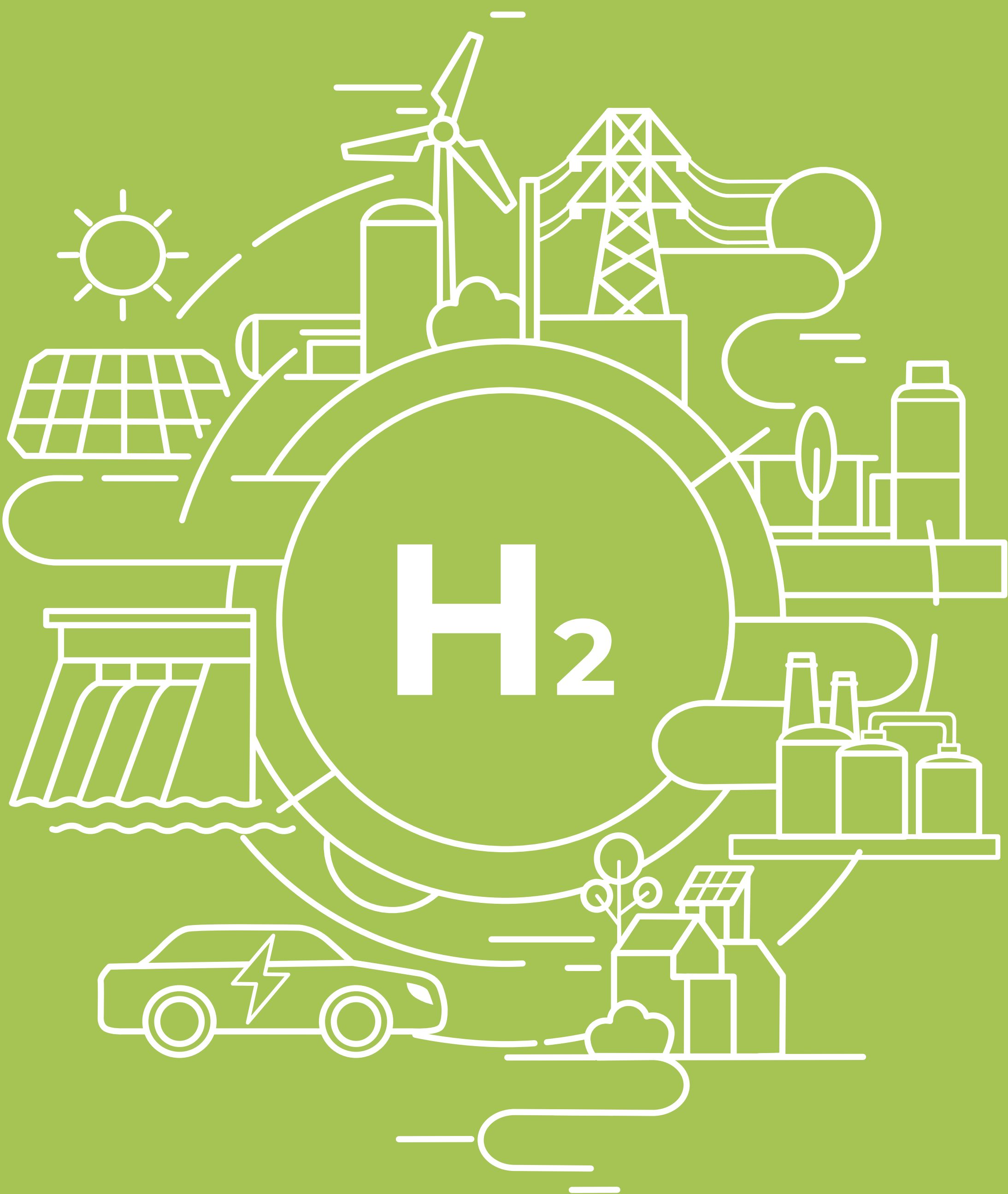
TOWARDS THE Green Hydrogen Roadmap in Paraguay



CONCEPTUAL FRAMEWORK

Guidelines to promote the development of green hydrogen for sustainable socio-economic growth in Paraguay

REPÚBLICA DEL PARAGUAY
Ministerio de
OBRAS PÚBLICAS
Y COMUNICACIONES
Viceministerio de
MINAS Y ENERGÍA

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Preface

The project "Towards the Green Hydrogen Roadmap in Paraguay" comes as an answer to the National Energy Agenda (AEN) and proposes green hydrogen as an energy vector that can contribute to the development of the country's energy sector, mainly in the area of transportation. This strategic and innovative approach to the energy use of H_2 is mentioned in a significant number of objectives and goals of the Agenda, and highlights the advantages of the energy use of green H_2 by taking advantage of the large surplus of hydroelectricity.

WE ARE CONVINCED THAT IT WILL BE AN EFFECTIVE TOOL THAT WILL HELP THE COUNTRY MEET ITS INTERNATIONAL COMMITMENTS: THE PARIS AGREEMENT AND THE 2030 SUSTAINABLE DEVELOPMENT GOALS (SDGS), AS IT PRESENTS GREAT OPPORTUNITIES FOR INCREASING NATIONAL ENERGY SECURITY AND DRIVING THE DECARBONIZATION OF CERTAIN AREAS OF THE ENERGY SECTOR.

We in the National Government believe that Paraguay could take advantage of its favorable conditions, such as its abundant water and energy resources and its strategic geographic location in the center of South America. The country has significant potential to become a Logistics and Renewable Energy Hub. In addition, it also currently has the third largest barge fleet in the world. With proper planning, the country could also drive the development of the hydrogen economy throughout Latin America and the Caribbean.

We believe that hydrogen represents great opportunities that will promote technological development and the energy transition, and that the incorporation of this technology will result in the acquisition of knowledge and the development of appropriate regulations and legal frameworks.

We are grateful for the support of the Inter-American Development Bank in conducting the project and to all the national institutions involved.

Carlos Zaldivar
Vice-Minister of Mines and Energy

Abbreviations and Acronyms

A

ANDE
National Electricity Administration - Paraguay

F

FCEV
Fuel Cell Electric Vehicle

H

HVO
Hydrotreated Vegetable Oil

H_2
Hydrogen

M

MAWP
Maximum Allowable Working Pressure

N

NREL
National Renewable Energy Laboratory, 36

P

PETROPAR
Petróleos Paraguayos (Paraguayan Petroleum)

S

SWRO
Sea Water Reverse Osmosis

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01.

Introduction

01. INTRODUCTION

The use of hydrogen as an energy vector is not a recent development; more than 200 years ago it was proposed for use as a means of obtaining mechanical work. At the beginning of the 19th century, the first internal combustion engine using hydrogen as fuel was manufactured. Since then, many uses have been given to this precious chemical element; from aerospace applications, to agriculture in the production of fertilizers, and even in oil refining. So much so that hydrogen demand has tripled since 1975 (IEA 2019).

