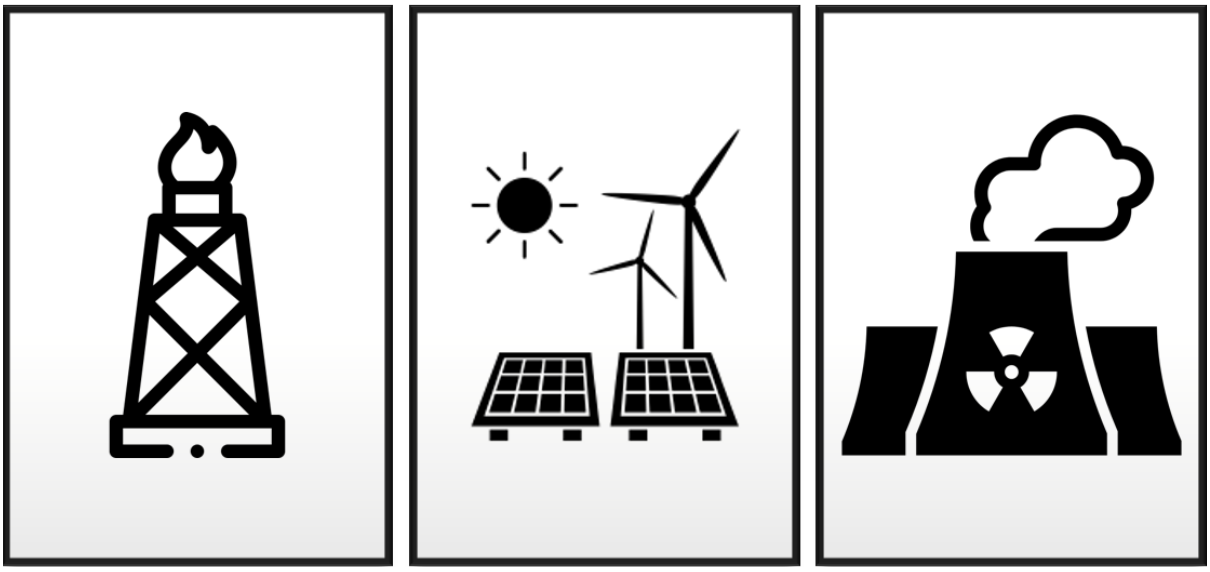
- **Operational Costs**: The QEGS is the cheapest as there is significantly less nameplate generation and storage required. In-addition to this, there are large operational costs for nuclear. The OpEx costs for QEGS, QERS, and QENS are $50.9 billion, $67.07 billion, and $87.55 billion respectively

- **Required Jobs**: The QERS requires the most construction jobs, estimated at 253,491, which is over 100,000 more than the QEGS, which is estimated to require 145,972 construction jobs. In-addition to this, the expected operational jobs for the QERS scenario is 14,183, while the QEGS requires 10,802. The QENS is in between these two values. The reason that the QERS is expected to need the most jobs is due to this scenario implementing the largest amount of new nameplate generation and storage capacity, which increases the number of jobs. The QEGS has the least new nameplate capacity, and hence the least estimated new jobs for construction and operation. The QENS has an estimated new nameplate capacity between these two scenarios, and therefore has an estimated jobs count between these two as well.

- **Available Data and Project Cancellation**: Available data in this field of research was highly inaccurate, with vast amounts of data either missing, or large contradictions between multiple sources. In-addition to this, the recent political and economic climate as resulted in various projects either cancelled or had their funding restricted while the research investigation was ongoing.

- **Cost-effective scenario:** The QEGS scenario was the most cost effective in-comparison to the renewable and nuclear scenario. The removal of base-load generation significantly increased costs as more storage is required, and renewable generation is less efficient. In-addition to this, nuclear generation has significant costs compared to all other forms of generation.

4.0 Research Question 2 – Grid Transmission and Stability



4.1 RQ2-01 Construction and Operation of Transmission Infrastructure

4.1.1 Scope and Assumptions

Reference	Scope/Assumptions	Explanation
AS211	All costs are inclusive of inflation at a rate of 2.5% per annum	The Reserve Bank of Australia (RBA) expects the Consumer Price Index (CPI) to increase between 2-3% per annum long term, which is within its inflation targets. This affects all areas of the economy, and more specifically build cost and operational costs for power stations, which is more relevant to this investigation.
AS212	Transmission assets with the same name are considered the same transmission line	In the direct export from the Australian Government, there are some transmission assets which have the same name, with one line item being the main line, and some smaller offshoots having the same name. Therefore, these offshoots are considered in as the same transmission line
AS213	2037 is the average Transmission line replacement year	In the excel transmission mode, it is assumed that the average year for replacement is 2039, as this is half way through 2025 to 2054. This is relevant to AS
AS214	REZs transmission DNE for QEGS scenario as there are no REZs	Due to a dominant amount of generation capacity planned to be built surrounding existing generation infrastructure. Therefore, there is not any new REZs in this scenario.
AS215	Transmission lengths for each capacity was calculated by averaging existing infrastructure lengths for the respective capacity	This method is a clear way to ascertain a technique for length calculation for the new infrastructure
AS216	There are no grid connection costs for PHES	PHES projects require direct connection to large scale transmission, therefore no grid connection costs will be estimated

4.1.2 Relevant Background Information and Context

Current Queensland Transmission Infrastructure and Network Scope

As of 2025, the Queensland energy grid consists of 23,673km of grid transmission infrastructure (Australian Government, 2025), which is owned and operated by Powerlink. From Brisbane, this network ranges 1000km west to Quilpie, and up to 2000km northwest to Normanton. The network comprises of two capacity standards, which includes 132kV and 275kV. An overlay of the networks scale can be seen in the figure below (Figure 22).

Figure 22 – Existing Transmission Infrastructure Network in Queensland (Australian Government, 2025)

Transmission Capacity

In his report, Thomas Heath outlines a range of transmission capacities in MW for each voltage of transmission infrastructure. It is clear that as transmission voltage (V) increases, the transmission capacity (W) increases as well while amperage (A) remains constant, this can be seen in the equation below:

$$W = V \cdot A$$

Table 19 below displays the high-end, low-end, and average capacity in MW for each rated voltage transmission line in kV.

Table 19 – Average Capacity of Transmission Infrastructure by Voltage Capacity (Thomas Heath, 2024)

Voltage (kV)	**Low End Capacity**	**High End Capacity**	**Average Capacity (MW)**
22	5	10	7.5
66	30	50	40
110	100	120	110
132	120	160	140
220	250	350	300
275	350	500	425
330	500	700	600

4.1.3 Data Collection Methods, and Result Methodology

Initially, a direct export of transmission lines, courtesy of the Australian Government, was acquired, and was used for all stages apart of large-scale grid transmission. All data presented is in the 'RQ2-01 Transmission' sub-model.

Reinvestment into Existing Infrastructure

Utilising a Powerlink report, all transmission lines requiring reinvestment over the coming years were identified. These powerlines were identified in the export, and total lengths were combined by capacity type, which was either 132kV or 275kV. A cost estimate was produced by Powerlink to reinvest in prior projects; therefore, this figure was used and a cost per km was calculated. Total costs for reinvestment were subsequently calculated using this figure.

Large-Scale Grid Transmission

Utilising the exported data, the number of transmission lines present in each LGA was identified by voltage capacity and presented in a table. This was completed in the 'Transmission' sub-model. The total transmission capacity, projected generation, and projected storage (MW) was calculated for each LGA. Any shortfalls where the generation/storage is greater than the transmission requirements were identified, and therefore new transmission infrastructure was combined with existing infrastructure. This ensured that transmission capacity was always above the generation/storage requirements.

The average distance of existing transmission lines by the relevant capacity was identified in the exported data from the Australian Government. Utilising this, the total distance of required transmission lines was calculated, and utilising a cost per km from multiple sources, the final cost for transmission infrastructure was procured.

Generation and Storage Connection Costs

The AEMO IASR Assumptions Workbook provides a cost estimate to calculate connection cost based upon the nameplate capacity P. The methodology for calculation is similar to that of the build cost methodology and is done in the same sub-model for RQ1. The equation for connection cost calculations can be found below:

$$Connection\ Costs = P(kW) \cdot \left(\frac{\$}{kW}\right) \cdot 1.025^{(Commissioning\ Date - 2023)}$$

A sample of the various functions used in RQ2-01 can be found below in Table 20.

Table 20 - Sample Functions used for RQ2-01

Function name	**Function**	**Description**	**Sample Cell**
Transmission Capacity	=C3*$B3 + C4*$B4 + C5*$B5 + C6*$B6 + C7*$B7 + C8*$B8 + C9*$B9	Calculates transmission capacity by multiplying the number of transmission lines, separated by voltage (V), and the associated nameplate capacity (MW)	C10
Total expected nameplate generation and storage by LGA	=SUMIFS('RQ1-01 - QEGS'!$X$2:$X$269,'RQ1-01 - QEGS'!$H$2:$H$269,"Generation",'RQ1-01 - QEGS'!$J$2:$J$269,'RQ2-01 Transmission'!C$2)	This function sums the total generation capacity for each scenario by LGA	C13
Total distance of transmission lines by type	=$F67*B67	This function sums the total number of transmission lines, separated by voltage, by the average distance of each transmission voltage rated line	H67
Cost per Transmission Line ($B)	=ROUND(($L67*H67*1.025^(2039-2025))/1000,2)	This function calculates the total cost adjusting for inflation	O67

4.1.4 Results Analysis and Discussion

Upgrade of Existing Transmission Infrastructure

In Powerlink's '2024 Transmission Annual Planning Report' (TAPR), a range of transmission lines were listed as approaching their end of technical life. This classification is given to transmission infrastructure which is set for decommissioning within 10-15 years. These grid transmission lines are to be inspected and maintained to support grid transmission requirements through the energy transmission. Classified into two grid transmission capacities, in-total there was 807km of 132kV capacity, and 1790km of 275kV capacity classified as approaching end of technical life. Proposed reinvestments have been announced for some of these transmission lines. A reinvestment is an act where power line assets are assessed, refitted to extend the assets technical lifespan.

