T&T GREEN HYDROGEN

THE ROADMAP FOR A

GREEN HYDROGEN ECONOMY

IN TRINIDAD & TOBAGO

IDB
Inter-American Development Bank

National Energy
CORPORATION OF TRINIDAD AND TOBAGO

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Preface

Trinidad and Tobago is once again on the verge of innovating and leading the regional energy sector in Latin America and the Caribbean. Over many years, the country has become a respected and reliable global player in the supply of energy products, which in turn has delivered important benefits for the country's economic development. Green Hydrogen, which is generated via electrolysis from renewable energy sources, is the latest energy alternative which has the potential to significantly reduce carbon emissions. Trinidad & Tobago now has the opportunity to be one of the first countries to add Green Hydrogen to its energy product mix, thus further enhancing the country's contribution to global decarbonization efforts.

In this context, we are pleased to announce the results of a Green Hydrogen study which was developed as in collaboration between the Inter-American Development Bank (IDB) and the National Energy Corporation of Trinidad and Tobago (National Energy), with the support of the Ministry of Energy and Energy Industries (MEEI) and the advisory services of KBR. This new study highlights the opportunity to expand the country's portfolio of products based on low carbon solutions which are expected to be in high demand in international markets, and once again position the country at the forefront of innovation in the global energy market.

We welcome this report on Green Hydrogen which sets a futuristic vision for the country. Notably, the report identifies key demonstration projects to be introduced in the short term. These projects, which will act as pilot initiatives to deliver visible and tangible results in the coming years, are an indication of new developments taking place in the energy sector in Trinidad and Tobago. Moreover, these initiatives will be attractive propositions to encourage further private sector investment in the country. Certainly, the private sector has an important role to play particularly as an engine to promote foreign direct investments, technology transfer, and ultimately job creation. Therefore, we praise the authors for including the regulatory and policy actions that are needed to foster further private sector participation in the energy sector and ultimately help the country achieve a low-carbon energy matrix in the future.

There are two aspects of the report on which we would like to elaborate. First, the development of the Green Hydrogen market must be established in an inclusive manner and as part of a fair and just transition. Although there is little disaggregated data on gender in the energy sector in Trinidad and Tobago, the estimates indicate women are generally under-represented. According to the Trinidad and Tobago Central Statistical Office (CSO), women make up approximately 41 per cent of the national workforce. However, in the energy sector (petroleum and gas sector, including production, refining

and service contractors), women accounted for less than 20 per cent of that segment of the workforce in 2017[1]. On this basis, we would support the country to work on these new market opportunities bearing in mind closing of the gender gap.

Moreover, as new skills and competencies will be required in the new processes to expand the production of renewable energy and launch green hydrogen production; the country will have to rigorously manage the transition to ensure that no worker is left behind and there are proper safety nets built to protect those who are most vulnerable. Experience from other countries indicates that an important activity in a fair and just transition is to provide proper retooling and reskilling to the workforce. In this respect, Trinidad and Tobago is in a very advantageous position considering its expertise built over time in offshore hydrocarbon operations which can be transferable to offshore renewable energy production.

Second, these emerging activities in Trinidad and Tobago will be deployed combining the latest and most modern digital tools and technologies. These activities will also contribute to and be aligned with Trinidad & Tobago's Digital Transformation Strategy 2023-2026[2], in particular the categories of Digital Economy and Digital Government. Moreover, the IDB is implementing a country strategy with Trinidad & Tobago for the period 2021-2025[3], which aims to help the country advance its digital transformation agenda to achieve more sustainable and inclusive growth. The utilization of modern electrolyzers to produce green hydrogen and the use of wind measurement devices to improve the prediction of wind patterns are examples of how technology and digital solutions can deliver important benefits to the country.

It is worth noting the important role of institutions in developing this market. National Energy has been at the forefront of major developments in the energy sector in the country such as the development and ownership of the steel mill and ISCOTT dock in 1981, the country's first urea plant in 1984 and first methanol plant in 1987. As a 100% state-owned agency, National Energy's mandate as determined by the Government of Trinidad and Tobago is to conceptualize, promote, facilitate, and develop sustainable energy-based industries locally and internationally. It is the vision of National Energy as part of the NGC Group that sustainable development is the fundamental foundation principle for long term growth – the needs of today must be balanced with guarantees for future generations[4]. This will require a transition to sustainable power sources such as

[1] The Energy Chamber of T&T: Harnessing all the talent from the energy sector. Accessible at: https://energy-now.tt/blog/harnessing-all-the-talent-from-the-energy-sector

[2] Accessible here: https://mdt.gov.tt/digital-transformation-strategy.php

[3] Accessible at: https://www.iadb.org/en/news/idb-approves-new-country-strategy-trinidad-and-tobago-digital-transformation

[4] NGC Annual Report (page 38). Accessible at: https://ngc.co.tt/wp-content/uploads/2022/10/NGC-2021-Annual-Report.pdf

renewable energy, as well as accelerating decarbonization of hydrocarbon-based value chains. The results of this study are fully consistent with these principles.

Moving forward, we encourage you not only to read this report but to actively engage in the development of this new market. We believe it is in the best interest of the country that we include the private sector, public sector and civil society in this development. It is really an exciting time to be part of the energy sector in Trinidad and Tobago!

Carina N. Cockburn
IDB Country Representative

Dr. Vernon Paltoo
President – National Energy

Contents

Abbreviations

CAPEX	Capital Expenditures
CO_2	Carbon dioxide
GDP	Gross Domestic Product
GW	Giga Watt
H_2	Hydrogen
H_2O	Water
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
KG	Kilograms
KTPA	Kilo tonnes per annum
LCOA	Levelised Cost of Ammonia
LCOE	Levelised Cost of Electricity
LCOH	Levelised Cost of Hydrogen
LNG	Liquefied Natural Gas
MIGD	Million Imperial Gallons per Day
MTPA	Million tonnes per annum
MW	Megawatt
T&T	Trinidad and Tobago
TRLs	Technology readiness levels
OPEX	Operational Expenditures
USD	United States Dollars
US DOE	United States Department of Energy
WRAP	Wind Resource Assessment Programme

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Executive Summary: Trinidad and Tobago is ready to scale green hydrogen

A Caribbean nation in pole position

Trinidad and Tobago is at the beginning of an exciting, yet challenging, energy transition journey as a regional energy leader and a powerhouse in petrochemicals. Its oil and gas infrastructure, including storage and export facilities, as well as operational experience gives this nation a head start when it comes to developing a hydrogen economy – in fact it is in the best starting position in the Caribbean and Latin American region.

The energy sector already accounts for 40% of GDP and 80% of export earnings (GEFC, 2022), through the production and exports of oil and gas as well as petrochemicals – ammonia and methanol. This existing heritage and the associated established infrastructure provide Trinidad and Tobago with the key competitive advantage over other nations exploring hydrogen exports with Point Lisas in Trinidad well positioned to be a centre for hydrogen and downstream green products.

Many of the building blocks are already in place to position Trinidad and Tobago as a regional green hydrogen and ammonia / methanol trading, storage and production hub for the Caribbean and the Americas. Right now, there is a dynamic, thriving energy ecosystem and existing markets for these products, with long-standing trade relations, shipping and export routes for energy exports. Compared to many other countries globally, Trinidad and Tobago has a head start, with the ability to capitalize on existing infrastructure, know-how and capabilities to gain a head start in this market.

When it comes to the evolving energy landscape, Trinidad and Tobago will continue to play a major role as a natural gas exporter whilst leveraging existing heritage and facilities to attract investment from around the globe and exploit green energy carriers, thereby ensuring sustainable economic growth in the future. The transformation of Trinidad and Tobago can mirror Singapore, also an island nation, which started as an oil trading hub. With the right approach Trinidad and Tobago can position to be the leading production, storage and trading hub for the Caribbean region in green hydrogen and green products.

Global context, global change

As climate change policies around the globe build momentum, many nations are intensifying efforts to decrease their reliance on fossil fuels, slash emissions and decarbonise energy value chains. In the race to net zero emissions by 2050, the use of coal and oil will decline rapidly, with reliance on LNG (with carbon capture) as a transition fuel, In this scenario, hydrogen has a key role to play as a future energy vector. By 2050, 12% of the world's energy demand will be met by hydrogen, most of which will be green with a quarter of this traded across borders (IRENA, 2022).

In the near to medium terms, hydrogen trade across borders, i.e., international shipping will require transformation to hydrogen carriers such as ammonia and methanol amongst others until the technologies associated with liquid hydrogen shipping matures to allow for large scale commercialization. Hence, globally, an increase in demand of ammonia and methanol is predicted. By 2050, 690 Mtpa of ammonia will be required with 80% used as chemical feedstock and fuel for shipping and 20% as hydrogen carrier. Green methanol also features prominently in global decarbonization as the prime candidate for green shipping with a predicted annual production of 500 Mtpa by 2050.

Unprecedented highs in the current global ammonia market will also accelerate the development of green ammonia, which will become cost competitive with the current grey prices. All these factors put the Caribbean nation in a powerful position to capitalise on change.

Realising the hydrogen economy

A hydrogen economy for Trinidad and Tobago is built on the premise that the nation leverages its existing hydrocarbons and fossil fuel infrastructure and know-how, to build capacity in another track – green hydrogen and green products. The country already has a captive demand of 1.5 Mtpa of grey hydrogen consumed by its petrochemical industry and this market could eventually be green.

The Caribbean nation is well placed to start positioning itself in the market for low-carbon ammonia and methanol, with the introduction of carbon capture on existing downstream facilities, before transitioning to renewable energy and green hydrogen, once the upstream green infrastructure is in place. The country will need the right enabling policies, regulatory frameworks, as well as institutional support that builds capacity, which will in turn attract foreign direct investment.
As renewable energy and green products capacity grow, this will form the foundation

for the sustainable economic future of Trinidad and Tobago. This will also assist in the transfer of skills from the oil and gas sector, with some degree of reskilling, training, and upskilling and allow a new generation of workers to build capacity in the assembly, maintenance, and operation of wind turbines, electrolyser facilities and green hydrogen infrastructure.

The future energy landscape

By 2065, Trinidad and Tobago could aim to install 57 GW of offshore wind nameplate capacity, translating to 25 GW of power that feeds electrolysers, producing 4 Mtpa of green hydrogen. Through this programme, Trinidad and Tobago will generate net benefits in the billions creating thousands of jobs in the construction, operation and maintenance sectors. This ensures sustainable economic growth for Trinidad and Tobago, and also enables Trinidad and Tobago to maintain its leadership in the petrochemicals sector and in the Caribbean region.

To convert this roadmap into reality, the country will need to invest in the upstream development of the hydrogen value chain, from wind turbines to electrolysis plants, as well as ensure that downstream infrastructure for green ammonia and methanol is expanded. Through this process it will create a vibrant and local green energy sector with supply chains, know-how and capacity.

The immediate next steps consist of a two-track approach that are heavily interlinked – securing funding for this programme and launching demonstration projects in the country. Funding sources such as climate finance, carbon markets, private sector and national finance will be explored by creating financing mechanisms that promote renewable energy and green hydrogen projects. Demonstration projects will be planned and implemented where the end use of green hydrogen is tested in the existing petrochemical industry through the production of green ammonia and methanol, transportation sector through public transport and cement manufacturing.

Renewable energy, and green hydrogen represents an incredibly bright future for Trinidad and Tobago in the years ahead. The right economic, political, and social environment is needed to bring about a more sustainable future. If developed cohesively the country has the potential to become a green energy superpower, an aspiration that is well within reach of Trinidad & Tobago.


