Department of State Development, Infrastructure, Local Government and Planning

Gladstone and Townsville Hydrogen Opportunities Study

Part 3 Report | January 2021

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1. Introduction and rationale

1.1 Background

This report builds on the Gladstone and Townsville Hydrogen Opportunities Study Part 1 and Part 2 Reports prepared for the Department of State Development, Infrastructure, Local Government and Planning (DSDILGP) in response to the *Queensland Hydrogen Industry Strategy 2019-2024*; a five-year plan to grow a sustainable hydrogen industry that supports renewable resources, creates jobs and strengthens Queensland's economy[1].

The Part 1 Report reviewed the available literature, case studies and produced a conceptual hydrogen schematic. The report identified the international, national, and local hydrogen successes and challenges, and discussed the opportunities for the industry in the export and domestic markets. The outcome of the report was understanding that there are a number of interrelated criteria that must be met to establish a hydrogen industry in Queensland.

The Part 2 Report involved the development of scenarios for the establishment of three hydrogen plants of varied size and production capacity. The scenarios allowed for integrated plants with the co-location of downstream technologies. These scenarios provided information for consideration by Government to assist with integrated land use and ports planning, infrastructure and services corridor planning and programming, including the potential for common user infrastructure. From this information, the Part 2 Report identified, developed, and refined spatial and locational criteria for the establishment of a hydrogen plant, which was a key outcome of the overall study.

1.2 Purpose

The Gladstone and Townsville Hydrogen Opportunities Study Part 3 Report applies the research outcomes from the assessment of the state of hydrogen globally, nationally and locally undertaken in Part 1 and the development and growth scenarios, and spatial sighting criteria identified in Part 2, to identify potential areas for establishment of a hydrogen plant. This was undertaken through the development of a limited Multi-Criteria Analysis (MCA) process and applied to the Gladstone and Townsville State Development Areas (SDAs). The purpose of this Part 3 report is to document the general identified locations for a hydrogen plant in the above-mentioned SDAs.

The overall study considers a hydrogen industry development pathway from demonstration plants for domestic consumption and export. The study also considers:

- The potential for transitional development from brown/grey hydrogen, blue hydrogen to green hydrogen
- The integration with existing fossil fuelled and renewable electricity generation sites.

1.3 Scope and methodology

Of the three main reporting stages of this study (shown in Figure 1), the following tasks have been undertaken to develop Part 3:

- Synthesis of Part 1 and Part 2 Reports

1 Queensland Hydrogen Industry Strategy, State of Queensland 2019-2024

- Conducting preliminary site evaluation using GHD's InDeGO platform for identification of spatial physical constraints criteria
- Applying secondary fine-grained evaluation using the application of infrastructure proximity criteria to identify potential areas for development.

Figure 1 Study methodology

1.4 Limitations

This report has been prepared by GHD for Department of State Development, Infrastructure, Local Government and Planning and may be used and relied on by Department of State Development, Infrastructure, Local Government and Planning for the purpose agreed between GHD and the Department of State Development, Infrastructure, Local Government and Planning as set out in Section 1.2 of this report. This report may be distributed by the Department of State Development, Local Government, Infrastructure and Planning to other State Government agencies.

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The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer Section 1 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

2. Emerging hydrogen industry development

This Section discusses the existing landscape of the hydrogen industry locally, nationally, and globally from the Part 1 Report. These insights are drawn from desktop review of the available background information including published hydrogen roadmaps and case studies.

This Section also summarises development scenarios and key hydrogen industry requirements to establish a hydrogen production facility in Queensland, identified in the Part 2 Report. The development scenarios and industry requirements were based on stakeholder consultation, desktop reviews and high-level market assessment outcomes to document potential demand opportunities for the region as well as hydrogen production capacity within Australia.

2.1 Hydrogen overview

2.1.1 Hydrogen production

Hydrogen is a carbon-free energy source, producing only water when combusted. Presently there are several processes for producing hydrogen. Figure 2 below represents the various types of hydrogen production, as well as potential end uses of hydrogen. Further detail on production methods and end uses is provided below.

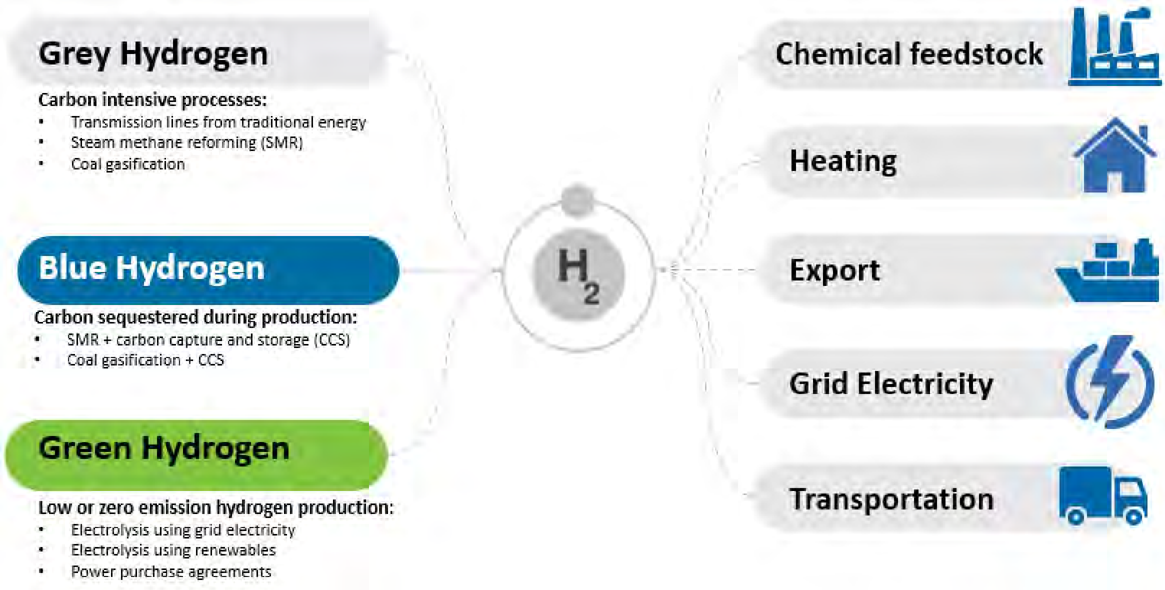


Figure 2 Hydrogen production and application[2]

The most prevalent production processes are steam methane reforming and coal gasification, which are both fossil fuel dependent and carbon intensive. This process is commonly referred to as **grey / brown hydrogen**. The World Energy Council (WEC) and Hydrogen Council estimates that between 96% and 99% of hydrogen is currently produced using fossil fuels via carbon intensive processes, which may be attributed to the low cost of production, and the access to fossil fuels[3].

2 In Figure 2, the power purchase agreements are most likely to be synthetic PPAs, that is, a “strike price” is agreed between a green hydrogen project and a power generator for power generated by a renewable energy facility, rather than physical PPAs.

3 Innovation Insights Brief 2019

Blue hydrogen is grey / brown hydrogen where the carbon dioxide (CO_2) that is emitted during production is sequestered via carbon capture and storage, thereby reducing the CO_2 emitted during production.

Green hydrogen is the process of electrolysis to split hydrogen (H_2) and oxygen (O) from water (H_2O) and sourcing energy from renewable energy sources including wind or solar. This process has zero carbon emissions, and, has traditionally has a high cost of production and relies on the availability of reliable, low cost renewable energy sources. Technological improvements and the growth of the renewable energy market are reducing costs to make this extraction method more competitive.

Figure 3 provides the breakdown of the crude conversion rate to produce 1 kg of hydrogen. It demonstrates that the production of hydrogen using renewables, has zero emission outputs. The use of traditional grid electricity and fossil fuels has the highest emission outputs per kg of hydrogen.

The Hydrogen Council highlights significant amounts of renewable energy is required to support the transition to decarbonised energy system[4]. Hydrogen technologies have the power to enable this transition to a zero or low-carbon energy system. Investments in Japan and Korea are rapidly developing technologies to assist in this decarbonisation of hydrogen production (green hydrogen).

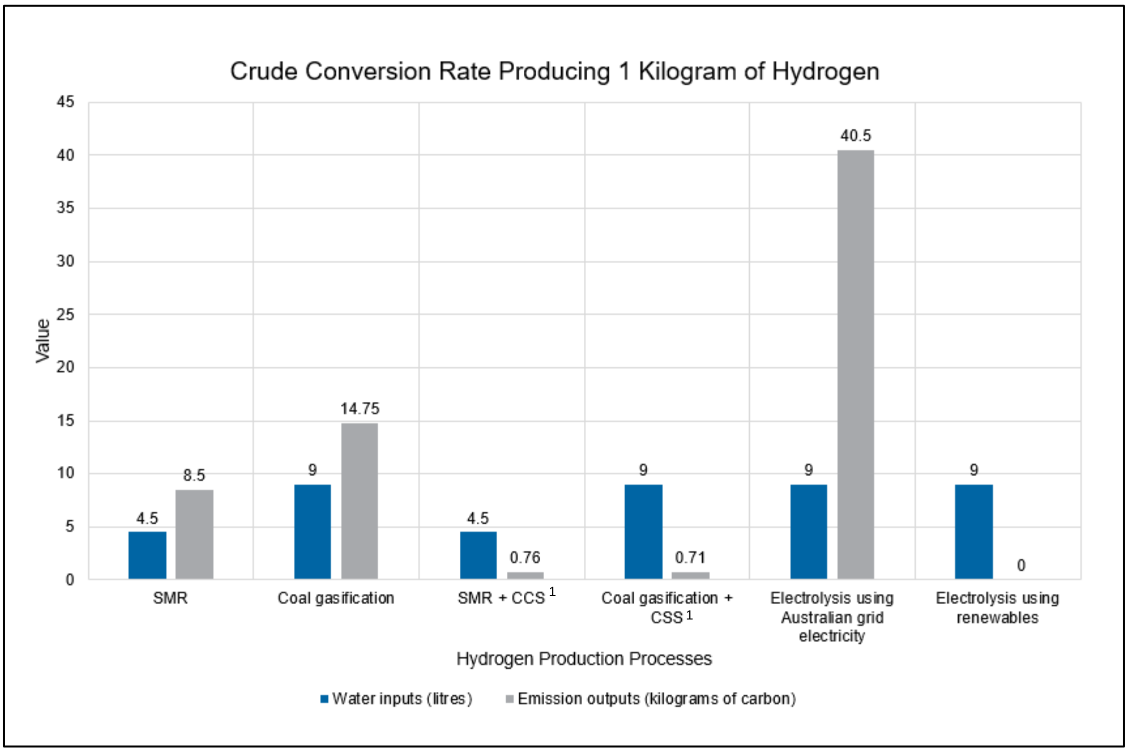


Figure 3 Inputs / Outputs to Produce 1 Kilogram of Hydrogen

Source: COAG Energy Council Hydrogen Working Group 2019

[1]Does not include energy required for sequestration.

2.1.2 Hydrogen use

Currently hydrogen is being mainly used as a feedstock for industrial purposes including ammonia for fertiliser, as well as for food, electronics, glass, and metal industries[5].

4 How Hydrogen Empowers the Energy Transition, Hydrogen Council 2017

5 Chemical Economics Handbook, IHS Market, 2018

The potential applications for hydrogen are more diverse than current applications, which may contribute to a more viable global and domestic hydrogen industry. A unique advantage of hydrogen is that it can service multiple sources on demand and, therefore, in practice a single hydrogen plant, could secure offtakes with several applications depending on available infrastructure, policy and demand profiles[6].

As illustrated in Figure 2 above, the outputs from hydrogen production could be applied to the following areas:

- Industrial/chemical feedstock:
  - Around the world, 90% of hydrogen production is used within the chemical industry, 50% of which goes towards ammonia production. Australia currently produces more than 2 million tonnes per annum (mtpa) of ammonia and this could rise to more than 350 mtpa of hydrogen as a feedstock for ammonia production from natural gas without CCS[7]. The global ammonia market was recorded as $48.65 billion (USD) in 2016[8], and expected to exceed 5% compound annual growth between 2019 and 2024[9]
- Transport:
  - The use of hydrogen as a fuel for transport is already financially viable in terms of the cost / kg but is limited most notably by infrastructure barriers and technology (transport) availability. It is expected that the use of hydrogen in the transportation industry will proliferate rapidly once these barriers are overcome[10]
- Electricity storage:
  - Electricity supply can be improved using hydrogen in seasonal storage. This is most likely to benefit densely populated areas with high levels of demand on existing power supply grids[11]. Hydrogen electrolysis plants also offer the potential to provide frequency control ancillary services (FCAS) (load raise or lower)
- Industrial and residential heat:
  - It is possible for hydrogen to substitute natural gas and liquefied petroleum gas (LPG) in the residential and industrial heat supply chain as it can be directly burned to produce energy or heat. Currently, natural gas provides as much as 44% of cumulative household energy needs for as many as 70% of homes across Australia[12]. In most cases, hydrogen could use existing gas pipelines to heat buildings, cooking and providing hot water
  - Hydrogen is also an alternative method of storing energy to fuel industry and households. Stored hydrogen using fuel cell technology is more cost-effective at scale, have a longer storage period and more tolerant of harsh conditions[13]
- Export:
  - There are opportunities for the export of hydrogen as other countries around the region seek alternative forms of energy. Australia is an established exporter with over 20.58 million tonnes of LNG exported in 2018 and Queensland is considered a

6 National Hydrogen Roadmap, CSIRO 2019

7 Australian Hydrogen Strategy, COAG 2019

8 Ammonia Market Size, Share and Trends Analysis Report, Grand View Research 2017

9 Ammonia Market – Growth, Trends, and Forecast (2020 – 2025), Global market Insights 2020

10 Chemical Economics Handbook, IHS Market, 2018

11 Chemical Economics Handbook, IHS Market, 2018

12 North Queensland levels of natural gas consumption may differ from national average

13 Hydrogen for Australia's Future, Hydrogen Strategy Group 2018

precursor for the industry. The Queensland Gas Scheme, which commenced in January 2005 required electricity retailers and other liable parties to source 13% of the electricity they sell or use in Queensland from gas-fired generation[14].

2.2 Current industry setting

A number of key bodies and working groups have been established in an attempt to guide the development of hydrogen as an alternative energy source. These include the International Energy Agency (IEA), and the World Energy Council (WEC), who are leading the strategic outlook for an emerging global hydrogen industry.

The level of interest from government, industry and international bodies is resulting in an increased forecast in hydrogen demand and how the demand may be met by countries that are well placed to produce and export hydrogen. Locally, Australia has determined at all levels of government that establishing Australia as a prominent supplier of hydrogen presents a lucrative opportunity for the economic growth of regional Australia. The IEA and WEC identify Australia as a potential 'green hydrogen production powerhouse'[15].

Australia, nationally, is advancing the integration of renewable energy (green hydrogen), through publishing *Australia's National Hydrogen Strategy*[16] (November 2019). Australia's ability to occupy a share of the hydrogen market will be determined by various influences, which are likely to be similar to those factors that support Australia to be a supplier of the global market for other energy resources.

In May 2019, the State of Queensland released the *Queensland Hydrogen Industry Strategy 2019-2024*. Queensland is well placed for hydrogen production with a highly skilled workforce, an established export industry, ideal proximity to markets, significant biomass / renewable energy resources, plus the many existing and planned renewable energy projects underway[17].

2.2.1 Market assessment and production transmission

Overview

As of 2017, global hydrogen production had remained relatively stable at 55 million tonnes per annum. However, typical production methods for these exports were not low emission procedures[18]. Key inhibitors to building demand for hydrogen energy applications include the fact that it is not currently cost competitive with other sources of energy, such as fossil fuels. According to CSIRO's National Hydrogen Roadmap, if hydrogen can be offered at a cost of less than \$2/kg (\$16.67/GJ), it could viably provide a cost-competitive option to replace natural gas turbines for dispatchable generation[19].

Generally, interest in green hydrogen as an attractive substitute fuel is growing at a steady pace because of various contextual changes such as a global shift towards prioritising decarbonisation strategies through mechanisms such as the Paris Agreement.

Market projections

Making projections as to the likely future global hydrogen economy and the likely use of hydrogen for energy applications is difficult because it is still in the early stages of adoption, yielding a large degree of uncertainty. GHD's study has uncovered a wide range of possible uptake projections with a large degree of variation in their outlooks, this is because:

14 Minister for Mines and Energy, the Honourable Geoff Wilson 2007

15 COAG Energy Council Hydrogen Working Group 2019

16 Energy Council Hydrogen Working Group 2019; World Energy Council 2019

17 Queensland Hydrogen Industry Strategy, State of Queensland 2019-2024

18 Acil Allen, Opportunities for Australia from Hydrogen Exports, 2018

19 National Hydrogen Roadmap, CSIRO 2019

- The factors behind the projections differed across sources. One of the most notable differences was the base case hydrogen volumes that were used. Currently, most demand stems from the non-energy sector
- Time periods also varied. Despite this, the studies that were reviewed concluded that the sector will undergo a considerable expansion between the years 2030 and 2040
- Various publicly available forecasts foresee significantly different outcomes for demand levels. This is due to a large degree of uncertainty and different methods of demand forecast measurement that have been implemented whereby some sources used joules while others used tonnes.

Table 1 provides a comparison of the sources examined in the literature review and their estimated demand forecasts for various scenarios for the years 2030, 2035, 2040, 2045 and 2050. It is important to note the large degree of variance in demand forecast as time progresses. The projections for hydrogen uptake in the year 2050 have a range of 460 million tonnes (Mt) per annum, which demonstrates that there is a large degree of ambiguity regarding the outlook for hydrogen.

