QNP GREEN AMMONIA PROJECT
FEASIBILITY STUDY
KNOWLEDGE SHARING REPORT

June 2020

Lead organisation

Queensland Nitrates Pty Ltd (QNP)

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23 September 2019

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30 April 2020

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Report purpose

The purpose of this report is to share the learnings from QNP's green hydrogen to ammonia feasibility study undertaken in 2019 and 2020.

Acknowledgement

This project received funding from ARENA as part of ARENA's Advancing Renewables Program.

Disclaimer

The views expressed herein are not necessarily the views of the Australian Government, and the Australian Government does not accept responsibility for any information or advice contained herein.

Important Notice

QNP has prepared this report for the purpose of fulfilling its knowedge sharing agreement with the Australian Renewable energy Agency (ARENA).

The report has been prepared using information collected from multiple sources throughout the study.

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Table of Contents

List of Tables

List of Figures

1 Introduction

The purpose of this report is to provide information regarding the QNP green hydrogen to ammonia project feasibility study. The study was undertaken from September 2019 to April 2020 by Queensland Nitrates Pty Ltd (QNP), Worley and Neoen. The study explored the opportunity to develop an electrolyser plant with capacity to produce 3,500 Tonnes/Year (T/y) of green hydrogen and a small-scale ammonia plant capable of converting that hydrogen into green ammonia (20,000 tonnes/Year (T/y))

This report contains a description of the project, and the consortium partners as well as providing discussion regarding the technical feasibility of the project. This is followed by a discussion of the commercial feasibility of the project and the potential for an unsubsidised large scale ammonia plant to be commercially viable.

The feasibility study determined that the project is technically viable, but it requires significant government support in the form of grants and concessional loans to be commercially viable. A pathway towards commercially viable large scale green ammonia production was identified.

This report is written for a broad audience including government, academia, research institutions, developers and financiers of both electrolysis and small-scale green ammonia plants.

2 Executive summary

Queensland Nitrates Pty Ltd (QNP) partnered with Neoen and Worley to undertake a feasibility study into the development of Australia's first green hydrogen to ammonia plant at QNP's Moura site. The proposed facility includes a 30 MW electrolyser and a small-scale ammonia plant consuming 208 GWh of electricity. The plant will produce 3,500 tonnes/Year (T/y) of green hydrogen to yield 20,000 T/y of green ammonia to displace ammonia which is currently purchased by QNP for use at its ammonium nitrate facility at Moura.

QNP's Moura facility produces ammonium nitrate which is the key ingredient in explosives that are used in the Queensland mining industry. The current facility produces hydrogen via steam reforming of natural gas. The addition of nitrogen under suitable conditions (i.e. Haber-Bosch process) yields ammonia which is subsequently used to manufacture ammonium nitrate. QNP currently has an imbalance between ammonia production capacity and ammonium nitrate unit capacity and makes up the shortfall in ammonia production through the purchase of ammonia.

The "QNP green hydrogen to ammonia project" seeks to displace purchased ammonia by manufacturing "green" ammonia on site. The precursor to green ammonia production is the production of electrolytic hydrogen through disassociating water using renewable electricity.

QNP will utilise 100% of the hydrogen produced in the project for internal use to manufacture ammonium nitrate to satisfy existing contracts, hence QNP does not need to seek new markets for either the hydrogen, ammonia or the downstream ammonium nitrate that will be produced,

The feasibility study explored whether aligning a series of existing mature and commercialised processes in novel alignment could yield a technically and commercially feasible project. The study found that the technologies themselves are technically feasible. Much of the learnings from the feasibility study arose from the novel alignment of the renewable energy generation assets, the electrolysers, the hydrogen storage and the ammonia plant.

The ammonia plant is designed to be operated continuously at consistent rates, while the electrolysers will be operated intermittently to minimise electricity cost meaning that hydrogen storage is required.

Key questions addressed by the feasibility study included:

- Operating characteristics of large scale electrolysers
- Capital and operating costs
- Optimal location for the renewable electricity generation assets relative to the Moura site
- Grid stabilisation benefits
- Optimal electrolyser load factor – this question is particularly interesting since higher load factors incur higher power prices, but lower capital cost and vice versa
- Optimal hydrogen storage requirements
- Vendor readiness

The feasibility study determined that the generation assets could be located remote from the plant and the demand responsive behaviour provided a valuable grid stabilisation service. The highest technically viable electrolyser load factor, with higher power price but lower capital cost was the optimal solution.

The feasibility study determined that the project is economically viable with sufficient funding support in the form of grants (e.g. from ARENA) and concessional loans. Without funding assistance, the margin between the cost of inputs (primarily energy) and the value of the output (ammonia, a commodity with pricing linked to global benchmarks) is insufficient to support the project.

There are several options that could improve the project's economics, these include; increased funding support, lower capital cost, lower electricity energy price, reduced electricity transmission and other operating costs, introduction of a carbon price, increased global ammonia prices and increasing the size of the plant and selling "excess" green ammonia to third parties.

The figure below shows the footprint of the QNP green hydrogen to ammonia plant adjacent to QNP's existing facility at Moura, Queensland.

Figure 1 – Proposed green hydrogen to ammonia plant in context of the existing QNP ammonium nitrate plant

3 Project Description

Queensland Nitrates Pty (QNP), Neoen and Worley (the Consortium) undertook a feasibility study into the development of Australia's first green hydrogen to ammonia plant. The proposed facility includes a 30 MW electrolyser and a small-scale ammonia plant. The project will produce 3,500 T/y of hydrogen to yield 20,000 T/y of ammonia which will displace ammonia currently purchased by QNP for use in its ammonium nitrate facility at Moura. Renewable electricity to power the electrolysers will be 100% sourced from Neoen's renewable assets portfolio in Queensland via a Power Purchasing Agreement.