However, its industrial utility is not the only appeal of this chemical element. The great benefit that stands out in the current context is the possibility of it being a carbon-free energy vector, a quality in line with global initiatives to mitigate climate change.

ELECTRICITY AND HYDROGEN CAN BE TRANSFORMED BIDIRECTIONALLY, WHICH FACILITATES ENERGY TRANSPORT AND STORAGE.

Hydrogen itself can be used to provide final energy services with low or near-zero emissions, with the caveat that for this condition to be met it must be obtained from renewable sources (IEA 2019). Currently, the most economical method of large-scale hydrogen production is the reforming of natural gas (or oil). However, this method of hydrogen production involves considerable levels of emissions (IEA 2019).

Interest in hydrogen as an energy source has grown in recent decades. Numerous research studies have been conducted and a number of countries even have policies in place to encourage investment and incentivize the development of hydrogen energy technologies in sectors such as transportation (IEA 2019) or in industrial sectors where electrification is not very practical. More and more countries are joining these initiatives and planning the development of a hydrogen economy as a component of their government policies. In this regard, several of these countries have adopted strategies the initial stages of which consist of research, development and demonstrations of technology intended to undertake actions to reduce CO_2 emissions and gradually reduce dependence on fossil fuel energy sources.

These government policies, for the most part, are aimed at the use of hydrogen in the overland transportation sector, oriented to the areas of passenger vehicles, buses and trucks (See Table 1), including the development of electrolyzer technology and hydrogen plants[1] that can ensure the supply for these types of mobility, defining the routes for hydrogen-based transportation as the pillars of future sustainable economic development. This is because, on the one hand, the transport sub-sector is a major contributor to CO_2 emissions in the energy sector and, on the other hand, battery-electric mobility is only suitable for

1 A hydrogen plant is a facility for the production of hydrogen.

light transport, for the time being, i.e. low tonnage and/or short average daily travel distance. In addition, there are initiatives in place that aim to encourage the use of hydrogen energy in other transport sectors, including the railroad, the maritime sector and especially in the river sector, where the use of large vessels for transporting goods or passengers is a solution for the future. All these ventures and policies being promoted globally have helped to underpin interest in the use of hydrogen energy and also demonstrate that the technology offers broad potential for use, which with the right incentives could help reduce dependence on carbon-intensive sources.

TABLE 1.

SOME TARGETS SET IN LEADING COUNTRIES IN HYDROGEN TECHNOLOGY DEVELOPMENT

Country	Goals
France	– 5,000 passenger vehicles by 2023 – 20,000-50,000 passenger vehicles by 2028 – 200 trucks by 2023 – 800-2, 000 trucks by 2028
Japan	– 200,000 passenger vehicles by 2025 – 800,000 passenger vehicles by 2030 – 1,200 buses by 2030 – 10,000 buses by 2030
South Korea	– 80,000 taxis by 2040 – 4,000 buses by 2040 – 3,000 trucks by 2040 – 81,000 passenger vehicles by 2022 – 2.9 million passenger vehicles by 2040 (3.3 million exported) – 1.5 GW capacity by 2022 – 15 GW combined production (7 GW export, 8 GW domestic) by 2040 – 0.47 million tH_2/y by 2022, – 1.94 million tH_2/y by 2030 – 5.26 million tH_2/y by 2040
Nether-lands	– 15,000 passenger vehicles and 3,000 trucks by 2025 – 300,000 passenger vehicles 2030 – 500-800 MW of installed capacity by 2025 – 3-4 GW installed capacity by 2030

Source: (IEA 2019)

Latin America is no exception in the promotion of green hydrogen. Countries such as Costa Rica, Brazil and Uruguay, to mention a few, have shown interest and identified the potential for hydrogen use. Some time ago, they started to promote initiatives related to this issue. Likewise, the government of Paraguay, through the Vice Ministry of Mines and Energy (VMME), is currently in the development phases of a Strategy for the Use of Hydrogen in the Transport Sector, for both overland and river transportation(BID OLADE 2020)[2].

Paraguay has an almost 100% renewable energy generation matrix with surpluses of up to 71% of the total generation (VMME 2019)[3] coming entirely from hydroelectric power plants. Only a few isolated locations, far away from power grids, still rely on petroleum derivatives to generate electricity. Nonetheless, its share is much less than 1%. Paradoxically, the final energy consumption matrix presents strong participation of petroleum derivatives, around 41% (VMME 2019), which are entirely imported. While the share of electricity is only about 16% (VMME 2019). In addition, a large part of the hydroelectricity that Paraguay produces (71%) (VMME 2019)is currently exported to the partner countries of the binational projects (under the terms established in the respective bilateral treaties), due to the lack of demand to commercialize this energy within the country.

The import of fossil fuels not only exposes the country to high macroeconomic vulnerability, due to price instability, but is also one of the main causes of foreign exchange outflows from the country, with strong consequences on the balance of payments. Furthermore, the transportation sector is mainly responsible for the consumption of a large part of these fossil fuels, accounting for around 93% of sector consumption[4] (VMME 2019). In addition, a condition that is not very favorable to Paraguay is that of being a landlocked country, since it is heavily dependent on land and river transport for the goods it produces, even at the domestic level, the distribution of goods is carried out by these means, directly affecting the final price of the products. The main sectors affected by the behavior of oil derivative prices are urban public transportation, agriculture and livestock, road and river transportation, which in a broad sense all affect the country's economy.

In terms of national objectives, Paraguay has proposed to reduce the consumption of fossil fuels by 20% and increase the consumption of renewable energies by 60% by 2030[5], according to the National Development Plan Paraguay 2030 (PND 2030)(STP 2014). In this context, under the National Energy Policy 2040 (PEN 2040), the government committed to **promoting the substitution of imported fossil fuels with bioenergy, electricity and other energy sources of national origin.** This is reinforced by the Paraguay Sustainable Energy Agenda 2019-2023[6] published in early 2021 by the VMME.

Hydrogen as an energy vector for the transport sector is presented as one of the innovations of the National Energy Agenda. The strategic and innovative vision of the energy use of H_2 is mentioned in a significant number of objectives and goals of the aforementioned agenda, highlighting on

2 BID OLADE. 2020. "Fuel Substitution Analysis of the River Transport System of the Paraguay – Paraná Waterway." http://www.olade.org/publicaciones/analisis-de-sustitucion-de-combustibles-del-sistema-de-transporte-fluvial-de-la-hidrovia-paraguay-parana/.

3 In 2018, gross hydroelectricity generation amounted to 59,210 GW, and approximately 42,205 GW were exported.

4 In 2018, energy supply from petroleum derivatives was 2,686 KTEP, and final consumption in the transportation sector was 2,490 KTEP.