Table 1 Estimated Forecasted Global Hydrogen Demand (million tonnes hydrogen)[20]

	2018	2030	2035	2040	2045	2050
EA 2018 Demand Estimate	70					
Shell		70	72	85	100	135
Acil Allen (med)		72	75	100	NA	NA
IRENA		90	NA	140	NA	230
Deloitte Scenario 1		75	85	120	180	305
Deloitte Scenario 2		70	72	80	115	175
Deloitte Scenario 3		70	70	75	100	150
Deloitte Scenario 4		70	70	72	72	80
Hydrogen Council		100	125	200	340	540
Average		77	81	109	151	230
Upper Limit (+25%)		96.4	101.6	136.3	188.9	288.4
Lower Limit (-25%)		57.8	60.9	81.7	113.4	173.0

Given the variability in demand projections, criteria were applied to assess and rank the reliability and relevance of each projection. The criteria included the originality of the data, the assumptions made in the study, how recently it was published, the relevance of the contents to this study, and the geographic coverage of the study.

Figure 4 demonstrates the project range and average demand based on aggregate demand figures taken from a comprehensive evaluation of the key literature pertaining to the global

20 Various sources

outlook for the hydrogen industry, focusing on green hydrogen. The literature that was reviewed poses various scenarios up to 2050. The range is +/-25% of the average. There is a projected large degree of variance as time progresses. The projections for hydrogen uptake in the year 2050 have a range of 230 million tonnes per annum, which in turn leads to a large degree of ambiguity regarding the outlook for hydrogen.

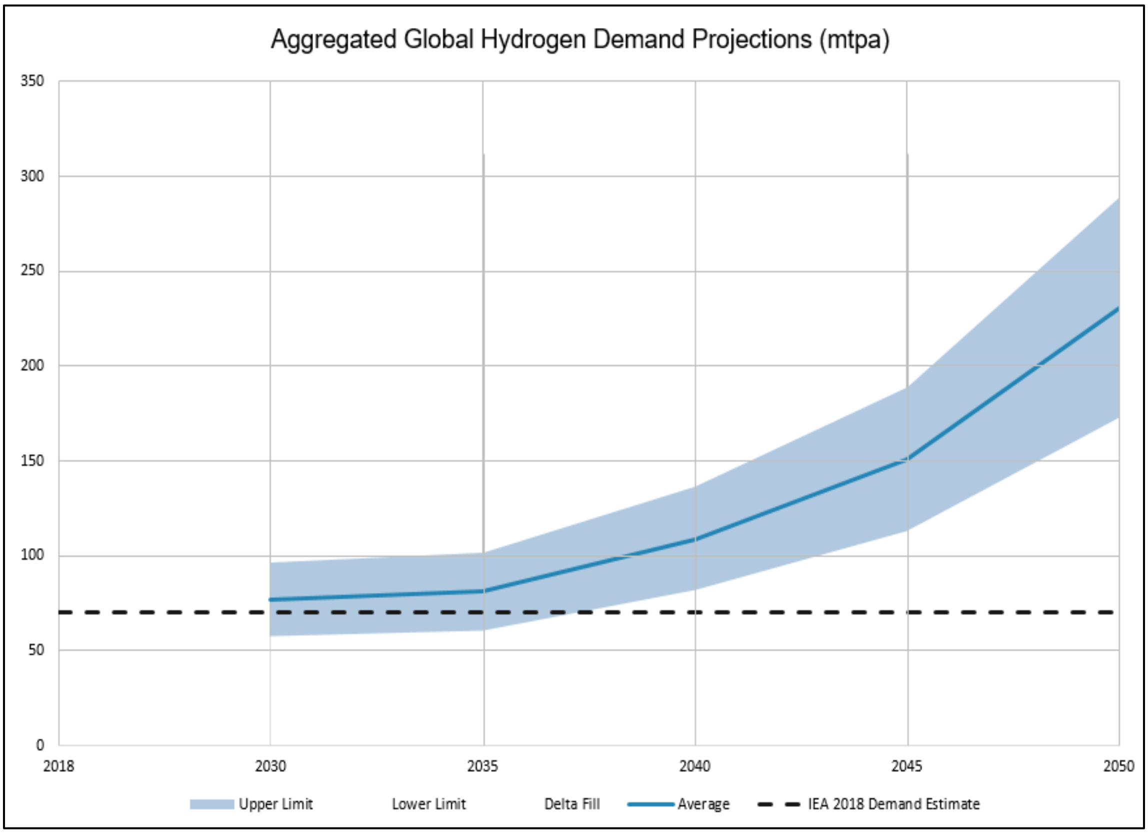


Figure 4 Aggregated estimated global hydrogen demand projection

A unique advantage of hydrogen is that it can service multiple sources on demand and, therefore, in practice a single hydrogen plant, could secure offtakes with several applications depending on available infrastructure, policy and demand profiles[21].

2.2.2 Stakeholder engagement outcomes

GHD integrated stakeholder consultation into the Task 2 methodology to capture the industry's knowledge and perceived and real challenges for an emerging hydrogen industry in Queensland. The following section of the report provides an overview and analysis of the results from the stakeholder consultation undertaken.

Key findings from the online consultation are detailed below:

- Stakeholders identified that Queensland has a number of key regional strengths to support the development of a hydrogen production and export industry. These include **good renewable energy resources, experience in supporting large scale industry development**, as well as the availability of **well serviced industrial land**, (water and transport), with the potential for colocation of industrial uses. In contrast, stakeholders perceived **actual energy cost / availability for large scale development**, **constrained electricity transmission infrastructure and existing port facilities' capabilities** as the greatest regional challenges / constraints that may inhibit the development of hydrogen production and export in Queensland

21 National Hydrogen Roadmap, CSIRO 2019

- Stakeholders consider **water for hydrogen production is the most important supporting infrastructure for a hydrogen facility**. Power distribution, power generation (renewables – wind, solar) and port infrastructure were considered the second-most important supporting infrastructure. This reinforces respondent's perception on supporting infrastructure's proximity to a hydrogen facility. Water for hydrogen production and power distribution are considered the supporting infrastructure that should be the closest to support the development of a hydrogen facility
- Stakeholders intend to produce hydrogen for domestic use including feedstock for local ammonia and transport. Solar, wind and natural gas are perceived by stakeholders as the most viable energy source options, while pumped hydro and biomass are perceived as the least viable. However, it is more widely perceived that the export market is where hydrogen demand would be generated and provide the most benefit and interest from external investors
- The demand for hydrogen is not expected to change / shift in the context of current global uncertainties (COVID - 19).

Overall, stakeholders identified a need for the industry to be able to scale up to respond to changes in demand. This will have an impact on the production output and spatial requirements for the plant. It is also generally considered positive to collocate production facilities in proximity to downstream activities and the relevant supporting infrastructure.

2.3 Summary

The literature reviewed and stakeholder engagement activities undertaken for the emerging hydrogen industry reveal there are potential demand opportunities for the region, which could support the 230 million tonnes per annum average global demand projected by 2050. While currently being used as a feedstock for industrial purposes, the potential applications of hydrogen are much more diverse including chemical/feedstock, transport, electricity storage, and industrial and residential heat.

The literature review and demand scenarios have set the scene for the hydrogen industry within the region. The next Section of this report adopts the research from Section 2 and applies this to the development of key spatial criterial necessary for the establishment of an integrated hydrogen plant.

3. Establishing a hydrogen plant

This Section conceptualises the key technical considerations to establish an integrated hydrogen plant, drawing upon the production processes and spatial requirements discussed in the Part 1 and Part 2 Reports. Three differently sized hydrogen plant development scenarios were developed from these findings to build the limited MCA prepared in Section 4 of this report.

3.1 Conceptual hydrogen plant

Hydrogen may be utilised as an energy supply in a range of domestic and international markets as a carbon-free fuel; however, it is not currently economically viable to transport hydrogen at atmospheric conditions due to the low energy content of hydrogen gas. Hydrogen gas has a very low volumetric energy value and requires large volumes, even when compressed to high pressures. It takes approximately 14 litres of hydrogen compressed to 20MPa to contain the same energy as 1 litre of diesel. This makes compressed gaseous hydrogen economically unviable as a mode of transporting large amounts of energy from place to place exempt via pipeline, and if the hydrogen is to be exported to other countries.

Water electrolysis using renewable electricity is currently considered as a viable green hydrogen technology. Other technologies are either still in development or are not considered truly ‘green’, such as steam methane reforming with carbon sequestration, as it is still dependent on fossil fuel feedstocks.

Once the hydrogen gas is produced at scale, it is converted into a hydrogen carrier, which stores hydrogen in a denser form. Of these, ammonia (as liquid; either under cryogenic conditions or compressed to liquid at ambient temperature), liquefied hydrogen (cryogenically cooled hydrogen) and methylcyclohexane (an organic hydrogen carrier) are identified by industry as the most likely candidates as carriers.

Ammonia is a mature technology and the most practical of these, however, the industry is not developed enough to make a conclusion on the best carrier.

Figure 5 illustrates the simplified process diagram for hydrogen carrier production. The potential flow schematic for hydrogen production and hydrogen carriers are provided in Figure 6. Table 2 also provides a comparison of the potential hydrogen carriers.

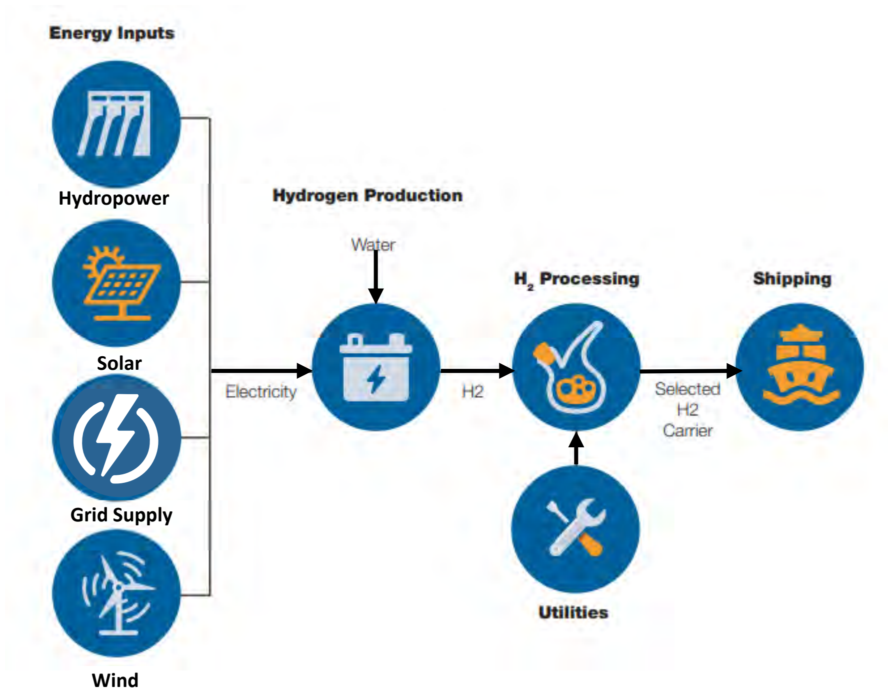


Figure 5 Simplified process diagram for hydrogen carrier production

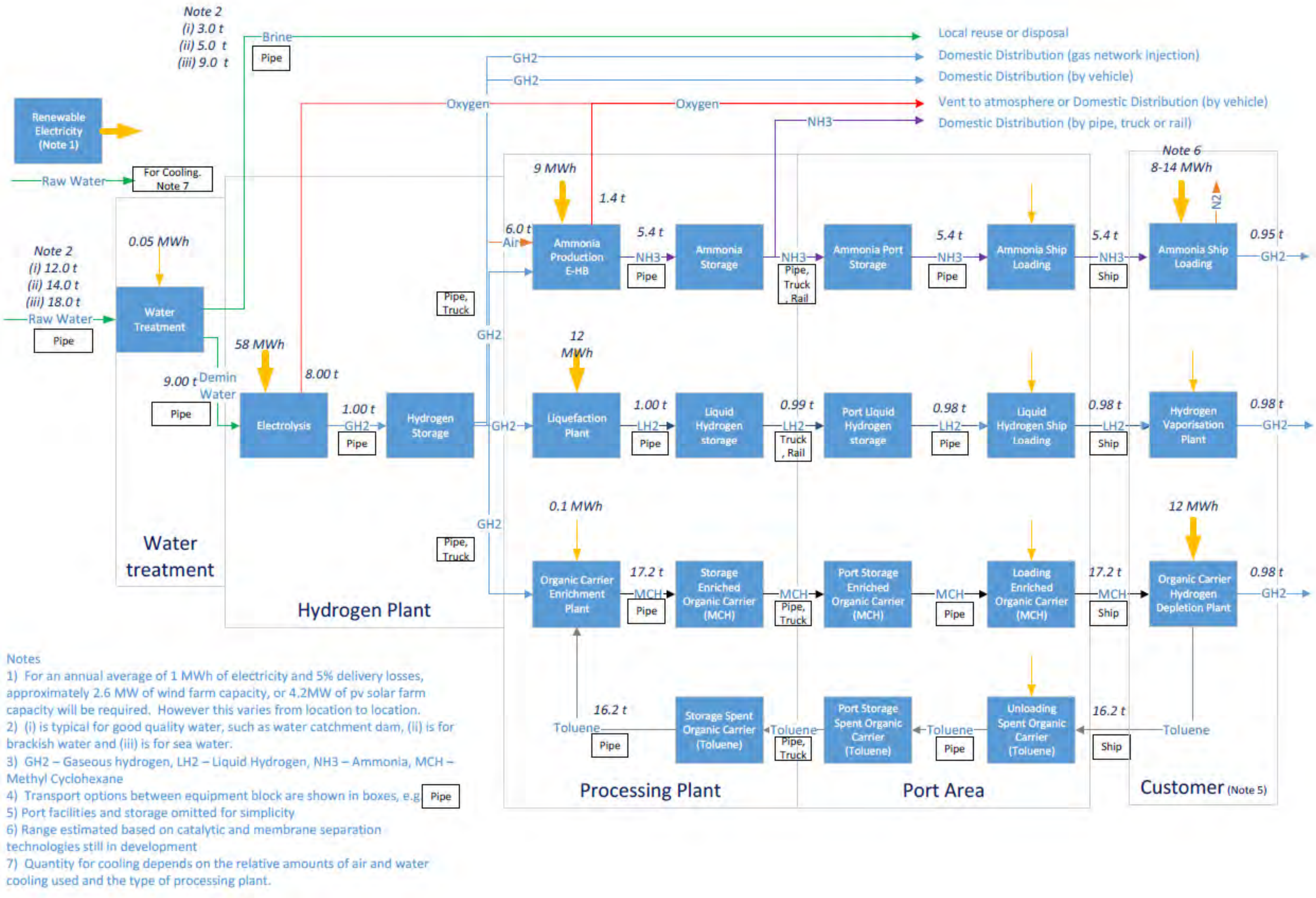


Figure 6 Flow schematic for production of hydrogen and hydrogen carriers

Table 2 Comparison of potential hydrogen carrier

Carrier	Energy density (MJ/kg; MJ/L LHV)	Density (kg/m^3)	H_2 density* (kg/kg)	Process to convert to carrier	Process to reconvert to H_2	Energy required to get to transportable state (MJ/kg)	Energy required to get to useable form (back to H_2)	Other issues
Gaseous H_2	119.96 (MJ/kg); 0.45 (MJ/L)	3.758 (@ an assumed 50 ºC and 50 barg)	1	Compression and cooling	None required, other than letdown to user pressure	7.67	Let down - generate energy	Low density - high volumes required. Flammable - storage of more than 50t at a site renders it a Major Hazardous Facility.
Liqufied H_2	120.04 (MJ/kg); 9.67 (MJ/L)	80.54	1	Cooling to -255 ºC (cryogenic loops as per LNG analogy)	Utilise ambient conditions to regasify, have to manage operating pressure	42.51	Utilise ambient conditions to regasify	Insulation of equipment - temperatures are low enough to cause O2 in air to liquefy. Flammable if vaporised - Storage of more than 50t at a site renders it a Major Hazardous Facility.
Ammonia	18.9 (MJ/kg); 13.21 (MJ/L) or 11.18 (MJ/L)	698.8 (@ an assumed -35 ºC and ambient pressure) OR 591.5 (@ an assumed ambient temperature and 10.5 barg pressure)	0.151	Generate N_2 (usually via air separation which is a cryogenic separation, thus energy intensive). Compress N_2 and H_2 to 230 barg and pre-heat to 450 ºC. Catalytic reaction (Haber-Bosch process).	Catalytic decomposition of NH_3 - membrane reactor (CSIRO) or PEM technology.	9-11.25 MJ/kg NH3; thus 59.6-74.5 MJ/kg H2	26 MJ/kg H2 theoretically; around 38-40 MJ/kg in practice	Ammonia toxicity. Storage of more than 200t at a site renders it a Major Hazardous Facility.
MCH	43.38 (MJ/kg); 32.28 (MJ/L)	744	0.132	Hydrogenation reaction of toluene (toluene presents some issues of its own - storage and transport a challenge), catalytic reaction at around 170 ºC and 10 barg.	Catalytic dehydrogenation of MCH at around 350 ºC and 1-3 barg.		~43.4MJ/kg H2	Toluene has to be stored and is toxic. The main concern around toluene's storage is whether it is to be shipped back to be reused, and if so, what should be done with the by products, which could include organic contaminated acid

*Mass of recoverable hydrogen as a proportion of the carrier mass.

3.2 Development scenarios

The following section of the report details the spatial criteria necessary for the establishment of a hydrogen plant. This includes the plant configurations, typical spatial requirements, utility service requirements, transportation requirements, colocation opportunities and safety and security.

To inform a high-level review of hydrogen plant requirements, the production scenarios in Table 3 below have been adopted. The development scenarios below were developed based on existing ammonia production facilities and through a process of calculating the amount of hydrogen required to produce the current ammonia production. This has then been scaled for the individual outputs and plant sizes. The size 3 plant is approximately 50% of the size of a very large ammonia plant, which is approximately 8 times larger than what is currently considered a very large hydrogen liquefaction plant.