Ammonium nitrate is the key ingredient in explosives that are used in the Queensland mining industry. QNP's Moura facility, which has been in operation since 2000, produces approximately 25% of the ammonium nitrate used in the Queensland resources sector. The current facility produces hydrogen through steam reforming of natural gas. The resulting hydrogen is mixed with nitrogen over a catalyst at high pressure and temperature (i.e. Haber-Bosch process) to yield ammonia, which is subsequently used to manufacture ammonium nitrate.

Following plant debottlenecking, the ammonium nitrate capacity of the Moura facility is greater than the capacity of the upstream ammonia plant. The shortfall of ammonia production is currently made-up through ammonia purchases which are linked to global ammonia benchmark prices.

The "green hydrogen to ammonia project" seeks to displace the purchased ammonia by manufacturing 20,000 T/y of green ammonia on site. QNP will utilise 100% of the hydrogen and ammonia produced in the project for internal use to satisfy existing customer contracts and hence does not need to seek markets for hydrogen or ammonia sales or additional ammonium nitrate sales.

The production of "green" ammonia is undertaken in two key processing steps, water electrolysis to produce hydrogen followed by ammonia production, with key inputs to the process being water and renewable electricity. Key metrics associated with this project are:

a) Water (~75 ML/y) is to be sourced from the Dawson River (QNP currently has secure access to 1320 ML/y);
b) Renewable energy is to be supplied though a Power Purchase Agreement (PPA) with Neoen.
c) 30 MW alkaline electrolyser which uses ~208 GWh of electricity to produce 3,500 T/y of hydrogen;
d) Production of 20,000 T/y of Ammonia in a small-scale ammonia synthesis plant using the Haber-Bosch process;
e) The hydrogen production rate will vary in response to electricity price and network requirements, while the ammonia synthesis plant will operate continuously. To balance these operating modes, hydrogen storage is required.

The ammonia plant will operate continuously, but the electrolysers will operate intermittently to avoid peak power prices and match renewables power availability. Hydrogen storage provides buffer capacity between these operations.

The Neoen solar and wind farms will be located remote from the QNP plant and the renewable electricity will be supplied over the NEM. QNP will be able to supply grid stabilisation services to the network.

The existing 66 kV transmission line from the nearby Moura substation to the QNP plant is incapable of carrying the load for the 30 MW electrolysers. A new 132 kV line will be built from the substation to the plant to carry both the new and existing plant power loads.

The basic project concept is summarised in Figure 2 below and a schematic of the project is shown in Figure 3 on the following page.

Figure 2 – Project concept schematic

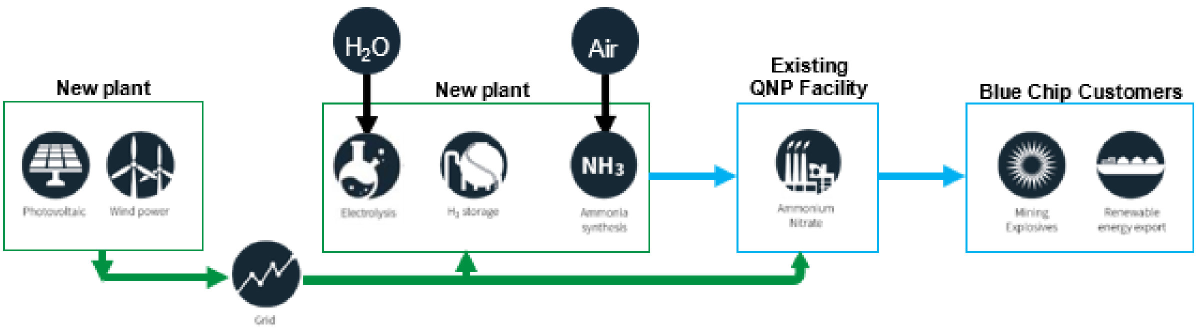
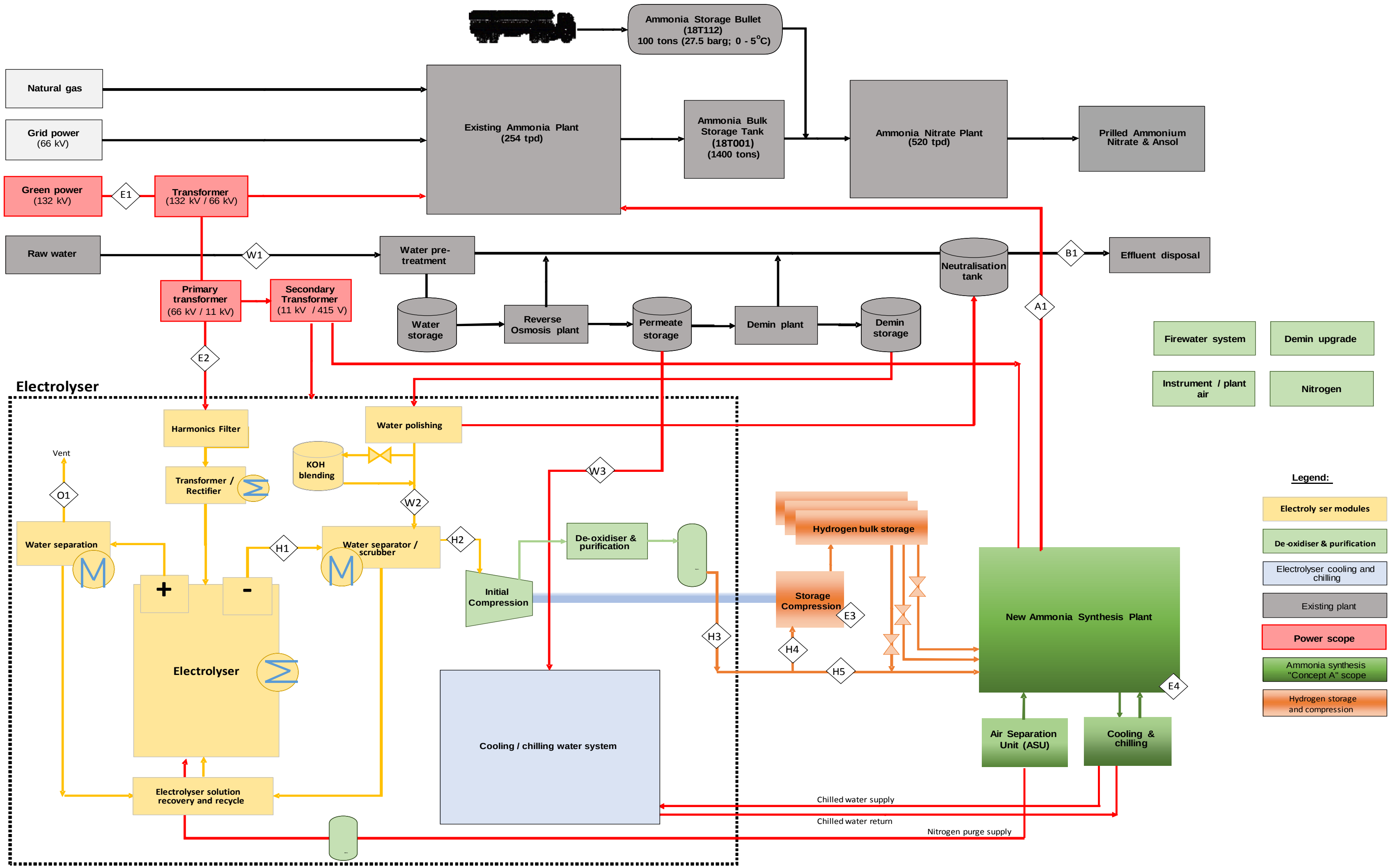