5 Within the annual percentage of total energy consumption at the national level.

6 A technical document that outlines the roadmap for public institutions in the country's energy sector. It does not seek to replace strategic and operational plans, but rather is an instrument whose role is to guide public policy.

different occasions the advantage of the energy use of green hydrogen that Paraguay can obtain from its own renewable energy sources.

The 2019-2023 National Energy Agenda proposes green hydrogen as an energy vector that can contribute to the development of the country's energy sector, recommending from the outset the evaluation of its use as a fuel for long-distance transportation. In this sense, its pillars of Renewable Sources and Electric Development seek to implement an Evaluation Program for Hydrogen Fleets with the goal of implementing a pilot project for its production and use. Additionally, the Environment and Society aspect establishes as a goal the inclusion of the use of H_2 in a National Strategy for Sustainable Mobility, through a demonstrative pilot plan.

In addition to the goals at the national level, the country also assumed some commitments at the international level: The Paris Agreement and the 2030 Sustainable Development Goals (SDGs). With regard to The Paris Agreement, Paraguay reaffirms its international climate commitments (Congreso de la Nación Paraguaya 2016). Meanwhile, regarding the SDGs, there are several goals[7] related to the use of new technologies aimed at reducing the effects of climate change, the transition to renewable energies, the reduction of air and atmospheric pollution, always with a focus on sustainable development, suggesting long-term investments in key sectors, such as transportation, and particularly in developing countries(Comisión ODS Paraguay).

HOWEVER, PARAGUAY COULD TAKE ADVANTAGE OF ITS FAVORABLE CONDITIONS, SUCH AS ITS ABUNDANT WATER AND ENERGY RESOURCES AND ITS STRATEGIC GEOGRAPHIC LOCATION IN THE CENTER OF SOUTH AMERICA.

The country has a significant potential to become a logistics and renewable energy hub. In addition, it currently has the third largest barge fleet in the world[8]. With proper planning, the country could also leverage the development of the hydrogen economy throughout Latin America and the Caribbean. For Paraguay, hydrogen as an energy vector represents great opportunities to promote technological development and energy transition, not only in the transportation sector but also in industry and other sectors. It would be a 100% domestic fuel that would take advantage of the large hydroelectricity surpluses, making a significant contribution to the value chain and the different productive sectors.

7 Objectives 7, 9, 11, 13 and 17.
8 Available online at: https://www.lanacion.com.py/negocios/2018/04/13/paraguay-tiene-la-tercera-mayor-flota-fluvial-del-mundo/


Hydrogen H_2
H_2
Hydrogen
H_2

02.

A brief description of the transportation sector

02.

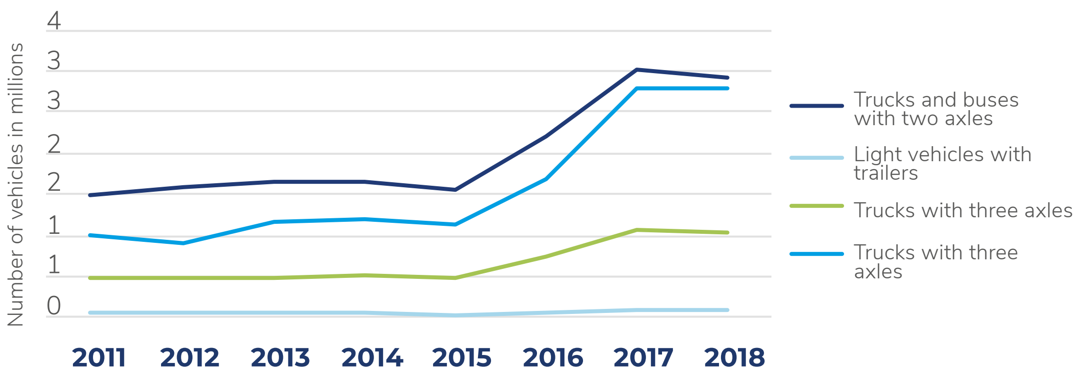
A BRIEF DESCRIPTION OF THE TRANSPORTATION SECTOR

The contribution of the Transportation Sector to the Paraguayan economy is invaluable as it is a landlocked country. As an economic sector, it is responsible for 4% of the country's GDP, according to BCP data[9]. In 2018 it was responsible for the movement of goods for export worth USD 9 billion (mainly soybeans and their derivatives as well as meat products, in that order), and imported goods worth USD 13 billion (petroleum, electronic equipment, cars, fertilizers and pesticides in that order) (OEC World 2020.000Z; WITS 2018).

With respect to the characterization of the sector, according to the 2018[10] Transportation Statistics Yearbook published by the National Transportation Directorate, as of that year there were 291 licensed companies of the international cargo transportation service that were registered to operate. With a total of 568 trucks, 9,533 tractor-units, 9,108 semi-trailers, 64 trailers, a total fleet of 18,705 registered vehicles in the hands of these companies. As for inter-municipal passenger transportation companies, there were 111 companies operating different routes throughout the country. The same document states that, in terms of the total number of vehicles registered by type throughout the country, there are 83,898 trucks, 3,077 wagons, 9,426 buses, 2,361 trailers and 9728 minibuses. A total of 108,490 transports for utility and service uses. In addition, the yearbook indicates, in terms of vehicle movement by category, in 2018, that the movement of 2,913,062 trucks and buses with two axles, 96,929 light vehicles with trailers, 1,021,574 trucks with three axles and 2,788,305 trucks with more than three axles were recorded. A total movement of 6,819,870 vehicles for transportation and services. As can be seen in Chart 1), traffic volume has experienced a considerable increase since 2015.

CHART 1.

VEHICLE MOVEMENT BY CATEGORY (IN NUMBER OF VEHICLES)



Source: Author's compilation based on DINATRAN Statistical Yearbook 2011-2018.

9 Available at https://www.bcp.gov.py/anexo-estadistico-del-informe-economico-i365
10 Information available at: http://www.dinatran.gov.py/docum/Anuario_2018.pdf.