Figure 23 – An overlay of 132kV Grid Transmission Lines approaching end of technical life against grid transmission assets (Australian Government, 2025)

Figure 24 – An overlay of 132kV Grid Transmission Lines approaching end of technical life against grid transmission assets (Australian Government, 2025)

In Powerlink's 2018-2022 'Powerlink Queensland Revenue Proposal', a proposed reinvestment into the 41.4km 'Biloela to Moura 132kV transmission line' was proposed at a cost of $44.9 million. In all reinvestment plans for 132kV transmission lines, Powerlink replaces the circuit all together (Powerlink, 2025). Dividing the reinvestment cost against length, and applying inflation to 2037 (AS213), a figure of $1.69 million per kilometre was estimated to retrofit these 132kV rated power lines. Therefore, an estimate basis on the reinvestment of all 132kV transmission infrastructure is projected to cost $1.36 billion, adjusting for inflation.

In-addition to this, a reinvestment was proposed for the 65.3km 'Greenbank to Mudgeeraba 275kV transmission line' was planned at $69.7 million for the project. For this project and all other reinvestments into 275kV transmission infrastructure, the following is completed: "Tower painting, member and hardware replacement, and OHEW replacement of existing 275kV double circuit transmission line" (Powerlink, 2022). Applying the same methodology as above (AS213), the cost per kilometre for reinvestment into 275kV transmission lines was $1.67 million per km. Therefore, the estimated cost to reinvest into all relevant 275kV transmission lines is $2.98 billion, adjusting for inflation. Therefore, the total cost for reinvestment into 2,597km to extend the service life of relevant transmission grid infrastructure is $4.34 billion adjusted for inflation.

Medium Scale Transmission

Utilising the export from the Australian government on current transmission infrastructure in Queensland, transmission shortfalls in LGAs were identified for each transitional scenario.

- The QEGS had a combined deficit of 8848MW of transmission capacity across nine LGAs spread across the state. These LGAs included:
  - Barcaldine Regional Council (-36.69MW)
  - Carpentaria Shire Council (-900.23MW)
  - Cook Shire Council (-172.36MW)
  - Longreach Regional Council (-4.13MW)
  - Mount Isa City (-1322.52MW)
  - Southern Downs Regional (-766.21MW)
  - Townsville City (-435.36MW)
  - Weipa Town (-0.47MW)
  - Western Downs Regional Council (-5200.36MW)

- The estimation of transmission capacity required for the QERS scenario was 12188MW spread across 14 LGAs. The affected LGAs included:
  - Banana Shire Council (-815.78MW)
  - Carpentaria Shire Council (-1.38MW)
  - Etheridge Shire Council (-286.35MW)
  - Flinders Shire Council (-3035.62MW)
  - Gladstone Regional (-1677.8MW)
  - Goondiwindi Regional Council (-329.11MW)
  - Gympie Regional (-15.21MW)
  - Longreach Regional Council (-4.13MW)
  - Mackay Regional (-449.68MW)
  - Mareeba Shire (-325MW)
  - Toowoomba Regional Council (-120.25MW)
  - Torres Shire (-0.16MW)
  - Weipa Town (-0.47MW)
  - Western Downs Regional Council (-5127.57MW)

- The total transmission capacity shortfall across all LGAs in the QENS scenario sits at 11053MW across 12 LGAs. These LGAs included:
  - Banana Shire Council (-1665.78MW)
  - Carpentaria Shire Council (-1.375MW)
  - Etheridge Shire Council (-286.35MW)
  - Flinders Shire Council (-923.16MW)
  - Gladstone Regional (-1677.8MW)
  - Gympie Regional (-15.21MW)
  - Longreach Regional Council (-4.13MW)
  - McKinlay Shire (-325MW)
  - South Burnett Regional (-1106.58MW)
  - Toowoomba Regional Council (-120.25MW)
  - Torres Shire (-0.16MW)
  - Western Downs Regional Council (-4927.57MW)

The LGA which has the largest shortfall of transmission capacity compared to expected generation is the Western Downs Regional Council. This one LGA represents between 42.3% of transmission capacity shortfalls in the QERS, to 58.77% of total transmission capacity shortfalls in the QEGS. Other LGAs which require significant transmission investment includes the Banana Shire Council, and South Burnett Region.

Data driven from the direct export of transmission infrastructure was analysed and an average length was calculated for each transmission line categorised by voltage capacity (kV). In-addition to this, a range of different cost estimates, with an applied inflation adjustment to 2037 (AS211 & AS215), was identified and formulated. Table 21 has these values, and can be seen below:

Table 21 – Transmission Line Capacity, Length, and Cost Estimates

Voltage	**Average Capacity (MW)**	**Average Length (km)**	**Cost per KM ($B) (2025)**
22	7.5	16.3	0.525
66	40	36.4	1.131
110	110	14.1	1.5
132	140	28.5	2.154
220	300	96.8	2.692
275	425	59.1	3.677
330	600	79.4	4.846

To rectify this transmission shortfall, the model implements new transmission infrastructure to ensure that transmission capacity is always greater than transmission requirements. Therefore, Table 22 displays the number of new transmission infrastructure lines by voltage to meet this requirement. The number of lines ranges from 12 in the QEGS, to 17 in the QERS. The QERS requires more infrastructure due to the scenario having the largest transmission capacity shortfall.

Table 22 – New Transmission Infrastructure Required to meet Capacity

Voltage (kV)	**QEGS**	**QERS**	**QENS**
22	2	4	4
66	3	4	6
110	0	2	0
132	2	2	2
220	2	3	3
275	3	2	2
Total	12	17	15

Utilising data from Table 19Table 22 in relevant information, the total length of transmission infrastructure (km) and the total cost to build this new infrastructure was calculated and is displayed in Table 23 and Table 24Table 24 respectively.

Table 23 – New Easement length of Transmission Lines (km)

Voltage	**QEGS (km)**	**QERS (km)**	**QENS (km)**
22	32.6	65.2	65.2
66	109.2	145.6	145.6
110	0	28.2	0
132	57	57	85.5
220	193.6	290.4	290.4
275	177.3	118.2	118.2
330	952.8	1349.8	1191
TOTAL	1522.5	2054.4	1895.9

Table 24 – Total Cost to Build Medium Transmission Infrastructure

Voltage	**QEGS**	**QERS**	**QENS**
22	0.02	0.05	0.05
66	0.17	0.23	0.23
110	0	0.06	0
132	0.17	0.17	0.26
220	0.74	1.1	1.1
275	0.92	0.61	0.61
330	6.52	9.24	8.16
TOTAL	**8.54**	**11.46**	**10.41**

The cost of the new long-distance transmission infrastructure ranges from $8.54 billion in the QEGS model, to $11.46 billion in the QERS model. The largest cost by voltage type across all three scenarios was the 330kV transmission line, ranging from 76% to 81% of total grid transmission costs.

Generation and Storge Connection Costs

The connection of the new generation and storage assets to the energy grid is the last step to linking these projects to consumers. The connection cost is small scale grid transmission to the existing infrastructure. This cost is based upon a cost per kW of nameplate generation, therefore scenarios with higher nameplate generation such as the QERS, will have higher connection costs.

Table 25 contains the grid connection cost by asset type for each scenario. Analysis shows that the QERS scenario has the highest connection cost of $20 billion, while the QEGS has the lowest connection cost of $14 billion. The largest asset type to this cost is wind generation, contributing significantly more in all scenarios, apart from the QEGS which the largest contributor is solar generation.

Table 25 – Connection Costs ($ Billions) for each Scenario by Asset Type

	QEGS ($B)	QERS ($B)	QENS ($B)
CCGT with CCS	4.61		
Solar	6.91	7.71	5.63
Wind	3.13	9.85	8.37
Nuclear			0.64
Solar Thermal		0.09	0.09
BESS	0.81	2.43	1.90
PHES		*	*
TOTAL	**15.46**	**20.06**	**16.63**

'*' – Please refer to AS216

Overall Transmission Upgrades and Connection Costs

Finally, the total costs for each scenario by cost type can be seen in Table 26. The highest cost is clearly the QERS model, as there is significantly more nameplate generation and storage compared to other models. In-addition to this, the generation and storage total is more spread out throughout the state, and in areas where there is a lack of existing infrastructure. The QEGS, with its lower required investment, utilised existing infrastructure as its new assets were positioned nearby existing infrastructure. Therefore, more infrastructure was required. Total costs for RQ2-01 ranged from $27 billion for the QEGS, to $36 billion for the QERS, while the QENS was estimated to cost $31 billion.