H2
ENERGY
STORAGE

T&T GREEN HYDROGEN

01

Introduction

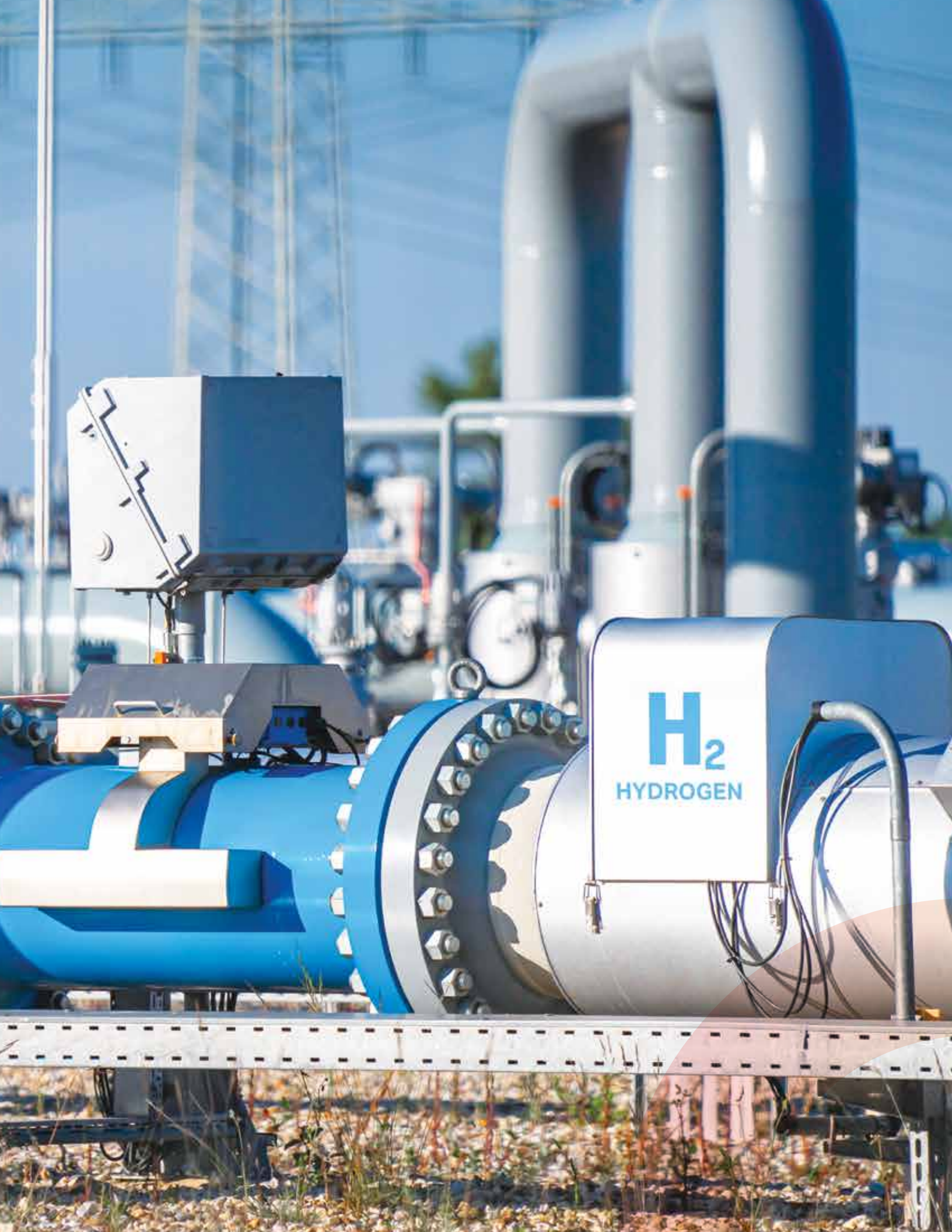
For over 100 years, the oil and gas sector has been and continues to be the primary driving force behind Trinidad and Tobago's economy. As one of the largest oil and gas producing countries in the Caribbean, the energy sector in Trinidad and Tobago historically accounted for approximately 40% of the country's Gross Domestic Product (GDP) primarily through LNG exports (GEFC, 2022) and petrochemicals, and contributing to 80% of total export earnings. Trinidad and Tobago was among the first countries to utilize natural gas for power generation in the 1970's, with the energy sector evolving and natural gas being the major hydrocarbon produced and processed by downstream users.

International climate change policies are building momentum globally, with nations intensifying their efforts to reduce carbon emissions, decrease reliance on fossil fuels and decarbonise their energy value chain to achieve Net Zero. Simultaneously, global energy demand has been rising steadily in the past half century, driven by population growth, industrial activities, and advances in both developing and developed countries. To meet this increasing energy demand whilst supporting the drive to reduce greenhouse gas emissions, the energy industry is challenged by a significant change in landscape. One where the use of coal and oil for energy generation declines rapidly by 2050 with the use of LNG (specifically LNG with carbon capture) as a transition gas and hydrogen as the future energy vector (IEA Net Zero by 2050, 2021).

These climate change policies supporting net zero emissions by 2050 combined with the changing energy market, decreasing production costs for renewable energy, and technology advancements are leading to the creation of a global green energy market with significant investment ($1,200 billion of investment in low-carbon hydrogen through to 2030 – IEA Global Hydrogen Review, 2021). Nations around the globe, including competitors of Trinidad and Tobago in the traditional oil and gas sector, are already positioning themselves to take advantage of this new market. To date, 37 countries have announced their hydrogen strategies targeting a total of 87.6 GW of installed electrolyser capacity by 2030, with another 18 countries in the process of preparing their hydrogen strategies (BNEF Global Hydrogen Strategy Tracker, 2022).

As Trinidad and Tobago continues to be a leading regional natural gas exporter, this changing energy market provides a unique opportunity to expand into clean energy alternatives and ensure sustainable economic growth for the country. Focusing on green hydrogen in Trinidad and Tobago will create a green industry that has the potential to expand through synergies with the existing oil and gas sector, generate additional revenue through export of green products, create additional jobs for the country, and reduce carbon emissions.

Realising the potential for Trinidad and Tobago in the green energy market, the Government of Trinidad and Tobago, represented by the National Energy Corporation of Trinidad and Tobago Limited (National Energy) entered into an agreement with the Inter-American Development Bank (IDB) to develop a green hydrogen roadmap for Trinidad and Tobago. Following a competitive process, this study was awarded to KBR, who have worked with IDB, National Energy and key local stakeholders, to deliver the first phase of the green hydrogen study that concluded with the main findings presented in this summary report. The full details of the work undertaken are captured in technical reports which will be made available at a later stage.


H2
HYDROGEN

02

Green Hydrogen in Industry

Globally, hydrogen demand is primarily driven by industry: oil refining, ammonia, and methanol production and steel production, whereas in Trinidad and Tobago, hydrogen demand is mainly driven by ammonia and methanol production. Hydrogen can be categorised as grey hydrogen, traditionally produced from methane (CH_4), split using steam into CO_2 and hydrogen; or brown / black hydrogen produced from coal with significantly higher levels of CO_2 emissions per unit of hydrogen produced.

Blue hydrogen follows a similar process to grey, with additional technologies required to capture the CO_2 produced when the hydrogen is split from methane (or coal), and either sequestered underground or utilised by industry. Green hydrogen is produced by electrolysing water, utilising electricity from renewable sources to split water (H_2O) molecules into hydrogen and oxygen. This pathway differs from grey and blue hydrogen, resulting in significantly lower levels of CO_2 emissions.

Whilst the hydrogen colours are used widely in industry, the industry is coming to the realisation that colours alone can be deceiving as it is oversimplified and does not provide a "real" view of the carbon emissions across the hydrogen value chain. This is creating a desire to transition from hydrogen colours to carbon intensity, which allows for quantification of carbon emissions throughout the value chain from production through to final end-use. As the hydrogen market develops, hydrogen standards will be developed which will drive the classification of hydrogen and define the thresholds for carbon intensity to qualify for green v/s low-carbon hydrogen.

Green hydrogen – sector application

The applications for green hydrogen go beyond its current use in industry and extends to energy storage, green mobility and green products (chemicals, synthetic fuels, steel, cement), providing significant decarbonisation potential for these existing industries. The potential application of green hydrogen in the industries present in Trinidad and Tobago is classed as:

- unavoidable for captive industries such as the chemical industry[5]
- high potential for steel and cement production
- medium potential as industrial heat input and in the transportation sector through heavy goods vehicles, public transportation and local ferries
- low potential for power generation, the electrification of industries, and for light vehicle use

[5] Unavoidable in the context of a Net Zero scenario. Where the role of hydrogen replaces natural gas as feedstock and energy source in these industries where practicable and the freed up natural gas available for export.

GREY HYDROGEN

SMR (Steam Methane Reforming) or gasification-the most common method today that releases large volumes of CO_2.

Methane or Coal

BLUE HYDROGEN

SMR or gasification with carbon capture (85-95%)-this releases more emissions than green but less than grey.

Methane or Coal

GREEN HYDROGEN

Electrolysis-this releases few or no greenhouse gas emissions.

Renewable Electricity

Figure 1: The hydrogen colours explained: grey, blue, and green (Authors Elaboration, 2022)

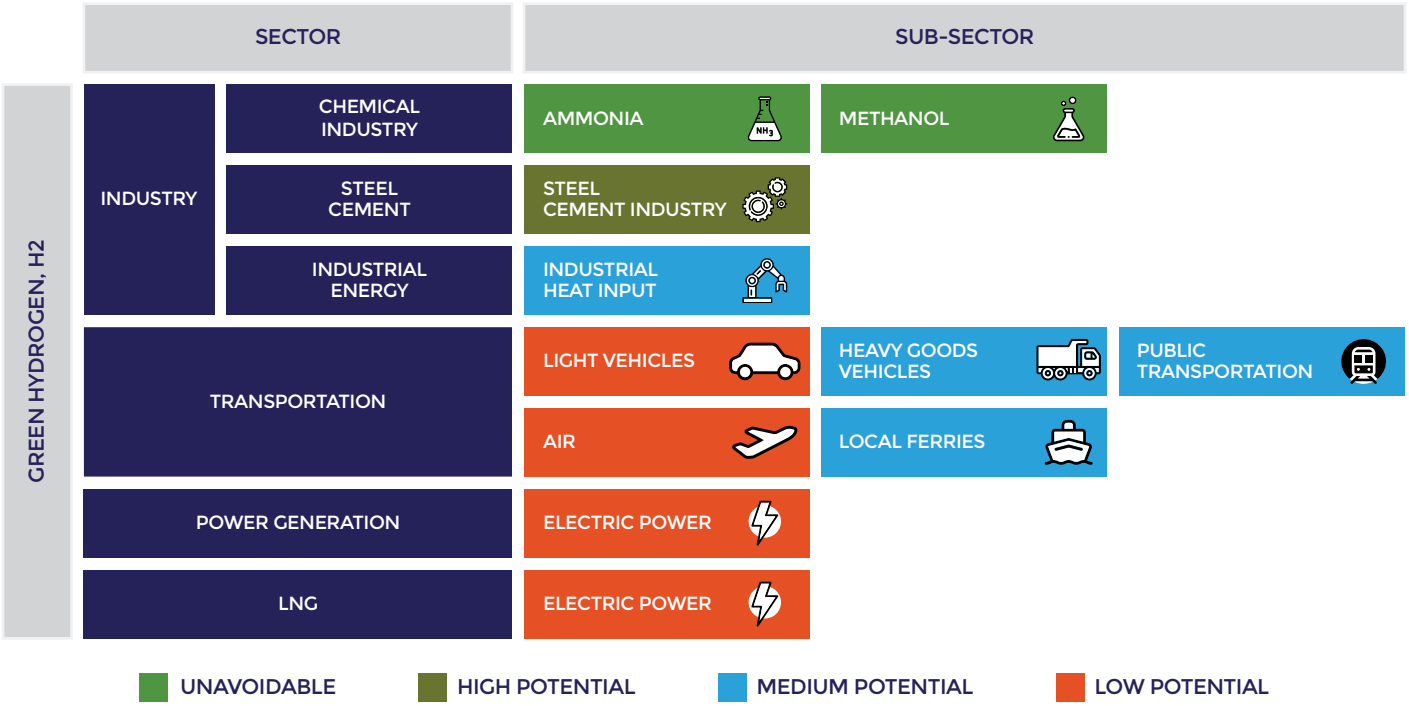


Figure 2: Sector assessment of Trinidad and Tobago (Authors Elaboration, 2022)

In Trinidad and Tobago, the currently installed infrastructure has a capacity for approximately 1.7 Mtpa of hydrogen.