21 LINEA 21 21
PASAJE 3.600
SAJONIA AZARA
BUS CLIMATIZADO
BSV 817


V.M.T
FISCALIZACION

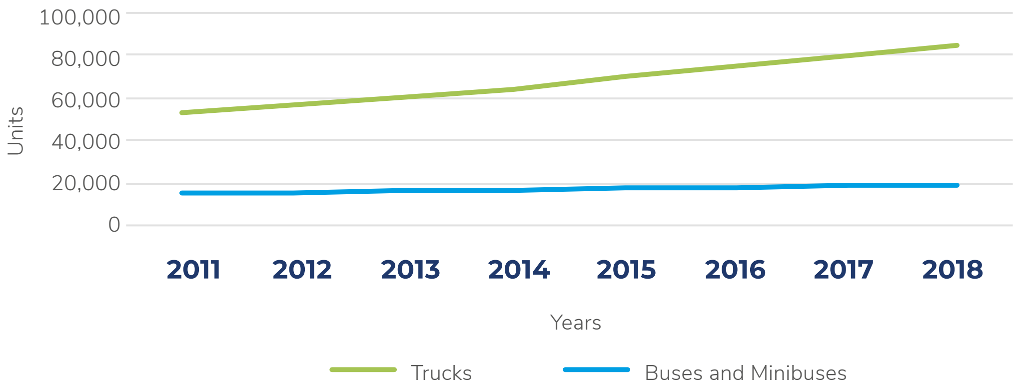

PASAJE 3.400
V.M.T
FISCALIZACION


LINEA 12

In the segment of exclusively cargo and passenger transportation the average annual growth rate of the registered truck fleet in the country was 7%, while for Buses and Minibuses it was 3%, for the period 2011 - 2018 as shown in Chart 2. There is a noticeable trend towards growth in both cases. These types of vehicles are mainly consumers of diesel fuel with long annual distances, making them important contributors to CO_2 emissions.

CHART 2.

NUMBER OF TRUCKS, BUSES AND MINIBUSES REGISTERED ANNUALLY



Source: Author's compilation based on DINATRAN Statistical Yearbook 2011-2018.

Another characteristic of the vehicle fleet is that it is relatively old due to the fact that most of them are second-hand imports, and the fleet itself in all categories is quite old, ranging from 15-18 years to 20-21 years, with poor efficiency and emissions standards (CMMolina 2019). This represents an opportunity to convert the fleet to sustainable alternatives. As for the origin of the vehicle fleet, almost 50% are imported from Asia, of which a large portion corresponds to Korean and Japanese manufacturers (CADAM 2019).

Regarding the movement of import and export cargo in the river transport sector, a total flow of 2,201,346,909 tons and 1,482,185,886 tons, respectively, was recorded[11].

[11] See http://www.dinatran.gov.py/docum/Anuario_2018.pdf

03.

The future of the national electrical infrastructure

03 THE FUTURE OF THE NATIONAL ELECTRICAL INFRASTRUCTURE[12]

The Paraguayan electrical system counts on an abundant supply of hydroelectricity in power plants, with a current installed capacity of 8,810 MW, which could reach 11,541.86 MW by 2030 (ANDE 2016). This allows Paraguay to be an important exporter of electricity. In addition, the country has great potential for solar photovoltaic[13] power plants; and the installation of numerous hydroelectric generation plants is being studied, which will allow for the increase of the current capacity, as well as the upgrading of the existing facilities. In summary, there are about 30 planned projects for power generation (see Attachment, Table 10). In addition, according to ANDE's Power Generation and Transmission Master Plan, there are 2 major hydroelectric projects under consideration that would add approximately 2,372.5 MW to the national generation capacity (ANDE 2016). This reveals the possibility of significant future increases in the production of the national electrical system.

On the other hand, as for the National Interconnected System[14] (SIN), by 2025, 227 transmission and transformation projects will have been executed, broken down as follows: 5 new 500 kV transmission lines totaling 10 GVA, to deliver energy to the main productive points of the country with an addition of 6,975 MVA in transformation capacity (500/220 kV). In addition to the above, 25 new 220 kV lines and 22 new 66 kV structural lines will be installed, which will allow higher levels of reliability and flexibility for the operation of the system. To strengthen the transformation infrastructure by 2025, the installed capacity is expected to increase by 2,033 MVA for 220/66 kV; 3,218 for 220/23 kV and 2,007 MVA for 66/23 kV. A total of 3 new 500 kV, 25 new 220 kV and 14 new 66 kV substations will be constructed.

TABLE 2.

SIN FEATURES FOR 2025

Lines	Length (km)	Transformers	Capacity (MVA)
500 kV	1.438	500/200 kV	11.725
220 kV	6.711	220/66 kV	4.390
66 kV	1.659	220/23 kV	5.360
-	-	220/23 kV	4.364

Source: (ANDE 2016)

12 Based on the Power Generation and Transmission Master Plan(ANDE 2016) . According to ANDE's publications, in the course of 2021 it would be presenting its next Works Plan with a timeframe extending to 2030. It is expected that the projects described in this section will be executed and even reinforced with the provisions of the new plan.

13 Solar energy potential of 1,112,221,024 MWh/year (ANDE 2016).

14 This is how ANDE refers to the Paraguayan Transmission System (500 kV, 220 kV and 66 kV). (ANDE 2016)

3.1

VILLA ELISA AND ALTO PARANÁ

Regarding the distribution centers in the city of Villa Elisa, ANDE's Works Plan foresees the construction of a 220/23 kV substation, with a transformation capacity of 80 MVA. It is planned to add 18 feeders at the Lambaré substation in the coming years, which will discharge the feeders of the substation itself, also serving the Villa Elisa and Bus Terminal districts. Overall, 12 new feeders would be built at the new Villa Elisa substation to discharge the feeders of the Lambaré, Tres Bocas and San Antonio substations. By 2021, a total of 24 feeders are expected to be installed at the Villa Elisa substation.

The infrastructure in Alto Paraná is in good condition. By 2025, the following installed capacities will be in place, 220/66 kV transformation with 120 MVA, 220/23 kV with 285 MVA and 66/23 kV with 150 MVA, and at the medium voltage distribution level (23 kV) there will be an installed capacity of 1,752 MVA in substations, covering not only Alto Paraná but also Canindeyú. In addition, it is important to point out that ANDE in its planning for the year 2025 has incorporated the assumption of the expansion of the Hernandarias Industrial Park, so that the infrastructure of this area will be gradually strengthened to meet a possible growth in demand.

04.
Liquid biofuels

04.