Table 3 Production scenarios of hydrogen and carriers

Product	Size 1	Size 2	Size 3
Hydrogen			
Hydrogen production (tpa)	8,687	34,748	86,870
Ammonia production			
Ammonia (tpa)	46,504	186,017	465,043
Density (t/m^3)	0.73	0.73	0.73
Ammonia (m^3/a)	63,704	254,818	637,045
MCH (organic carrier) production			
MCH (tpa)	138,992	555,968	1,389,920
Density (t/m^3)	0.77	0.77	0.77
MCH (m^3/a)	180,509	722,036	1,805,091
LH2 production			
LH2 (tpa)	8,513	34,053	85,133
Density (t/m^3)	0.07	0.07	0.07
LH2 (m^3/a)	121,614	486,471	1,216,186

3.2.1 Plant Configurations

Plant configuration has implications to the footprint and logistics, which strongly influence locational requirements. The key process plant blocks are:

- Water treatment – water treatment is generally located at the hydrogen production plant, but part of the water treatment plant may be located separately, for example if it involves desalination. Treated water can be transported long distances in underground pipelines
- Hydrogen production – hydrogen plants are a large power consumer and may be best located close to a robust power grid connection point. Gaseous hydrogen can be transported long distances in underground pipelines
- Plant to convert hydrogen to liquid hydrogen (LH2), anhydrous ammonia or methylcyclohexane (MCH) – heavy industrial plants with hazardous products. Ammonia and MCH can be transported long distances in underground pipelines. However, LH2

cryogenic pipelines have limited practical and economic transport range, and longer distance may economically require cryogenic vehicle/vessel transport

- Product storage for shipping and ship loading – generally close to the port due to high capacity ship loading rates and distance limitations on low temperature ammonia or cryogenic hydrogen pipelines. For low temperature ammonia pipelines, pipelines in the order of 3-5 km, and definitely less than 10 km in length are preferred. If the distance to port is more than 10 km, an ambient temperature buried pipeline to transport ammonia is preferred. Cryogenic liquid hydrogen is generally transported in well insulated tanker vessels due to the extremely low temperature required. A cryogenic hydrogen pipeline could be up to several hundred meters long, but more than that is unlikely to be practical in this application.

Maximum practical pipeline length is a key criteria when trying to determine optimal location of liquefaction plants and cryogenic storage; refrigeration/liquefaction as close to port as possible is preferred, keeping in mind cost and availability of land close to port as well as separation distances (in particular for storage) required from general activities and personnel movement.

The plant configurations are shown in Figure 7. The top configuration shows all plants may be separately located to suit their requirements. The middle option shows the water treatment plant located at the hydrogen production site, which would be supplied with power and water. The bottom option shows an integrated plant with all process blocks at or near the port. This requires a large power supply and water supply to be available near the port.

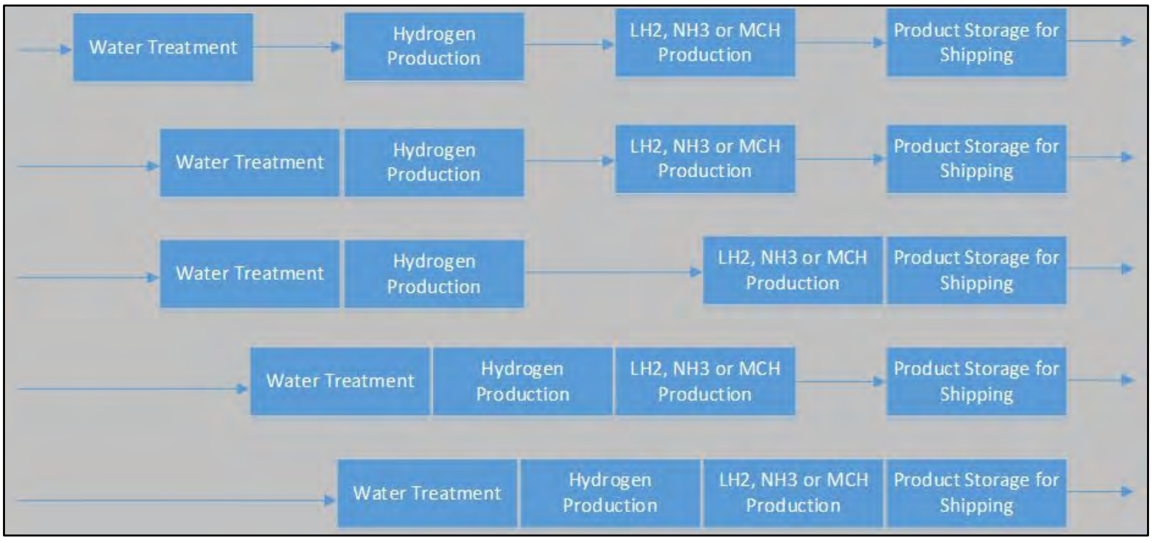


Figure 7 Plant configuration options

The preferred scenario from a planning and logistics point of view would be to develop an integrated plant at or nearby a port. Overall, an integrated plant would be more efficient in that production and processing components are co-located.

3.2.2 Hydrogen plant spatial requirements

A high-level schematic layout (not to scale) of an integrated hydrogen to ammonia plant was developed as part of the Part 2 Report, based on the key spatial requirements outlined above. The schematic is a general layout arrangement of the individual components that would be required onsite for both domestic and export markets. Appendix C provides a copy of the schematic plant layout.

3.2.3 Hydrogen plant key requirements

Typical spatial requirements

The typical spatial requirements of a H2 production plant and downstream technology components are another key component to considering a plant's location. The requirements are a function of production components, storage, tanks and/or overall site arrangements necessary to operate a viable plant.

The tables below identify the spatial requirements for H2 production plant and downstream technology components. For the purposes of co-locating, the combined spatial requirements of H2 and the downstream technology(ies) should be considered (example: H2 production plus ammonia). These can greatly increase the spatial requirements to support the development, which further impacts other infrastructure requirements.

Table 4 Spatial requirements, H2 production

Parameter	Measurement	Size 1 8,687 tpa	Size 2 34,748 tpa	Size 3 86,870 tpa
H2 production				
Site *(land area + storage)*	m^2	4,375	18,375	45,938
Land area	m^2	4,375	18,375	45,938
Storage (waste water brine based on 30 day retention)	m^2	1,352	4,046	7,700
Tank arrangement	-	2 tanks (13m dia)	4 tanks (17m dia)	6 tanks (20m dia)
Tank footprint	m^2	265	908	1885

Table 5 Spatial requirements, ammonia production

Parameter	Measurement	Size 1 46,504 tpa	Size 2 180,017 tpa	Size 3 465,043 tpa
Ammonia production				
Site *(land area + storage)*	m^2	14,418	54,329	111,480
Land area	m^2	9,160	36,640	91,599
Storage area (product)	m^2	5,258	17,689	19,881
Tank arrangement	-	2 tanks[22] (12m dia)	4 spheres (22m dia)	4 spheres (24m dia)

22 For most tank arrangements, a separation of one tank diameter is assumed between tanks. Added to that is a standard requirement for separation of tanks from a fence line, road or equipment.

Parameter	Measurement	Size 1 46,504 tpa	Size 2 180,017 tpa	Size 3 465,043 tpa
Ammonia production				
Tank footprint (included in Storage area)	m^2	226	1,521	1,809

Table 6 Spatial requirements, H2 liquefaction

Parameter	Measurement	Size 1 8,513 tpa	Size 2 34,053 tpa	Size 3 85,133 tpa
H2 liquefaction				
Site *(land area + storage)*	m^2	6,959	36,473	61,373
Land area	m^2	4,150	16,600	41,500
Storage area (product)	m^2	2,809	19,873	19,873
Tank arrangement	-	1 sphere (15m dia)	6 spheres (24m dia)	6 spheres (24m dia)
Tank footprint	m^2	177	2,715	2,715

Table 7 Spatial requirements, MCH (organic carrier) conversion

Parameter	Measurement	Size 1 139,050 tpa	Size 2 556,200 tpa	Size 3 1,390,499 tpa
MCH (organic carrier) conversion				
Site *(land area + storage)*	m^2	26,415	84,020	207,549
Land area	m^2	9,855	39,500	100,000
Storage (product)	m^2	16,560	44,520	107,549
Tank arrangement	-	4 spheres (20m dia)	4 spheres (20m dia)	8 spheres (24m dia)
Tank footprint	m^2	1,257	1,257	5,620

Transport requirements

Transport of hydrogen

From a technical perspective, hydrogen is not a difficult resource to transport in that it may travel via pipeline, road tanker, rail carriages or vessels. The type of transport suitable for the transport of hydrogen is highly dependent on volumes and distances, and any options analysis should also take into consideration cost and risk. Low volumes of hydrogen would benefit from road tanker as the number of trucks per annum can be controlled based on output and there are no large infrastructure expenses. In contrast, high volumes of hydrogen would benefit from construction of a pipeline which can have a larger upfront expense, however, relatively lower running costs over time, and less interface with the community. Temporary use of these transport methods, excluding pipeline, may also be considered for initial production. If this occurs, a common depot may be a suitable solution to provide a common storage point and feed point into any domestic or export distribution.

Transport of carrier products

Depending on volumes, transportation of the carrier product is generally by road tankers (for small volumes) or by pipeline to storage and or export facilities. The option of road transport may be a practical solution to the transport of smaller volumes of product over longer distances although truck movements would be limited by the capacity and suitability of the transport network (traffic volumes, hazardous material routes, etc.) and capacity of the end point facilities. Table 8 shows the number of truck movements per annum required for the transport of GH2, LH2 and carrier product from the different plant capacity sizes. The table indicates that road transport is not considered practicable for any of the larger scale plants.

Table 8 Trucks dispatched

Parameter	Measurement	Size 1 8.687 tpa	Size 2 34,748 tpa	Size 3 86,870 tpa
H2 Production				
Trucks dispatched	Per day	63	254	634
	Per annum	23,133	92,352	231,330
Ammonia production				
Trucks dispatched	Per day	6	12	30
	Per annum	2,212	4,424	11,060
H2 liquefaction				
Trucks dispatched	Per day	11	21	54
	Per annum	3,923	7.846	19,616
MCH (organic carrier) conversion				
Trucks dispatched	Per day	17	34	86
	Per annum	6,268	12,535	31,338

There are several issues associated with the transport of the carrier product which will influence the preferred transport option from plants. For reference, large Australian container ports have around five thousand truck visits per day. In isolation these traffic volumes may not seem like a lot however they need to be viewed in context of the road capacity.

Port landing and storage requirements

There are no limits to the practical distance between hydrogen production and export locations, however, it is widely supported that the distance should be kept to a minimum to reduce pipeline/transport costs. Depending on the carrier process, the distance between an integrated plant and port can vary more greatly.

If an integrated plant is not established on port land, a port landing will require additional storage facilities while the resource is awaiting export by vessel. Liquefied hydrogen and refrigerated ammonia will also require considerable energy usage to remain at a suitable condition while awaiting export. The key criteria for hydrogen export ports are detailed in Figure 8.

Figure 8 Requirements for hydrogen export ports

A range of infrastructure upgrades may be required for Australia's ports to be capable of exporting hydrogen at scale. Infrastructure requirements vary according to the chemical state in which the hydrogen is to be transported and the vessel size on which it is to be transported.

3.3 Hydrogen industry requirements: MCA criteria

The Part 2 Report of the Gladstone and Townsville Hydrogen Opportunities Study identified the spatial and infrastructure requirements for the establishment of a hydrogen plant and carriers (downstream technologies) that can be used in selection and evaluation of alternative sites. Appendix A provides a consolidated table of these findings.

The application of all these criteria could be used to identify potential suitable locations for the model plant anywhere within the State (subject to land availability and legislative framework). SDAs offer generous areas of potentially suitable land for industry, however, a most selective use of criteria is applied in this study that is specific to an integrated hydrogen plant.

3.4 Summary

The production process and spatial requirements discussed in this Section were key considerations for developing three development scenarios for an integrated hydrogen plant. Refer to Appendix A for the consolidated table of the MCA criteria and Appendix C for a copy of the schematic plant layout developed. The following Section applies the MCA for the large capacity (size 3) integrated plant, with the electrolysis plant and carrier plant on the same site, to the Gladstone and Townsville SDA using the InDeGO Method, to identify suitable areas for development.

4. Selecting and evaluating potential hydrogen plant sites

4.1 Overview

The Gladstone and Townsville Opportunities Study has investigated and identified the land use planning, infrastructure and services required to support development of an integrated hydrogen plant and developed MCA criteria to be used in the selection and evaluation of sites for hydrogen plants. While the MCA criteria and evaluation methodology could be generally applied across the state of Queensland and broader Australia, the focus of this assessment was the Gladstone and Townsville SDAs, the rationale being:

- SDAs are clearly defined areas intended to promote economic development by:
  - Facilitating and concentrating industrial development in appropriate locations that minimise impacts to the environment and surrounding communities
  - Providing accessibility to key transport infrastructure, particularly ports and rail
  - Providing for the efficient provision of other enabling infrastructure
  - Providing efficient application processing and certainty for proponents
- Gladstone and Townsville SDAs were specifically chosen as potential hydrogen industry hubs due to their proximity to Queensland priority ports, key connections to major road and rail networks, availability or connectivity to high voltage electricity networks and access to reliable water supplies
- Both these SDAs already accommodate a number of large-scale, higher impact industries and potential complementary supply chain activities such as renewable or storage facilities
- Both SDAs offer generous areas of potentially suitable land well located with respect to available infrastructure and sufficiently remote from urban areas or other sensitive receptors.

This Section outlines the methodology and high level-results of the site selection process applied to the Gladstone and Townsville SDAs.

4.2 Methodology

4.2.1 Step 1: GIS Modelling to identify candidate areas

GIS analysis identified the candidate areas for industrial development in the Gladstone and Townsville SDAs using the InDeGO (Infrastructure Development – Geospatial Options) method. For this project, three production (development) scenarios were generated representing three levels of output. Different plant configurations were also considered, including an integrated plant where the electrolysis and carrier plant are co-located, and the alternative of separate sites for each plant component. For this assessment, a large capacity (size 3) integrated plant, with the electrolysis plant and carrier plant on the same site, has been evaluated using the InDeGO method.

This methodology uses GIS technology to select optimum locations for a hydrogen plant based on geographically characterised social, economic, engineering, planning and environmental criteria. Using the InDeGO method, the criteria are considered in terms of constraints and opportunities, geographically and mathematically. The spatial criteria used for applying the InDeGO method were developed in the Part 2 Report through research undertaken in Part 1.

As this assessment focussed on finding potential areas within SDAs, only those criteria required to select and evaluate developability (rather than to identify broad localities) were adopted, and these addressed the physical suitability of areas within the designated SDAs. Physical constraints included Native Title, tenure, waterways (WWBW), storm tide, erosion prone areas, bushfire prone areas, regional ecosystems, regulated vegetation, slope, and flood depth (available for Townsville only).

The InDeGO scoring system was used to assess the performance of potential areas within the SDAs against the criteria. The scores reflect the range of suitability or feasibility for a given criterion, from there being no constraints through to being extremely constrained. Physical constraints were scored as follows:

- 1 = not constrained
- 35 = moderately constrained
- 70 = highly constrained
- 99 = extremely constrained.

Physical constraints were then overlayed on top of each other and scores added together to give a sum score. Final traffic light system scoring was 1-10 = low constraint (**dark green**), 10-500 = moderate constraint (**light green**), 500-999 = high constraint (**orange**), 999+ = extremely constrained (**red**), as shown in Table 9 below.

Table 9 InDeGO scoring

Suitability	Score range	Meaning
Low constraint	1 – 10	The area has low constraints; it is generally physically suitable for a hydrogen plant.
Moderately constrained	10 – 500	The area is moderately constrained and may be suitable for a hydrogen plant, following further investigations.
Highly constrained	500 – 999	The area is highly constrained and unlikely to be physically suitable for a hydrogen plant, without incurring major development costs.
Fatal flaw	999 +	The area is extremely constrained and generally considered unsuitable for the development of a hydrogen plant.

Appendix A provides a detailed list of the MCA criteria. Appendix B provides the constraints category for each associated score of the MCA criteria. The InDeGO method is explained more in Appendix D.

The outcomes of the InDeGO model are presented in traffic light maps showing those areas with the highest suitability, based on the application of the physical criteria. The areas are then subjected to further evaluation in Step 2 below.

4.2.2 Step 2: Identifying shortlisted areas

A second evaluation process was undertaken on the shortlisted areas identified from the traffic light mapping. Additional criteria from the MCA list relating to proximity to a port and other key infrastructure were applied to identify those physically suitable areas also meeting the proximity criteria. While these criteria could also be used in Step 1, separating them enables greater transparency of the impact of individual criterion. This second step narrows down the search to shortlisted areas (polygons) that warrant further evaluation for the location of a hydrogen plant. This is the level of evaluation provided for in this Stage 3 report.

The proximity requirements included:

- Within 10km of the port (this criteria was awkward to apply for the Gladstone SDA given the geographic extent of the port, a more appropriate measure for subsequent assessments may be from a particular berth or wharf facility)
- Within 1km of a major road corridor
- Within 5km of an electrical substation
- With 1km of a 275kV transmission corridor.

It is noted that potential changes to proximity to roads, and other complimentary services such as gas pipelines may modify the final scoring. In some instances, future projects for gas pipelines had been discussed by the stakeholder groups, however no information was provided for inclusion into this study.

4.2.3 Step 3: Selection of preferred site

Although it is understood it is no longer the requirement of this project, the next step in the evaluation process would be a comparative ranking of each of the shortlisted areas against those applicable MCA criteria and definition of optimal locations. This would also include the consideration of additional non-spatial criteria (such as land ownership, settlement patterns, nature of adjacent industrial uses and specific information on servicing potential) for ranking the optimal locations within the Gladstone and Townsville SDAs for hydrogen plants.

In some instances, short listed areas may be eliminated following closer examination of these additional criteria.