Figure 3 - Overview schematic



4 The consortium

The Consortium consists of three members who have each contributed resources, funds and expertise during the project. This is not a formal legal consortium but if the project progresses it will involve contractual relationships between QNP and Neoen (Power Purchasing Agreement) and QNP and Worley (Engineering and project management services).

QNP is a 50/50 joint venture between CSBP, a wholly owned subsidiary of Wesfarmers, and Dyno Nobel Asia Pacific, a wholly owned subsidiary of Incitec Pivot.

QNP own, operate and maintain the present Moura facility and if the project progresses, it will own, operate and maintain the electrolysers, hydrogen storage, ammonia and balance of plant facilities to be constructed at Moura in this project.

QNP was the funding signatory with ARENA for the project.

Neoen is an independent renewable energy power supplier, formed in 2008, with solar, wind, and battery energy generation facilities now in 10 countries with a total installed capacity globally exceeding 3 GW. Neoen has over 1GW of wind, solar and battery assets in operation or under construction in Australia, with an in-country investment exceeding AUD $2B, and a reputation for commercial innovation.

Neoen will be providing the renewable based electrical supply for this project. If the project progresses, Neoen will own and operate the renewable energy and enabling assets required for this supply and provide the required electricity service to QNP through a Power Purchase Agreement (PPA).

Worley is an Australian based global engineering and related services company operating in the resources and energy sector, who will project manage the project. Worley is a 100% owner of Advisian, who will also provide services to the project.

Advisian and the broader Worley Group undertook the overall process modelling and integration engineering, as well as project management and a range of environmental, social and regulatory approval work. Worley may also provide EPCM delivery for the hydrogen and ammonia assets if the project progresses.

5 Technical feasibility

The feasibility study determined that the green hydrogen to ammonia project is technically feasible. The project aligns a series of existing mature and commercialised processes in novel alignment.

The key design criteria for the feasibility study was that the 20,000 T/y ammonia plant operate continuously and at a consistent rate on a 24/7 365 day per year basis to provide feedstock ammonia to the existing downstream QNP ammonium nitrate plant. At the same time, the electrolysers need to operate on a price / availability basis to optimise renewable power costs. The trade-off between load factor, power price, electrolyser capital costs and hydrogen storage capital costs was a focus of the feasibility study.

The feasibility study obtained quotations from seven electrolyser vendors and four ammonia plant vendors. All provided detailed capital and operating cost estimates and operational characteristics of their proposed plant. This level of vendor response enabled the project to confirm equipment selection and determine capital and operating costs with a high degree of confidence.

The following table describes the technical feasibility considerations explored during the feasibility study.

Table 1: Feasibility Study key technical considerations

Key interface	Description
Renewable energy generation assets	Power will be sourced from Neoen renewable assets portfolio in Queensland. The renewable energy assets are planned to have significantly larger generation capacity than the QNP electricity offtake. This difference between generation capacity and offtake enables a high load factor to be achieved. Securing long term downstream contracts such as the one with QNP is a key element for supporting the development of renewable generation assets
Location of renewable energy assets	Options for placing the renewable energy generation assets behind the meter or remote from the site were explored. The remote asset solution was found to be optimal. The project will provide grid stabilisation and response services to the network.
Connection of facilities to the national electricity grid	The existing 66 kV network between the Moura substation and the QNP facility does not have the capacity to accommodate the increase in power demand associated with the green ammonia project. The network could be upgraded though twinning the existing 66 kV network or installing a new 132 kV system. The latter was found to be preferable.
Target plant availability	The existing QNP ammonia synthesis plant achieves a very high utilisation rate though a pragmatic design with limited redundancy. The green ammonia project sought a similar approach. Early discussions with vendors confirmed that targeting 98% availability for both the electrolyser and ammonia synthesis plants would yield an overall 96% availability with minimal sparing.
Target plant load factor	Higher load factors reduce the size of electrolysers, hydrogen storage and power infrastructure required for the project, but this