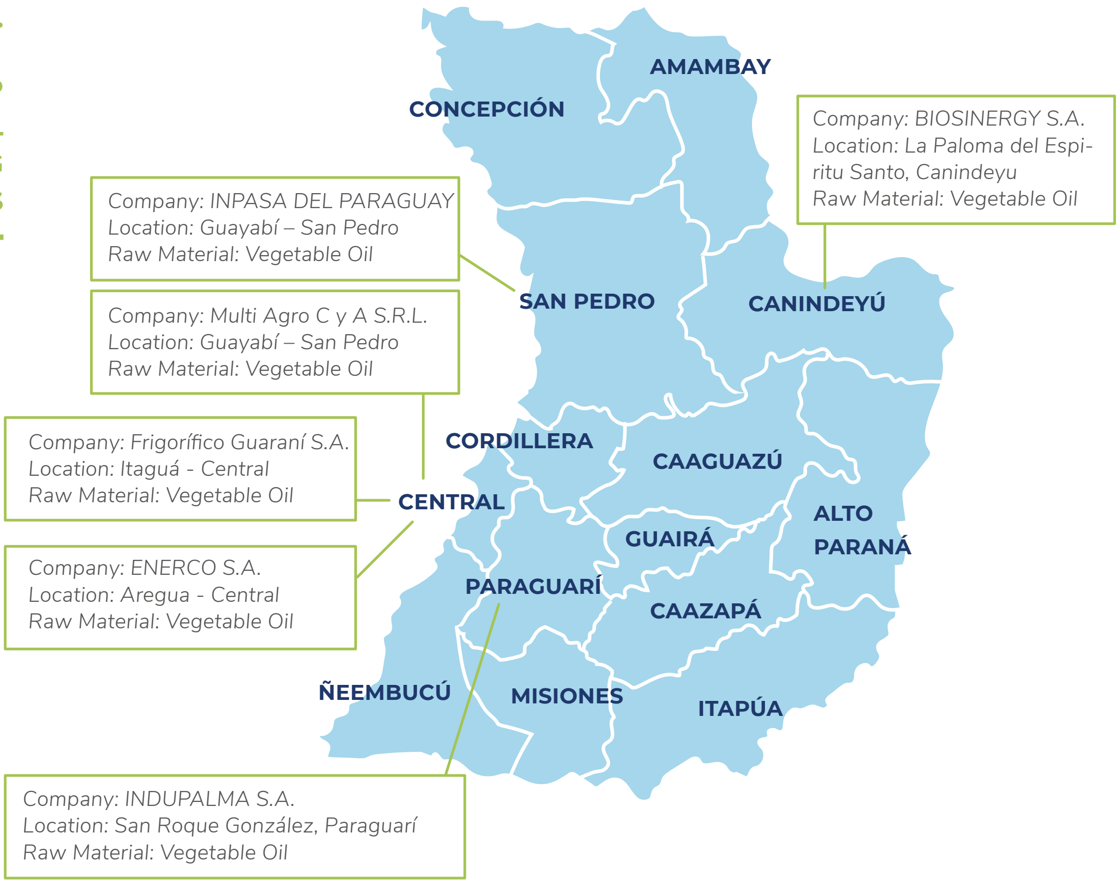
LIQUID BIOFUELS

However, it is not seen as a competition for hydrogen, it could, in fact, be considered complementary in the production of other types of products such as Hydrotreated Vegetable Oil or HVO, moreover, hydrogen production is not limited to soil availability, unlike biofuels.

The liquid biofuel industry in Paraguay has a legal framework to promote biofuels that offers tax benefits to producers. The legal framework is important not only because of the benefits it offers, but also because of the legal certainty it provides and the clarifications on the specifications required for their production. Among biofuels, biodiesel has an installed annual production capacity of 139,000,000 liters and ethanol has an installed annual production capacity of 695,000,000 liters. The following maps (see Chart 3and Chart 4) show the names of the companies, type of raw material and their locations.

CHART 3.

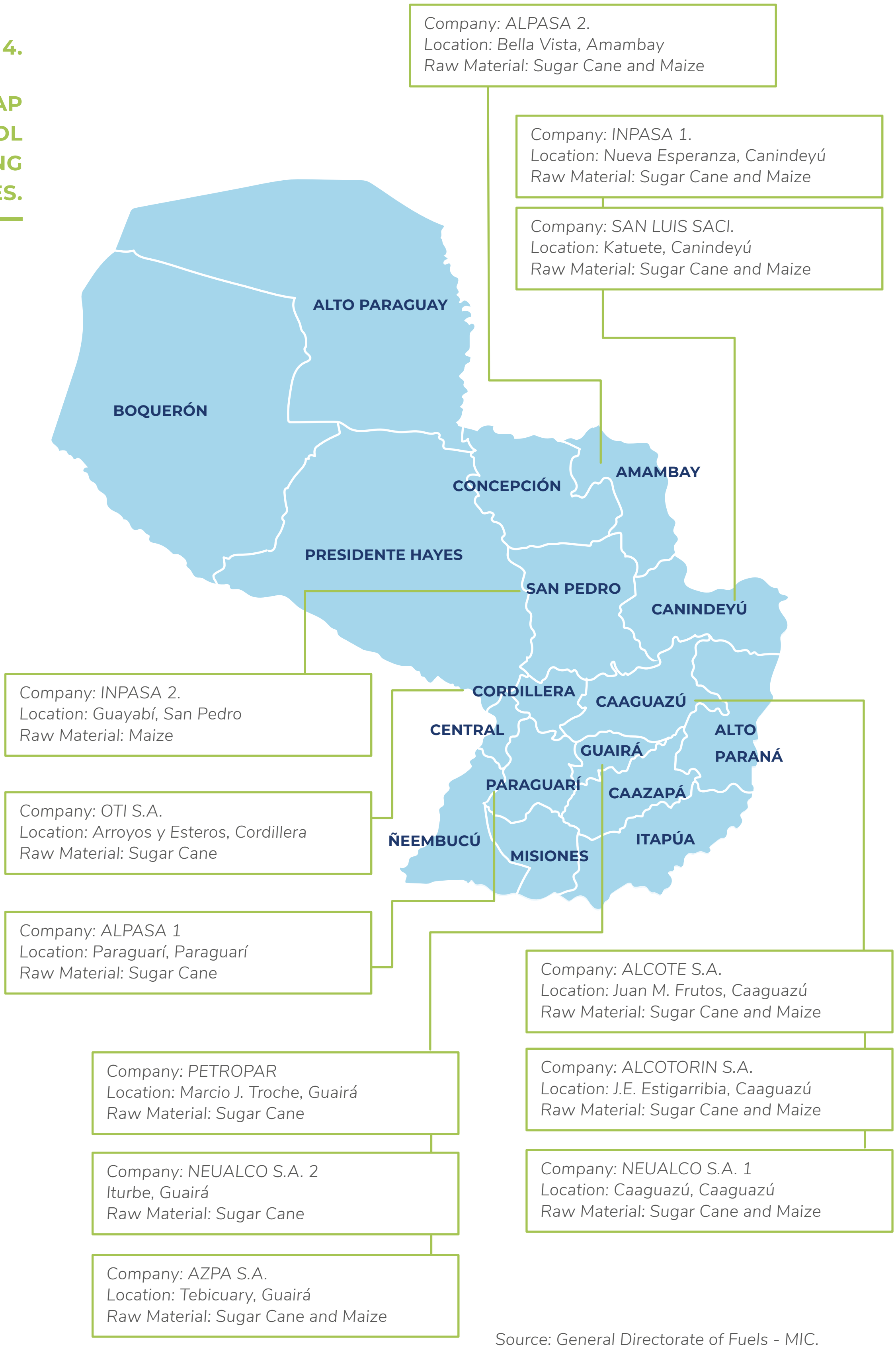
LOCATION MAP OF BIODIESEL PRODUCING INDUSTRIES



Source: General Directorate of Fuels - MIC.