Table 26 – Total Costs for RQ2-01 by Transitional Scenario

	QEGS ($B)	QERS ($B)	QENS ($B)
Required Reinvestment	4.34		
Large-Scale Transmission	8.54	11.46	10.41
Asset Connection Costs	15.46	20.06	16.63
Total	27.12	35.86	31.38

4.2 RQ2-02 Construction and Operation of Grid Stability Infrastructure

4.2.1 Scope and Assumptions

Reference	**Scope/Assumptions**	**Explanation**
AS221	Build and Operational costs will rise 2.5% per annum	The Reserve Bank of Australia (RBA) expects the Consumer Price Index (CPI) to increase between 2-3% per annum long term, which is within its inflation targets. This affects all areas of the economy, and more specifically build cost and operational costs for power stations, which is more relevant to this investigation.
AS222	Combined time constant of flywheel and generator is the same as a new purposed built generator (6s)	Due to a lack of a publicly available plan on the repurposing of these facilities, the time constant of generator and flywheel is the same as a purposed built facility
AS224	Fast-acting frequency regulation infrastructure such as batteries are not costed within this research question.	The costings for the FFG assets have already been completed in a prior research question. Please see RQ1-01 for costings
AS225	Inertia shortfall cost analysis does not need to be completed for QEGS	The QEGS has enough natural inertia to maintain grid stability. Therefore, no inertia stability infrastructure is required to maintain grid stability.
AS226	Synchronous Condensers in the Powerlink plan are progressively brought in for each year	The Powerlink Synchronous Condenser plan does not specify the year at which each plant will be commissioned. Therefore, it was assumed that there would be one facility per year built from 2027 to 2035.

4.2.2 Relevant Background Information and Context

Grid Stability and Operational Frequency Control

Electricity Grid Stability is the ability for a grid to maintain an operational steady state, in regard to voltage and frequency, after a disturbance. These disturbances often result from either the following:

- Generation or Network Event: These events are a disruption in generation load or the grid transmission network and involve sudden decrease in generation capacity from the grid due to either generation or transmission issues
- Separation Events: Whereby an area which is served by the grid for electricity is cut off and disconnected, causing a separation. These are a result of a Generation or Network Event
- Multiple Contingency Events: An event whereby multiple Generation or Network Event occurs at a single time. This is typically a result of extreme weather conditions, which damage grid infrastructure.

This grid stability is regulated and maintained through a range of processes which includes inertia, voltage management, and fault ride-through. The primary mechanism which is of interest for grid stability is the inertia management (MWs). System Inertia management is the ability to maintain steady frequency and is currently conducted in the NEM by utilising inertia from rotating fossil fuelled turbines. This inertia reduces the effect imbalances between consumption and generation. As these fossil fuel generators begin to decommission and are replaced by renewable generation, the total grid inertia available is lost (ARENA. 2022).

Synchronised Condenser Facilities and RSCs

A synchronised condenser, also known as a synchronous compensator, or a synchronous capacity, is a solution to maintain grid frequency and stability as base-load generation is replaced by variable generation as the renewable energy transition progresses. This device uses a DC-excited synchronised machine whereby large shafts at either end do not attach to each other or driving equipment, meaning they freely rotate. Voltage stability and regulation from this device is directly due to dynamically absorbing or generating reactive power. Along with this, these devices provide synchronous inertia which improves frequency stability and short circuit strength.

In-addition to this, old fossil fuel generation generators can be repurposed to dedicated synchronised condensers facilities, also known as Repurposed Synchronised Condensers (RSG), which will provide grid system inertia over time. It is expected that these facilities will be able to provide similar system inertia, that of what the generation capacity of the plant was designed for, at a fraction of the cost and build time.

Case Study – South Australia

In 2016, South Australia was plagued by state-wide blackouts caused by severe weather damaging transmission and distribution infrastructure assets. This reduced synchronism within the grid, leading to a large imbalance between the supply and demand, leading to a suspension of electricity supply within the wholesale market of 13 days. One such recommendation was the implementation of synchronisation assets into the grid, more specifically synchronised condensers. The state energy provider, ElectraNet, implemented 4 synchronised condensers in 2019 for a total of 2,500MWs of synchronisation at a cost of $166 million (AMEO. 2019).

4.2.3 Data Collection Methods, and Result Methodology

To conduct an in-depth analysis on costing the infrastructure required to maintain grid system inertia above safe levels, a range of supporting information was collated. Initially, the grid inertia shortfall was identified through the 2024 Inertia Report by AEMO. Utilising the 2022 Queensland SuperGrid Infrastructure Blueprint, and grid support plans from Powerlink, the current inertia plan was identified for new purpose-built SC facilities, along with the RSC facilities. Costings identified in the Powerlink document was utilised to further cost the RSC, and to cost any additional SC facilities required to meet safe levels of system inertia within the Queensland section of the NEM. A sub-model was created, called the ‘RQ2-02 Stability’. The functions used in RQ2-02 can be found in Table 27.

Table 27 - Sample Functions used in RQ2-02

Function name	**Function**	**Description**	**Sample Cell**
OpEx Costs ($B)	=IF($C2<=G$1,$E2*1.025^(G$1-2034),"")	This function calculates the operational costs for each inertia facility considering inflation	G2
Total OpEx Costs ($B)	=SUM(G2:G12)	This function sums all the OpEx costs	G17

4.2.4 Results Analysis and Discussion

Predicted Inertia Decline and Shortfall

In the 2024 Inertia Report, AEMO predict a 256 MWs inertia shortfall from secure levels between 2027/28 within the Queensland portion of the NEM. The secure levels for available inertia within the grid to 2035 is 13,700 MWs, with satisfactory levels at 12,000MWs. This inertia shortfall is significantly revised from previous estimates, with the 2022 and 2023 Inertia report predicting a 10,352MWs and 1,660MWs shortfall respectively. Between the 2022 estimate, and the 2024 estimate, the inertia shortfall decreases by 97.5%, meaning the requirements for additionally synchronous condensers aside from those already planned are significantly reduced.

The 2022 Queensland SuperGrid Infrastructure Blueprint plans for 3310MW of previously operating coal generation capacity to be transformed and repurposed into synchronous condensers to improve grid stability. This capacity will come from the Stanwell, and the Tarong Coal Power Stations, starting from 2026/27 (QLD Government. 2022). Previously, it was expected that a large portion of existing fossil fuel generation turbines would have to be repurposed to RSC, however the implementation of fast-acting frequency regulation infrastructure, such as the implementation of batteries, has revised down the required system inertia.

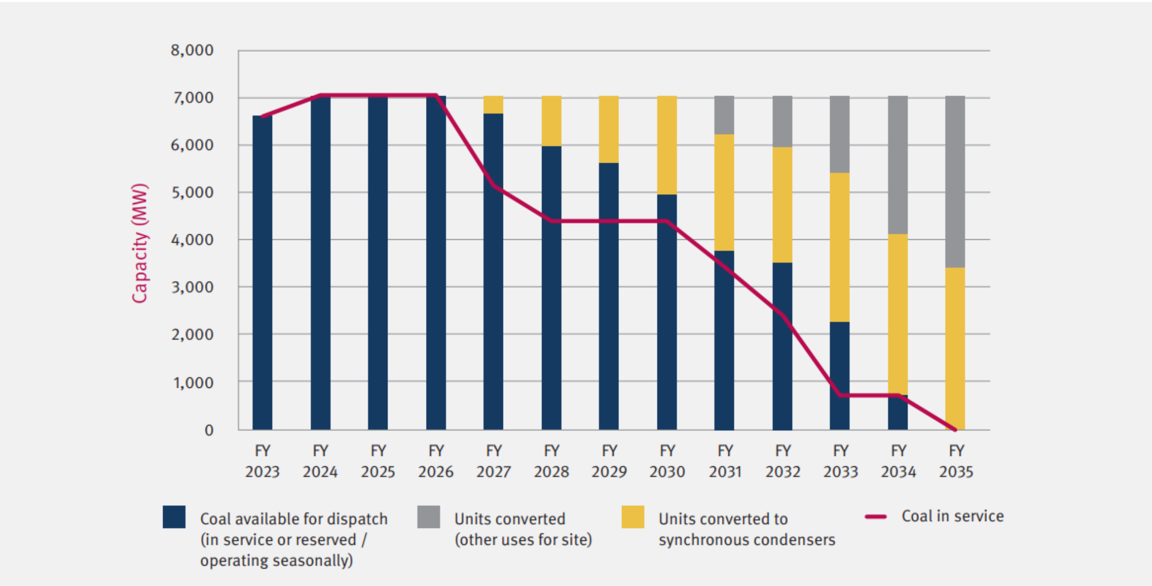


Figure 25 – Capacity of Potential for Coal Generation in Queensland (QLD Government. 2022)

In-addition to this, Powerlink Queensland predicts to install nine new synchronous condenser facilities in Queensland by 2033/34. The current plan to install calls for eight synchronous condensers in Central Queensland, and one in Southern Queensland (Powerlink Queensland. 2024). These synchronous condensers have the capacity up to 240MVA systems, with a combined total of time to constant of generator and flywheel being 6s. Therefore, the combined maximum capacity of these facilities is 12960MWs. In-addition to this, the synchronous condenser plan to support grid stability throughout the Queensland Energy Transition includes the repurposing of coal generators to synchronous condensers in Tarong and Stanwell coal power stations. In-addition to this, nine synchronous condensers are to be constructed in central and southern Queensland, and an additional synchronous condenser is required to eliminate the inertia shortfall, so inertia levels are consistently at secure levels. Due to the QENS maintaining 4GW of baseload generation over the QERS, the need for RSC are not required as there is more inertia in this scenario.

Economic Cost to Maintain Grid Stability

Relevant to the QERS and QENS, Powerlink currently have plans to install nine synchronous condensers in with a total combined capacity of 12960MWs. These facilities are expected to cost $1.72 Billion in capital cost to build, and an additional $282 Million in annual operation costs (PowerLink. 2024). Calculating the cost per MWs, the CapEx and OpEx costs are $132,700 per MWs, and $21,700 per MWs respectively.