	reduces power provision optionality, and demands a higher cost of power. Evaluation of different load factors determined that NPV was similar for different load factors. A high load factor of 80% was chosen to minimise capital expenditure.
Raw water supply	Raw water will be sourced from the Dawson River. Several options are possible including investing in a small off-river storage or purchasing water on market.
Filtered water supply	Additional filtered water capacity will be achieved through the installation of tube settler units.
Demin water processing	The existing QNP facility has sufficient demineralised water treatment capacity to accommodate the proposed plant.
Hydrogen generation	Alkaline electrolysers were selected as the preferred technology since they have sufficient speed of response to provide "FCAS services", whilst being safe, lowest cost and highest efficiency. The target availability of this facility is >98%.
Hydrogen storage	Two different hydrogen storage models are under consideration, namely: ▪ Containerised storage with storage pressure of 300 barg; ▪ Vertical carbon steel storage with storage pressure of 100 barg.
Ammonia synthesis plant	Small-scale ammonia synthesis plant. This deployment of Haber-Bosch technology adopts a scale used in the 1940s whilst taking advantage of modern catalysts and reactor bed designs. The target availability of this facility is >96%.
Utilising hydrogen in the existing QNP plant	QNP has undertaken numerous debottlenecking studies and was not able to identify a viable proposition to produce additional hydrogen from this project and its use elsewhere in the existing QNP plant. Other applications such as fleet fuelling may be possible. The required volumes would be relatively small.
Utilising oxygen in the existing QNP plant	No viable options were identified to utilise oxygen by products elsewhere in the QNP plant.
Electrolyser and ammonia synthesis bulk cooling requirements	The bulk cooling requirements for the electrolyser plant are considerably smaller than the ammonia plant and of a scale that can be accommodated with standard sized adiabatic cooling. The ammonia synthesis plant will independently use bulk cooling with either air cooling or adiabatic cooling.
Electrolyser and ammonia synthesis chilling requirements	Chiller requirements for the electrolyser plant vary considerably between vendors. When chilling requirements are less than 200 kW this will be integrated into the ammonia plant chiller. When chiller demand is greater than this, both units will provide chilling services separately.
Electrolyser to ammonia synthesis plant transfer pressure	The transfer pressure between electrolyser and ammonia synthesis depends on the selected electrolyser technology, purification system size and compressor rationalisation. 30 barg is standard pressure which yields cost effective purification systems and accommodates both PEM and atmospheric alkaline systems. If a pressurised alkaline system with 15 barg operating pressure

	were to be selected, then a 15 barg transfer pressure could be adopted.
Nitrogen supply	The new air separation unit (ASU) will provide nitrogen for the ammonia synthesis unit. It will also supply nitrogen to the electrolysers for use as a purging agent if required.
Plant and instrument air supply	The green ammonia plant is to operate independently from the existing plant, hence a new plant and instrument air system will be installed.
SCADA and monitoring	The new power switch room provides a convenient hub for aggregation of instrumentation and MCC associated with the new plant. A fibre-optic linkage between this building and the existing control room will enable primary control of the new facilities from the existing control room.
Rationalisation of compression	The new plant has four compression services, namely: 1. Electrolyser product to transfer pressure; 2. Hydrogen storage compression; 3. Ammonia synthesis plant feed (i.e. hydrogen and nitrogen) compression; 4. Syngas recycle compression; Services 3 and 4 are regularly aggregated into a single compression. Some design options consider aggregating services 1 and 2.
Ammonia plant production flexibility	Installing an ammonia plant with some over-capacity and ability to turndown could reduce the hydrogen storage requirements and potentially overall project cost depending on the increased ammonia plant costs.
Waste management	All wastes and effluents generated by the new plant will be catered for by the existing solid and liquid handling and disposal mechanisms on site. No new class of hazardous wastes will be created.

6 Commercial feasibility

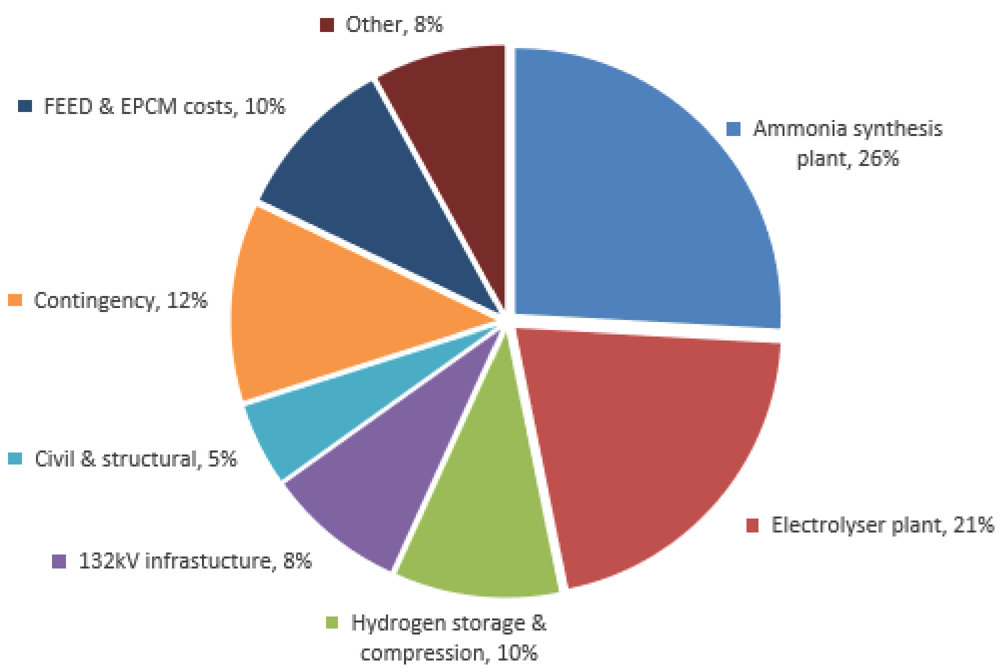
The feasibility study determined that the project is commercially viable with government support in the forms of grants (e.g. ARENA) and concessional loans.