CHART 4.

LOCATION MAP OF ETHANOL PRODUCING INDUSTRIES.



Source: General Directorate of Fuels - MIC.

4.1

REGULATIONS IN THE FUEL SECTOR

Paraguay has a legal framework for bio-fuels used in the transportation sector, through Law No. 2,748 on the Promotion of Biofuels of 2005, regulated by Decree No. 10,703 of 2013. The law established blending mandates for biofuels, tax incentives including reduced VAT and import duty exemptions on equipment. In addition, the government is prohibited from charging fees to biofuel producers for: metering, production, distribution, sale or otherwise. The benefits are provided for in Laws No. 60/90 and 2,421/04. Also, in 2019, Law No. 6,389 *"Establishing the promotion scheme for the sustainable production and mandatory use of biofuel suitable for use in diesel engines"*, and its Decree No. 3,500 of March 30, 2020, were enacted.

Also, there are an extensive number of decrees related to hydrocarbons, which regulate the quality, sale price, allows the import of certain products, among others (VMME, 2019). On the other hand, Decree No. 10,911/2000 regulates the refining, import, distribution and commercialization of petroleum fuels.

As regards hydrocarbons, its derivatives and related products, Law No. 1,182, which established Petróleos Paraguayos (PETROPAR) and its Charter, established that the function of this independent agency is to carry out the transportation, storage, refining and distribution of the aforementioned products.

05.

Paraguay in the time of Covid-19

05.

PARAGUAY IN THE TIME OF COVID-19

According to reports from the Inter-American Development Bank, the economic impact due to COVID-19 will be severe and will affect Paraguay at three levels: global, regional and domestic[15]. With regards to the impact at the domestic level, they indicate that the mitigation measures imply a strong impact on the economy, particularly on the tertiary sector, which represents more than half of the GDP and employment. These measures will also have a greater impact on informal workers, who make up a large majority in Paraguay (64.3% of non-agricultural employment), especially in the tertiary sector and on micro, small and medium-sized enterprises, which represent 98% of all registered companies and 52% of formal employment(Bastos et al. 2020.000Z). There is still much uncertainty surrounding the long-term economic impact figures. However, 2020 closed with an economic recession that resulted in negative GDP growth -1% over 2019 (BCP 2020); the growth projection before the coronavirus outbreak had been between 3% and 4%.

Other estimates suggest that the unemployment rate would increase by 12%, equivalent to an approximate loss of 223,850 jobs, and would also increase the number of people in poverty by 284,404 people (González 2020). In the first quarter release (January to March) of the Continuous Permanent Household Survey (EPHC), it was recorded that the employed population was down by almost 3% compared to 2019, in other words 86,179 people were already unemployed in the first quarter of 2020 as a result of the pandemic (DGEEC 2020)[16].

Among other issues, the EPHC 2020 for the second quarter (April to June), regarding adverse situations generated by COVID-19, indicates that 68.5% of households experienced a decrease in their income, 41.8% have reported having problems meeting their financial obligations such as rents and loans, 35.8% of households have problems finding work and 27.7% were suspended from work without pay (DGEEC 2020). This situation is not only worrying in the short term, but if sustainable solutions are not found, it could have dire consequences for the future of households and the country's economy.

15 (Bastos et al., s.a.) Available at: https://publications.iadb.org/es/el-impacto-del-covid-19-en-las-economias-de-la-region-cono-sur
16 (DGEEC 2020). Permanent Continuous Household Survey 2019-2020

06.

Hydrogen potential in Paraguay

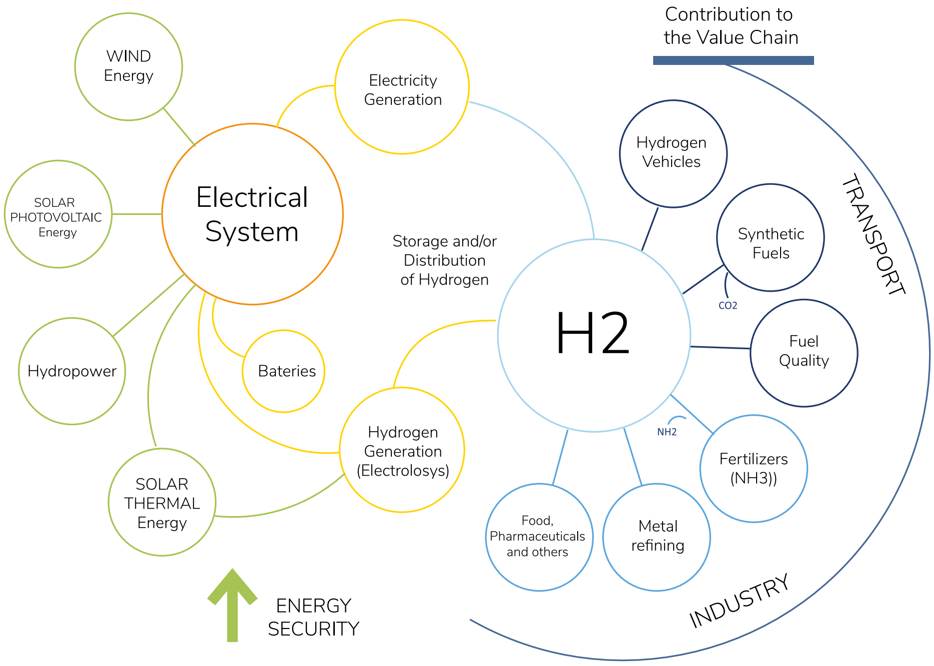
06. HYDROGEN POTENTIAL IN PARAGUAY

The characteristics of hydrogen make it a very versatile product, since it can be used as a raw material, as a fuel or even as an energy storage medium. A system integrated with a hydrogen supply offers numerous opportunities, as seen in Chart 5. The hydrogen market is constantly evolving, so much so that global hydrogen production in 2016 was 52 million tons while generating revenues worth USD 108 billion, and by 2025 production is expected to reach 111 million tons and revenues worth USD 182 billion. The largest markets will be in the Asian Pacific, China and India, and in Europe, Russia and the United Kingdom. However, it is expected that by 2025, 45% of hydrogen production will come from Asia, around 49.7 million tons[17]. In terms of hydrogen exports, the countries with the highest share of global exports by economic value are the United States (19%), China (15%), South Korea and Germany (both 11%).