As one of the leading exporters of ammonia and methanol, Trinidad and Tobago has a captive demand of 1.5 Mtpa of grey hydrogen for use as feedstock for these applications. For both chemicals, the use of green hydrogen is unavoidable. The production of green methanol[6] will also synergise with carbon capture facilities for the harder to abate sectors. For green methanol to be produced, the captured CO_2 must come from renewable sources such as biomass. This would mean that green methanol is carbon negative[7] as its production leads to the net removal of carbon dioxide from the atmosphere.

Of the 1.7 Mtpa of the grey hydrogen demand, 0.2 Mtpa is allocated to steel and cement production. Whilst steel production facilities are currently mothballed, the 0.2 Mtpa allocated allows for the possibility of the revival of this industry as green steel gains traction in the market. This is exemplified by buyers such as carmaker Volvo who have shown willingness to pay a premium for green steel.

[6] Green methanol is defined as methanol produced from hydrogen produced using renewable energy and carbon dioxide obtained from biomass in this report.

[7] This assumes that the boundary of the project begins at biomass production and ends at the produced methanol.

Whilst the cement production capacity within Trinidad and Tobago is small, the cement industry is nevertheless one of the major emitters of greenhouse gases with every tonne of cement produced emitting up to 622 kg of carbon dioxide. Green hydrogen could be used to fuel the cement facility to reduce emissions and produce green cement for local use, with the potential for exports if the market conditions are appropriate and local production capacities increased.

Green hydrogen can play a significant role in the transportation sector of Trinidad and Tobago, through the transition of heavy goods vehicles, long-haul carriers, and public transport to green hydrogen vehicles. In the shipping sector, green ammonia and methanol are expected to play a significant role in the decarbonisation of this sector, providing an opportunity for Trinidad and Tobago to transition local ferries to green fuels in the future.

03

Green Hydrogen for Exports: An opportunity for Ammonia and Methanol

Globally, IRENA predicts that 12% of the world's final energy demand will be met by hydrogen by 2050, of which 66% will be produced from renewable energy (green), and the remainder 34% from natural gas coupled with carbon capture (blue). Globally, a quarter of the green hydrogen produced will be traded across borders. With approximately half transported as hydrogen through pipelines, and the other half traded as ammonia (IRENA World Energy Transition Outlook, 2022).

The conversion of hydrogen to ammonia is already commercially and technically mature and applied at scale globally, with low costs associated with shipping of ammonia across borders. IRENA estimates that by 2050, 690 Mtpa of ammonia will be required with 80% used as chemical feedstock and fuel for shipping and 20% as hydrogen / energy carrier.
Like ammonia, methanol as green methanol, features prominently in global decarbonisation as the prime candidate as a green fuel in the shipping sector with a predicted annual production of 500 Mtpa of green methanol by 2050 (IRENA Innovation Outlook, Renewable Methanol, 2021).

On the other hand, the trade of liquid hydrogen is expected to be limited to regional boundaries as depicted in Figure 4, distributed through pipelines, in the near to medium term. In the longer term, as technology for liquid hydrogen matures to allow for large scale hydrogen liquefaction and shipping, industry expectations are that liquid hydrogen will be traded as a commodity in the global market.

The industry predictions highlights that both green ammonia and green methanol, produced from green hydrogen, will play significant roles in global decarbonisation. As hydrogen will be traded as ammonia or methanol in the near and medium term, Trinidad and Tobago, a global leader in the production and exports of ammonia and methanol can take advantage of the existing infrastructure, scale, and operational experience in the production of these chemicals to gain entry to this new market.

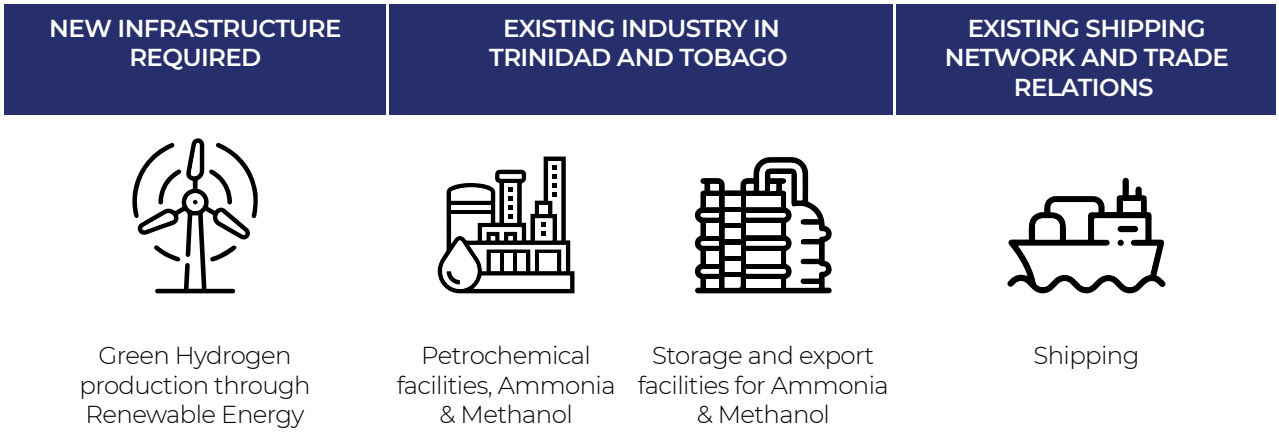
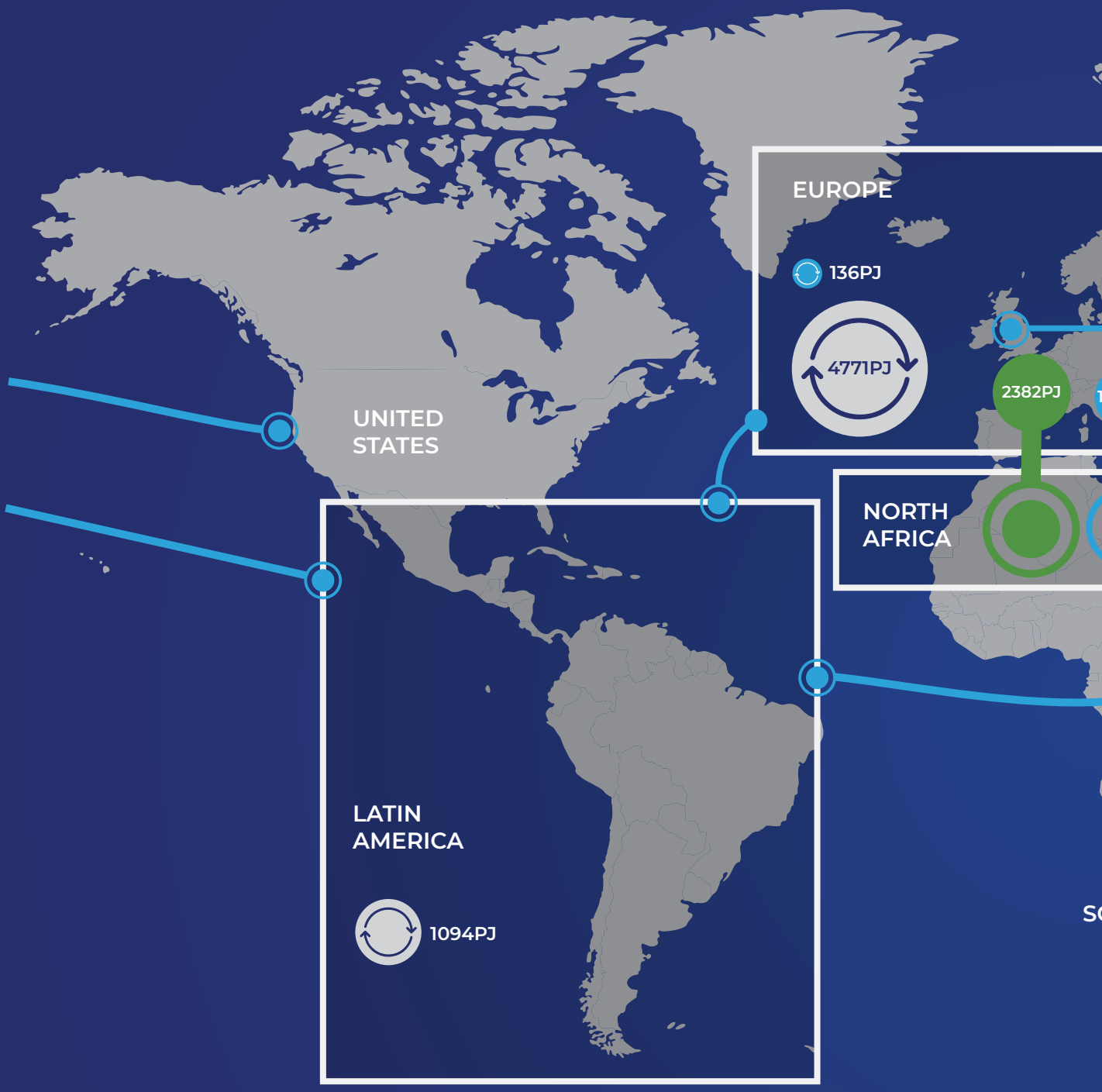


Figure 3: Trinidad and Tobago's value proposition – leveraging existing infrastructure (Authors Elaboration, 2022)



NH_3 Flow (PJ)	H_2 Flow (PJ)	LH_2 Flow (PJ)	LOHC Flow (PJ)
0 - 100	0 - 100	0 - 100	38
101 - 300	101 - 600	101 - 600	
301 - 800	601 - 900	601 - 900	

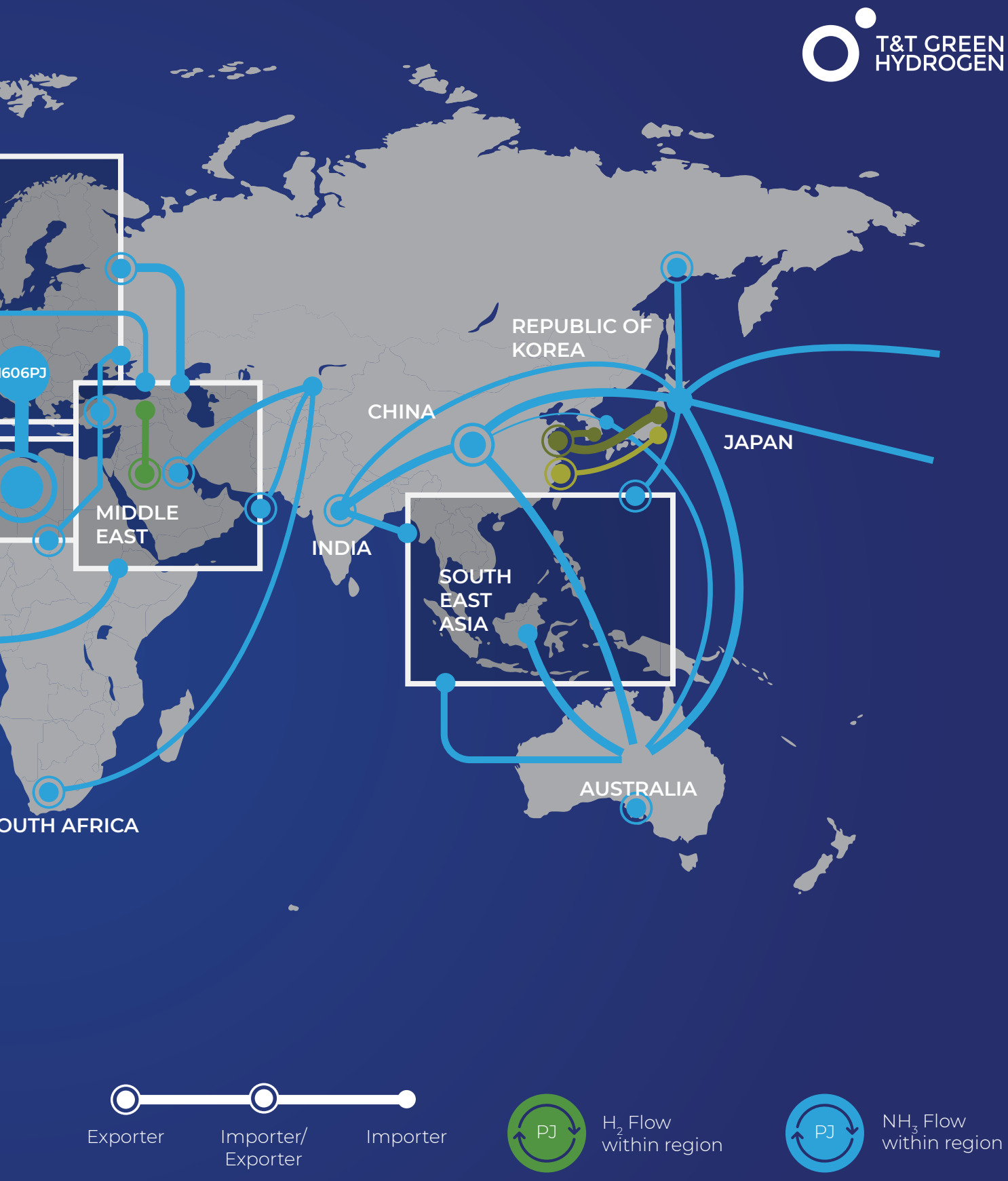


Figure 4: Global trade routes and carriers in 2050 (IRENA World Energy Transition Outlook 2022)

04

A Green Hydrogen Economy: Building the foundation for the future

A green hydrogen industry is heavily dependent on renewable energy such as hydropower, solar, wind, ocean, biomass and geothermal.