Due to the additional 256 MWs in inertia shortfall, an additional facility will be required to exceed safe inertia levels. Total CapEx and OpEx are expected to be $191 Million and $31.248 million respectively. Therefore, total costs for the new synchronous condensers is expected to cost $1.91 Billion in total build costs, and $313 Million in annual operation costs. Assuming these facilities begin operations in 2029, the OpEx cost through to 2054 is $9.29 billion.

In the QERS, RSCs are required as there is not enough natural energy within the grid generation system. Due to the design of power stations differing substantially case by case, the cost to repurpose existing generation infrastructure differs. Coal generation is considered more difficult to repurpose, however “in favourable circumstances, could match those of gas generator conversion” (ARENA. 2023), which is as low as 60% of the cost to build a new synchronous condenser facility, by unit cost.

The combined capacity of the generators planned for repurposing for synchronous inertia is 3310MW. Assuming a time constant of generator and flywheel of 6s (AS222), the total synchronous inertia capacity is 19860MWs. As the cost is 60% of that compared to a new synchronous inertia facility per unit inertia, the total cost of repurposing these facilities inclusive of inflation is $1.80 billion, with an OpEx cost of $5.57 billion.

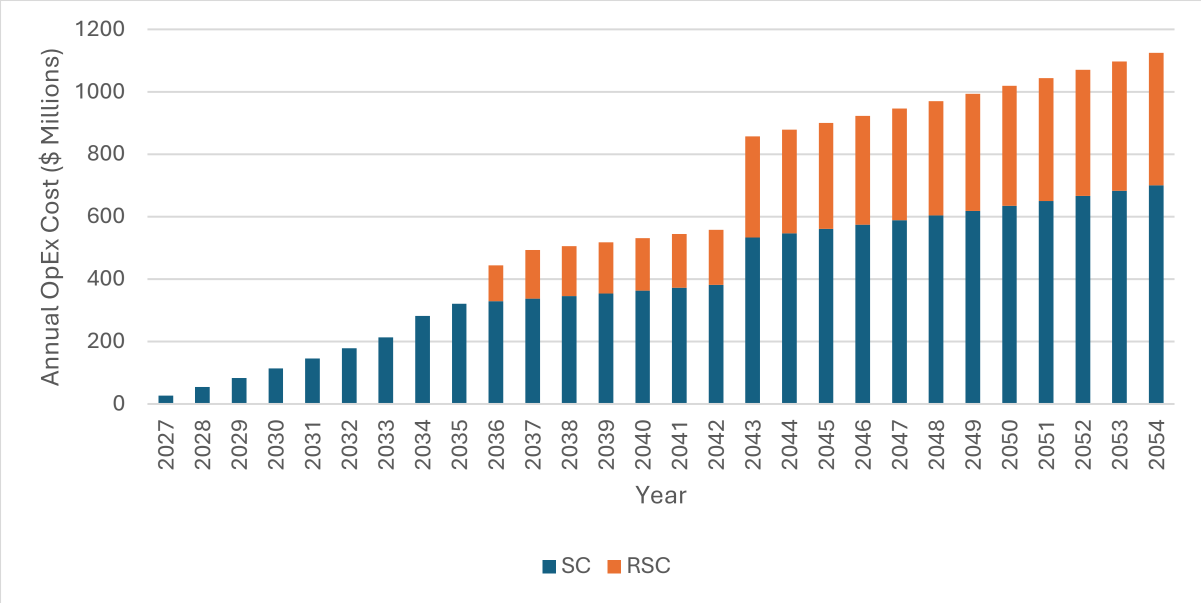


Figure 26 – Operational Costs for Synchronous Inertia Stability for the QERS

Therefore, the total CapEx and OpEx for the QENS is $1.91 billion, and $9.29 billion in respectively. While the same costs for QERS is $3.74 billion and $14.87 billion respectively.

4.3 Sensitivity Analysis

Parameter	Current Standard	Variance	Impact on Results
Capacity of Transmission Infrastructure	An average of transmission capacity, estimated by Thomas Heath was utilised	Low and High range values for transmission infrastructure could be utilised instead	If low range capacity values for transmission are utilised, more transmission infrastructure would be required as each transmission line has a lower capacity. High range values decrease the required investment into transmission infrastructure The cost deviation for the transmission infrastructure is 30%
Type of Transmission Lines	Only one standard of power lines was considered, which were aboveground single/double circuits	Other options could be considered; these include underground transmission lines	Underground transmission significantly increase the cost by a factor of 3-20 times that of an aboveground transmission (Powerlink, 2025)
Cost for RSC	A CapEx and OpEx cost estimate for RSC was utilised from ARENA estimating that RSC are 60% per unit of inertia than that of purpose build SC	Although there is a significant lack of information regarding this, a different estimate could be utilised	This would increase the cost of RSCs and hence increase the cost of the inertia stability plan for the QERS model

4.4 Limitations and Recommendations

A range of limitations and recommendations were identified to further improve an accurate engineering estimation. A primary limitation of this investigation is the futuristic nature of the source. These include:

- The Model does not consider transmission of electricity between large areas of Queensland (>1000km). Currently there are proposals outlined in Queensland Government PTIs to increase transmission between outlined areas in Queensland, such as Gladstone, North Queensland, South Queensland, and Central Queensland. These transmission projects include CopperString, Central to South Queensland transmission and more
- Information provided by Powerlink regarding reinvestment into existing transmission is highly vague, and requires more depth of detail regarding the year for specific line reinvestment
- The Powerlink synchronous condenser plan is extremely vague and has a large amount of uncertainty. First of all, there is a level of uncertainty regarding whether the cost of these projects are inclusive of inflation, and at what rate. Secondly, these projects are assumed to be built by 2034/35, though there is an assumption that these projects will be progressively brought in until this date, though this level of detail has not been specified.

4.5 Summary and Conclusions

The second research question had the primary aim of estimating the cost of expanding transmission infrastructure, along with sustaining grid stability, across the three scenarios. Information regarding current transmission infrastructure was procured from the Australian Government in a direct exported excel spreadsheet. Utilising this information, and information provided Powerlink, the required reinvestment for transmission was estimated. In-addition to this, required transmission upgrades were found by identifying transmission capacity shortfalls for each LGA were estimated by utilising this data, along with generation and storage capacity analysed in the prior research question. Connection costs from generation/storage asset to the transmission grid were estimated utilising data from AEMO. Finally, stability shortfalls were identified for each scenario, and the plan for each scenario was identified utilising information from Powerlink and the Queensland Government. All cost figures estimated utilised the 2.5% per annum increase in cost prices to mimic inflation to improve accuracy. Therefore, the key findings and estimations resulting from this research investigation into transmission infrastructure and stability were:

- **Reinvestment into Existing Infrastructure**: Although the information from Powerlink regarding required transmission infrastructure reinvestment was vague at best, it was estimated that 807km of 132kV and 1790km of 275kV transmission infrastructure required reinvestment. In-total, this was estimated to cost $4.34 billion, adjusting for inflation, for all three scenarios

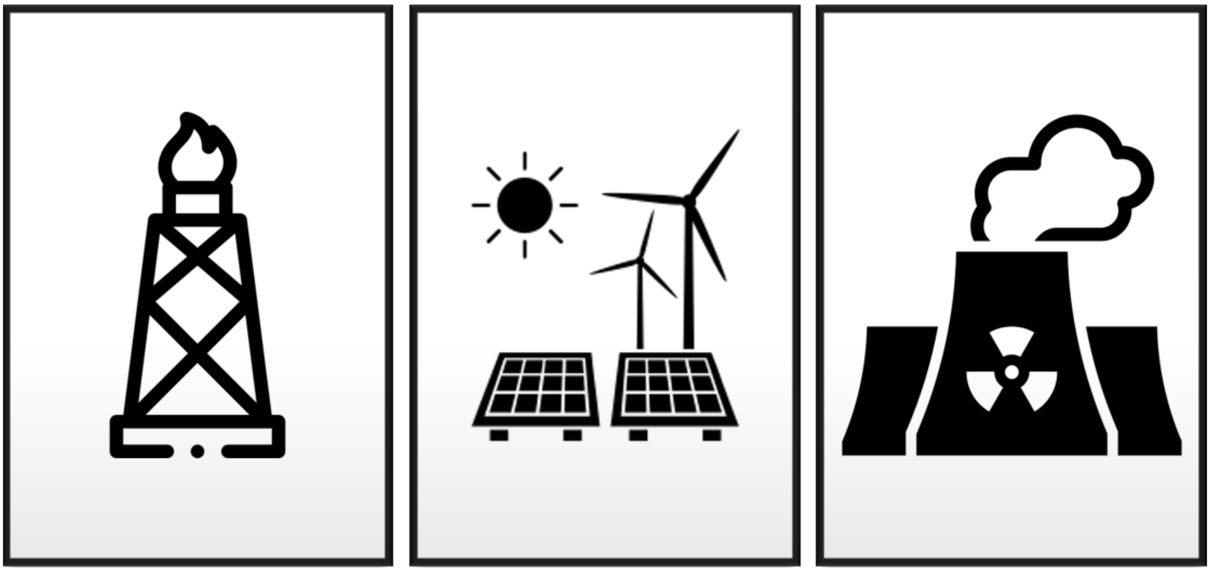
- **New Large-Scale Transmission**: Transmission capacity shortfalls for the QEGS, QERS, and QENS models were identified to be 8848MW, 12188MW, and 11053MW respectively. As the QERS model requires the most amount of new transmission capacity investment, it had the largest cost compared to the other three scenarios. The expected cost for this transmission upgrade is $11.46 billion, which is more compared to the QEGS and QENS, which is expected to cost $8.54 billion and $10.41 billion respectively.