Regionally, hydrogen production in 2016 in Central and South America was 4 million tons, generating revenues of USD 9 billion (a compound annual growth rate of 9%). By 2025, production is expected to reach 11 million tons and revenues of US$11 billion (a compound annual growth rate of 11%). In this region, Brazil is currently the most important market and is expected to remain so. Brazil's share of global hydrogen exports according to economic value was 3% in 2017. It is important to note that Latin America and Asia are very important trading partners. A large part of Paraguay's imports are Asian manufactured goods. Thus, it is very likely that the strong presence of hydrogen technologies in Asia will have implications for the use and development of the technology at regional and national levels.

CHART 5.

HYDROGEN INTEGRATION SCHEME TO THE ELECTRIC SYSTEM AND THE VALUE CHAIN.



Source: Based on (Chao 2017)

17 Grand View Research, 2018, Hydrogen generation Market Analysis and Segment Forecasts to 2025

The growing hydrogen market could represent a new business opportunity for Paraguay, and also allow it to develop the technology in order to take advantage of all the benefits of H_2, since the country has a huge potential for the production of green hydrogen at competitive prices of around 2.2 USD/kgH_2[18](Gustavo Arturo Riveros-Godoy y M. Rivarolo 2019) lower than those recommended by the International Energy Agency(IEA 2019).

LARGE ELECTRICITY SURPLUSES AT FAIRLY COMPETITIVE RATES MAKE LARGE-SCALE ELECTROLYTIC HYDROGEN PRODUCTION FEASIBLE.

In 2018, Paraguay exported 42.2 TWh of hydroelectricity while under the restricted terms of the binational treaties of the large hydroelectric power plants in operation in the international stretch of the Paraná River (VMME 2019). In addition, as mentioned in section 3, the country has a significant potential for the generation of electricity through solar photovoltaic technology. Therefore, according to(Rivarolo et al. 2019), the national electricity system can accommodate large enterprises for the production of electrolytic hydrogen, without major drawbacks for the country's electricity balance, and could even be used for the co-production of electrolytic oxygen.

Hydrogen presents great opportunities for increasing national energy security and driving the decarbonization of certain segments of the energy sector. For example, it can be used to promote the energy transition of the transport sector from land to maritime and even air mobility.

In terms of electricity systems, it can contribute to the storage of surplus electricity (available during off-peak hours) and its generation using fuel cells, and even provide auxiliary services for the management of electricity grids, which is totally feasible in the national context.

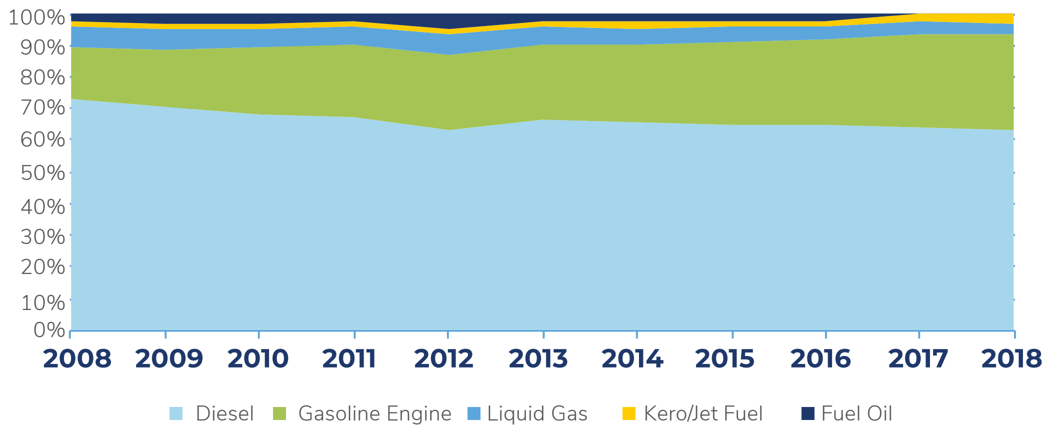
Globally, the COVID-19 crisis has shown **that air quality is strongly dependent on sustainable mobility** (Zander S. Venter et al. 2020). Paraguay is no stranger to this fact, since the transportation sector is responsible for the consumption of approximately 93% of imported petroleum derivatives(VMME 2019).

It is important to take into account that the consumption of petroleum derivatives has a 41% share in the final national energy consumption (VMME 2019), with diesel and gasoline being the main fuels consumed as shown in Chart 6. Therefore, **the transportation sector** is the **main niche for the introduction of hydrogen into the national energy matrix.**

18 Estimated price of Green Hydrogen produced on a large scale, obtained through electrolysis of water using electricity from renewable sources.

CHART 6.

NATIONAL CONSUMPTION OF PETROLEUM DERIVATIVES. PERIOD 2008-2018



Source: Energy Resources Directorate of the Vice-Ministry of Mines and Energy.

With respect to this high consumption of petroleum derivatives, the government has set a target of **reducing fossil fuel consumption by 20%**[19] **by 2030** (STP 2014). Consumption of 2,145.2 ktoe of petroleum derivatives is expected for the same year, according to national energy foresight studies for a reference scenario(Itaipú Binacional, Fundación Parque Tecnológico Itaipú y Fundación Bariloche 2015)[20]. This means that about 429.04 ktoe of **petroleum derivatives should no longer be required**. Considering this scenario for implementing hydrogen as an energy vector, it is possible to estimate that **it will be necessary to have an installed capacity of around 600 MW or an annual production of 90 thousand tons of H_2 by 2030**[21] **(illustrative)**, which could be used mainly as fuel for the cargo and passenger transport sector, both for overland and river transport. **This reduction could avoid the emissions of 1.3 million tons of CO_2**[22]. Its impact on the electricity system could be significant if the necessary transmission and distribution projects are not carried out and an adequate generation plan is not approved. It is estimated that this will **represent 6.8% of the current installed capacity** and 6.5% of the expected capacity for that year.

River transport is a special case for the replacement of petroleum derivatives with sustainable energy alternatives. Even today, the transportation of goods by this means is more efficient than land transportation (OLADE 2020). According to experts[23], it is a promising segment for the inclusion of hydrogen technologies that could energize the Paraguay-Parana waterway, where some 2,500 barges, 300 tugboats (R/E) and 50 self-propelled vessels (with power ranging from 4,000 HP to 6,000 HP) circulate, of which Paraguay accounts for 75%.

19 Annual % of total energy consumption nationwide
20 Energy Outlook for the Republic of Paraguay 2013-2040
21 Estimated based on assumptions and data from (Itaipú Binacional, Fundación Parque Tecnológico Itaipú y Fundación Bariloche 2015), further studies are required to determine precise values that reflect the possible demand for that year. Moreover, it is recognized that this is not the only strategy that the government could adopt to achieve the objective.
22 Same as above.
23 References based on meetings with PETROPAR experts, carried out within the framework of the consultancy.