The capital cost and operating costs, in particular electricity costs and ammonia plant capital, are such that an economically viable business case is only currently possible with government assistance. While the project is large scale relative to other electrolyser installations, the ammonia plant is small scale with a relatively high capital cost on a per tonne basis.

QNP has the option of continuing to purchase ammonia from third parties at prices linked to global ammonia benchmarks or manufacturing green ammonia. The feasibility study determined that purchasing ammonia is the preferred commercial outcome without substantial government support.

A breakdown of the project's capital costs is shown in Figure 4 below. The total project capital cost is $150M – $200M.

Figure 4 - Total Installed Cost – breakdown by key sector



The range of costs for the critical parts of the plant are summarised in Table 2 below. Costs for all electrolyser, hydrogen storage, hydrogen compression and ammonia plant options are sourced from international vendors. Australian content is restricted to civils, construction, tie in and installation costs.

The QNP site is not suitable for wind power generation. The project evaluated behind the meter solar power generation compared to remote large scale solar and transport of the generated electricity over the grid. Remote solar and wind power generation was the preferred option.

QNP's current 66 kV line is inadequate to cater for the 30MW electrolyser load. The project includes a new 132 kV transmission line for the 5km from the local Moura sub-station to the QNP plant. The new line will also carry the load for QNP's existing electricity load and therefore eliminate local distribution charges on the existing load.

Table 2: Range of Plant Costs

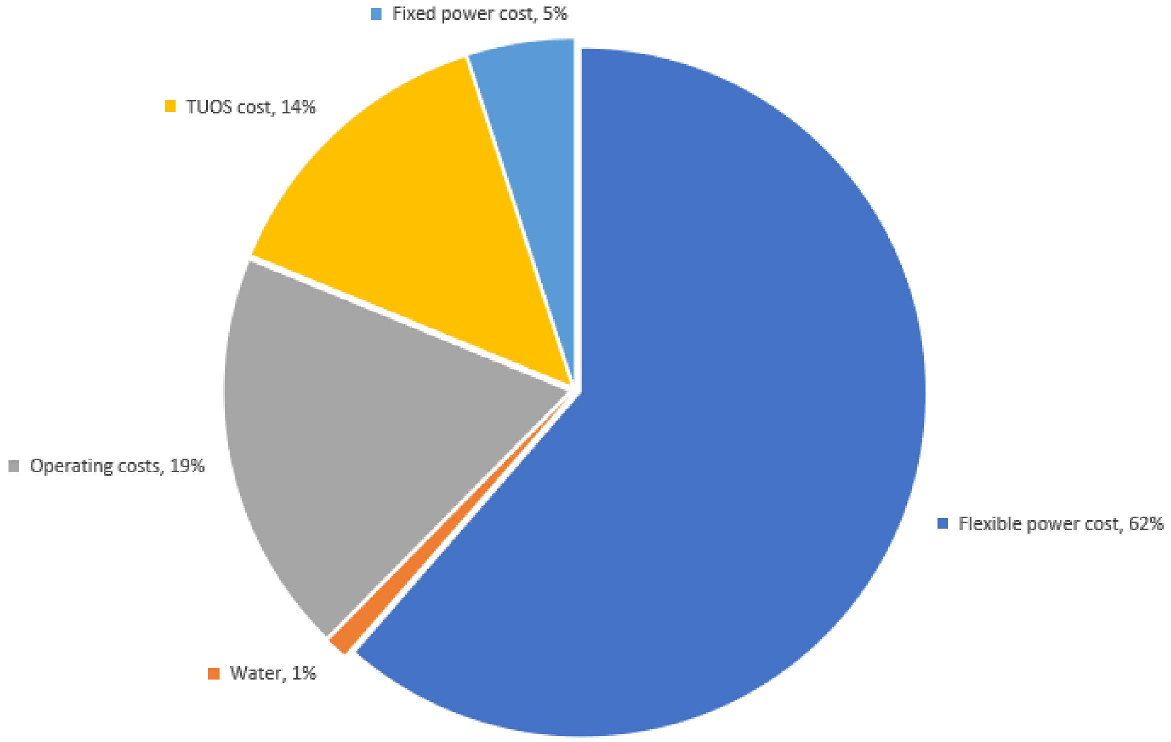
Plant Area	Cost range ($M)
Electrolysers (Alkaline & PEM)	25.9 – 69.5
Hydrogen storage and compression	11.6 – 38.3
Ammonia Plant	29.6 – 81.8
High voltage transmission line	14.2 - 22.87
Balance of Plant	14.2 – 18.5

A breakdown of the operating and maintenance costs for the project are shown in Figure 5 below. Operating costs are in the range of $10M - $15M per annum.
Electricity price will be below $45/MWh. Due to the scale of the load and the network services that the electrolysers will provide to the electricity grid, QNP believe that a significant reduction to the current High Voltage Transmission Charges (TUOS costs) can be achieved for the project. QNP has assumed that its current Transmission Loss factor (TLF) will be maintained.