4.2.4 Assumptions and caveats

This is a high-level evaluation of candidate and shortlisted areas limited to the Gladstone and Townsville SDAs (study area). The criteria adopted area not exhaustive, and there will be a range of other considerations that need to be considered when assessing the feasibility of individual (i.e. site-specific) opportunities, as noted above. The following assumptions and caveats have been adopted for this evaluation process:

- The size 3 production scenario for an integrated plant was adopted for the evaluation
- The key industry requirements (spatial only) outlined in Appendix A were adopted
- GIS modelling was limited to the following input data:
  - World imagery (for base map)
  - SDA land use categories
  - Sensitive land uses/receptors (including 500m and 1km buffers)
  - Environmental mapping: mapped waterways (including 100m and 200m buffer), regulated vegetation, storm tide inundation, erosion prone areas
  - Infrastructure: road mapping, energy distributor substations, electrical network, national electrical transmission lines
- The GIS modelled traffic light map is based on the cumulative physical constraints in the MCA criteria only.

4.3 Results

Based on the preceding methodology, a high-level evaluation of the Townsville and Gladstone SDAs has been undertaken. The results are outlined below.

In this instance, the study was limited to step 1 (GIS modelling) and step 2 (identifying shortlisted areas). Step 3 (selection of optimal locations) is highly dependent on a number of factors, in particular, the proponent's objectives and, therefore, has not been undertaken during this study. Instead, the potential next steps have been outlined in Section 5.3.

4.3.1 Step 1: Candidate sites

Individual layer constraints

As discussed in the Part 2 Report, land used to develop an integrated hydrogen plant should be generally free from constraints to maximise the allowable development footprint area while safeguarding the existing natural and built environment. The individual layer constraints mapping adds value in differentiating where a single layer may be identifying an area as extremely constrained, or where the cumulative impacts of multiple low constraint layers may be identifying a greater overall level of constraint over an area. This can inform whether further investigations over a site may be successful in mitigating low level risks or if the risk is too severe for one or two extremely constraining layers to accept. Figure 9 to Figure 16 show the results of the modelling for the Gladstone and Townsville SDAs, for each individual physical constraint.

Land use mapping

As shown in the mapping, the land has been zoned for predominantly industrial land uses, which is consistent with the intent for the SDA's to promote economy development in key Queensland locations by concentrating industrial development.

Sensitive land uses (as defined under Schedule 24 of the *Planning Regulation 2017*), which are likely to conflict with an integrated hydrogen plant use, are identified outside the boundaries of the SDAs. There is limited protrusion of the 500m and 1km buffers from these sensitive land uses into the SDA areas.

Environment mapping

The environmental mapping prepared for this study identifies protected areas, waterway barrier works and regulated vegetation.

Of the two, the Gladstone SDA is considered to contain a greater number of environmental values than Townsville. Land within the Gladstone SDA comprises approximately 5 protected areas in the eastern portion, and vegetation ranging from least concern regional ecosystems (RE) to category R vegetation. The predominant vegetation in the SDA is of concern RE. In contrast, the Townsville SDA does not contain any protected areas and vegetation is predominantly categorised as least concern RE.

Utilities facilities

The utilities facilities layer shows the Gladstone and Townsville SDAs are in good locations with proximity to key infrastructure. Each of the locations are provided with major road corridors providing access to key port and railway facilities. In most instances, the electrical infrastructure follow these road corridors and connect to substations inside the SDAs. These utilities facilities are more concentrated towards the urban areas of Gladstone and Townsville, which is to be expected.

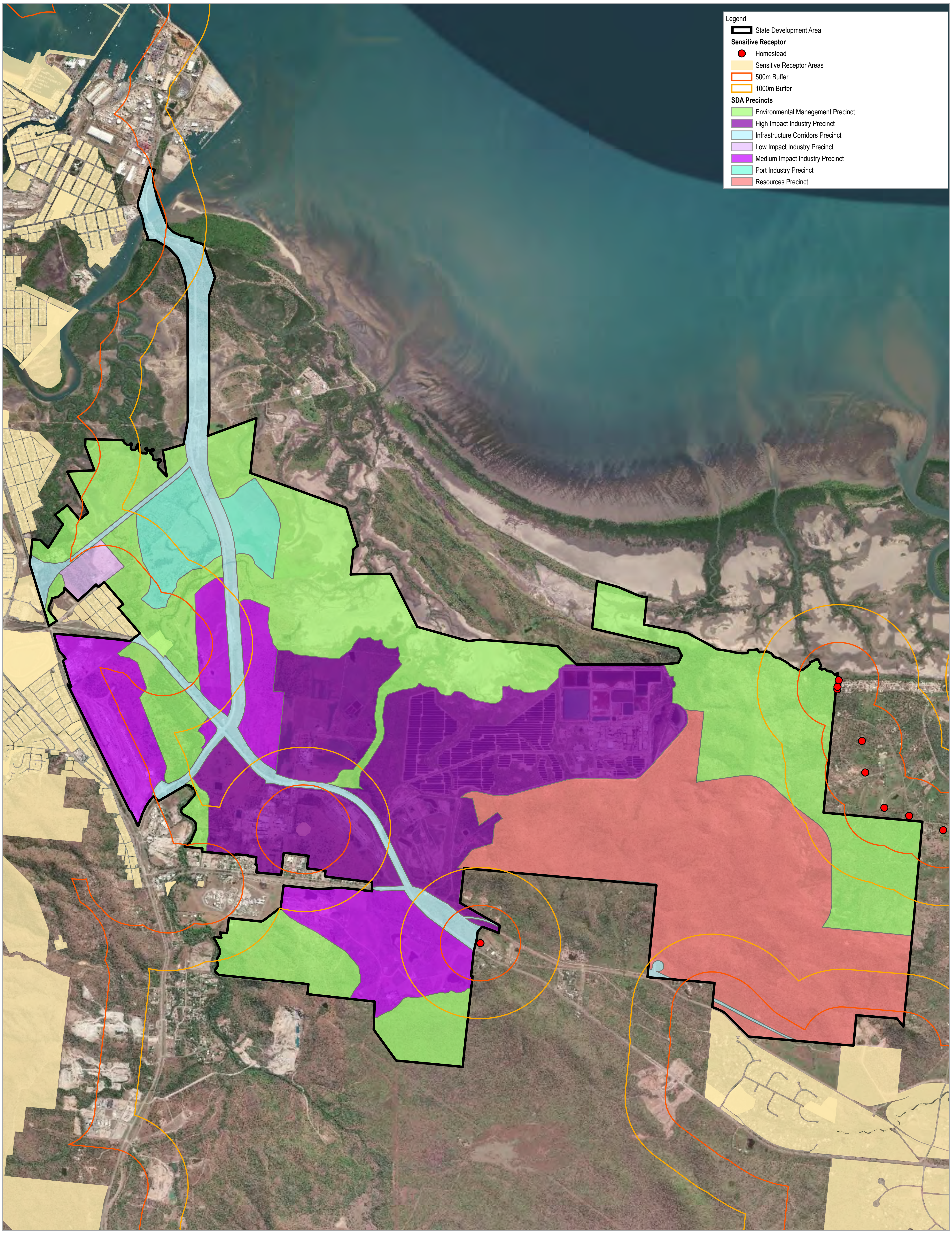
Flood mapping

The flood mapping layer shows the Gladstone and Townsville SDA flooding extent is minimal, concentrated along the coastline, subject to storm surges.

Cumulative constraints

Figure 17 and Figure 18 show the cumulative constraints InDeGO modelling for the Gladstone and Townsville SDAs. As expected, there are considerable areas of land within each SDA that would be physically suited for development (areas shown as dark and light green), with variations in topography having the greatest effect on the level of suitability. Areas unsuitable (shown in red) clearly reflect the impact of regional flooding and tidal surge close to the coast, and other absolute constraints such as urban land, areas of endangered regional ecosystems, waterways and steep land in excess of 15% grade.

In both SDAs, the amount of potentially suitable land close to the port appears relatively limited, constrained by tidal surge/coastal erosion of other environmental constraints. Gladstone SDA has extensive areas of potentially suitable land in the north and west of the SDA, although much of this is remote from the port and other infrastructure.



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Horizontal Datum: GDA 1994
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DSDMIP
Gladstone and Townsville Hydrogen Opportunities Study

Townsville State Development Area
Landuse

Project No. 12523263
Revision No. A
Date 16/07/2020

FIGURE 9

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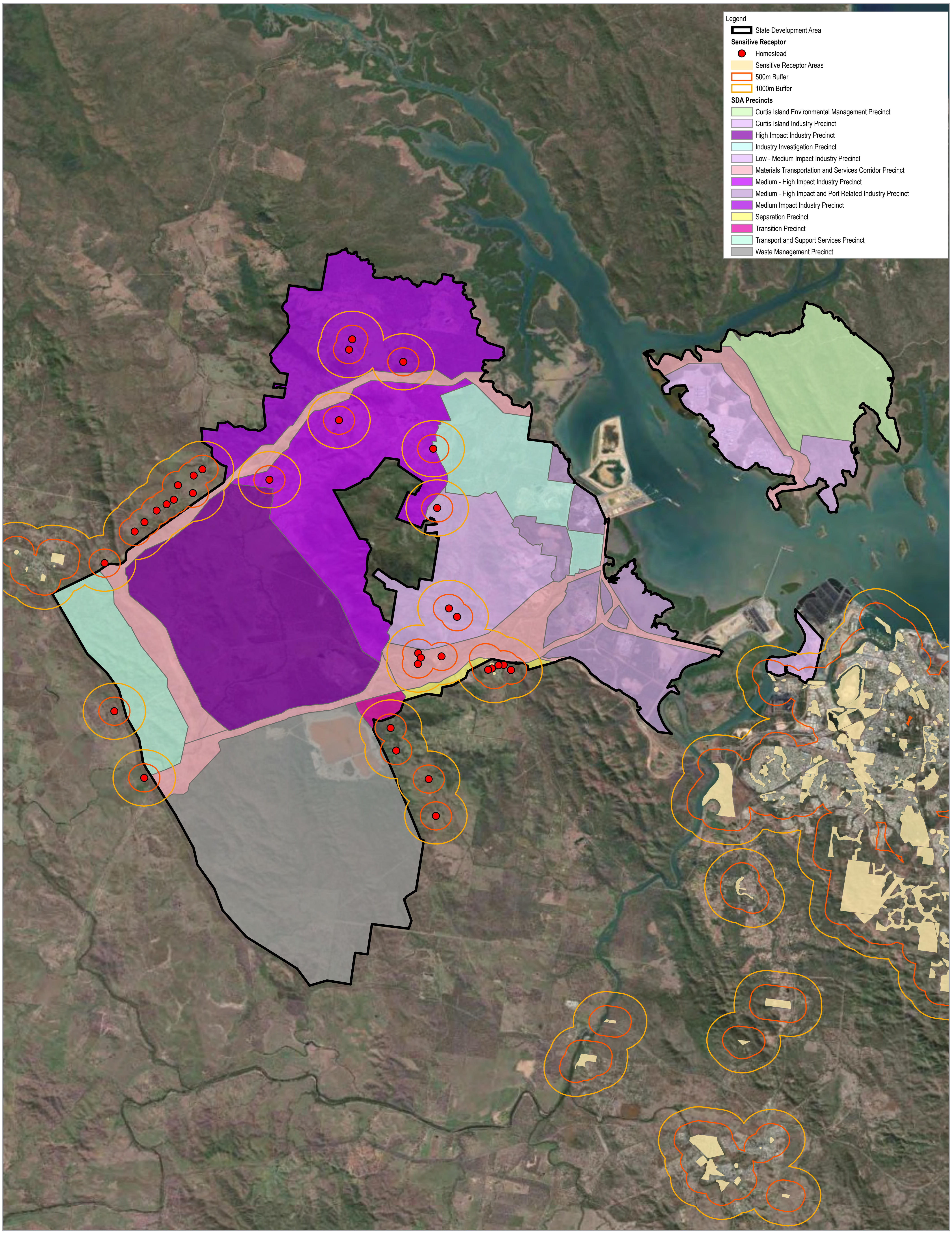

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Gladstone and Townsville Hydrogen Opportunities Study

Gladstone State Development Area
Landuse

Project No. 12523263
Revision No. A
Date 16/07/2020

FIGURE 10

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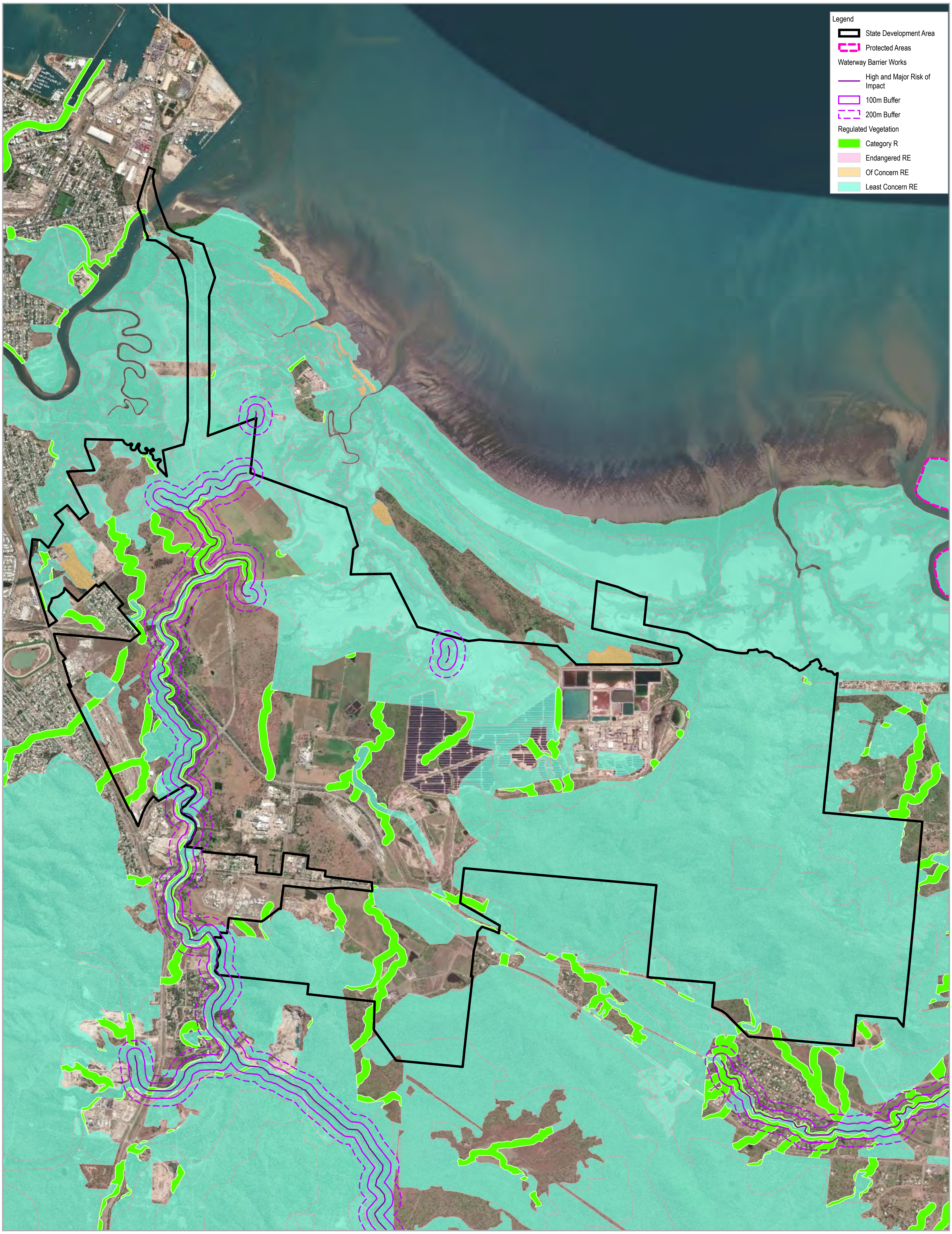

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Gladstone and Townsville Hydrogen Opportunities Study