- **Generation/Storage Connection Costs**: The QEGS model has the least required cost to connection generation and storage projects to large scale grid transmission as there is significantly less nameplate generation compared to the other two scenarios. The QEGS is expected to cost $14.24 billion, while the most expensive scenario is the QERS which will cost $20.06 billion.

- **Grid Stability Requirements**: Due to the abundant quantity of natural grid inertia in the QEGS, there is no requirement for dedicated infrastructure. The QENS, with less baseload generation, requires synchronous condenser facilities at a CapEx and OpEx cost of $1.91 billion and $9.29 billion respectively. With no natural grid inertia, the QERS requires both synchronous condenser facilities, in-addition to repurpose synchronised facilities from old coal power stations. This is expected to cost $3.74 billion in CapEx and $14.87 billion in OpEx.

- **Missing/Restricted Information**: Powerlink have not publicly disclosed a range of critical information resulting in assumptions having to be made. This information includes the commissioning date of synchronous condensers, and the year required for reinvestment into existing transmission infrastructure

5.0 Research Question 3 – Existing Fossil Fuel Infrastructure



5.1 RQ3-01 Decommissioning and Demolition

5.1.1 Scopes and Assumptions

In-order to cost the decommissioning of existing fossil fuel infrastructure, it is important to refine the scope and state assumptions:

Reference	Scope/Assumptions	Explanation
AS311	2.5% per annum increase in wage costs	The Reserve Bank of Australia (RBA) expects the Consumer Price Index (CPI) to increase between 2-3% per annum long term, which is within its inflation targets. This affects the cost of wages to workers in demolition, and the hire rate of equipment used. It is expected that wages will increase at 2.5% as a result of this
AS312	Ratio based estimation was conducted on materials utilised for building power stations	Currently, there are gaps in available research regarding current volume of materials at power specific power stations. Therefore, this estimation was used to find the volume of materials to be decommissioned
AS313	The Stanwell, Tarong, and Tarong North CPG will not be decommissioned in the QERS	These facilities are required for the grid system inertia plan for the QERS system; therefore a decommissioning estimate is not required to be made
AS314	Power stations built before December 2003 have asbestos	Coinciding with AS312, there is a severe lack of material makeup for power stations. It is known that there are power stations with asbestos in them, however which ones is not known. Australia formally banned asbestos in 2003, therefore it is assumed that any power station built up until this date has asbestos present in its structure
AS315	20% contingency applied to ensure no cost overruns	With demolition, there can be severe cost over runs.
AS316	Rates for scrapping or deposing of material is the same across all LGA	There is not enough available data online regarding LGA specific scrapping and dumping net costs, therefore a flat rate was used for every LGA across Queensland

5.1.2 Relevant Theory

Stages to Decommissioning Power Stations

As the current fossil fuel energy plants age, there will be costs to decommission and restore the site fit for future use. There are various programs which incentivise the decommissioning and demolition of these power stations to commercial/residential use. “These programs are often beneficial for communities where they occur but can shift the cost of decommissioning and remediation from shareholders and ratepayers to taxpayers” (Raimi. October 2017). This decommissioning typically has a magnitude of stages, including:

- Structure Demolition
- Material Haulage to Material Facilities
- Net Cost of Scrapping/Dumping
- Site Remediation Costs
- Contingencies

Environmental Liabilities and Recycling of Materials

While most materials which are expected to be extracted from decommissioning can be recycled, only a select few are considered as viable for recyclability. This is due to a range of reasons, predominately cost to recycle, and accessibility to recycling facilities. In Australia, there are various facilities for the recycling of materials and equipment, whereby currency is exchanged for the recycled goods. Recycling of these goods can be seen as a revenue stream in the often-costly process of demolition.

- The considered materials include steel, copper, aluminium, etc
- Equipment includes turbines, generators, electrical components, and various pipework systems

The concrete removal (typically found in foundation and structures), along with site waste byproducts like coal ash, is seen as a disposable and is not estimated to be recycled. In-addition to this, many power stations have environmental liabilities, which pose a threat to the environment and there are heavy regulations regarding the cleanup and disposal of these contaminants. These include asbestos, oil leaks, PCBs, and other hazards. For example, in Australia, December 2003, asbestos use was banned in construction due to the adverse health risks (AS314). This product was common in construction of commercial power stations, such as the Swanbank CPG station, which was recently demolition.

Construction/Demolition Workplace Relations

Workplace relations is a complex issue and refers to the relationship between employees, employers, and governmental institutions. A union is a framework of a collective of workers who advocate for workers in specific areas of occupations. These advocations are in the form of:

- Collective bargaining;
- Dispute resolution;
- Worker representation;

Unions have a range of techniques to increase pressure on decision making, with the main technique being labour force striking. When this occurs, all workers halt all work until an agreement is reach resulting in the union giving approval for work to continue. Unions primarily bargain for increases in worker pay, working conditions, labour laws, and regulatory framework. Once a strike occurs, the efficiency of the site processes decreases dramatically. In construction and demolition, strikes lead to cost and completion timeframe blowouts, which effectively increases pressure for primary contractors to resolve the situation.

Expected Materials in Power Stations

The four main relevant materials that is a concern for the decommissioning and demolition is concrete, steel, aluminium, and the asbestos used in construction. Concrete requirements for these power stations are considerably greater than other materials due to it being responsible for the primary material for foundation and the structure. Steel material requirements are considerably high as well as boilers and other mechanical equipment (primarily made out of steel) have significant weight. In-addition to this, steel reinforcement is used in foundations and concrete structures to increase durability and strength. Finally, the expected aluminium requirements is significantly lower due to aluminium primarily used in structural components and wiring. Aluminium is also significantly less dense compared to concrete and steel (Pacca. 2002).

A prior assumption was that power stations built before December 2003 have asbestos included in their material construction (AS314). The decommissioned Hazlewood power station is an example of one of these power stations. The 1,600MW facility contained over 65,000m^3 of asbestos and over 120,000m^2 of asbestos sheeting which had to be removed (Delta Group. Accessed 2025). Therefore, assuming a similar ratio of asbestos to capacity for current relevant power stations, the ratio per MW of cubic volume of asbestos is seen in Table 28. In-addition to this, 75m^2 of asbestos sheeting per MW of capacity is assumed to be utilised in the power station.

Table 28 – Metric tonne of required material to be demolition per MW generation (Pacca. 2002)

	Concrete	Steel	Aluminium	Asbestos (AS326)	TOTAL
CPG	195	68.2	0.65	65	263.85
GPG	81.4	58.5	0.26	65	140.16

Location of Power Stations to Facilities

Table 29 displays the closest large population centre which has a depot with the ability to dispose/recycle demolitioned materials from the power stations.

Table 29 – Approximate closest material recycling/dumping facility by material type

CPG		GPG	
Power Station	**Depot Location**	**Power Station**	**Depot Location**
Callide B	120km	**Condamine A**	90km
Callide C	120km	**Darling Downs**	90km
Gladstone	10km	**Swanbank E GT**	5km
Kogan Creek	90km	**Townsville Power Station**	10km
Millmerran	100km	**Yarwun Cogen**	10km
Stanwell	20km	**Barcaldine Power Station**	600km
Tarong	80km	**Braemar**	90km
Tarong North	80km	**Braemar 2 Power Station**	90km
		Mt Stuart	10km
		Oakey Power Station	30km
		Roma	350km

Cost Figures for Decommissioning

Table 30 has the estimated cost per Tonne for both demolition, and scrapping/dumping of different and relevant materials to this investigation. These materials are expected to be found in the power stations which will be decommissioned.

Table 30 – Cost per Tonne for Demolition and Scrapping/Dumping of Materials

Material	**Demolition ($/Tonne)**	**Scrapping/Dumping ($/Tonne)**	**Source**
Concrete	$70	$10	(iseekplant. 2025), (City of Moreton Bay, 2025)
Steel	$85	$100	(BNE Copper Recycling, 2023)
Aluminium	$50	-$500	(BNE Copper Recycling, 2023)
Asbestos	$850	$302	(Pro House Demolition. 2025), (City of Gold Coast, 2025)
*Asbestos Sheeting**	$92.5		(Pro House Demolition. 2025)

'*' - The Asbestos sheeting demolition costs for both the demolition and responsible dumping

The Australian Government Department of Infrastructure and Regional Development estimate that rural interstate road freight costs in 2015 is 8.5c per net tonne kilometre (Australian Government, 2017). The net tonne kilometre is the total tonnes of material hauled, multiplied by the kilometres of which the material is hauled. Adjusting for inflation, the 2025 cents per net tonne kilometre road haulage cost would be 11c per net tonne kilometre.

Finally, the Institute for Energy Economics and Financial Analysis expects that site remediation for fossil fuel generation is expected to cost $400,000 for each MW of nameplate generation capacity (IEEFA, 2025).

5.1.3 Data Collection Methods, and Result Methodology

Data collected from Pacca, S, and A. Horvath was multiplied by the nameplate generation capacity of each power station to calculate the total mass of concrete, steel, and aluminium of each fossil fuel power station. In-addition to this, and in-line with AS314, all power stations built before 2003 were assumed to contain asbestos in its structure. The ratio for asbestos, procured from Delta Group, was applied to these facilities and the total tonnage was calculated by multiplying with the nameplate generation capacity.