QNP currently has a priority 1 water allocation with Sunwater for supply of 1320 ML of water from the Dawson River and purchases another approximately 100 ML on market each year. The 75ML of water required for the project represents a 5% increase in QNP's water consumption. QNP has had preliminary discussions with Sunwater regarding options to obtain the water required for the project. A number of options are possible and water supply is not considered a high risk to the project.

Due to the unknown imposition timing or value of a carbon scheme, QNP has not assumed a carbon price in its evaluation of the viability of the project's business case. A sensitivity for a carbon price of $25/t CO2e is provided in Table 3 below.

Figure 5 - Breakdown of annual operating and maintenance cost estimate



The major levers to improve the economic viability of the project are shown in Table 3 below. The percentage figures represent the percentage of the potential total improvement in the project NPV that each lever could potentially provide.

The table below lists the major project NPV sensitivities and their impact on the project NPV. QNP has calculated the total NPV impact if all sensitivities contribute to an increase in NPV. The table shows to what extent each sensitivity contributes to this total NPV impact. For example, a $25/t CO2e carbon credit would increase the project NPV by 15% of the total of all the sensitivities shown. By comparison a 20% reduction in OPEX would increase the project NPV by 7% of the total NPV impact.

Table 3: Sensitivity analysis

Sensitivity	Impact on NPV (percentage of total sensitivities)
Increased grant and concessional debt terms	17%
$25/t CO_{2e} carbon credit	15%
Reduction in High Voltage Transmission Charges	14%
Savings on electricity load to existing QNP load	13%
20% change in CAPEX	10%
5% change in project revenue (changed purchased ammonia price)	9%
30-year project life rather than 25 years	8%
Reduction in electricity price	7%
20% change in OPEX	7%

7 Commercialisation pathway

QNP has evaluated a five step potential commercialisation pathway without subsidies for green ammonia production. These steps are:

- The 20kt pa green ammonia project that is the subject of the feasibility study'
- A brownfields plant with capacity to produce 88kt pa of green ammonia which would replace the current QNP ammonia production process
- A Greenfields plant with capacity to produce 88kt pa of green ammonia
- A Greenfields plant with capacity to produce 300kt pa of green ammonia
- A Greenfields plant with capacity to produce 1 million tonnes pa of green ammonia

As the scale of the plant increases and levers to improve viability, eg lower capital costs, a greater percentage of project finance, lower electricity cost and the introduction of a carbon price, the viability of the subsidy free business cases improves.

Large scale green hydrogen to ammonia plants will need to have co-located power generation and are therefore likely to be located inland. QNP understands that optimal locations for solar and wind plants of the scale required will be inland locations. QNP's current view is that the required scale of electricity consumption at 10,000 GWh pa precludes locating electricity generation remote from the electrolyser and ammonia plant. Electricity transmission costs will not be a factor for the large scale green hydrogen to ammonia plant although the electricity generator will be advantaged if they can access the grid. Desalinated water is likely to be the preferred water supply solution and an ammonia pipeline from the plant to the coast may be the optimal ammonia transport solution.

A viable business case without subsidies, grants or concessional loans was identified for the scenario of producing 1 million tonnes of green ammonia.

8 Lessons learned

The following table summarises the key lessons learned during the QNP green hydrogen to ammonia project feasibility study.

Table 4: Feasibility Study key lessons learnt

Item	Category	Topic	Lesson learnt / insight
1	Technical	Ammonia synthesis technology is evolving	The preferred architecture for an ammonia synthesis plant fed with electrolytic hydrogen is still evolving, as are technologies that seek efficiencies in novel hydrogen and nitrogen coupling approaches.
2	Technical	Electrolyser technology evolution	Our assessment of the cost of both alkaline and PEM technologies demonstrates that costs are already following cost reduction trajectories that were forecast in 2017. Alkaline technology appears to be the incumbent (at least as relates to the requirements of this project). Next generation technology offers are emerging with potential cost reductions.
3	Technical	Vendor saturation	Vendors of electrolysers, small ammonia synthesis plants and hydrogen storage systems are all straining under the surge in hydrogen development interest and therefore are rationalising their response effort. Vendors are assessing project outcome likelihoods when evaluating the effort to direct to prospective projects. Despite this trend, this project received eight (8) high quality bids.
4	Technical	Electrolyser power demand response speed	Based on vendor submissions, alkaline systems are slower in power response speed than PEM systems, but many vendors offer units capable of “regulatory” FCAS (i.e.> 3% load shift / second). Vendors can achieve different response speeds though modifications to separation system and rectifier design. The economic value of response speed will be unique to each project.
5	Technical	Hydrogen storage technology	Power demand responsive facilities either require the entire process system to modulate capacity (with associated cost for additional capacity) or have a storage system that can cycle in response to flow variation. In the case of the proposed electrolyser-based system, up to 6 cycles per day were anticipated. It has not been possible to refine the nomination of preferred hydrogen storage technology. Key trade-offs and costs are well understood, but the integration of plant footprint and safety considerations is still evolving. High pressure carbon steel pressure vessels are designed to cope with a defined number of pressure