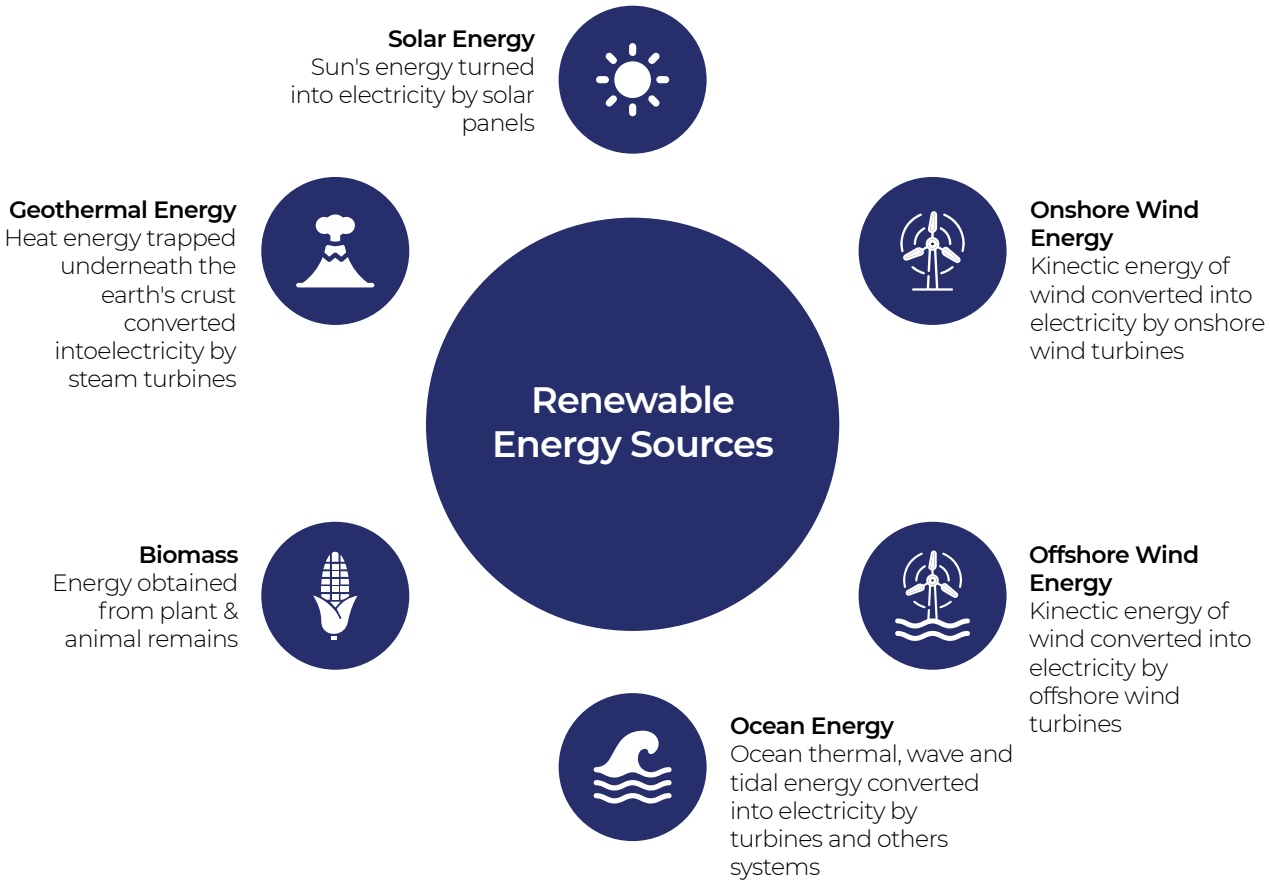


Figure 5: Sources of renewable energy (Authors Elaboration, 2022)

Investigating the potential of renewable energy generation in Trinidad and Tobago highlights several potential pathways with varying levels of energy outputs and potentials. Technology readiness levels (TRLs) as well as the availability of the renewable energy source in the country were considered to screen for the recommended renewable energy sources.

- Solar energy: A viable renewable energy source for Trinidad and Tobago that is mature in its technology development cycle. It is one of the cheapest forms of renewable energy but will face land constraints when deployed at scale.
- Onshore wind energy: Another mature technology that is also cheap. However, Trinidad and Tobago's onshore wind speeds are average compared to global wind regimes. While there are potential sites on the northern ridge of Trinidad, scaling potential is limited.

- Offshore wind energy: Fixed offshore platforms are a mature technology, whilst floating offshore platforms are still in development. Trinidad and Tobago has good offshore wind speeds compared to global regimes and their archipelago status provides significant offshore acreage that can be utilized for offshore wind development. Fixed offshore platform will be deployed in the near term and floating platforms in the medium to longer term.
- Ocean energy: Wave and tidal energy are at early demonstration stages and are not ready for near-term large scale commercial deployment.
- Biomass: Several pathways are now being studied utilizing agri-waste or specialty crops for energy generation. This can provide an opportunity for Trinidad and Tobago to implement circular economy and sustainability principles in the future as the related technologies mature.
- Geothermal energy: Potential for geothermal energy exists within the Caribbean islands, however, there has been limited exploration for Trinidad and Tobago and could be an area for further investigation as a source of energy and industrial heat.

Of all the renewable energy sources available in Trinidad and Tobago, offshore wind offers the largest potential for the island. An initial estimate of the potential areas available for offshore development indicates that on average Trinidad and Tobago could exploit up to 57GW of offshore wind across fixed and floating technologies, equating to 25GW in average energy output (accounting for the capacity factor associated with offshore wind technologies).

Fixed offshore wind turbines can be installed in the relatively shallow waters around Trinidad with floating wind turbines installed between Trinidad and Tobago as well as north of Tobago as depicted in Figure 6.

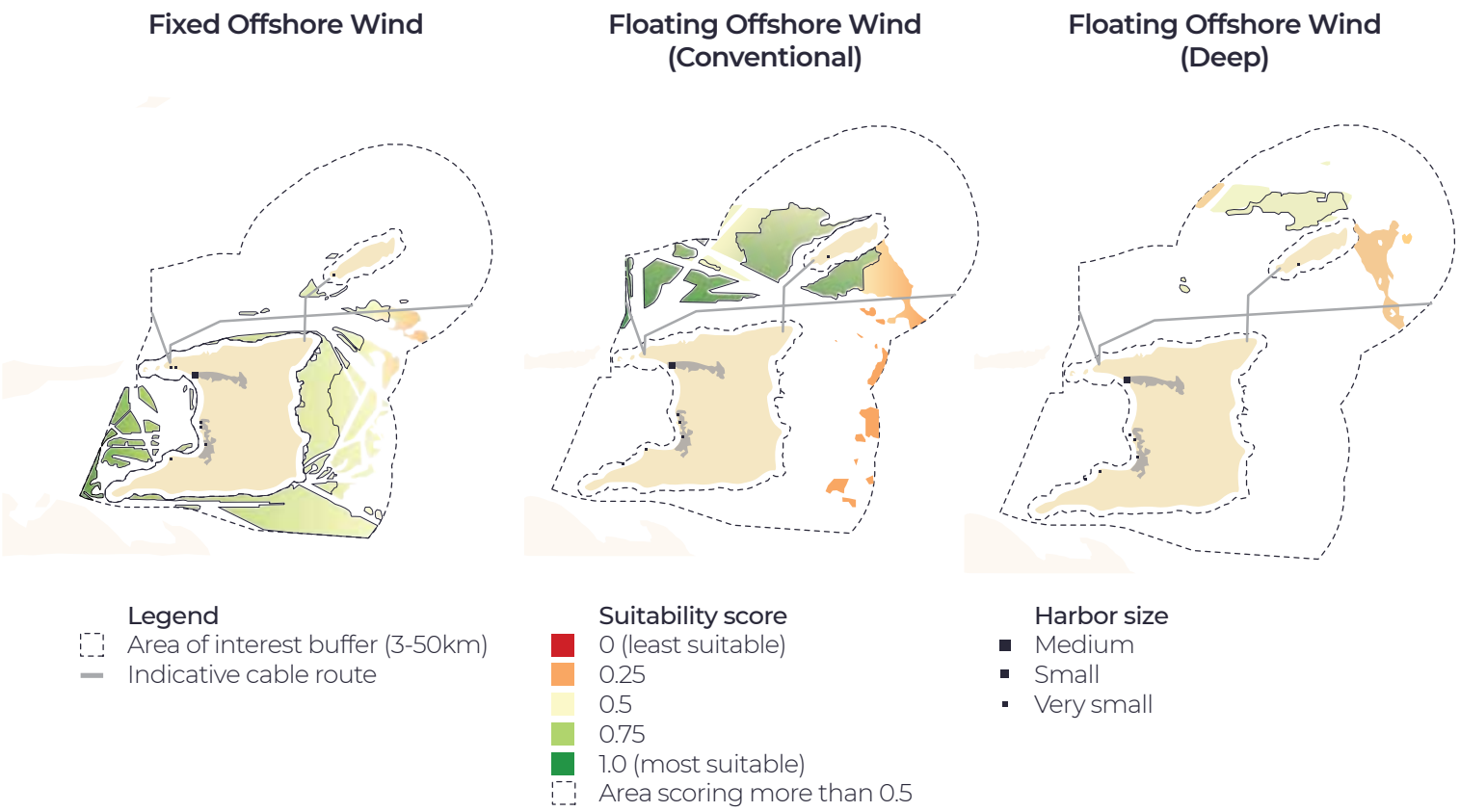


Figure 6: Offshore wind potential for Trinidad and Tobago (IDB, 2021)

Developing the green hydrogen industry in Trinidad and Tobago

If all 25 GW of average energy output from offshore wind was directed to electrolysers, 4 Mtpa of green hydrogen can be generated. This capacity is more than double the current demand for grey hydrogen in the country (1.7 Mtpa), providing the opportunity for Trinidad and Tobago to decarbonise the existing petrochemical industry and expand this industry in the future to contribute to the GDP growth of Trinidad and Tobago through additional export potential.

The development of a new industry that produces 4 Mtpa of green hydrogen will require a long-term vision and development programme. To date, Trinidad and Tobago has one renewable energy project in the pipeline and one clean hydrogen project. The former is a utility scale solar PV project, looking to generate 112MW of solar electricity through a joint venture between Shell Renewables Caribbean Limited, BP Alternative Energy Trinidad and Tobago and Lightsource bp. The latter is developed by NewGen Energy Ltd who are looking to use a combination of solar and energy efficiency-sourced power to produce low-carbon hydrogen to support ammonia production.

Expanding from these pioneer projects to build a hydrogen economy with 57 GW of installed capacity in renewable energy and 25 GW of output feeding electrolyser capacity will require a strong foundation built on right policy support, favourable conditions for industry adoption and institutional capacity to drive the development programme proposed in Figure 7.