Townsville State Development Area Environmental

Project No. **12523263**
Revision No. **A**
Date **16/07/2020**

FIGURE 11

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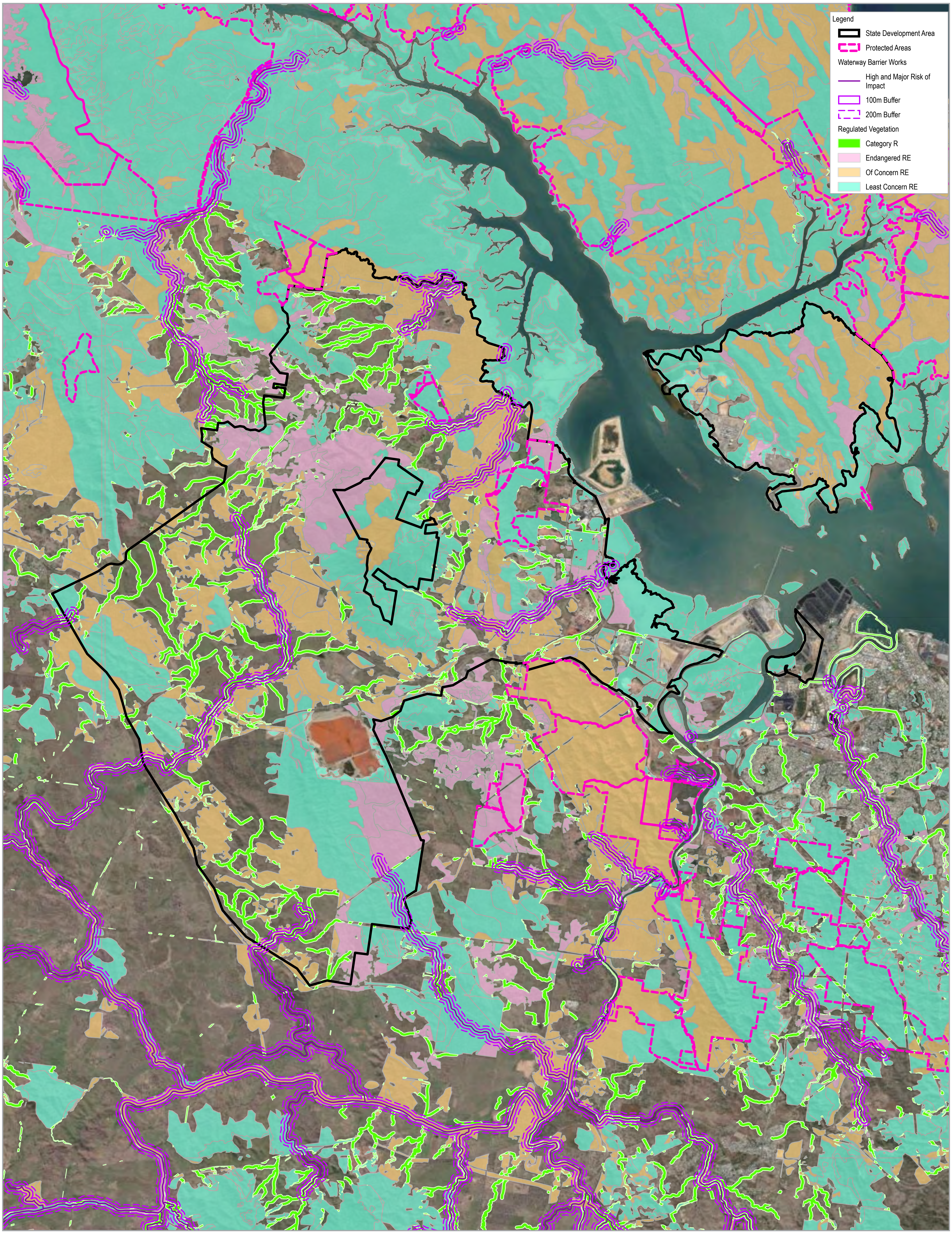

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DSDMIP
Gladstone and Townsville Hydrogen Opportunities Study

Gladstone State Development Area
Environmental

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Revision No. A
Date 16/07/2020

FIGURE 12

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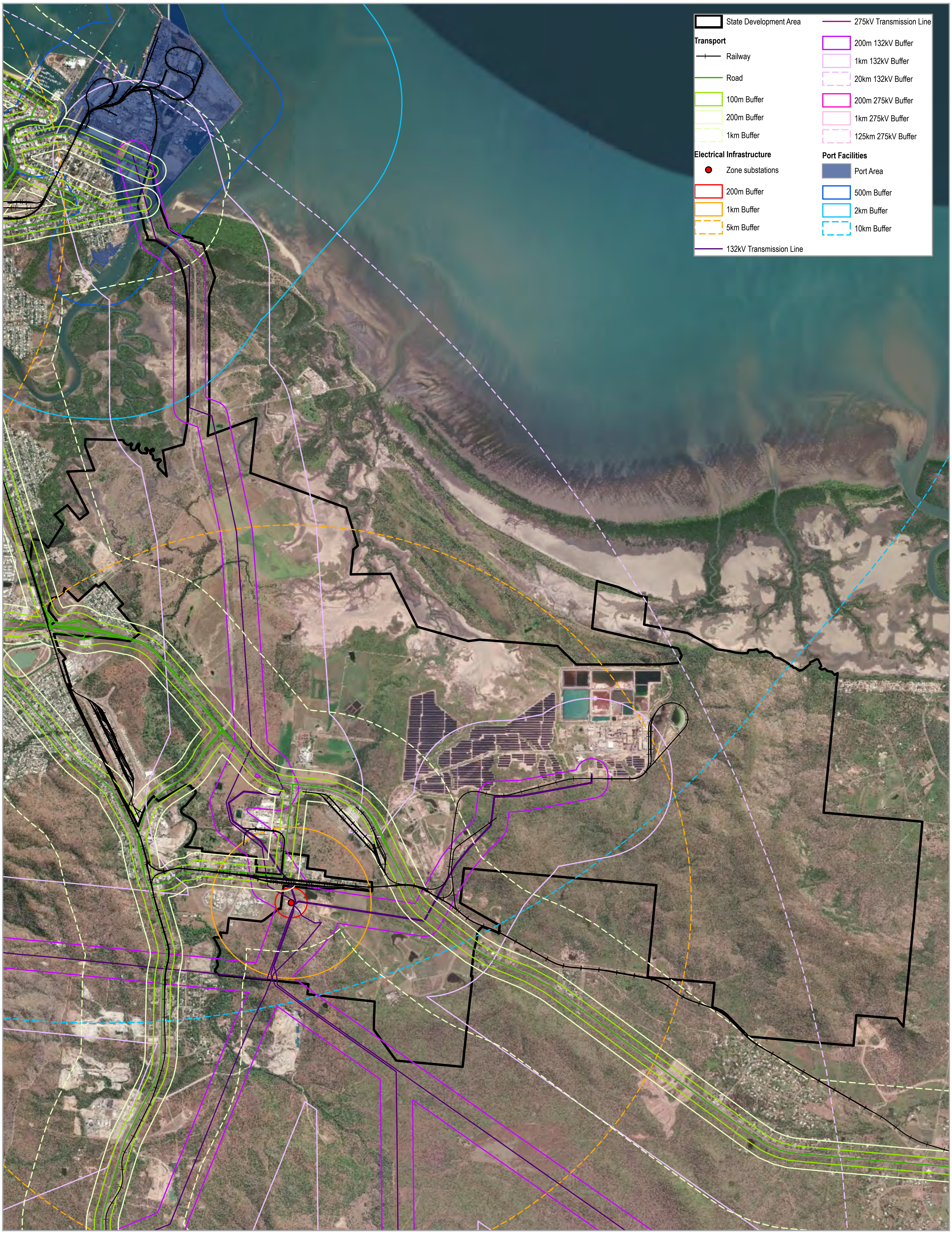

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DSDMIP
Gladstone and Townsville Hydrogen Opportunities Study

Townsville State Development Area
Utilities and Facilities

Project No. 12523263
Revision No. A
Date 16/07/2020

FIGURE 13

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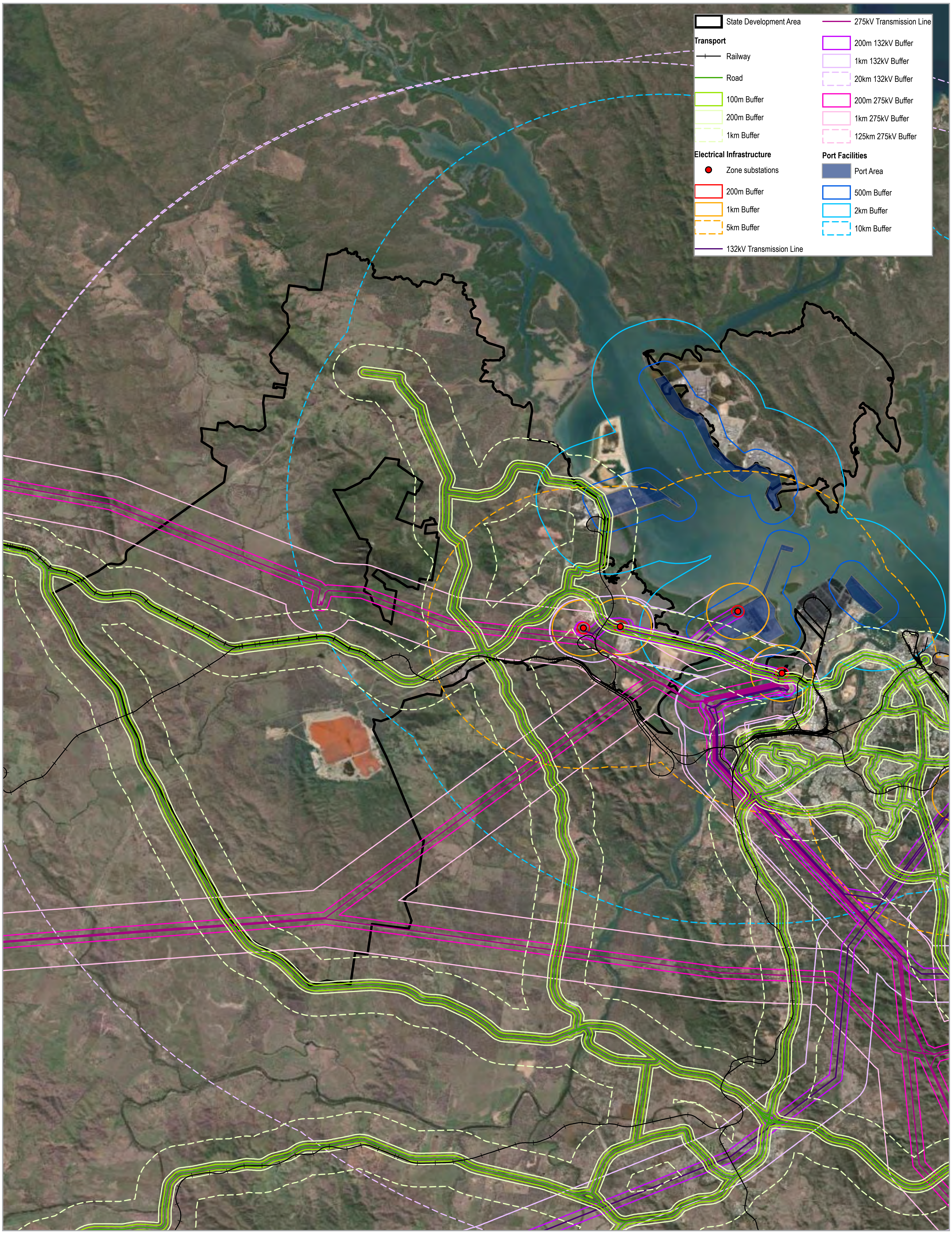

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Gladstone and Townsville Hydrogen Opportunities Study

Gladstone State Development Area
Utilities and Facilities

Project No. 12523263
Revision No. A
Date 16/07/2020

FIGURE 14

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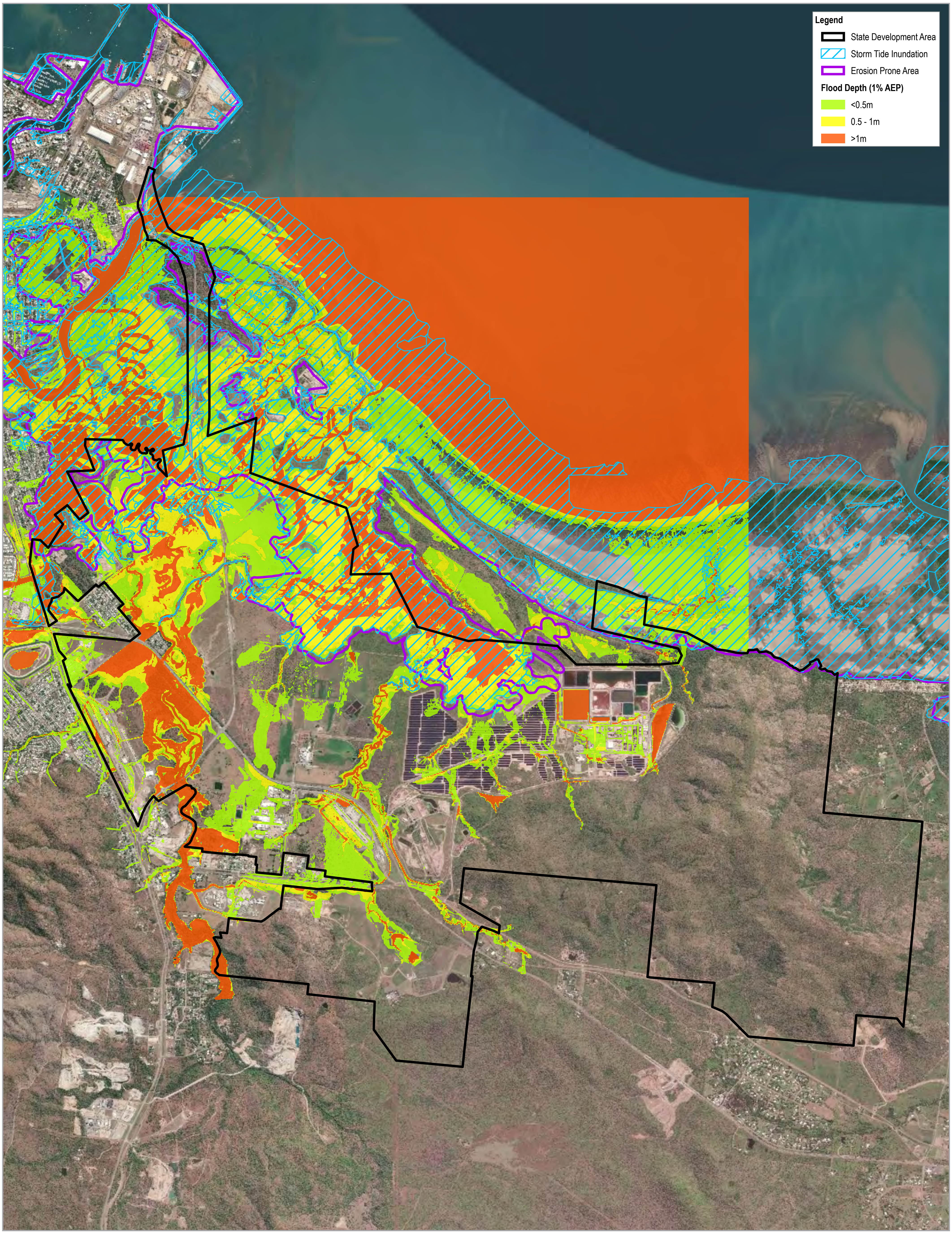

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Gladstone and Townsville Hydrogen Opportunities Study

Townsville State Development Area
Flood and Erosion

Project No. **12523263**
Revision No. **A**
Date **16/07/2020**

FIGURE 15

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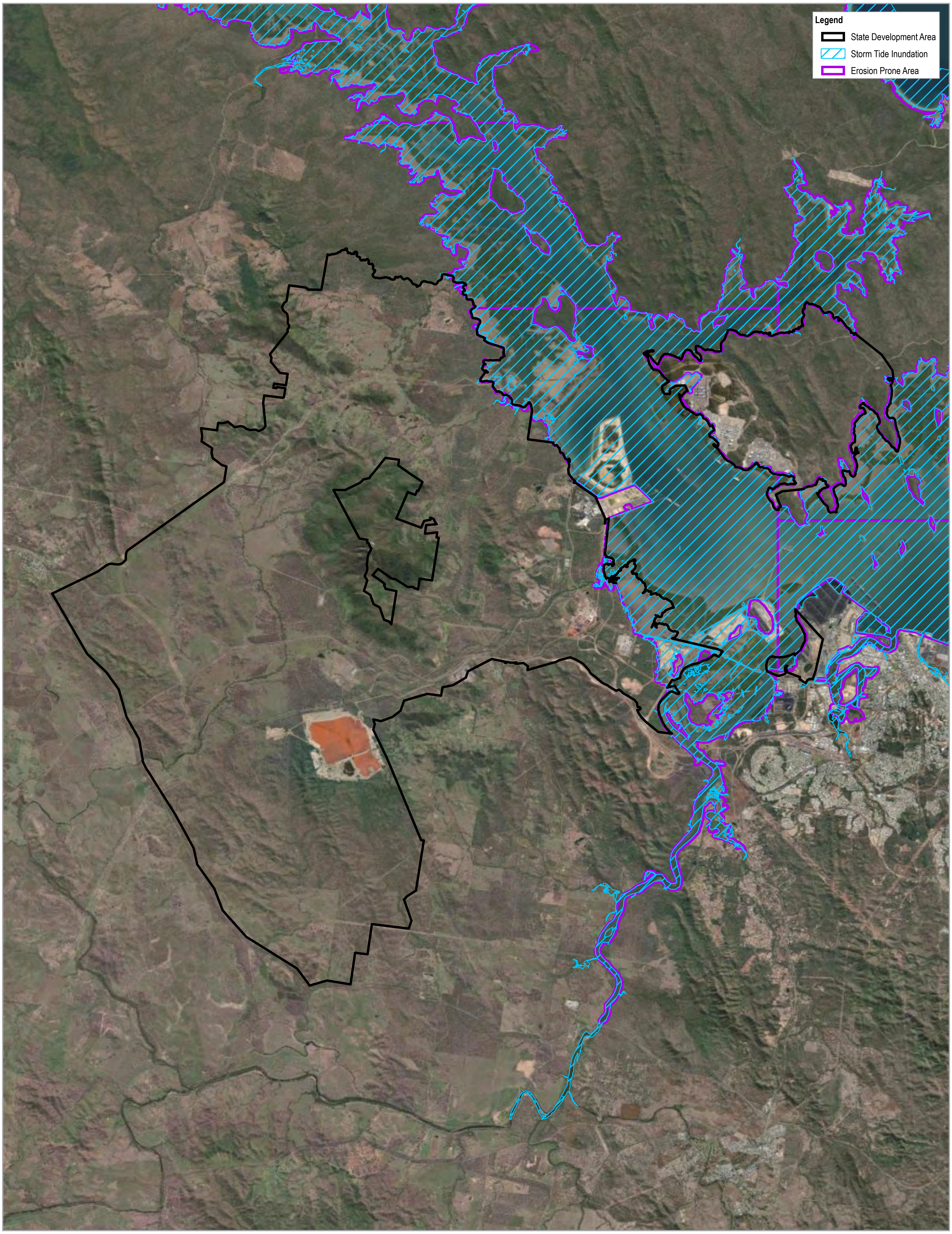

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DSDMIP
Gladstone and Townsville Hydrogen Opportunities Study