Following this, the closest large population centre close-by was estimated by length, and the material haulage was calculated to move all demolition materials to these scrapping and dumping facilities. This material haulage figure was provided by the Australian Government, revised to consider inflation to the respective decommissioning year. Once decommissioned, a cost estimate per tonne was found for scrapping for metals, crushing for concrete, and dumping for asbestos. An estimate for site remediation was found utilising the Institute for Energy Economics and Financial Analysis ratio figure. This figure was based upon the cost per unit of nameplate generation capacity. Finally, a contingency of 20% was applied, and all costs for decommissioning were summed for a total cost.

A separate sub-model was created called the 'RQ3-01 Decommissioning'. In Table 31, the sample functions utilised are presented.

Table 31 - Sample Functions used for RQ3-01

Function name	**Function**	**Description**	**Sample Cell**
Expected Materials by Material Type (Tonne)	=C3*195	This function calculates the total tonnage of materials by material type for each power station considering nameplate capacity and ratio of material compared to nameplate generation	I3
Demolition Costs ($M)	=ROUND(I3*70*1.025^(G3-2025),0)	This function calculates the demolition costs considering total tonnage of materials, and the cost per tonne to demolition the material. In-addition to this, an inflationary factor was added	Q3
Material Haulage ($M)	=ROUND(X3*M3*0.11*1.025^(G3-2025),0)	This function calculates the cost to haul materials from the site of demolition to a scrapping and dumping facility. It takes into consideration the total tonnage, cost per km to hual tonnes of material, and an inflationary costs	Y3
Scrapping / Dumping Costs ($M)	=ROUND(10*I3*1.025^(G3-2025),0)	This function calculates the total net cost for each site for scrapping / dumping considering total tonnage of materials, and the cost to scrap / dump and inflationary aspects	AA3
Remediation Costs ($M)	=C3*400000*1.025^(G3-2025)	This equation calculates the remediation costs for each site considering nameplate generation, ratio of cost per nameplate generation for site remediation, and the inflationary costs	AG3
Total Costs ($M)	=ROUND(AI3*SUM(V3,Y3,AE3,AG3),0)	This equation calculates the total sum of costs for each power station, considering demolition, material haulage, scrapping / dumping costs, site remediation, along with a 1.2x contingency	AK3
Total sum of costs by scenario ($B)	=ROUND(V22/1000000,1)/1000, =SUM(B25:B28)*B29	These functions calculates the total costs for each scenario by cost type ($B)	B25, B30

5.1.4 Results Analysis and Discussion

Material/Equipment Disposing and Recycling

CPG stations have a requirement for more materials in construction including concrete, steel, and aluminium compared to GPG stations. This is because of larger fuel handling and energy generation equipment systems and is reflected in the below chart which displays total mass of materials at each power station. Total mass was calculated from the metric tonne per megawatt generation of each cite, multiplied by the megawatt nameplate generation of each facility. The variety in material requirements can be seen in Figure 27 and Table 32 where CPG stations have higher demands for concrete and steel. Aluminium was omitted from this figure due to the total mass of the material having small values, primarily due to the low molecular density, and low construction usage.

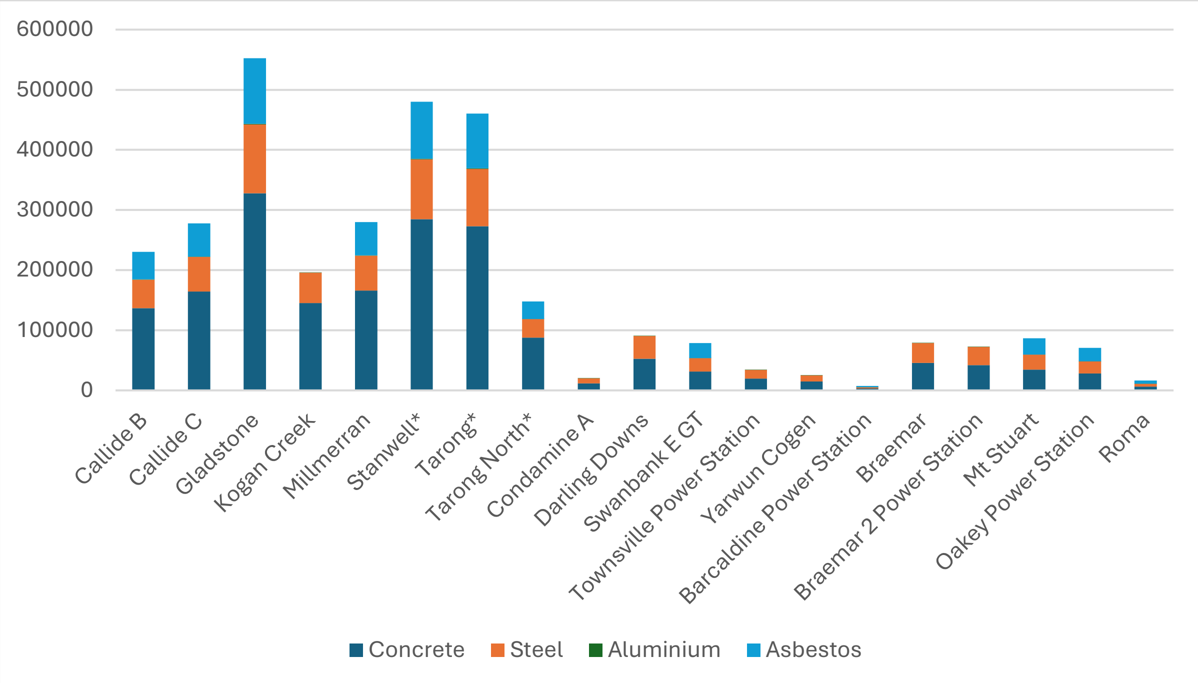


Figure 27 - Estimated Total Materials to be Decommissioned (Tonnes)

'*' – Please refer to AS313

The QEGS and QENS scenario require a total of 3.21 million cubic metres of materials to be demolitioned in the 19 power stations. Most of this metric consists of both reinforced concrete, which was used in the structure, and the steel which is utilised in the generation machinery. Table 32 displays the cubic meterage of materials which are required to be demolitioned for the QEGS and QENS.

Table 32 – Total volume (m3) of materials to be decommissioned in Queensland for QEGS & QENS

	Concrete	Steel	Aluminium	Asbestos	Total (m^3)	Asbestos Sheeting m^2
CPG	1585350	554466	5284.5	480090	2625190	553950
GPG	290435	208728	927	82680	582771	95400
TOTAL	1875785	763194	6212	562770	3207961	649350

Table 33 displays the cubic meterage of materials which are required to be demolished for the QERS. Total cubic meterage of demolitioned materials is expected to at 2.12 million cubic meters.

Table 33 – Total volume (m3) of materials to be decommissioned in Queensland for QERS

	Concrete	Steel	Aluminium	Asbestos	Total (m^3)	Asbestos Sheeting m^2
CPG	939900	328724	3133	264940	1536697	305700
GPG	290435	208728	927	82680	582771	95400
TOTAL	1230335	537452	4061	347620	2119467	401100

Utilising the estimated demolition costs for materials based upon the volume, an estimated demolition cost was formulated. For the QEGS and QENS, it is expected that total demolition costs will be $1.069 billion, while the QERS is expected to cost $688.5 million. This largely consisted in costs for the safe removal of the asbestos present, expected to cost $775.3 million and $486.2 million for all power stations respectively, or 73% of total costs. This is expected, as the demolition of structures and the removal of the material is highly regulated, with large costs to remove it in-line with regulations. These regulations are in place due to the high safety risk the material poses when dealt with no care.

Materials were hauled to the closest scrapping site, and a rate per net tonne kilometre was applied, with a total haulage cost of $26.3 million for the QEGS and QENS, while the QERS was estimated to cost $35.0 million. Net scrapping costs were estimated to cost $84.3 million and $155.8 million respectively. A clear trend formed, where gas generation with no asbestos present had a positive net return in scrapping. This was due to the cost return of metals for scrapping being higher than the cost to depose and crush concrete. Power stations with asbestos present had a negative cost return, as the asbestos presented a significantly higher cost due to dumping restrictions and precautions.

A large portion of the total costs for decommissioning the CPG and GPG assets is the site remediation costs. The site remediation is a significant part of the decommissioning process as land surrounding power stations need to be cleaned up for the land to be re-used in future re-zoning applications for commercial/industrial applications. Total remediation costs for the QERS were estimated at $5.183 billion, while the site remediation for QEGS and QENS was expected to cost $7.071 billion.

Table 34 displays the total costs for decommissioning across the three scenarios. The decommissioning costs of QEGS and QENS is estimated to cost $9.99 billion, while the QERS is expected to cost $7.179 billion. The additional 3310MW of CPG nameplate generation that is required to be decommissioned in the QEGS and QENS is expected to cost $2.81 billion. All three of these CPG power stations contain asbestos, which significantly increases costs. The overwhelming majority of these costs is directly derived from the site remediation costs, consisting of around 70%-80% of total costs.

Table 34 – Costs to Decommission QEGS, QERS, and QENS ($ Million)

	QEGS and QENS	QERS
Demolition Costs	1069.6	688.5
Material Haulage	35	26.3
Scrapping/Dumping Costs	150.7	84.3
Site Remediation	7071.1	5183.4
Contingencies	1.2	
Net Cost	9991.68	7179

The most expensive power station to be decommissioned was the 1680MW CPG Gladstone Power Station, estimated to cost $1.08 billion. On the other hand, the cheapest power station to decommission is expected to be 80MW GPG Roma Power Station, coming in at $51.3 million. The average cost to decommission per MW of generation nameplate capacity for CPG was $756.9 thousand, while GPG assets was $638.9 thousand. This is primarily due to the larger physical structure which CPG are contained in and the larger volume of generation machinery. A larger degree of the CPG power assets had asbestos compared to GPG, with 80% and 45% containing asbestos respectively.