The proposed development programme is built using a stepwise approach, with small utility scale renewable energy and electrolyser developments in the early years, building to larger scale projects as the local supply chains mature and Trinidad and Tobago gains valuable experience in the execution and delivery of green energy projects.

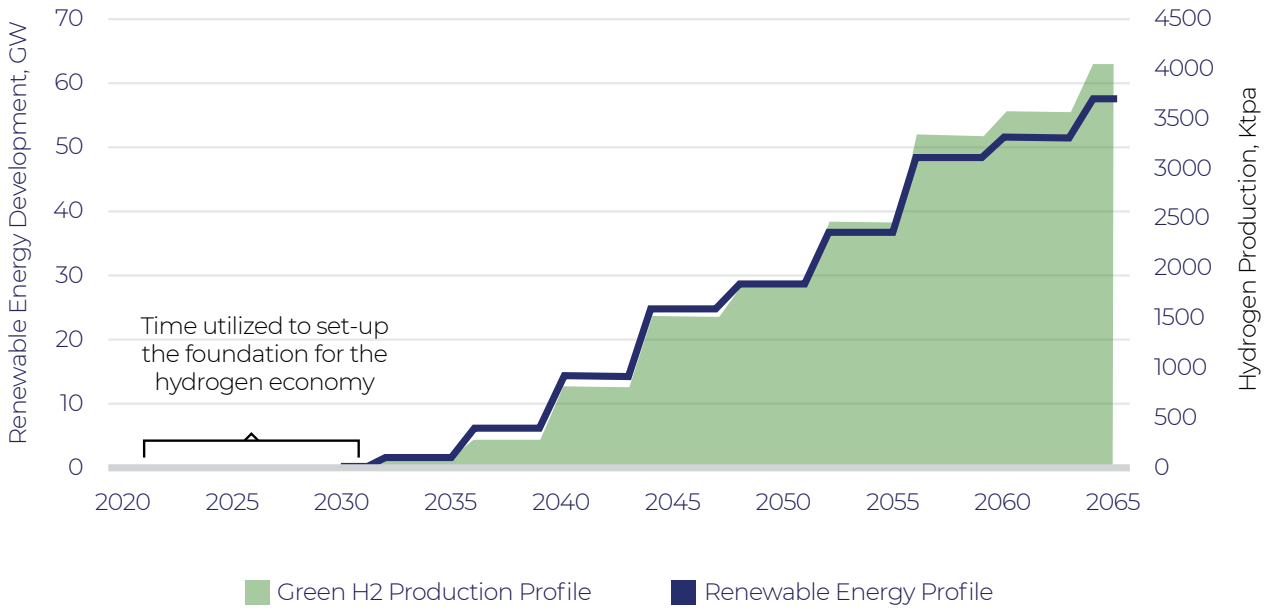


Figure 7: 35-year development programme for offshore wind and green hydrogen (Authors Elaboration, 2022)

Acting as fast-follower, Trinidad and Tobago will look to penetrate the green products market by the end of this decade, leveraging the expected cost reductions due to technology maturity and development of supply chains linked to both renewable energy and hydrogen electrolysis. This approach allows Trinidad and Tobago to spend the coming years building a strong foundation for the hydrogen industry, including:

- new policies;
- regulatory framework;
- further studies to confirm wind resource potential;
- demonstrating the end-use applications of green hydrogen in the Caribbean region; and
- capacity building and developing local human capital.

With this proposed development programme, 2052 is a key milestone for Trinidad and Tobago, which is when all the grey hydrogen currently used by the petrochemical industry (1.7 Mtpa) could potentially be displaced by green hydrogen as depicted by Figure 8 below. Phasing out of grey hydrogen from the petrochemical industry will result in natural gas previously used for grey hydrogen production being "saved" and hence redirected to LNG production for export. Further, with a stable supply of green hydrogen, Trinidad and Tobago can maximise production from existing facilities and invest in new infrastructure, such as transformation facilities (hydrogen carriers), and facilities for liquid hydrogen storage and shipping. Trinidad and Tobago will also need to ensure that existing petrochemical capacities are maintained with extension of life or new facilities as required.

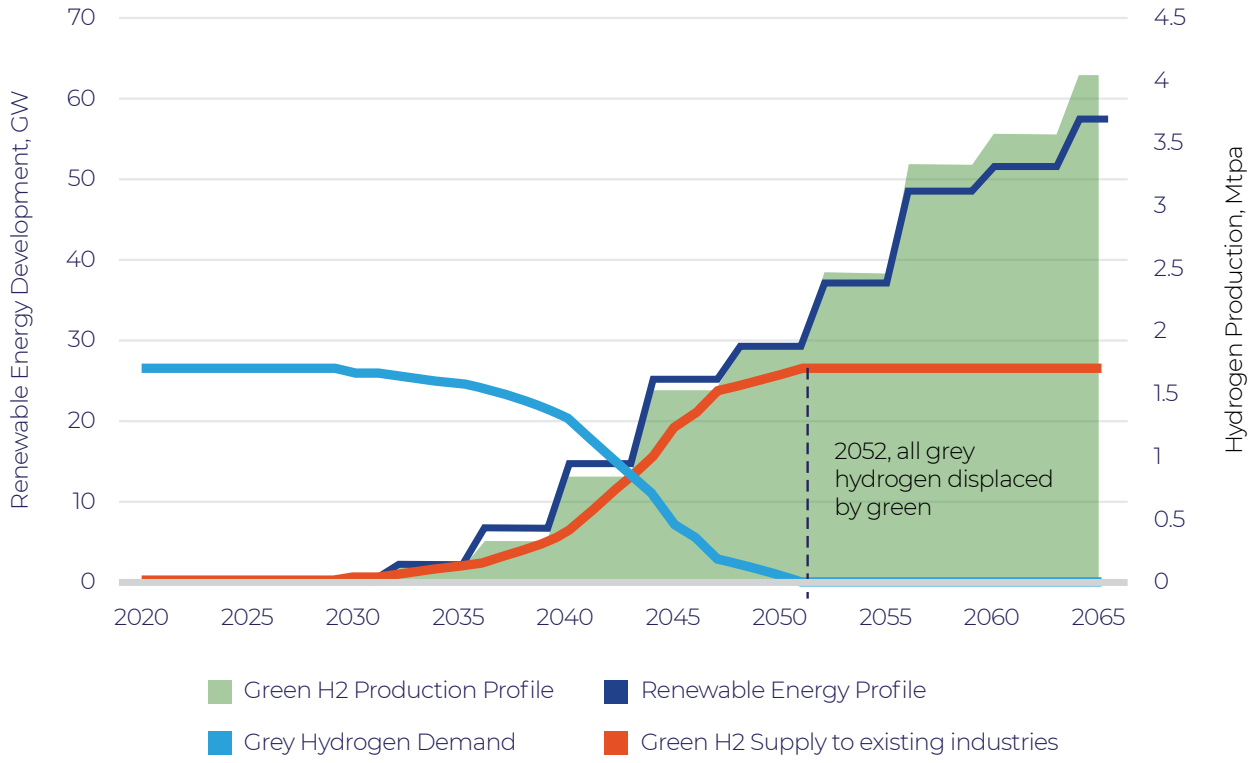


Figure 8: Green hydrogen production profile: displacing grey with green (Authors Elaboration, 2022)

The potential role of blue hydrogen

Trinidad and Tobago could also displace grey hydrogen in industry earlier than forecasted to achieve the required reduction in CO_2 through carbon capture and blue hydrogen. A hypothetical profile is presented here for blue hydrogen, where the blue hydrogen is used to transition from grey to green, as shown in Figure 9. With carbon capture technology retrofitted to existing ammonia and methanol plants, Trinidad and Tobago

will be well placed to position itself in the market for low carbon ammonia and methanol before fully transitioning to green products once renewable energy and green hydrogen developments are in place. In this hypothesis, blue hydrogen production will peak in 2040 providing 80% of the hydrogen demand from industry, and gradually decline as green hydrogen production expands.

Further assessment is required taking into consideration the investment required for CO_2 infrastructure, years of operation of CO_2 capture facilities, long term natural gas availability as well as the required policy and regulatory framework to support development of the blue hydrogen sector.

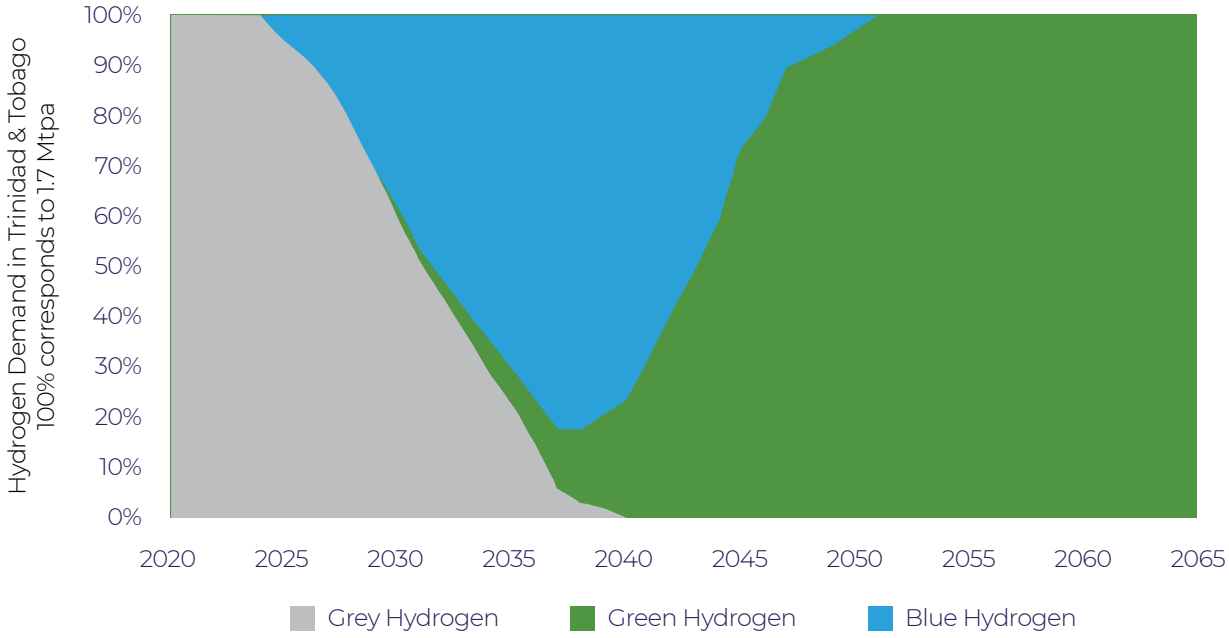


Figure 9: Blue hydrogen as "transition pathway" (Authors Elaboration, 2022)

05

Green Products Market: Competitiveness of Trinidad and Tobago

Trinidad and Tobago's value proposition lies in leveraging its existing petrochemical facilities, operational experience, and associated infrastructure. All other nations exploring green hydrogen and hydrogen derivatives will need to invest in the transformation facilities (ammonia, methanol or other hydrogen carriers) as well as storage and export facilities, and this will require not only high levels of CAPEX, but also the workforce and know-how required to build, operate and maintain these facilities, all of which are pre-existing in Trinidad & Tobago. To assess Trinidad and Tobago's competitiveness, Trinidad and Tobago's cost of hydrogen production, as well as transformation to ammonia was assessed.

The analysis conducted yielded the Levelised Cost of Hydrogen (LCoH) envelope as depicted in Figure 10 for Trinidad and Tobago, with an average LCoH of US$5.80 per kg of H2 produced in 2030 reducing to US$3.60 per kg of H2 produced in 2050, with the potential to achieve lower LCoH figures of US$3.60 by 2030 and US$2.70 by 2050 through technology cost reductions, optimisation of renewable energy costs, alternate choice of technology suppliers as well as the set-up of local supply chains to support the green hydrogen industry.