Gladstone State Development Area
Flood and Erosion

Project No. **12523263**
Revision No. **A**
Date **16/07/2020**

FIGURE 16

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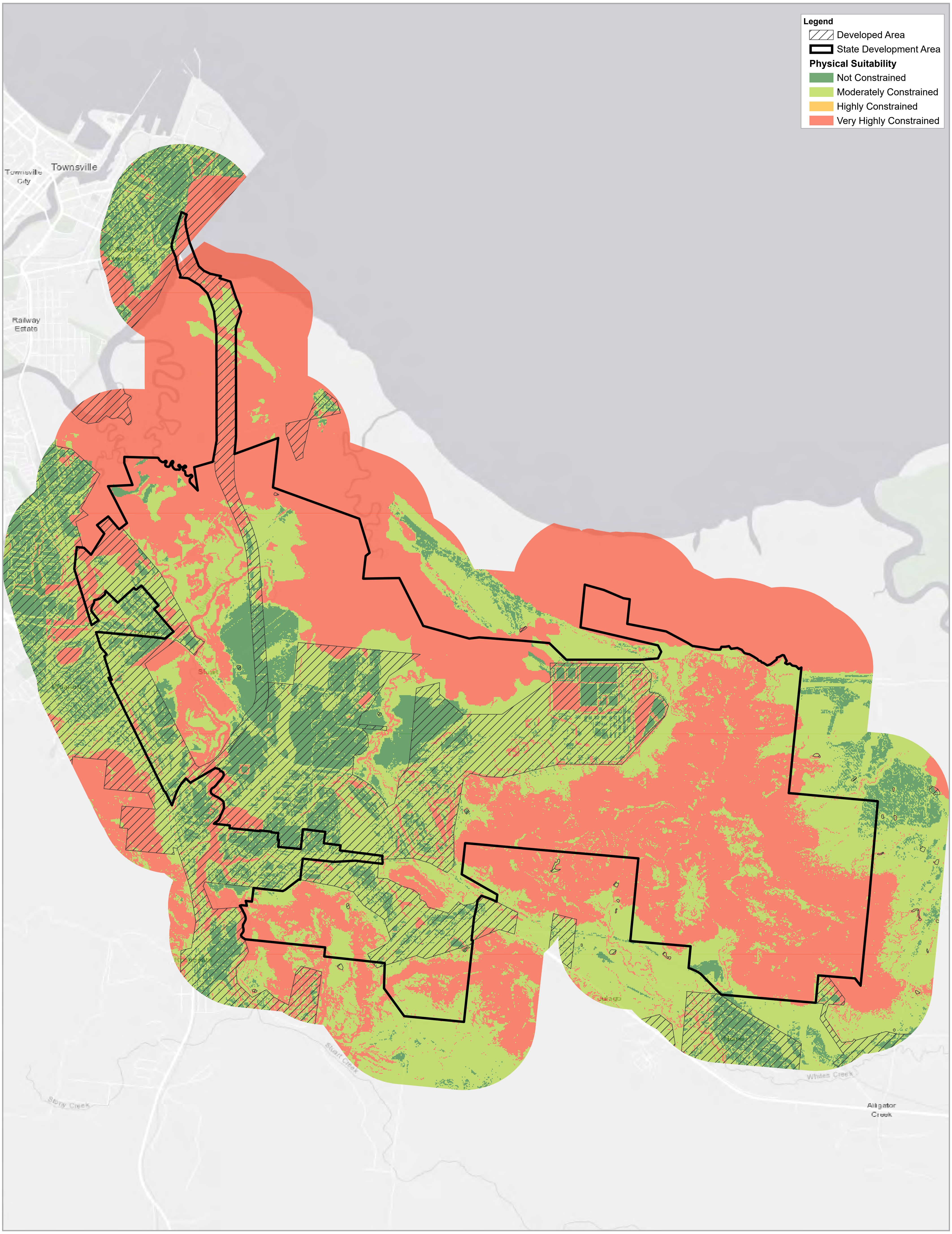

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DSDMIP
Gladstone and Townsville Hydrogen Opportunities Study

Townsville State Development Area Candidate Areas

Project No. 12523263
Revision No. C
Date 9/11/2020

FIGURE 17

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Print date: 09 Nov 2020 - 13:41

Data source: GHD: Physical Suitability (2020); DSDMIP: State Development Areas (2020)
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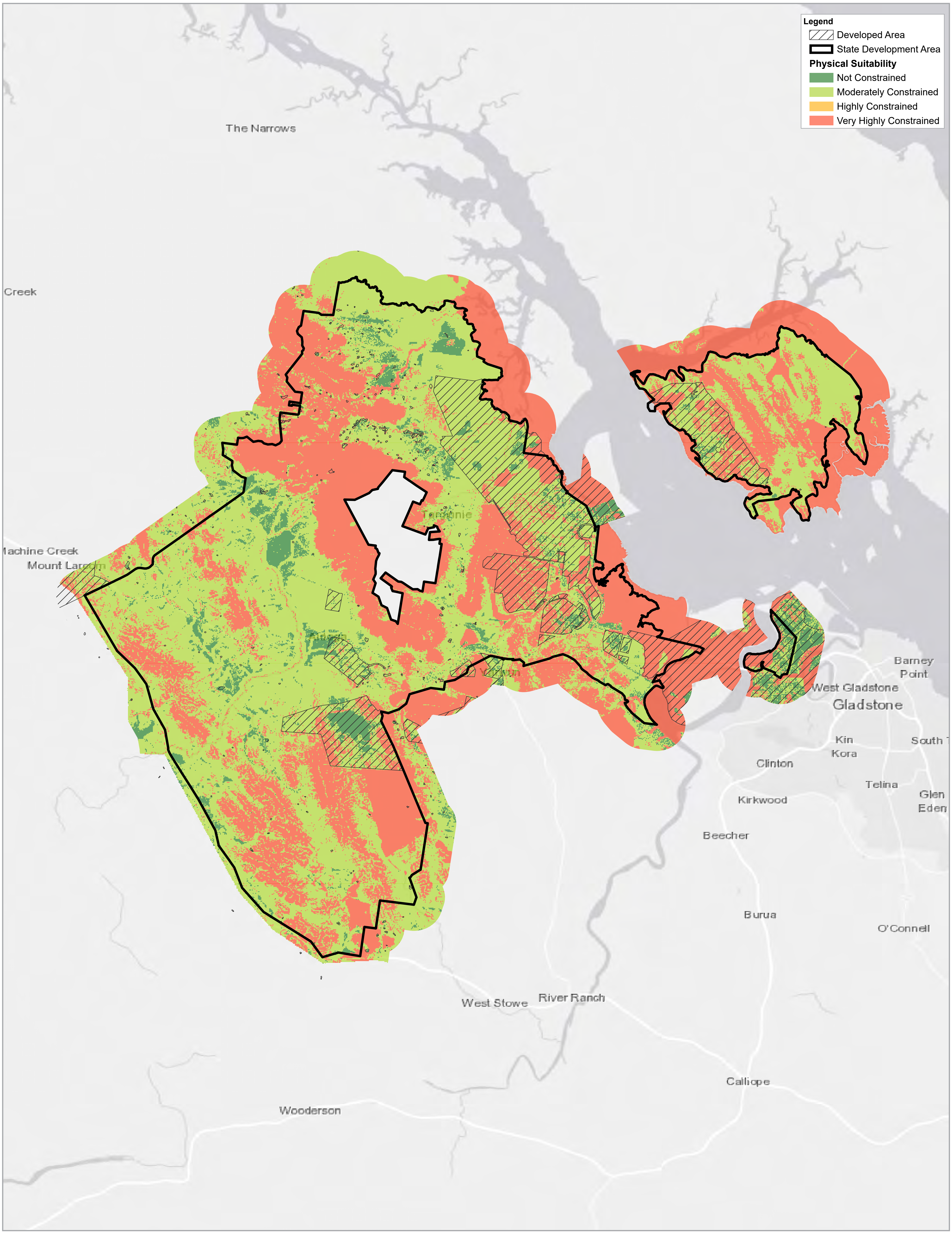

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DSDMIP
Gladstone and Townsville Hydrogen Opportunities Study

Project No.	**12523263**
Revision No.	**C**
Date	**9/11/2020**

Gladstone State Development Area Candidate Areas

FIGURE 18

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Print date: 09 Nov 2020 - 13:40

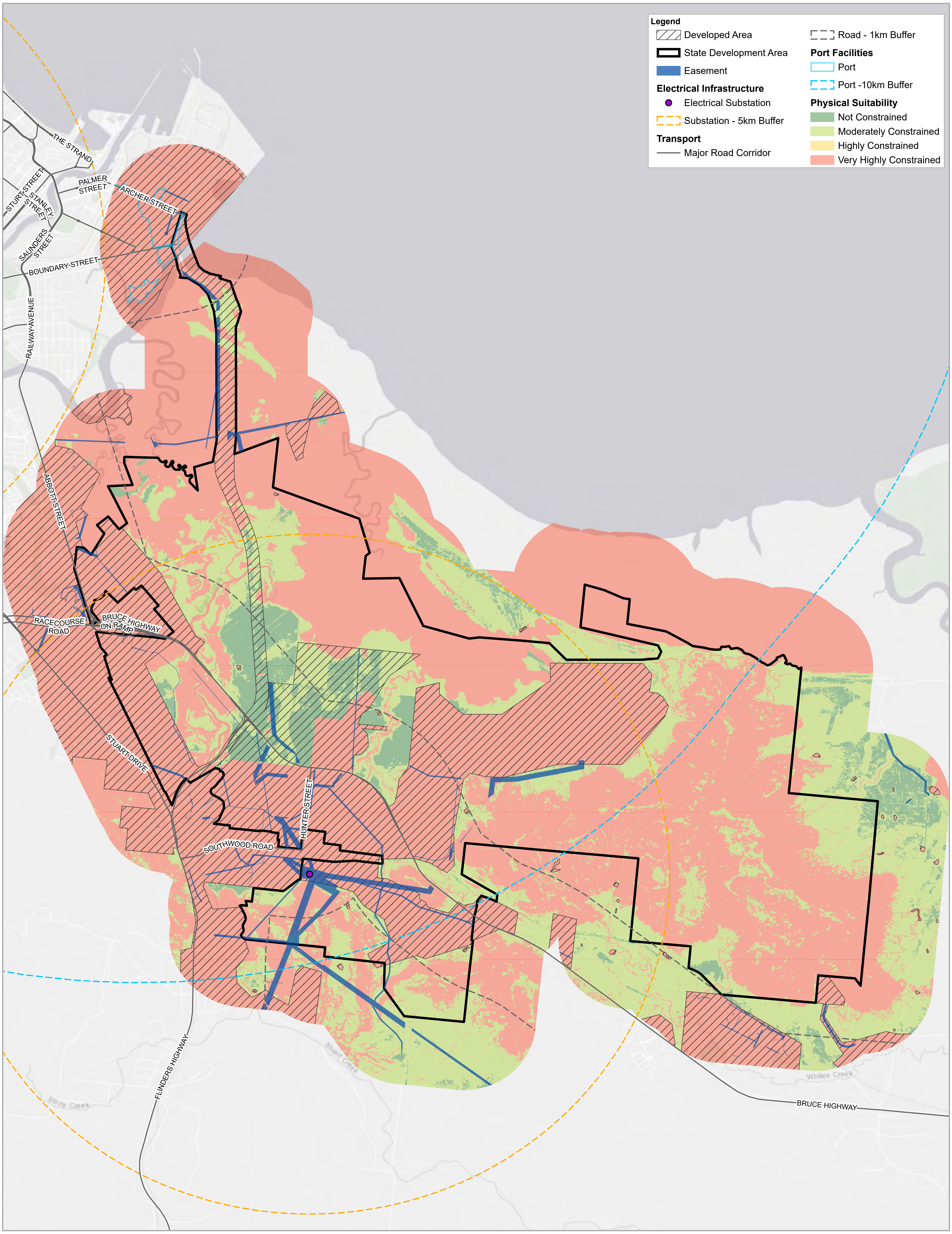
Data source: GHD: Physical Suitability (2020); DSDMIP: State Development Areas (2020)
World_Light_Gray_Reference: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community
World_Light_Gray_Base: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community. Created by: xlee

4.3.2 Step 2: Shortlisted areas

Accessibility to port, power and road infrastructure were the criteria adopted for the Step 2 evaluation to identify shortlisted areas. The proximity requirements from the MCA criteria were mapped and shortlisted areas identified in Step 1 falling within the proximity requirements were identified. For confidentiality reasons, the shortlisted areas' polygons have not been presented in this report's mapping. These have been provided as a separate document to the DSDILGP.

Figure 19 and Figure 20 show the mapping results of the InDeGO modelling for the Gladstone and Townsville SDAs, exclusive of the shortlisted areas (polygons). While there are still considerable areas of land within each SDA that would be physically suited for development (areas shown as dark and light green), there is an increase in areas unsuitable (shown in red) reflecting the impact of proximity requirements for infrastructure.

In both SDA's, the amount of potential suitable land close to the port remains relatively limited, as was found in Step 1: candidate sites.



Based on or contains data provided by the State of QLD (DNRME) 2020. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability,completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for marketing or be used in breach of the privacy laws.

Paper Size ISO A3

0 1

Kilometres

Horizontal Datum: GDA 1994
Grid: GCS GDA 1994

N

DSDMIP
Gladstone and Townsville Hydrogen Opportunities Study

Townsville State Development Area
Proximity Requirements

Project No. 12523263
Revision No. A
Date 27/11/2020

FIGURE 19

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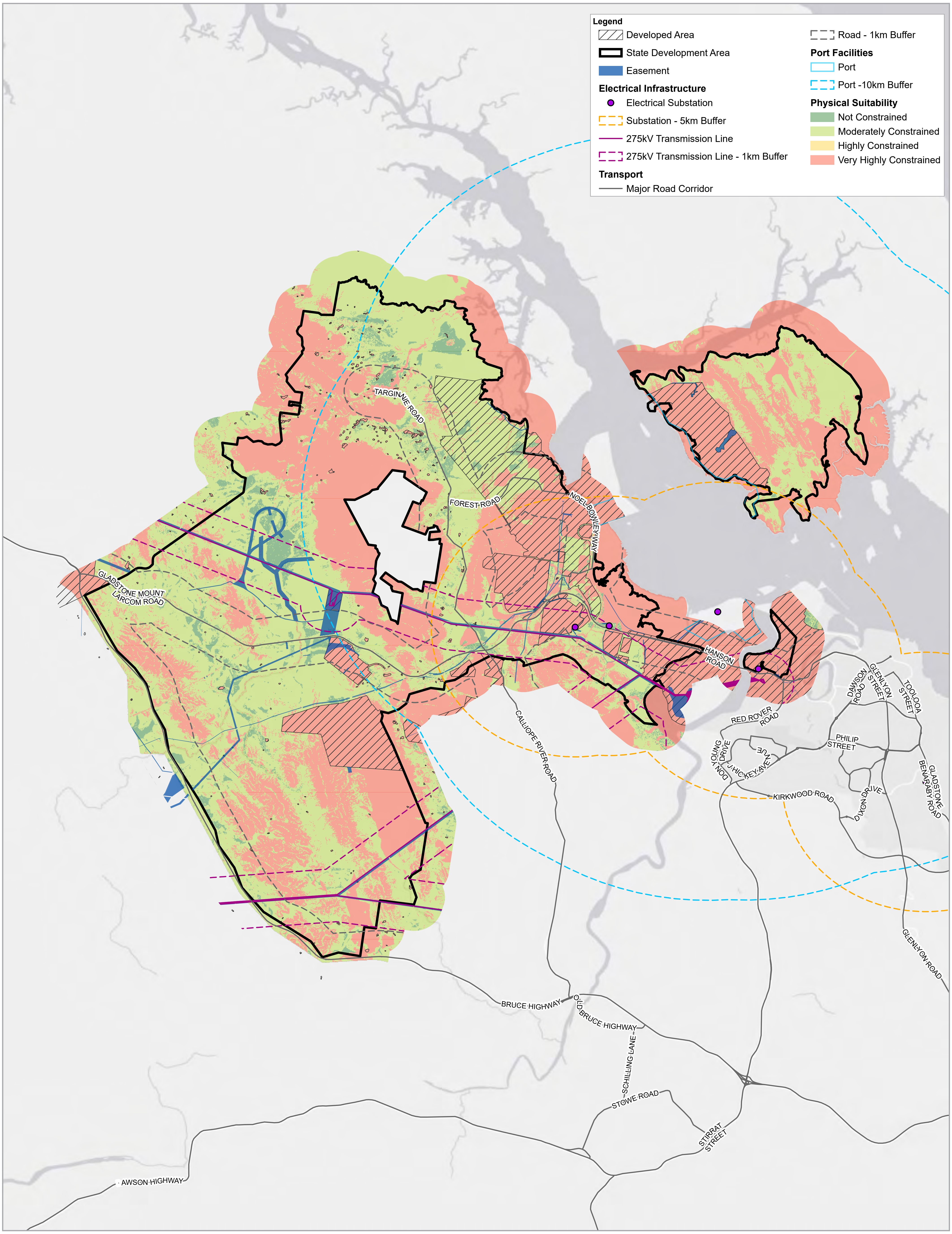
Print date: 27 Nov 2020 - 08:35

Data source: GHD: Port Area digitised, Physical Suitability, Proximity Buffers (2020); DSDMIP: State Development Areas (2020); DNRME: Road (2019); Ergon: Substations, Electrical Network (2020); GA: National Electrical Transmission Lines (2010) World_Light_Gray_Base: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community. Created by: xlee



DSDMIP
Gladstone and Townsville Hydrogen Opportunities Study

Gladstone State Development Area
Proximity Requirements

Project No. 12523263
Revision No. A
Date 27/11/2020

FIGURE 20

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Print date: 27 Nov 2020 - 08:35

Data source: GHD: Port Area digitised, Physical Suitability, Proximity Buffers (2020); DSDMIP: State Development Areas (2020); DNRME: Road (2019); Ergon: Substations, Electrical Network (2020); GA: National Electrical Transmission Lines (2010) World_Light_Gray_Base: Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community. Created by: xlee

4.4 Planning framework

To progress the selection of any shortlisted area, it is important to review the relevant planning framework as an overarching consideration for facilitating an integrated hydrogen plant.