Due to the methodology utilised to calculate the decommissioning costs, power stations with a higher capacity are expected to have a significantly higher decommissioning cost. Figure 28 displays the total cost for decommissioning per Power Station below:

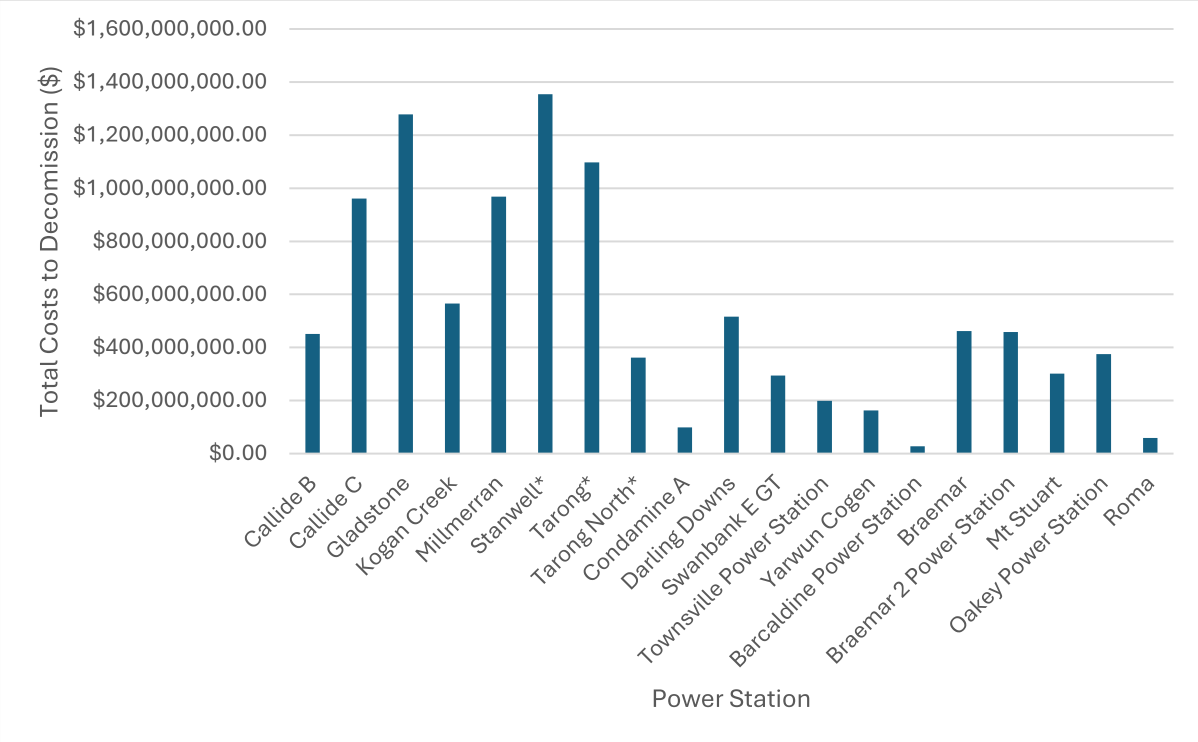


Figure 28 – Power Station Decommissioning Cost adjusted for Inflation (AS324).

'*' – Please refer to AS313

5.2 Sensitivity Analysis

Parameter	**Current Standard**	**Variance**	**Impact on Results**
Metal Scrapping Price	The live price of scrap metal utilised was taken March 2025	This value fluctuates based upon live supply and demand. A different live price could be utilised instead	This will alter net scrapping for the considered metals. Live prices may be smaller or higher than the listed price utilised
Decommissioning Year for Power Stations	The current announced decommissioning date for power stations was utilised	There has been discussion recently regarding extending the life of coal generation in Queensland, therefore some power stations could have their life extended	This would increase inflationary costs of 2.5% per annum over the total years of lifetime extension
Asbestos Demolition	A rate of $850 per tonne for demolition	These values range from $150 to $900 and even more,	A resultant from this would be the severe change in Asbestos pricing

5.3 Limitations and Recommendations

A range of limitations and recommendations were identified to further improve an accurate engineering estimation. These include:

- Implementation of a more sophisticated total mass estimation of all fossil fuel power stations. Currently, a general approach was used whereby the total mass was calculated by multiplying a figure in tonnes per megawatt, by the nameplate generation capacity. This is general in nature as it does not consider different types of power stations, such as sub-critical and supercritical CPG stations, specific geographic design modifications, and various other differences. This recommended approach lacks credible information available for research, and is therefore not possible to implement into the existing model. Access to restricted information regarding specific masses for each material in the structure of each power station would greatly increase the accuracy of the investigation

- It is unknown how exactly the various components in these power stations were going to be used post decommission/demolition. Therefore, the model used an assumption whereby all material was sold for scrap or disposed of if recycling was not an option. This neglects the possibility whereby some components could be reused; however, a lack of data prevented an analysis into this

- The cost for both Asbestos and Metal demolition was difficult to find, and there was a significant amount of variance in listed prices online. In further investigations, it is recommended that these figures are to be taken from a quote estimation from an experienced demolition contractor

5.4 Summary and Conclusions

In-conclusion, the third and final research question had the aim of determining the cost to decommission existing fossil fuel generation infrastructure across the three different scenarios. The sites which are expected to be decommissioned were identified for each scenario, whereby all fossil fuel generation was considered for the QEGS and QENS, and all but Stanwell, Tarong, and Tarong North CPG was considered for QERS. Following this, identification of the volume of materials present in the power station structure was identified, and a cost estimation was provided for demolition of these materials. The material haulage to scrapping/dumping facilities, along with the net costs of this scrapping and dumping was also provided. Finally, site remediation costs and a 20% contingency was applied, and final costs were evaluated. The major findings from these scenarios were:

- Estimation of Volume of materials used in each power station
- Demolition costs for these materials
- Material haulage and net costs at scrapping/dumping facilities for these materials
- Site remediation costs all applied with a 20% contingency for cost overruns

Aligning with the aims and scope of RQ3, the conclusions below were identified;

- **Volume of Materials & Demolition**: In-total there is expected to be 3.21 million m^3 of material to be decommissioned for the QEGS and QENS, while there is expected to be 2.12million m^3 of material for QERS. In-addition to this, a total of 649350m^2 and 401,100 m^2 of asbestos sheeting is required to be removed respectively. The QERS does not require three older CPG stations to be decommissioned (AS31)

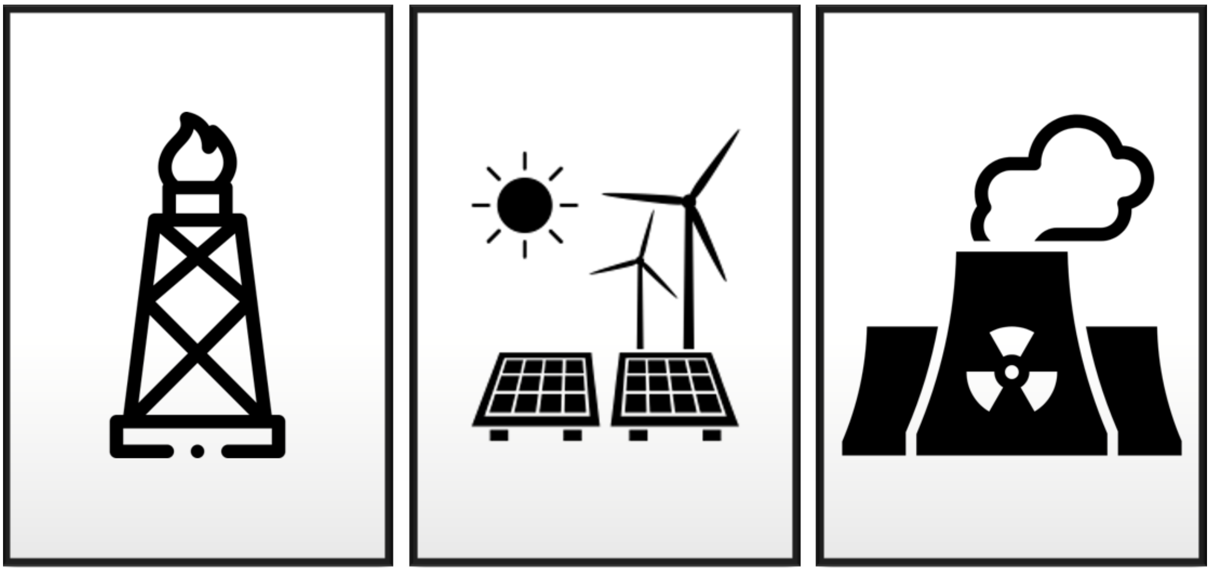
- **Demolition Costs**: The demolition costs for the QEGS and QENS, along with the QERS was estimated to be $1.07 billion and $688.51 million respectively. Asbestos presented the largest cost to demolition, consisting of around 75% of total costs for the 12 power stations which were estimated to contain it

- **Scrapping/Dumping Net Costs**: The cost of material haulage depended on two factors, the volume of materials to be hauled, and the distance. The combined material haulage and net scrapping/dumping costs for the QEGS and QENS, along with the QERS, was $185.75 million and $110,618 respectively.