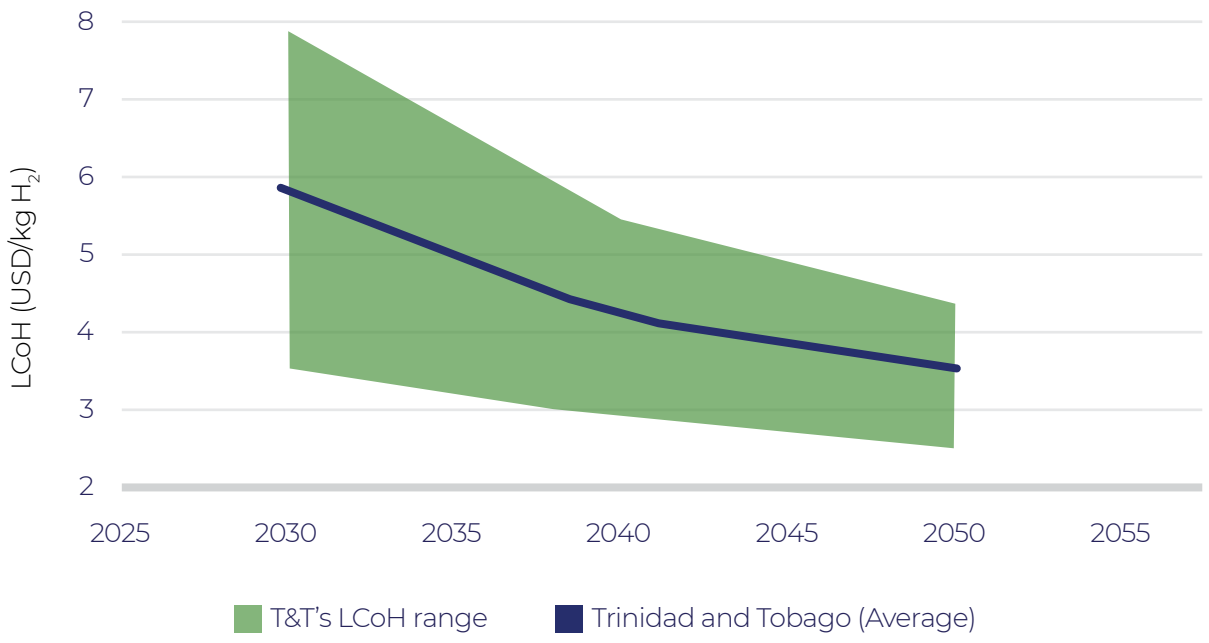


Figure 10: LCoH range for Trinidad and Tobago (Authors Elaboration, 2022)

Translating this LCoH to Levelised Cost of Ammonia (LCoA) production, yields the envelope shown in Figure 11, where Trinidad and Tobago could achieve an averag

e LCoA of US$1,100 per tonne of NH3 produced in 2030 reducing by almost half to US$690 per tonne of NH3 produced in 2050. The LCoA presented here leverages the existing infrastructure (transformation, storage and export facilities), thereby providing competitive green ammonia production costs to other potential competitors.

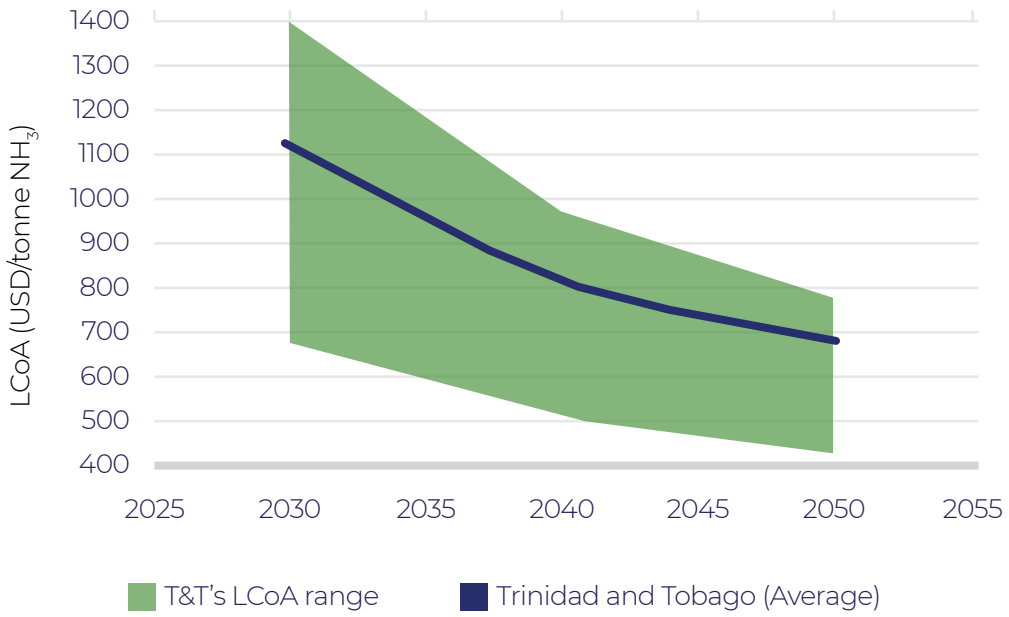


Figure 11: LCoA range for Trinidad and Tobago (Authors Elaboration, 2022)

Despite the current LCoA being higher than the historical price of grey ammonia[8], the right levers can allow Trinidad and Tobago to achieve a LCoA that is within this historical price or lower. This would depend on the extent of the effect of levers such as quicker technology advancements, technology cost reductions and development of local supply chains. Where these levers would reduce the LCoH resulting in a lower LCoA.

Previously trading at US$540 per tonne, recent prices for grey ammonia cargoes in Northwest Europe are reaching record highs of US$1650 - US$1680 per tonne (S&P Global, 2022). Whilst these unprecedented prices are largely due to global challenges such as the COVID-19 pandemic and the Russian-Ukraine war, climate change policies and carbon taxes are expected to keep the price of natural gas above its historical price towards the end of this decade. Thus, as natural gas and grey ammonia prices stabilise, high grey ammonia prices are expected to remain. Overall, the current high prices of grey ammonia catalyses the development of the green ammonia market while climate change policies and carbon taxes will only increase the competitiveness of green ammonia.

[8] Grey ammonia is trading at an average of US$540 per tonne. FOB Black Sea price (IHS Markit, 2022).

It is also worth noting that a market for green hydrogen or its derivatives does not exist to allow for international trade of these products. As green facilities come online in the next 2-3 years, this market will start to take shape. At the onset, before market mechanisms for the trade of green products become established, the price of green ammonia is likely to track grey ammonia in the commodity market. It is also expected that towards the end of this decade, as natural gas prices stabilise and fall from current highs, climate change policies and carbon taxes may keep prices of grey ammonia at higher levels than the historical trading price of ammonia. This would create an uncompetitive market for grey ammonia and further boost the green market.

Trinidad and Tobago is in a unique leadership position, where the country not only possesses an extensive oil and gas heritage, but also the infrastructure associated with the ammonia industry, both of which can be leveraged alongside existing trade relations and geographical location for the country to position not only as green exporter but also as regional green hydrogen (or green products) storage and trading hub for the Americas and the Caribbean regions. Trinidad and Tobago can adopt a similar transformational journey of another island nation, Singapore, which started as an oil trading hub. Singapore had no crude oil reserves but imported crude oil primarily from the Middle East and provided storage, bunkering and later refining and blending facilities and exported the oil products into Asia. This was enabled by its geographical location, intervention by the government in economic activity and planning as well as Singapore's history as an entrepot, which provided them with the competitive advantage to store and distribute oil and oil products. Whilst Trinidad and Tobago is starting from a different position to Singapore, there is a parallel comparison between these two island nations that can be explored to enable the future positioning of Trinidad and Tobago in the regional market as well as global market."

06

The Roadmap for a Hydrogen Economy

Creating a hydrogen economy is not only a massive undertaking but also a delicate one (The Economist, 2021). However, this undertaking is well within reach of Trinidad and Tobago through government intervention in policy and regulation, careful planning and actions from stakeholders.

The proposed roadmap for Trinidad and Tobago is based on a 35-year development programme, and is split into 3 horizons, where:

- Horizon 1 focuses on setting up a strong foundation for the future of Trinidad and Tobago. The most critical part of the roadmap, Horizon 1 looks to achieve consensus amongst all local stakeholders, develop the required enabling policies and regulatory framework as well as establish visible decarbonisation initiatives in the country. The first offshore wind pilot is also envisaged towards the end of Horizon 1.
- Horizon 2 builds on Horizon 1 and the enabling environment developed to initiate the first utility scale renewable energy project as well as green hydrogen production facility, fully launching Trinidad and Tobago on this pathway. By the end of Horizon 2, Trinidad and Tobago will have installed 25 GW of offshore wind with 10.5 GW output to feed electrolysers to produce 1.5 Mtpa of green hydrogen.
- Horizon 3 reinforces the leadership of Trinidad and Tobago in the new energy sector, reaching 57 GW of offshore wind capacity with 25 GW output to feed electrolyser to produce 4 Mtpa of green hydrogen by 2065.

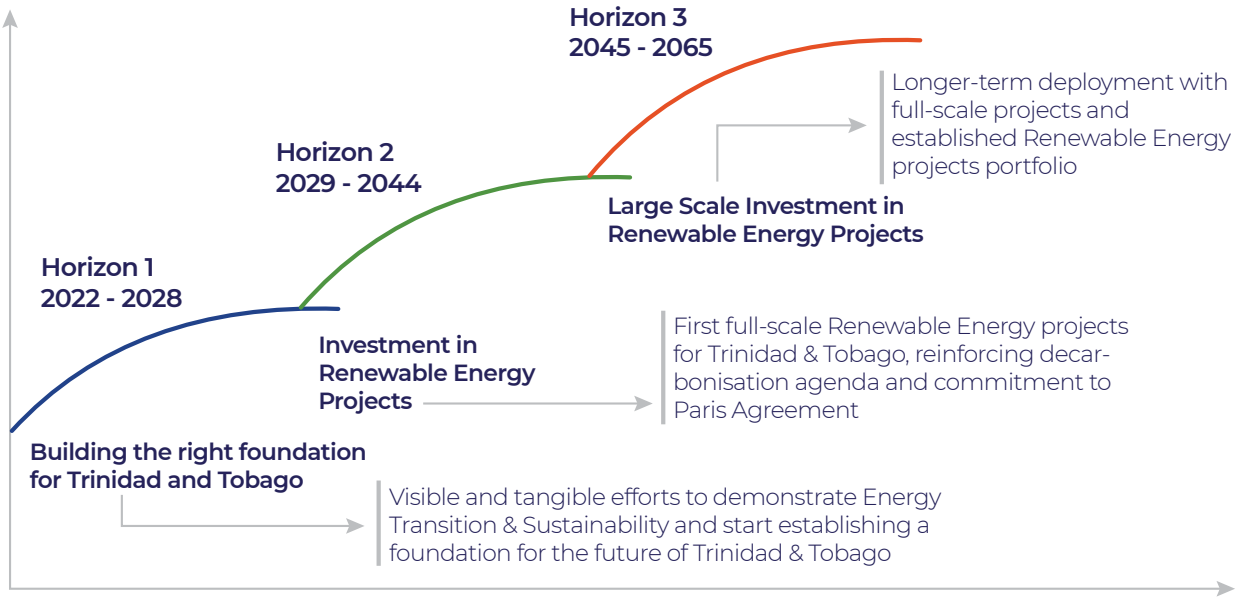


Figure 12: Trinidad and Tobago's hydrogen economy: the horizons

(Authors Elaboration, 2022)

To convert this roadmap into reality, Trinidad and Tobago will need to invest in the upstream development of the hydrogen value chain. This would involve investment into renewable energy and hydrogen electrolysis for production of green hydrogen, as well as the maintenance and expansion of existing downstream infrastructure for production of green ammonia and green methanol.

The full development programme involves 57 GW of renewable energy capacity through offshore wind technology, producing 25 GW of power feeding to electrolysers that produce 4 Mtpa of green hydrogen, generating net benefits in the billions and creating thousands of jobs in the construction, operation and maintenance sectors, whilst significantly reducing CO_2 emissions in Trinidad and Tobago.