This framework currently neglects to provide a streamlined approval pathway for hydrogen production facilities and ancillary infrastructure such as renewable energy and refuelling stations. To close this gap, the Queensland Government intend to collaborate with other jurisdictions to develop a policy framework for the emerging hydrogen industry. In the interim, the Queensland Government has established a hydrogen inter-departmental working group to coordinate hydrogen-related activities across the State's departments[23].

The Queensland Government has published the Queensland Hydrogen Investor Toolkit intended to *"assist investors with project planning for hydrogen developments in Queensland. It provides an overview of the planning and other regulatory approvals information in Queensland[24]."* The document is not static in that it will be regularly updated as engagement with project proponents and experience with hydrogen projects feeds new information.

4.5 Summary

The InDeGO analysis undertaken for this Part 3 report has drawn on individual constraints layers to identify candidate and shortlisted areas for a future integrated hydrogen plant. While the analysis has been limited to the Gladstone and Townsville SDAs, the MCA criteria and methodology developed could be generally applied across Queensland and Australia.

Based on the results of this analysis, there are considerable areas of land within each SDA that would be physically suited for development. To progress further, we recommend undertaking a comparative ranking for shortlisted areas in consideration of the applicable MCA and additional non-spatial criteria.

23 State of Queensland, Department of State Development, Manufacturing, Infrastructure and Planning, 2019

24 State of Queensland, Department of State Development, Local Government, Infrastructure and Planning, 2020

5. Key findings and next steps

5.1 Objective of Part 3 report

The Gladstone and Townsville Hydrogen Opportunities Study Part 3 applied the criteria developed through research undertaken in Part 1, and the development scenarios identified in Part 2, to identify potential areas for establishment of an integrated hydrogen plant within the Gladstone and Townsville SDAs through a limited Multi-Criteria Analysis (MCA) process.

Alternative plant configurations and plant sizes were addressed in the Stage 2 report. For the Part 3 report, a large capacity (Size 3) integrated plant, with the electrolysis plant and carrier plant on the same site has been used for the site selection modelling. The purpose of this Part 3 report was to document the shortlisted locations for a hydrogen plant in the Gladstone and Townsville SDAs.

5.2 Key findings

The application of selected MCA criteria to the Gladstone and Townsville SDAs identified a short list of potential areas within each SDA for the potential location of a hydrogen plant.

The areas identified are approximate only and limited in accuracy by the scale of mapping. As such, they are not meant to show the detailed extent of potentially suitable land but rather the general area in which more detailed evaluations would be warranted.

5.3 Next steps

Should DSDILGP decide to progress the selection of a preferred site for an integrated hydrogen plant within each of the SDAs, the following are the recommended next steps:

- Ground truth the shortlisted areas identified in this Part 3 report to confirm the physical suitability and review the nature of any existing land uses within and/or adjacent to each area
- Refine the short list of areas based on this ground truthing and higher scale analysis of data layers
- Consider other non-spatial contextual criteria (such as land ownership, settlement patterns, nature of adjacent industrial uses and specific information on servicing potential)
- Define optimal locations within the shortlisted areas
- Undertake a comparative ranking of each of the optimal locations within the shortlisted areas against all applicable spatial and non-spatial MCA criteria to identify a preferred site (or sites)
- Engage with relevant State and local authorities to confirm the serviceability of the preferred site or identify any required measures to address serviceability issues.

6. Conclusion

6.1 Hydrogen’s success beyond 2020

The overall Gladstone and Townsville Hydrogen Opportunities Study fills a gap in informing a holistic overview for the broader hydrogen industry from developing a schematic plant layout to MCA to determine the spatial criteria for the establishment of an integrated hydrogen plant.

The **Part 1 Report** consolidated the findings of the available literature and case studies to produce a conceptual hydrogen flow schematic. For North Queensland’s Townsville and Gladstone SDAs, the *Queensland Hydrogen Industry Strategy 2019-2024* maps out a strategic five-year plan to grow and sustain the State’s emerging hydrogen industry. This strategy advances the vision of the *Australia’s National Hydrogen Strategy 2019*. While there are limited applications of hydrogen currently, the long-term future of Australia’s emerging hydrogen industry is well-supported by government and industry leaders through recent publication of roadmaps and feasibility assessments.

In reviewing these technical publications, the conceptual hydrogen flow schematic outlined that hydrogen may be used as an energy supply, however, is not currently economically viable to transport at atmospheric conditions (due to the low energy content). Therefore, hydrogen carriers are strongly recommended. This flow schematic was then refined to develop the **Part 2 Report’s** three hydrogen plant scenarios of varied size and capacity. The development scenarios established a baseline for identifying, developing and refining the locational criteria for a hydrogen plant and consolidated in a table (Appendix A).

Key stakeholders intend to produce hydrogen for domestic use, however, describe hydrogen export as the greatest short-term opportunity for hydrogen production within Australia. This reinforced much of the literature drawn upon in Part 1 that Australia’s ability to establish itself as a prominent exported of hydrogen is reflective of the success of the LNG industry in Queensland. Part 2’s market projections estimate a future global hydrogen economy with average demand ranging from 173.0 to 288.4 million tonnes hydrogen per annum by 2050.

Growing a sustainable hydrogen industry domestically, to take advantage of this new export market, is a key Queensland Government objective. Integration of renewable energy in the form of green hydrogen into Queensland’s energy offering has the potential to provide economic, environmental policy and social opportunities. The **Part 3 Report** analysed and identified potential locations for a future integrated hydrogen plant in the Gladstone and/or Townsville SDAs. Using the InDeGO spatial application method, GHD has conducted a preliminary site evaluation of the spatial physical constraints criteria identified. The findings revealed that there are considerable areas of land within each SDA that would be physically suited for development. These areas provide land that would support an integrated hydrogen plant, in that they are in good locations with proximity to key infrastructure and a low level of overall constraints. These locations may avoid or minimise the duplication of infrastructure, impacts to the environment, loss of amenity and transport conflicts.

The Gladstone and Townsville Hydrogen Opportunities Study highlighted that the success of the hydrogen industry for both the export market and domestic uses will be reliant upon the availability of a number of interrelated criteria (Figure 21), grouped broadly into the following categories:

- **Physical** requirements to support production, including proximity to ports for export, land mass, and infrastructure

- **Technology** advancements / availability
- **Environmental** impacts on the receiving environment, and more broadly the use of fossil fuels for production
- **Financial / economic** drivers for local and international investment
- **Risk** to surrounding land uses, sensitive receptors, and the environment
- **Statutory** limitations or agility to respond to emerging technologies and trends in land use
- **Community perception / stakeholder expectations** in regard to risk to human health, impact on the environment, creation of jobs and industry.

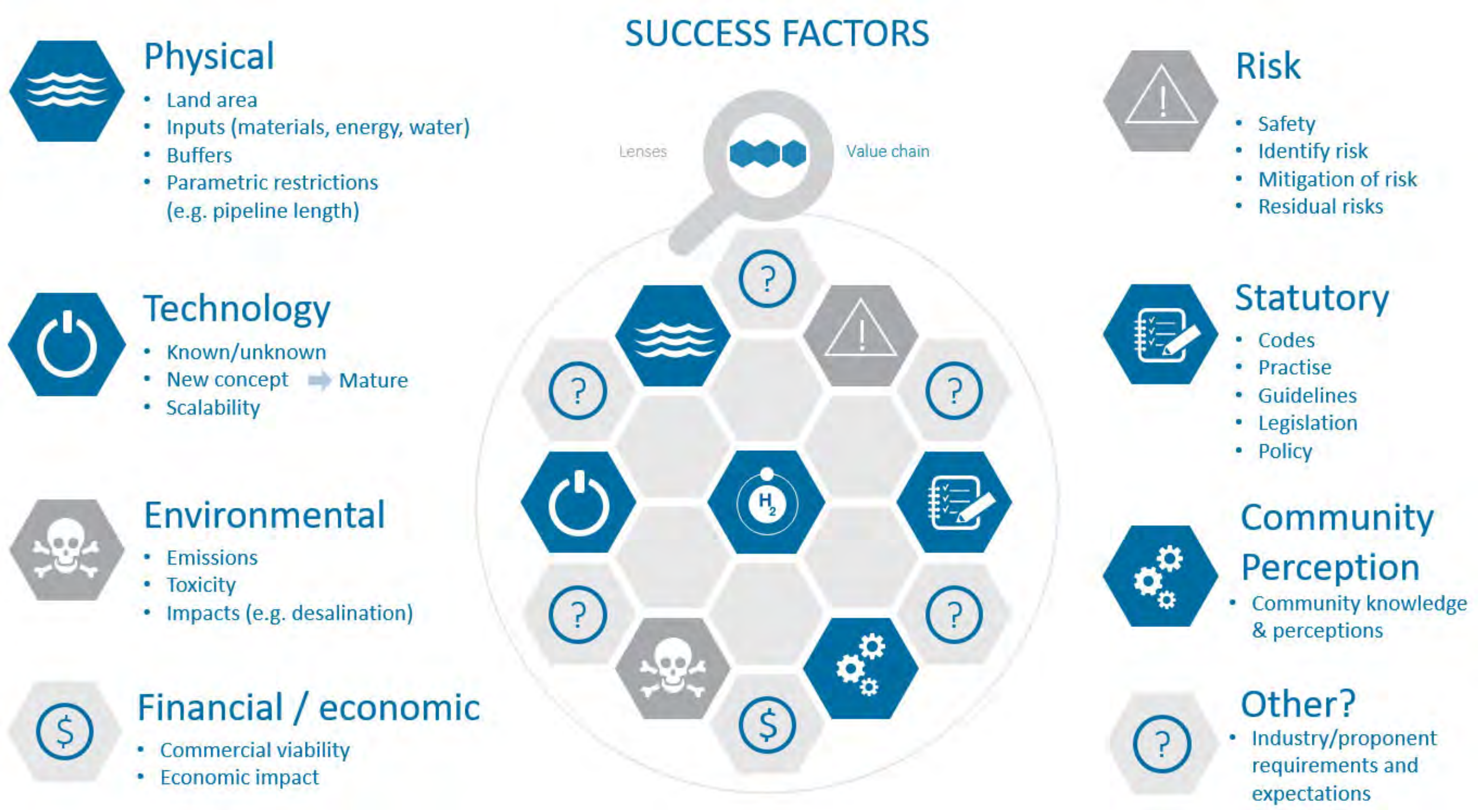

Figure 21 Hydrogen industry inputs

This study's holistic overview of the emerging hydrogen industry reveals potentially significant domestic opportunities and provides a toolkit of steps necessary to analyse a defined area to identify shortlisted sites. To expand DSDILGP's investigations into the emerging hydrogen industry in Queensland, GHD recommends broadening the investigation of potential sites to other regions throughout the state using the InDeGO method.

7. References

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Appendices

Appendix A – MCA criteria

MCA for hydrogen plant

	Production			Downstream technologies								
	H_2			**Ammonia**			**H_2 liquefaction**			**MCH (organic carrier) conversion**		
	Size 1	Size 2	Size 3	Size 1	Size 2	Size 3	Size 1	Size 2	Size 3	Size 1	Size 2	Size 3
	8,687 tpa	34,748 tpa	86,870 tpa	46,504 tpa	180,017 tpa	465,043 tpa	8,513 tpa	34,053 tpa	85,133 tpa	139,050 tpa	556,200 tpa	1,390,499 tpa
Non-derivative specific												
Preferred zoning	Industry Zoning (Industry Zone, Low Impact Industry Zone, Medium Impact Industry Zone, High Impact Industry Zone, Special industry Zone, Industry Investigation Zone)											
Environmental	A site should be generally free from constraints having regard to physical, airshed, infrastructure, and land use considerations. Where land is constrained, further investigations may be required, or the land may be too constrained and unsuitable for development of a hydrogen plant / downstream technologies.											
Legislative approval pathway	• Commonwealth approvals • Overarching project approvals: – Option 1: material change of use development approval and determination of a major hazard facility – Option 2: co-ordinated project and determination of a major hazard facility • Specific assessable development approvals.											
Tenure	Freehold (site) or leasehold (site and pipeline corridor)											
Native Title	Site to have Native Title extinguished											
Derivative Specific												
General												
Site (m^2) *(land area + storage)*	4,375	18,375	45,938	14,418	54,329	111,480	6,959	36,473	61,373	26,415	84,020	207,549
Land area (m^2)	4,375	18,375	45,938	9,160	36,640	91,599	4,150	16,600	41,500	9,855	39,500	100,000
Storage (m^2).[25]	1,352	4,046	7,700	5,258	17,689	19,881	2,809	19,873	19,873	16,560	44,520	107,549
Tank arrangement [18]	2 tanks (13m dia)	4 tanks (17m dia)	6 tanks (20m dia)	2 tanks[26] (12m dia)	4 spheres (22m dia)	4 spheres (24m dia)	1 sphere (15m dia)	6 spheres (24m dia)	6 spheres (24m dia)	4 spheres (20m dia)	4 spheres (20m dia)	8 spheres (24m dia)
Tank footprint (m^2)	265	908	1885	226	1,521	1,809	177	2,715	2,715	1,257	1,257	5,620
Separation distances[27]												
Min (m)	5.8[28]	5.8	5.8	38	45	45	23	23	23	3	3	3
Max (m)	14[29]	14	14	150	180	180				10	10	10
Infrastructure (Power)												
Use (MW)	77	308	770	10	41	102	7	29	73	2	6	16
Power line distance limit @ 33kV (km)	Not suitable	Not suitable	Not suitable	150	40	Not suitable	210	60	Not suitable	+500	240	100

[25] Product storage for H2 is minimal, storage is for brine based on 30 day retention and half diameter separation between tanks.
[26] For most tank arrangements, a separation of one tank diameter is assumed between tanks. Added to that is a standard requirement for separation of tanks from a fence line, road or equipment.
27 Standard separation distances have been adopted from AS2022, Table 3.1.
[28] Separation distance for bulk compressed gaseous hydrogen from most equipment/objects.
[29] Separation distance for bulk compressed gaseous hydrogen from roads, buildings, fence lines.

	Production			Downstream technologies								
	H_2			Ammonia			H_2 liquefaction			MCH (organic carrier) conversion		
	Size 1	Size 2	Size 3	Size 1	Size 2	Size 3	Size 1	Size 2	Size 3	Size 1	Size 2	Size 3
	8,687 tpa	34,748 tpa	86,870 tpa	46,504 tpa	180,017 tpa	465,043 tpa	8,513 tpa	34,053 tpa	85,133 tpa	139,050 tpa	556,200 tpa	1,390,499 tpa
Power line distance limit @ 66kV (km)	80	Not suitable	Not suitable	+500	150	60	+500	210	80	150	150	120
Power line distance limit @ 132kV (km)	300	70	30	+500	+500	220	+500	+500	300	+500	+500	380
Power line distance limit @ 275kV (km)	>500	300	120	+500	+500	+500	+500	+500	+500	+500	+500	+500
Infrastructure (Water)												
Use (electrolyser + brine H_2 only) (ML/a)	136	543	1335	3	11	29	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Disposal (ML/a)	32	125	313	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Co-locating activities	No	No	No	With hydrogen production/connected with pipeline to hydrogen production/co-located at port/connected to port with pipeline			With hydrogen production/connected with pipeline to hydrogen production/location at port preferred.			With hydrogen production/connected with pipeline to hydrogen production/location at port preferred.		
Infrastructure (Transport)												
Road (t/truck) – bulk product	0.215 (tube trailer at 20 MPag) - 0.615 (cylinders on truck at 30 MPag) Calculated 0.376 tonnes / tube trailer Alternative transmission for gaseous hydrogen is a hydrogen pipeline, or injection into a natural gas pipeline (most NG pipeline material selection will allow for up to 20 mole% H_2 in the line)			21 (assume single trailer / tank combination)	42 (assume B-double with 2 x tank)	42 (assume B-double with 2 x tank)	2.17 (assume single trailer / tank combination)	4.34 (assume B-double with 2 x tank)	4.34 (assume B-double with 2 x tank)	22 (assume single trailer / tank combination)	44 (assume B-double with 2 x tank)	44 (assume B-double with 2 x tank)
Trucks dispatched (per annum)	23,133 (63 per day)	92,352 (254 per day)	231,330 (634 per day)	2,212 (6 per day)	4,424 (12 per day)	11,060 (30 per day)	3,923 (11 per day)	7.846 (21 per day)	19,616 (54 per day)	6,268 (17 per day)	12,535 (34 per day)	31,338 (86 per day)
T50 ISO Tank Containers (t/ISO)	Not Applicable	Not Applicable	Not Applicable	14.3	14.3	14.3	Not Applicable	Not Applicable	Not Applicable	15.1	15.1	15.1
ISO (per annum)	Not Applicable	Not Applicable	Not Applicable	3,250 (9 per day)	13,001 (36 per day)	32,502 (89 per day)	Not Applicable	Not Applicable	Not Applicable	9,210 (25 per day)	36,839 (101 per day)	92,096 (252 per day)
Rail (t/carriage) – bulk product	Assume same load as road tube trailer	Assume same load as road tube trailer	Assume same load as road tube trailer	38	38	38	8.3	8.3	8.3	38	38	38
Carriages (per annum)	Same as road tube trailer	Same as road tube trailer	Same as road tube trailer	1,225 (3 per day)	4,900 (13 per day)	12,251 (34 per day)	1,027 (3 per day)	4,109 (11 per day)	10,272 (28 per day)	3,699 (10 per day)	14,796 (41 per day)	36,990 (101 per day)
Number trains (per annum)	276 (0.75 per day)	1,102 (3 per day)	2,754 (7.6 per day)	27.84 (0.08 per day)	111.4 (0.31 per day)	278.5 (0.76 per day)	12.3 (0.03 per day)	49 (0.13 per day)	122.3 (0.34 per day)	82 (0.23 per day)	329 (0.9 per day)	822 (2.25 per day)
Infrastructure (Port)												
Berths (load hours per annum)	Not Applicable			93	372	930	608	487	1217	348	1,390	927

	Production			Downstream technologies								
	H_2			Ammonia			H_2 liquefaction			MCH (organic carrier) conversion		
	Size 1	Size 2	Size 3	Size 1	Size 2	Size 3	Size 1	Size 2	Size 3	Size 1	Size 2	Size 3
	8,687 tpa	34,748 tpa	86,870 tpa	46,504 tpa	180,017 tpa	465,043 tpa	8,513 tpa	34,053 tpa	85,133 tpa	139,050 tpa	556,200 tpa	1,390,499 tpa
Vessel calls (per annum)	Not Applicable			3 (based on current small size vessel – 23,000m3)	12 (based on current small size vessel – 23,000m3)	29 (based on current small size vessel – 23,000m3)	97 (based on small volume existing vessel – 1,250m3)	18 (based on future mid size vessel – 27,000m3)	45 (based on future mid size vessel – 27,000m3)	14 (based on current small size vessel – 16,000m3)	56 (based on current small size vessel – 16,000m3)	35 (based on current mid size vessel – 46,000m3)
Storage	Not Applicable			As for plant storage – one or the other should be allowed for. Generally preferred to produce hydrogen carrier close to port and store for practical and economic reasons. Most likely carrier to produce away from port is ammonia.								