- **Site Remediation & Contingency**: Site remediation posed the largest cost to the decommissioning process. Total costs for site remediation was $7.07 billion and $5.18 billion respectively for the two models.

- **Total Costs**: Combining all these costs, with an applied 20% contingency for cost overruns, the total cost for the QEGS and QENS was $9.91 billion, while the QERS was estimated to cost $7.18 billion. The difference in cost is directly attributed to the three power stations which were not decommissioned in the QERS model (AS314), of which costed $2.81 billion to decommission. These facilities were old coal generation plants with large nameplate capacities, and abundant asbestos present

6.0 Evaluation and Conclusions



The aim of this research investigation and report was to clearly evaluate the cost of the energy transition in Queensland. A thorough engineering analysis was conducted involving various stakeholders and resources to determine the various costs involved with this. This analysis factored many different transitional approaches relevant to Queensland, and included:

- QEGS – Queensland Energy Gas Scenario
- QERS – Queensland Energy Renewable Scenario
- QENS – Queensland Energy Nuclear Scenario

Key transitional factors were identified and divided into three research questions. The conclusions from each research question can be seen below:

- **RQ1 New Generation and Storage**
  This first research question involved costing the new generation and storage projects expected to be built to transition the energy grid. It is expected that the installation of 32.25GW to 41.43GW of new generation will cost between $340.68 billion to $361.22 billion. The cheapest scenario is the QERS, while the most expensive is the QEGS. The QERS represents the cheapest scenario per GW of nameplate generation. In-addition to this, the energy transition will require an estimated 145,000-270,000 construction and 10,800-14,200 operational jobs.

- **RQ2 Grid Transmission and Stability**
  The second research question involved costing the reinvestment into existing transmission infrastructure, new transmission infrastructure, and grid stability infrastructure. Required reinvestment into 2,597km of existing infrastructure was estimated to cost $4.34 billion, while new transmission infrastructure will cost between will cost between $22.78-31.52 billion. Finally, new purpose-built grid stability facilities is expected to cost between $0 in the QEGS to 18.58 billion in the QERS.

- **RQ3 Decommissioning of Existing Fossil Fuel Generation**
  Finally, the last research question involved providing a cost estimate to decommission existing fossil fuel generation. The considered costs were demolition, material haulage and scrapping, site remediation, with an applied 20% contingency for cost overruns. The decommissioning of this generation in the QERS is expected to cost $7.18 billion, while the QEGS and QENS is expected to cost $9.91 billion.

Overall, the scenario which is estimated to cost the least is the QEGS, valued at $399.55 billion, while the most expensive scenario is the QENS, costing $411.07 billion. The QERS is expected to cost $402.3 billion. A summary of costs by transitional approach for each research question can be found in Table 35.

Table 35 – Summary of Costs for the Cost of the Energy Transition by Transitional Scenario

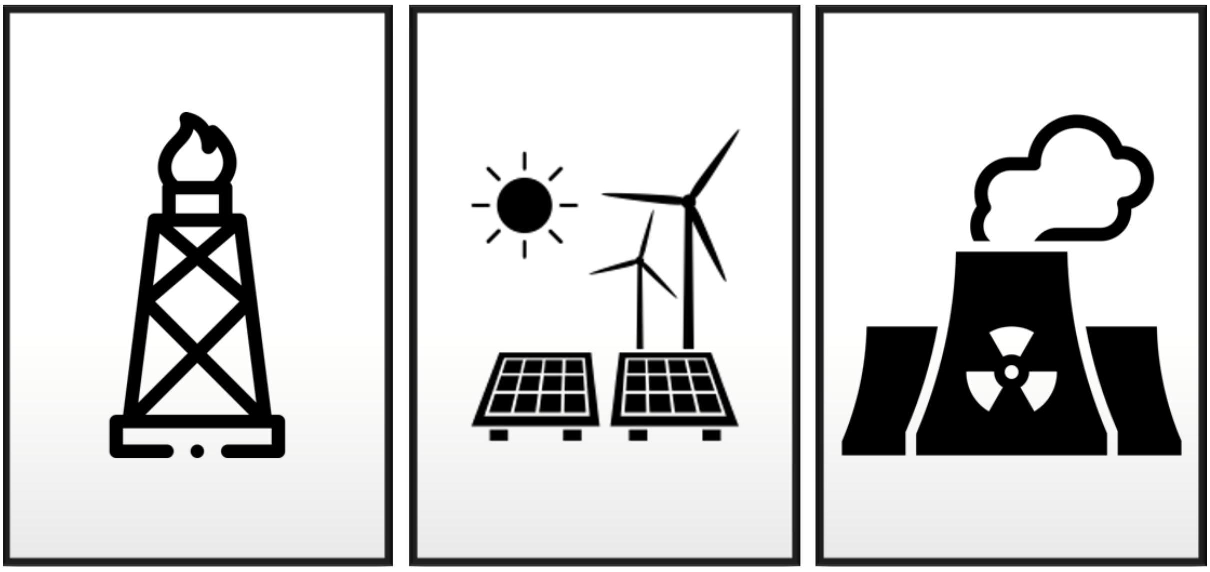
Cost	Description of Costs	QEGS	QERS	QENS	Cheapest
RQ1-01	Quantitative analysis of capital expenditure, operational, and maintenance costs with building these projects.	361.22	340.68	358.5	QERS
RQ2-01	Analysis on costs to proposed grid projects including investment into existing and new transmission infrastructure	27.12	35.86	31.38	QEGS
RQ2-02	Estimation and analysis of costs to maintain grid stability within the Queensland transmission grid	0	18.58	11.2	QEGS
RQ3-01	Estimation of net costs involved with decommissioning including labour hire, removal of unwanted material, recycling of materials, and site restoration to planned approval regulations.	9.99	7.18	9.99	QERS
Total Costs		**399.55**	**402.3**	**411.07**	**QEGS**

It is clear that the QEGS proposes the best value for the cost required at face-value, however this scenario does have its challengers, both technologically, and politically. First of all, the backbone technology of this scenario, CCGT with CCS, has not completely matured whereby the emission free CCS has not become commercially viable. This is due to CCS requiring additional energy than that of what is produced at the power plant (Zero Carbon Analytics, 2025). It is theorised that with technological advancements, this will reduce over time and increase the feasibility of emission free CCGT with CCS.

In-addition to this, there is a large deviation of estimates to cost nuclear generation, all from differing stakeholders each with different agendas. Data was utilised from AEMO and CSIRO, each governmental agencies with no bias. Due to the recent events of the Australian election, whereby the Liberal National Coalition opposition, the party which proposed this nuclear plan, was defeated, this plan looks unlikely to proceed (ABC, 2025). This result points to a lack of public support and high polarisation. To provide the best investigational comparison, data was utilised from AEMO and CSIRO, each governmental agencies with no bias.

Therefore, the transitional scenario highly recommended and most likely to be implemented is the QERS scenario. This scenario has already been announced and is currently implemented in various grid and economic transitional plans. Therefore, the cost of new generation and storage, grid transmission and stability, and decommissioning of existing fossil fuel generation is expected to cost $402.3 billion in Queensland.

7.0 References



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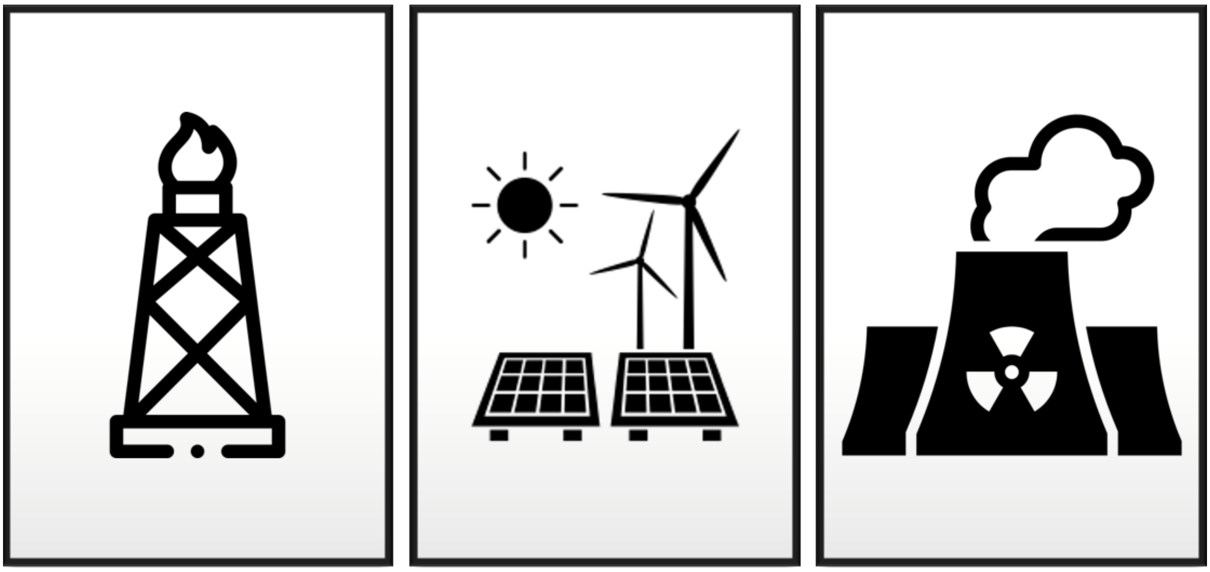
8.0 Appendices



8.1 Appendices 1 – Thesis Data Spreadsheet

A copy of the thesis model can be distributed to interested parties through contacting Harris Lynch through the email harrislynch@outlook.com