			cycles, and costs escalate significantly with pressures >200 barg. The use of high-pressure carbon steel pressure vessels which can be blown down in the case of a fire have lower capital cost but will require more maintenance / replacement. Composite overwound pressure vessels (COPV) is an evolving technology which supports mobile transport and high levels of pressure cycling. These vessels can cope with many more pressure cycles and become cost effective with pressures >300 barg. However, emergency blow down of these vessels is more challenging, hence passive protection systems may need to be adopted. The higher-pressure systems challenge conventional compression design, but novel compression has not evolved sufficiently to have value for this project. Two different hydrogen storage models are under consideration as the project progresses, namely: ▪ Containerised storage with storage pressure of 300 barg; Vertical carbon steel storage with storage pressure of 100 barg.
6	Technical	Process safety for COPV based hydrogen storage containers	A continuous focus on safety in design identified that the best industry practice for hydrogen storage safeguarding involves passive fire protection of all bottles and installation of blast panels mounted in the roof of the containers.
7	Technical	Developed an understanding of turndown considerations	The maximum level of turndown that an electrolyser can achieve is often highly contentious. The client seeks the maximum turndown range in order to minimise “fixed” power costs. Vendors recognise that there are capital cost and safety implications of greater turndown ranges. Achieving greater turndown range often requires more complex transformer / rectifier systems and modulation of the ancillary systems. The capacity to provide “hot standby” appears to be a cost-effective alternative to straining for turndown capability. Pilot plant demonstrations are considered to be key qualifiers of vendor claims.
8	Operations	Operational control of the electrolysers and hydrogen storage level	The partners determined that in order to maintain a continuous and consistent supply of hydrogen to the ammonia plant, the operation of the electrolysers and hydrogen storage requires close collaboration between Neoen and QNP.
9	Commercial	Cost of electrolytic ammonia synthesis plants	Compared with conventional ammonia synthesis plants, the level of complexity of an electrolytic ammonia synthesis plant is low. Unfortunately, based on vendor cost submissions the removal of complexity does not significantly reduce cost. Net energy efficiency of a “green” ammonia plant is lower than conventional ammonia plants.

10	Commercial	Developed an understanding of key electrolyser CAPEX / OPEX trade-off	Electrolyser vendors have several key CAPEX vs OPEX trade-offs to balance when submitting an offer, eg • Pushing unit operating capacity at expense of efficiency and electrolyser life; • Complexity of rectification system relative to desired rate of response and AC system (i.e. harmonics) impacts; Having an understanding of key trade-offs enables a client to set preferences and reduces the range of options that vendors must negotiate
11	Commercial	Flexibility of a diverse renewable energy portfolio	The electrolysers will be operated to ensure that the amount of hydrogen in the hydrogen tank is always maintained between minimum and maximum thresholds to ensure continuous operation of the ammonia plant. In addition, the plant needs a certain level of firm electricity to operate. In order to meet these operational constraints and provide a high capacity factor,s Neoen has oversized the wind and solar assets which means the project can leverage a renewable energy supply without being exposed to the intermittent nature of renewables.
12	Commercial	Target load factor	The project determined that a similar NPV was obtained at a range of load factors (for this project). Hence the highest load factor and lowest capital solution is optimal. Electrolyser units come in standard sizes and hence will be “over-sized” to some extent. This leaves the possibility for higher generation / lower load factor, or operation at target load factor with higher efficiency. Operating with the higher generation rate (and marginally lower efficiency) was found to be preferable.
13	Commercial	Value of ammonia synthesis plant flexibility	Increasing the capacity of a small-scale ammonia synthesis plant has a small economic penalty. If this plant can modulate production capacity relatively quickly, i.e. 20% shift in capacity within an hour, then the capacity of hydrogen storage (and associated cost) can be reduced significantly. Collective design development between plant operator and electricity supplier is required to determine the optimal hydrogen storage capacity.
14	Commercial	Project commercial viability	The green ammonia production pathway has not achieved cost parity with conventional ammonia production (at the proposed scale). The project is commercially viable with funding assistance. The major driver of project economics is the margin between electricity costs and the value of the ammonia. Electricity costs must fall or carbon pricing / green premium increase in order that ‘green” projects achieve cost parity with conventional ammonia production.
15	Commercial	Identifying a contracting	Considering the relative immaturity of electrolyser technology and optimisation considerations with an

		strategy that balances risk Vs certainty. contracting "commercial tension" approach	ammonia synthesis plant, there is a continued need for technical development through FEED. Conventional FEED engineering practices do not allow for design fluidity (and learning) whilst maintaining competitive market tension. The proposed FEED execution approach will engage multiple contractors to enable continued technical advancement (e.g. sharing of IP within a safe environment) whilst maintaining "commercial tension" for ultimate design.
16	Regulatory	Regulatory advances	The implementation of hydrogen projects will need to support / advance the application of Australian standards as they relate to high pressure tubing, low ignition energy instrumentation, hydrogen storage vessel inspection requirements and the hydrogen safety case.
17	Australian expertise	Australian capacity	Australian research into higher efficiency green ammonia production and low-cost hydrogen transport options is world leading (e.g. Monash Uni, CSIRO). Key electrolysis and ammonia plant vendors all have good representation in Australia and appear to be prepared to support semi-commercial investments here.

9 Risk management

The following table lists the major technical and non-technical risks facing the project and the associated risk mitigation strategies.

Table 5: Major Project risks and Risk Mitigation

Risk description	Mitigation strategy
Business case assumptions not delivered during delivery and commissioning phase (e.g. capital cost exceeded)	"Feasibility study / FEED / detailed design risk transfer strategy. Performance guarantee.
Reduction in global ammonia price	Obtain independent review of forecast global ammonia prices
Sufficient grant funding from ARENA or NAIF loan amount and/or concessionality not available	Early engagement re Heads of Agreement and funding negotiations.
Inability to resolve grid connection	Early engagement with Powerlink
Poor integration with existing QNP plant	Rigorous engineering change management. Rigorous overview of FEED, detailed design and construction
Electricity supply not confirmed	Execute PPA
Pandemic	Australian health measures. Close management of project and vendor timelines
Potassium Hydroxide (10-15%, 30%) rundown mixes with ammonium nitrate, sodium hydroxide and sulphuric acid rundown	Review Potassium Hydroxide disposal options with vendors.
High pressure and large quantity hydrogen storage	Complete hazardous area classification study
Dissimilar materials resulting in corrosion	Conduct dissimilar metals study and include carbon fiber to aluminium and stainless steel
Lack of secondary egress	Ensure secondary emergency egress is included in emergency response
Loss of containment of ammonia	Project to consider methods to avoid or mitigate ammonia loss of containment (minimisation of leak sources, alarms, trips, emergency de-inventory)
Hydrogen embrittlement of piping during start-up resulting in crack /fracture	Project to confirm likelihood of embrittlement with different materials and choose appropriate material

10 Project stakeholders

The following table lists the project's stakeholders. The project has identified a range of engagement methodologies including media releases, in person meetings, letters, content on the ARENA website and attendance at community forums.