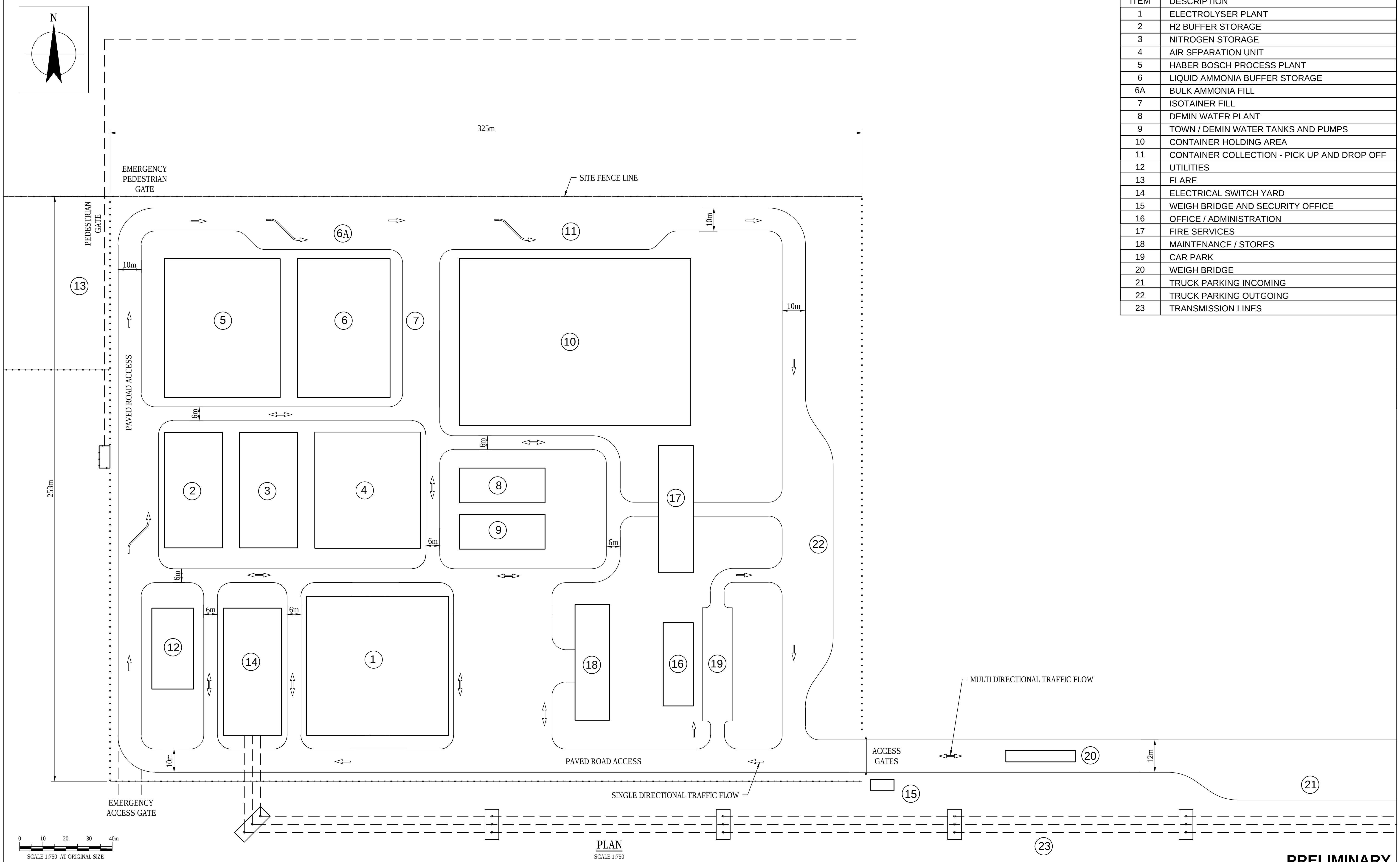
Note: Figures are based on desktop investigations, and limited vendor consultation has been undertaken.

Appendix B – MCA Criteria, Constraint Categories

Index	Layer Name	Issue	Constraint Type	Buffer (m)	Field SF	Specific Features	Field Calc	Calculation	Good 1	Moderate 35	Low 70	Fatal Flaw 999	Comments
1	SOC_NativeTitle_NNTT_20200109	Native Title, Aboriginal Heritage	Suitability				DETOUTCOME	if DETOUTCOME == 'Native title exists (non-exclusive)': return 70 else: return 1	NT extinguished, no heritage sites	NT extinguished, heritage sites	NT exists		
2	PLANCAD_Cadastre_DNRME_20200413	Within Freehold or leasehold	Suitability				TENURE	if TENURE in {'Freehold', 'Lands Lease'}: return 1 else: return 35	Within Freehold or leasehold	Everything else			
3	INWAT_WaterwayBarrierWorks_Stream_DAF_20160715	Avoid waterways and associated corridors	Proximity	100, 200	FISH_PASS	3,4		if BUFF_DIST == 100: return 70 elif BUFF_DIST == 200: return 35 else: return 1	> 200 m from waterway that is high or major WWBW	100 - 200m from waterway that is high or major WWBW	0 - 100 metres of waterway that is high or major WWBW	Waterways	
4	Flood	Avoid areas subject to flooding	Proximity						Above mapped flood levels	Above mapped flood depth of 0.5m	Above mapped flood depth of 1m	Below mapped flood depth of 1 m	Flood mapping on line (for Townsville, possible Gladstone)
5	INWAT_StormTide_100ARI_DNRME_20140503	Avoid areas subject to tidal inundation or erosion	Suitability				grid_code	if grid_code == 1: return 999 else: return 1	Above tidal surge and erosion areas			Below tidal surge and erosion prone areas	Xing to check for data
6	ENV_ErosionProneArea_DNRME_20150708	Avoid areas subject to tidal inundation or erosion	Suitability				SHAPE_Area	if SHAPE_Area > 0: return 999 else: return 1	Above tidal surge and erosion areas			Below tidal surge and erosion prone areas	
7	ENV_RegionalEcosystems_v11_DNRME_20200430	Avoid areas of regulated vegetation	Suitability				VM_STATUS	if VM_STATUS in ('non_remnant'): return 1 elif VM_STATUS in ('hvr_leastc','rem_leastc'): return 35 elif VM_STATUS in ('hvr_oc','rem_oc'): return 70 else: return 999	Avoid regulated vegetation	Least Concern Regional Ecosystems	Of Concern Regional Ecosystems, MSES Regulated vegetation (Cat R)	Conservation, Endangered Regional Ecosystems	
8	ENV_MSES_RegulatedVeg_Cat_R_GBR_Riverine_DES_20200409	Avoid areas of regulated vegetation	Suitability				RVM_CAT	if RVM_CAT == 'R': return 70 else: return 1					
9	ENV_ProtectedAreas_DES_20200113	Avoid areas of conservation	Suitability				EST_TYPE	if EST_TYPE in {'RR','SF'}: return 70 else: return 999					
10	ENV_BushfireProneArea_DNRME_20140901	Avoid areas of bushfire risk	Suitability				CLASS	if CLASS == 'Medium Potential Bushfire Intensity': return 1 elif CLASS == 'High Potential Bushfire Intensity': return 35 elif CLASS == 'Very High Potential Bushfire Intensity': return 70 else: return 1	Medium Bushfire Hazard	High Bushfire Hazard	Very High Bushfire Hazard		
11	Topography	Avoid areas of steep slope	Suitability						1-2%	<5%	5-15%	>15%	15% is high but included for consistency with report
12	PLANCAD_TCC_City_Planning_Scheme_Zoning_TCC_20200715	Distance from sensitive receptors	Proximity	500, 1000, 30000				if BUFF_DIST == 500: return 70 elif BUFF_DIST == 1000: return 35 else: return 1	> 1000m from residential, commercial & recreational areas	500-1000m from residential, commercial & recreational areas	<500m from residential, commercial & recreational areas		
13	SOC_RecreationAreas_DNRME_20150706	Distance from sensitive receptors	Proximity	500, 1000, 30000				if BUFF_DIST == 1000: return 35 elif BUFF_DIST == 500: return 70 else: return 1	> 1000m from residential, commercial & recreational areas	500-1000m from residential, commercial & recreational areas	<500m from residential, commercial & recreational areas		
14	SOC_Homesteads_GHD_digitised_20200715	Distance from sensitive receptors	Proximity	500, 1000, 30000				if BUFF_DIST == 1000: return 35 elif BUFF_DIST == 500: return 70 else: return 1	> 1000m from residential, commercial & recreational areas	500-1000m from residential, commercial & recreational areas	<500m from residential, commercial & recreational areas		Planning scheme/ aerial photography
15	STR_Port_Area_digitised_GHD_20200715	Proximity to ports	Proximity	500, 2000, 10000, 30000				if BUFF_DIST == 500: return 1 elif BUFF_DIST == 2000: return 35 elif BUFF_DIST == 10000: return 70 else: return 999	<500m	<2000m	<10,000m	>10,000m	check port areas
16	UTIL_ElectricalNetwork_Ergon_20200109	Proximity to 133kV	Proximity_133kV	200, 1000, 20000, 50000	OP_VOLT	132.000 kV		if BUFF_DIST == 200: return 1 elif BUFF_DIST == 1000: return 35 elif BUFF_DIST == 20000: return 70 else: return 999	<200m	<1000m	1000m - 20kms	>20kms	These distances reduced to reflect search is within SDA or industrial precint
17	UTIL_NationalElectTransmissionLines_GA_2010	Proximity to 133kV	Proximity_133kV	200, 1000, 20000, 50000	CAPACITY_kV	132		if BUFF_DIST == 200: return 1 elif BUFF_DIST == 1000: return 35 elif BUFF_DIST == 20000: return 70 else: return 999					
18	UTIL_NationalElectTransmissionLines_GA_2010	Proximity to 275kV	Proximity_275kV	200, 1000, 125000, 250000	CAPACITY_kV	275		if BUFF_DIST == 200: return 1 elif BUFF_DIST == 1000: return 35 elif BUFF_DIST == 125000: return 70 else: return 999					
19	UTIL_ZoneSubstation_Ergon_20200109	Proximity to HV substation (>133kV)		200, 1000, 5000	OP_VOLT	132.000 kV		if BUFF_DIST == 200: return 1 elif BUFF_DIST == 1000: return 35 else: return 70	<200m	<1000m	1000m - 5000m		
20	INWAT_Reservoirs_DNRME_20150511	Promity to infrastructure	Proximity	200, 1000, 5000, 30000				if BUFF_DIST == 200: return 1 elif BUFF_DIST == 1000: return 35 elif BUFF_DIST == 5000: return 70 else: return 999	<200m	<1000m	1000m - 5000m	>5000m	
21	TRANS_Baseline_roads_and_tracks_DNRME_20191219	Proximity to major roads	Proximity	100, 200, 1000				if BUFF_DIST == 100: return 1 elif BUFF_DIST == 200: return 35 else: return 70	<100m	< 200m	<1000m		

Appendix C – Schematic Plant Layout

ITEM	DESCRIPTION
1	ELECTROLYSER PLANT
2	H2 BUFFER STORAGE
3	NITROGEN STORAGE
4	AIR SEPARATION UNIT
5	HABER BOSCH PROCESS PLANT
6	LIQUID AMMONIA BUFFER STORAGE
6A	BULK AMMONIA FILL
7	ISOTAINER FILL
8	DEMIN WATER PLANT
9	TOWN / DEMIN WATER TANKS AND PUMPS
10	CONTAINER HOLDING AREA
11	CONTAINER COLLECTION - PICK UP AND DROP OFF
12	UTILITIES
13	FLARE
14	ELECTRICAL SWITCH YARD
15	WEIGH BRIDGE AND SECURITY OFFICE
16	OFFICE / ADMINISTRATION
17	FIRE SERVICES
18	MAINTENANCE / STORES
19	CAR PARK
20	WEIGH BRIDGE
21	TRUCK PARKING INCOMING
22	TRUCK PARKING OUTGOING
23	TRANSMISSION LINES



PLAN
SCALE 1:750

PRELIMINARY

No	Revision	Note: * indicates signatures on original issue of drawing or last revision of drawing	Drawn	Job Manager	Project Director	Date

Schematic Plant Layout

H2 to NH3

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DO NOT SCALE

Drawn	Designer
Drafting Check	Design Check
Approved (Project Director)	
Date	
Scale 1:750	This Drawing must not be used for Construction unless signed as Approved

Client

Project

Title

Original Size **A1** **Drawing No:** **Rev:**

Appendix D – InDeGO Method

InDeGO: spatial MCA methodology

Overview

The spatial MCA methodology applied in this project was a method developed by GHD, known as the InDeGO method. Using this method, GIS identified the candidate sites for a hydrogen plant in the Gladstone and Townsville SDAs.

This methodology uses GIS technology to select optimum locations for a hydrogen plant based on geographically characterised social, economic, engineering, planning and environmental criteria. Using the InDeGO method, the criteria are considered in terms of constraints and opportunities, geographically and mathematically.

Production scenario and criteria

For this project, three production (development) scenarios were generated representing three levels of output. Different plant configurations were also considered, including an integrated plant where the hydrolysis and carrier plant are co-located, and the alternative of separate sites for each plant component. For this assessment, a large capacity (size 3) integrated plants has been evaluated using the InDeGO method. As this assessment focussed on finding potential areas within SDAs, only those criteria required to select and evaluate developability (rather than to identify broad localities) were adopted, and these addressed the physical suitability of areas within the designated SDAs. Physical constraints included Native Title, tenure, waterways (WWBW), storm tide, erosion prone areas, bushfire prone areas, regional ecosystems, regulated vegetation, slope and flood depth (available for Townsville only). The spatial criteria used for applying the InDeGO Method was developed in the Part 2 Report through research undertaken in Part 1. Refer to Appendix A for a copy of the criteria.

Table 10 Production scales (development scenarios) of hydrogen and derivative type

Product	Size 1	Size 2	Size 3
Hydrogen			
Hydrogen production (tpa)	8,687	34,748	86,870
Derivatives			
Ammonia production			
• Ammonia production (tpa)	46,504	186,017	465,043
• Density (t/m^3)	0.73	0.73	0.73
• Ammonia (m^3/a)	63,704	254,818	637,045
MCH (organic carrier) production			
• MCH (tpa)	138,992	555,968	1,389,920
• Density (t/m^3)	0.77	0.77	0.77
• MCH (m^3/a)	180,509	722,036	1,805,091
LH2 production			
• LH2 (tpa)	8,513	34,053	85,133

Product	Size 1	Size 2	Size 3
• Density (t/m^3)	0.07	0.07	0.07
• LH2 (m^3/a)	121,614	486,471	1,216,186

Scoring system

The InDeGO scoring system was used to assess the performance of potential areas within the SDAs against the criteria. The scores reflect the range of suitability or feasibility for a given criterion, from there being no constraints through to being extremely constrained. Physical constraints were scored as follows:

- 1 = not constrained
- 35 = moderately constrained
- 70 = highly constrained
- 99 = extremely constrained.

Physical constraints were then overlayed on top of each other and scores added together to give a sum score. Final traffic light system scoring was 1-10 = low constraint (**dark green**), 10-500 = moderate constraint (**light green**), 500-999 = high constraint (**orange**), 999+ = extremely constrained (**red**), as shown in Table 9 below.

Table 11 InDeGO scoring

Suitability	Score range	Meaning
Low constraint	1 – 10	The area has low constraints; it is generally physically suitable for a hydrogen plant.
Moderately constrained	10 – 500	The area is moderately constrained and may be suitable for a hydrogen plant, following further investigations.
Highly constrained	500 – 999	The area is highly constrained and unlikely to be physically suitable for a hydrogen plant, without incurring major development costs.
Fatal flaw	999 +	The area is extremely constrained and generally considered unsuitable for the development of a hydrogen plant.

Appendix A and Appendix B provide a detailed list of the MCA criteria used along with the constraints category for each associated score.

The outcomes of the InDeGO model are presented in traffic light maps showing those areas with the highest suitability, based on the application of these physical criteria. These areas are then subjected to further evaluation in Step 2 below.

Limitations

The criteria may not be exhaustive, and there will be a range of other considerations that need to be taken into account when assessing the feasibility of individual (i.e. site-specific) opportunity. The scale of data captured is also a limitation.

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Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
0	B. Schulz	M. Ross		S. Orr		29/01/2021

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