Building the right foundation for Trinidad and Tobago

Horizon 1 is defined as the period, 2022 to 2028, allocated to building a strong foundation for Trinidad and Tobago, and is key to achieving the vision. Broadly, the activities in Horizon 1 can be grouped into four different categories:

- demonstration projects to test the end-use applications of green hydrogen in Trinidad and Tobago
- the activities required to support the offshore wind developments, most importantly the offshore Wind Resource Assessment Programme (WRAP)
- planning for the renewable energy and hydrogen campaign and the most critical part
- the enablers that will support the development of this hydrogen economy

For the demonstration of end-use applications of green hydrogen in Trinidad and Tobago, all sectors were considered, before narrowing down to potential areas which can be explored further. The following criteria were used to identify potential demonstration projects:

- The value to Trinidad and Tobago, in identifying solutions and opportunities for the future as Trinidad and Tobago starts its energy transition journey
- Visibility to both the local and international communities
- Timeline for implementation
- Scalability and technology synergies
- Ability to attract private funding for RE development programme

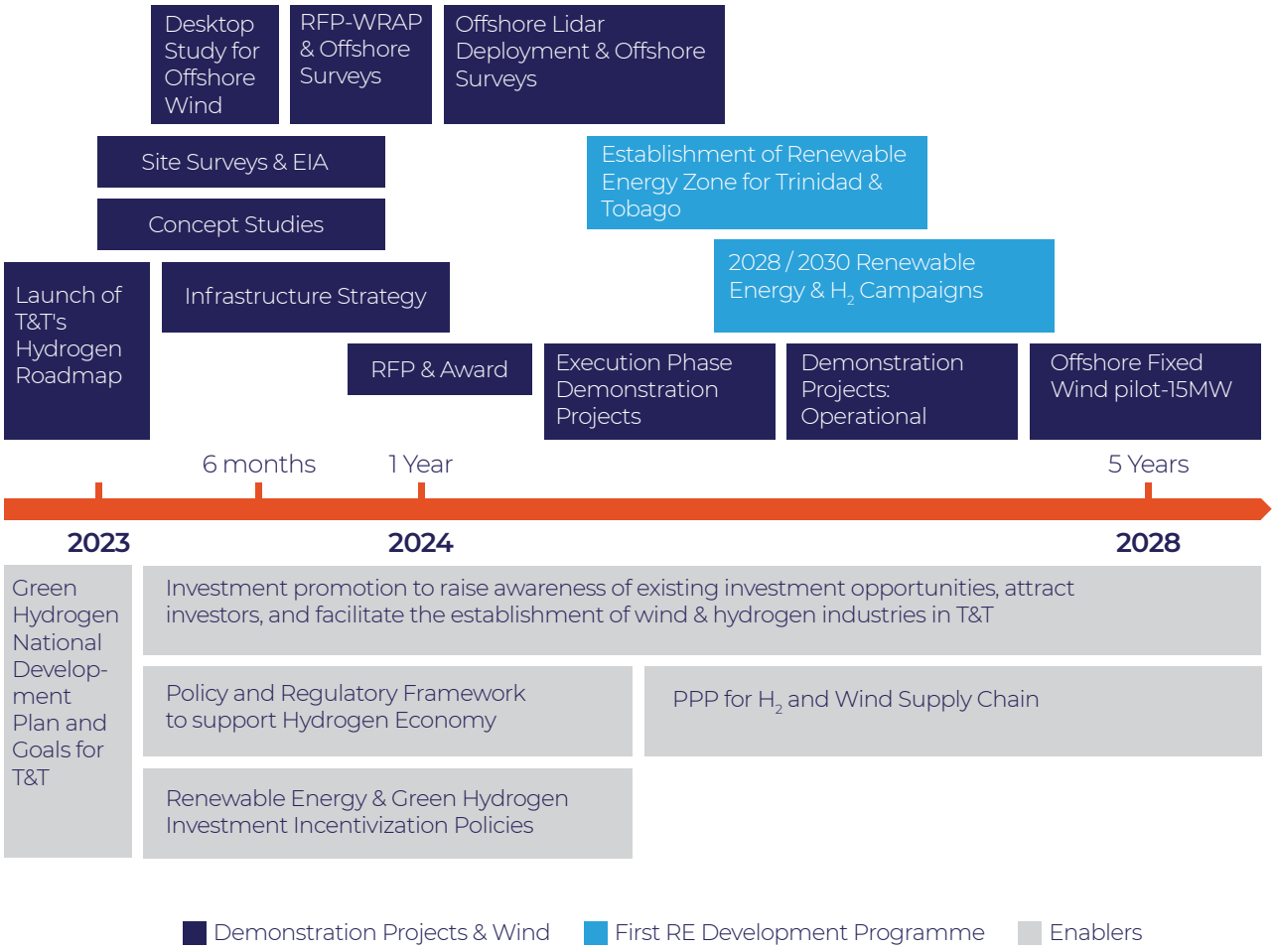
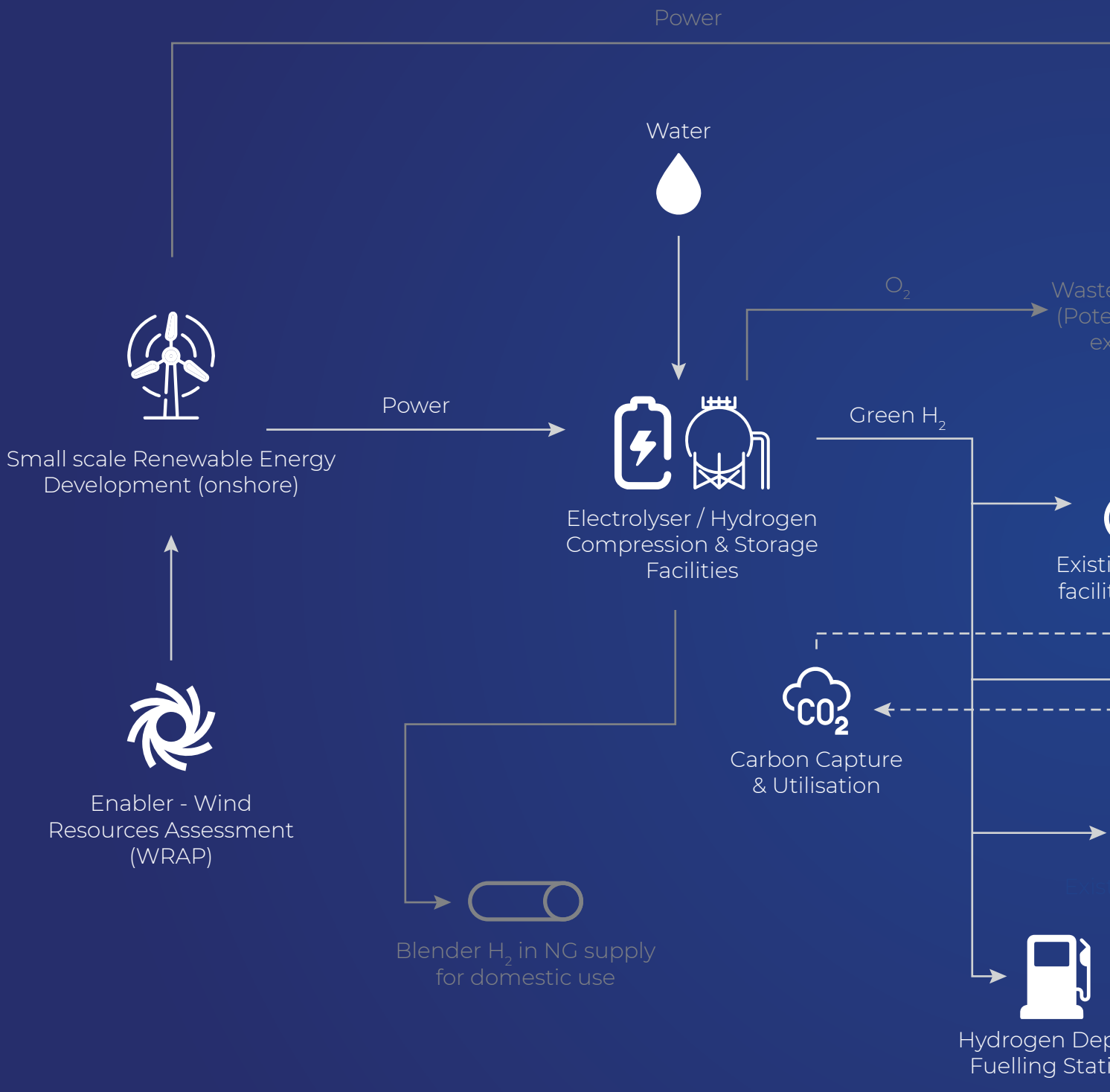


Figure 13: Horizon 1 implementation timeline (Authors Elaboration, 2022)

The assessment concluded that renewable energy generation and green hydrogen production, with the end-use of green hydrogen tested in the petrochemical sector through the production of green ammonia and green methanol, the transportation sector through public transport and cement manufacturing as depicted in Figure 14, can be considered as demonstration projects for Trinidad and Tobago. The WRAP is included in Figure 14 as this is a key activity that underpins the offshore wind programme, and the first RE development and offshore pilot for 2028.

Demonstrating end-use applications of Green Hydrogen



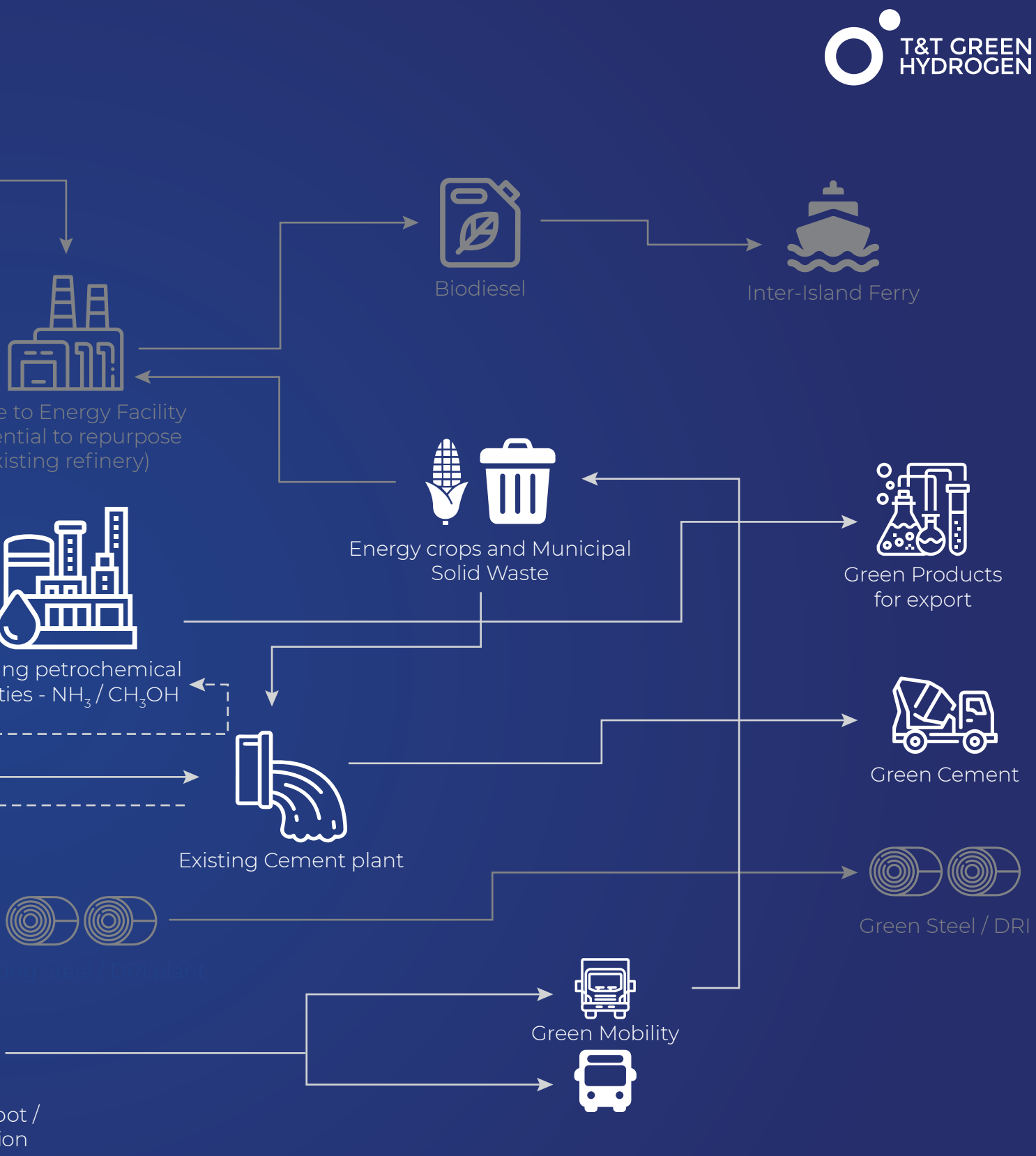


Figure 14: Horizon 1 – Demonstrating end-use applications of green hydrogen (Authors Elaboration, 2022)

Planning for the demonstration projects is already underway with the focus areas being sources of funding and stakeholder engagements.