Table 6: Project Stakeholder Groups' Likely Interests and Key Considerations

Stakeholder group	Likely interests and key considerations
Key QNP customers	Potential opportunity to reduce the carbon footprint of their supply chain
Key QNP suppliers	Potential employment and business opportunities.
Australian Government, including ▪ Australian Renewable Energy Agency (ARENA) ▪ Northern Australia Infrastructure Fund (NAIF) ▪ Department of Industry, Science, Energy and Resources ▪ Department of Infrastructure, Transport, Regional Development and Communications ▪ Department of Prime Minister and Cabinet	The Feasibility Study has been partially funded by ARENA. Funding for the balance of the project will be sought from ARENA and NAIF. Various Australian government agencies will be interested in promoting the benefits of the project, because it relates to the renewable hydrogen industry.
Queensland Government, including ▪ Department of Environment and Science ▪ Workplace Health and Safety ▪ State Development, Manufacturing, Infrastructure and Planning ▪ Industry Development and the Commonwealth Games ▪ Natural Resources, Mines and Energy ▪ Economic Development Queensland ▪ Department of Transport and Main Roads	Queensland government agencies will be interested in promoting the benefits of the project, because it relates to the renewable hydrogen industry and also for the potential employment opportunities. Liaison is also required with the Queensland government regarding regulatory approvals.
Local Members of Parliament, including: ▪ Federal Member for Flynn, Ken O'Dowd	Local Members of Parliament will be interested in understanding how the project will benefit the local economy and community.

▪ Federal Member for Hinkler and Minister for Resources, Water and Northern Australia, Keith Pitt ▪ State Member for Callide, Colin Boyce	Minister Pitt will be interested in Northern Australia development projects, as well as water consumption and resources projects
Local Government, Banana Shire Council	The project will require approvals and planning support from Local Council. Banana Shire will be interested in understanding how the project will benefit the local economy and community.
Local community, including: ▪ Neighbouring landholders ▪ Moura community residents ▪ Banana town community residents ▪ Biloela community residents ▪ Moura community services and groups ▪ Banana Shire community services and groups ▪ Local businesses ▪ Local Indigenous groups	Neighbouring landholders will be interested in understanding project benefits and impacts.
Local regional development groups, including: ▪ Moura Chamber of Commerce ▪ Banana Shire Business Network ▪ Enterprise Biloela Association Inc	Various regional development groups will be interested in understanding the potential project benefits (such as supplier opportunities) and how they can facilitate consultation with key stakeholders regarding this matter.
Infrastructure and utility providers / groups, including: ▪ SunWater ▪ Ergon Energy ▪ Powerlink	Infrastructure and utility providers/groups will likely be primarily interested in project related infrastructure and service delivery requirements.
Relevant unions	Relevant unions will be interested in understanding employment opportunities and impact on the existing workforce.
Neighbouring industry, including: ▪ Anglo American ▪ Baralaba Coal Company ▪ WestSide	Neighbouring industry will likely be interested in obtaining hydrogen (e.g. for mine haul trucks), understanding project timeframes and logistics.
Media	The media will be interested in any newsworthy stories regarding the project – which in this case will likely relate to hydrogen technology.

11 Conclusion

The major technical conclusion of the study is that a 30MW electrolyser capable of producing 3,500 T/y of hydrogen operating at an 80% load factor, 16 hours of hydrogen storage and a 20,000 T/y small-scale ammonia plant is technically viable.

The optimal location of the renewable energy generation assets is at a location remote from the QNP Moura plant. Scale of the renewable assets and the opportunity to provide grid stabilisation services more than offset the transmission costs incurred.

However, the project is only commercially viable with substantial government assistance in the form of grants and concessional loans. A pathway towards commercial viability of large scale green hydrogen and ammonia plants without subsidies has been identified.

12 Acronyms and abbreviations

Acronym / abbreviation	Term
ARENA	Australian Renewable ENergy Agency
ASU	Air Separation Unit
AUD	Australian Dollars
barg	Measure of pressure “bars, gauge”
CAPEX	CAPital EXpenditure
CO_{2e}	Carbon dioxide equivalent
COPV	Composite Overwound Pressure Vessels
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EPCM	Engineering, Procurement and Construction Management
FCAS	Frequency Control Ancillary Services (Regulation & contingency services)
FEED	Front End Engineering Design
GW	Giga Watts
GWh	Giga Watt hour
H_2	Hydrogen
HAZID	HAZard IDentification
HV	High Voltage
kg	kilogram
km	kilometers
kV	kilo volts
kWh	kilo Watt hours
LF	Load factor
m	meter/s
MCC	Motor Control Centre
ML	Mega Litres
ML/y	Mega Litres per year
MW	Mega Watt
NAIF	Northern Australia Infrastructure Facility
NEM	National Energy Market
NH_3	Ammonia
NPV	Net Present Value
O_2	Oxygen
OPEX	OPerating EXpenditure

pa	per annum
PEM	Proton Exchange Membrane (an electrolyser technology)
PPA	Power Purchasing Agreement
QNP	Queensland Nitrates Pty Ltd
T/y	Tonnes per year
TIC	Total Installed Cost
TUOS	Transmission (network) Use Of System