Potential programs and funding sources available to support the implementation of the demonstration projects are being explored, including climate finance, such as funding sourced from international financing sources; carbon markets, such as funding sources which focus on action measures; private sector investment and national finance, such as funds provided by the Government of Trinidad and Tobago.

Stakeholder engagements are key to ensuring the successful definition and implementation of Horizon 1 activities which underpin the green hydrogen roadmap for Trinidad and Tobago. During the execution of the study, engagement with key stakeholders consisting of private sector, public sector and academia yielded valuable insights and feedback on the progress made so far. A process for continuous stakeholder engagement will be implemented whereby feedback can be continuously harnessed with regular stakeholder engagement sessions.

- Engagements with the public sector will be undertaken to support the development of the foundation required for the hydrogen economy. This will take the shape of developing a regulatory framework with the required policies to support the plan and accelerate the hydrogen economy in Trinidad and Tobago.
- The private sector has a significant role to play through partnerships with the Government of Trinidad and Tobago to first deliver the demonstration projects and subsequently the green hydrogen roadmap. It is envisaged that a competitive process will be put in place to explore private sector partners for the potential demonstration projects, with the aspiration to form partnerships underpinned by a sound business model and well-articulated commercial strategy.
- The academic sector and civil societies will be included in all stakeholder engagements with continuous feedback to ensure public support and ensure quality and sustainability of the projects.

A hydrogen economy: resources and enablers

The proposed scale of development to achieve the roadmap presented will require strong institutional support to deliver on the targets identified, which will be a massive undertaking, whilst maintaining a delicate balance between planning for resources and enablers.

The key resources required for the development of a hydrogen economy in Trinidad and Tobago are offshore wind for renewable energy generation, water for hydrogen

production and land for the green industrial development.

- This study has identified a potential for offshore wind which needs to be confirmed and validated through offshore wind measurement campaigns. To this effect, a wind resource assessment programme (WRAP) is recommended with the offshore deployment of floating lidars to measure offshore wind speeds and metocean conditions. This assessment, estimated to cost approximately US$10 M, is the most important part in planning a wind farm and lies on the critical path with a minimum of 4.5 years. This timeline includes the start of the offshore wind study to the deployment of the first pilot offshore wind turbine towards the end of Horizon 1 (2028).
- Water used for electrolysis is usually supplied by treating fresh water or the desalination of salt water. Given current limitations on water resources in Trinidad and Tobago, desalination is the most likely method to supply water for green hydrogen production. Whilst Trinidad and Tobago have desalination plants, the capacity of these existing facilities (40 million imperial gallons per day (MIGD)) will not be able to cater for the additional 36 MIGD of water required for green hydrogen production, driving the need to invest in new desalination facilities to meet this significant increase in demand for water. The additional environmental impact associated with increased brine produced by the desalinations plants also needs to be taken into consideration.
- An initial estimate indicates that between 2.2 – 4.4 km^2 may be required for the development of the green hydrogen sector in Trinidad and Tobago, depending on the footprint required for balance of plant (BoP) equipment and the possibility of electrolyser stacking reducing the overall acreage needed. A green industrial park near Point Lisas would be the most suitable site for accessing the existing petrochemical industry as well as ports and storage facilities. As the green hydrogen sector develops, other potential areas around the islands can be explored.

Further to the above resources, the key enablers to the hydrogen economy are local supply chains, regulatory framework and existing infrastructure.

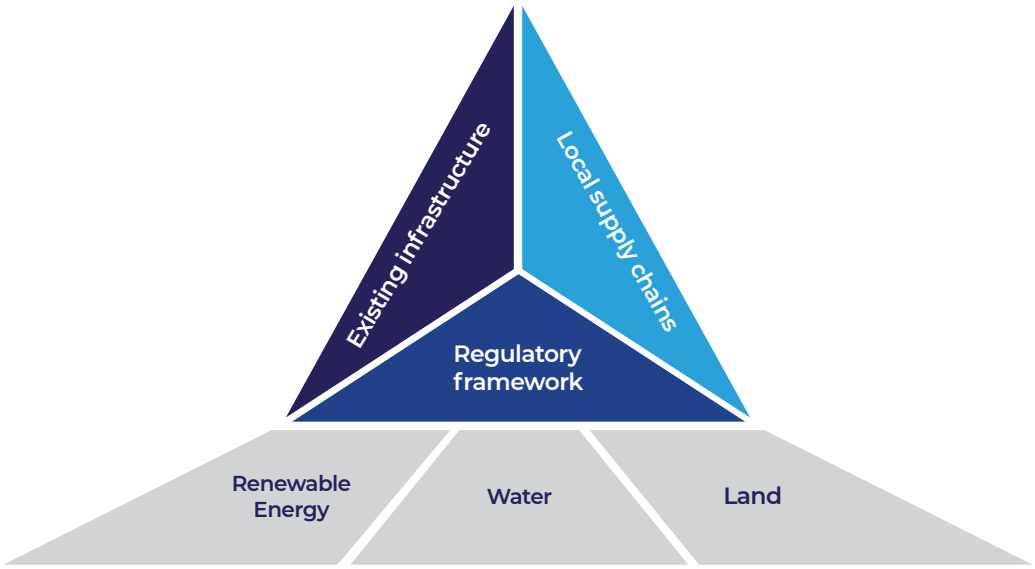


Figure 15: The key enablers to harness the potential of the resources available to Trinidad and Tobago (Authors Elaboration, 2022)

- Setting up a local supply chain for wind development and hydrogen production would support the long-term aspirations of Trinidad and Tobago, as well as the Caribbean region, in the development of a competitive green energy sector. A local supply chain will bring down costs associated with the renewable energy and electrolyser technologies, driving to a lower LCoH. New manufacturing facilities and assembly sites to support the supply chains will also create jobs for many, allowing for the current workforce to be upskilled. Moreover, transferable skills from the oil and gas can be used, giving rise to a new generation of workers skilled in the assembly, maintenance, and operations of wind turbines as well as electrolysis facilities.
- Building the right business environment in Trinidad and Tobago through enabling policies and a regulatory framework that builds, facilitates, and promotes an attractive environment for foreign investment through fiscal incentives, subsidies, tax holiday periods, government grants and lower profit taxes as well as facilitating the pathway of new developers and investors (ease of doing business). This also includes the creation of financing mechanisms to promote the development of renewable energy and green hydrogen projects and facilitate access to international funds.
- Existing infrastructure can be viewed in two separate segments, the existing petrochemical facilities (and associated storage and export facilities) and the electrical grid network, both of which are critical elements of the new hydrogen economy. Trinidad and Tobago's value proposition relies on the existing petrochemical facilities; most of which have been operating for more than 20

years. Planning for the upgrades, extension of life as well as integration of new facilities will be essential in enabling the roadmap for Trinidad and Tobago. Similarly, Trinidad and Tobago will need to upgrade its current electrical infrastructure and install new infrastructure including transmission networks to cope with the increase in electricity transmitted and distributed on the islands.

07

Conclusion

Leveraging its geography, the 100+ years of heritage in the oil and gas industry and a dynamic industrial ecosystem, Trinidad and Tobago can position as a key player in the evolving green energy landscape. With the potential of 57 GW of renewable energy through offshore wind technology, equating to 25 GW of output feeding electrolysers to produce 4 Mtpa of green hydrogen produced by 2065, Trinidad and Tobago has all the key ingredients required to enable a green hydrogen economy.

Globally, IRENA predicts that 12% of the world's final energy demand will be met by hydrogen by 2050, most of which will be green hydrogen and ¼ of this green hydrogen will be traded across borders. Of this, 45% will be shipped, mostly as ammonia. Demand for green ammonia in 2050 will reach 690 Mtpa with 80% used as chemical feedstock and fuel for shipping and 20% as hydrogen / energy carrier. Similarly, green methanol features prominently in global decarbonisation as the prime candidate for the shipping sector with an estimated annual production of 500 Mtpa by 2050.

These two commodities underpin Trinidad and Tobago's value proposition for a green hydrogen economy. As leading exporters of both ammonia and methanol, Trinidad and Tobago can leverage their existing petrochemical, storage and export facilities, as well as existing trade relations and shipping routes to position itself in this new market. Leveraging these existing facilities will increase the competitiveness of Trinidad and Tobago in the international green ammonia market, with an average LCoA of US$1,100 per tonne of NH3 produced in 2030 reducing by almost half to US$690 per tonne of NH3 produced in 2050. Whilst Trinidad and Tobago start with a LCoA that is higher than the historical trading price of grey ammonia (trading at an average of US$540 per tonne FOB Black Sea price, IHS Markit, ND), prices for ammonia cargoes in Northwest Europe are reaching record highs of US$1650 - US$1680 per tonne (S&P Global, 2022). These unprecedented highs in the global ammonia trade market are likely to accelerate the development of green ammonia which becomes cost competitive with the current grey prices, an opportunity which Trinidad and Tobago is well positioned to capitalise.

The roadmap for the development of a hydrogen economy in Trinidad and Tobago is presented as 3 horizons, with a development programme that spans 35 years. The most critical part of the roadmap, Horizon 1, looks to achieve consensus amongst all local stakeholders, develop the required enabling policies and regulatory framework as well as establish visible end-use applications of green hydrogen in the country. Horizon 2 builds on Horizon 1 and the enabling environment developed to initiate the first utility scale renewable energy projects as well as green hydrogen production, whilst Horizon 3 reinforces the leadership of Trinidad and Tobago in the new energy sector.

The full development programme involves 57 GW of offshore wind nameplate capacity

. These resources produce 25 GW of power that feeds electrolysers, producing 4 Mtpa of green hydrogen. Of the 4 Mtpa of green hydrogen generated, 1.5 Mtpa will go to existing ammonia and methanol markets, and the remainder going to applications that target new markets. These new markets not only include the aforementioned green ammonia and methanol, but also include liquid hydrogen and other new technologies as they mature. Through this programme, Trinidad and Tobago will generate net benefits in the billions, creating thousands of jobs in the construction, operation and maintenance sectors, whilst significantly reducing CO_2 emissions in Trinidad and Tobago . This ensures sustainable economic growth for Trinidad and Tobago, and also enables Trinidad and Tobago to maintain its leadership in the petrochemicals sector and in the Caribbean region.

The immediate next steps focus on the definition of the potential demonstration projects as well as funding sources. The demonstration projects may include renewable energy generation and green hydrogen production, with end-use of the green hydrogen tested in the petrochemical industry with the production of green ammonia and green methanol, transportation sector through public transport and cement manufacturing. Funding sources such as climate finance, carbon markets, private sector and national finance will be explored.

Trinidad and Tobago is at the beginning of a challenging and exciting journey. The country is able to continue playing a major role as a natural gas exporter whilst leveraging existing heritage and facilities to position in the evolving energy landscape, thereby ensuring sustainable economic growth in the future. This journey starts with setting up a strong foundation with the right enabling policies, regulatory framework and institutional support to launch Trinidad and Tobago's hydrogen economy.

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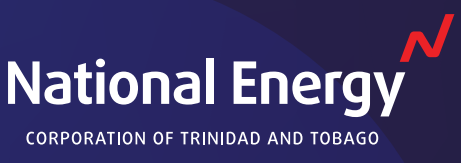
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