ON THE OTHER HAND, HYDROGEN IS CURRENTLY USED IN INTERNATIONAL INDUSTRIES EITHER IN PROCESSES OR AS A RAW MATERIAL, SOME OF THE SEGMENTS ARE: THE PETROCHEMICAL INDUSTRY, THE CHEMICAL INDUSTRY, THE METALLURGICAL INDUSTRY FOR THE PRODUCTION OF IRON AND METAL AND EVEN AS A HEAT SOURCE TO GENERATE HIGH TEMPERATURES IN INDUSTRIAL FURNACES.

Electrolytic hydrogen is also used in the food industry for the hydrogenation of vegetable oils (Galeano 2013). One of the cases recorded in Paraguay of the use of hydrogen as a raw material is in the hydrogenation of vegetable oils to obtain margarine. About 7% of the products exported by the country correspond to this type of food (OEC World), and the H_2 they use is obtained via electrolysis of water[24].

Another alternative use of hydrogen as a raw material is in green chemistry and in the manufacture of synthetic fuels by the Fischer-Tropsch method, for example. Hydrogen produced from the electrolysis of water and renewable energy is used to combine with carbon to produce a synthetic fuel. This carbon can be recycled from industrial processes or even captured from the air through filters. The combination of CO_2 and H_2 results in synthetic fuel, which can be gasoline, diesel, hydro methane, dimethyl ether, methanol, ethanol or even kerosene. At the moment, the production of synthetic fuels is a complex and costly process. However, increased production (economy of scale) and competitive electricity prices could make synthetic fuels significantly cheaper. Unlike biofuels, synthetic fuels do not compete for land that could be used for food production. And if renewable energy is used, synthetic fuels can be produced without the volume limitations that can be expected in the case of biofuels due to factors such as the amount of land available.

The possibility of producing hydro methane, methanol and ammonia locally for domestic use and export has also been studied (Rivarolo et al. 2014; Rivarolo et al. 2019). Hydro methane can be used to fuel natural gas vehicles, replacing gasoline and diesel. On the other hand, methanol can be used to produce fuel, solvents and antifreeze, and can also be exported to Brazil, which is one of the countries with the highest demand in the region (Rivarolo et al. 2014).

The production of hydrogen derivatives can promote the circular economy by using byproducts of other processes to extract CO_2 (Enerkem 2020). Carbon dioxide is used as a feedstock in the manufacture of almost all synthetic fuels, (Hirsch, 2020) and its production together with the use of green hydrogen can enable a green fuel supply chain by capturing CO_2 that would otherwise go into the environment. The country faces difficulties in the management of both solid waste and sewage, so this alternative would help to complement programs aimed at waste management (ABC, 2019; STP 2014).

Ammonia has a wide range of applications, particularly in the chemical industries, in low-temperature absorption cycles and in agriculture for the production of fertilizers: the latter application is of particular interest in the case of Paraguay (see Chart 7)[25]. However, this is not the only way to take advantage of ammonia. As a gas under

24 Interview with a representative of the company ContiParaguay S.A.

25 The use of chemical fertilizers in Paraguay has shown significant growth from 2002 to 2019, the annual demand for nitrogen fertilizers has increased from 34,934 tons to 150,075 tons (+ 429%).

normal conditions, and relatively easy to liquefy (at -33°C); it can be stored more efficiently compared to hydrogen: for this reason, ammonia can also be a convenient energy carrier for hydrogen (Rivarolo et al. 2019). In addition, liquefied ammonia has a higher energy density than hydrogen, 12.7 MJ/ltr, which makes it a candidate as an energy carrier for transportation in the future. On the other hand, (Galeano 2013) conducted a comprehensive study of the hydrogen market in Paraguay in the period 2001-2011, obtaining the results shown in Table 3. Hydrogen market in Paraguay in the period 2001-2011 (in tons/year). According to (Galeano 2013), in Paraguay the main industrial products that use hydrogen as a raw material in their manufacture are fertilizer urea and methanol.

TABLE 3.

HYDROGEN MARKET IN PARAGUAY IN THE PERIOD 2001-2011 (IN TONS/YEAR).

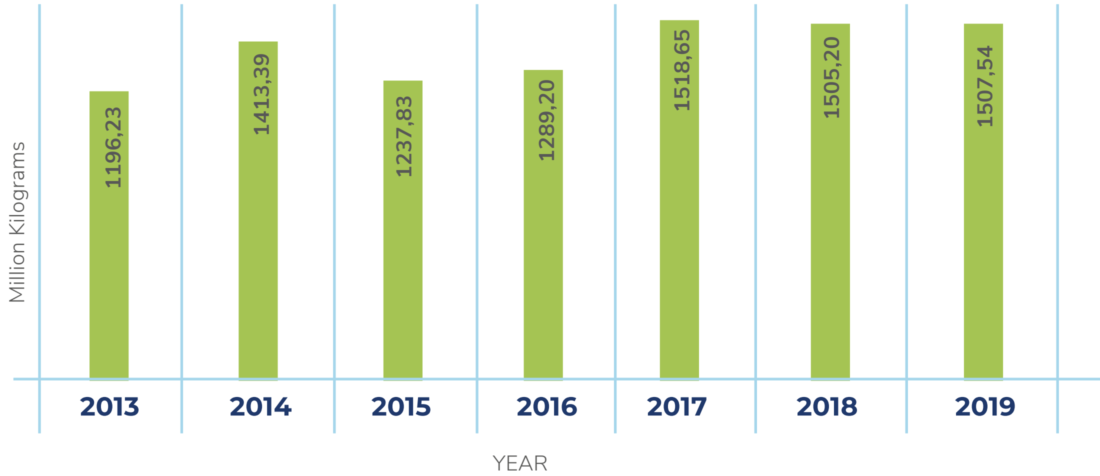
YEAR	AMMONIA	METHANOL	H_2O_2	HYDROGEN
2001	22.06	30.44	20.93	0.000
2002	18.53	41.96	31.40	0.000
2003	19.06	43.86	33.40	0.000
2004	21.88	62.31	36.04	0.000
2005	31.41	68.50	42.34	0.510
2006	42.18	150.02	42.40	1.049
2007	45.00	200.22	47.57	0.000
2008	37.24	186.75	41.75	0.179
2009	46.42	414.36	50.80	0.141
2010	64.24	315.66	78.09	0.196
2011	79.77	123.53	57.80	0.636

YEAR	UREA	HNO_3	$NaNO_3$	$(NH_4)_2SO_4$
2001	336.15	7.68	0.88	13.26
2002	359.03	4.82	1.06	29.89
2003	568.18	6.49	0.00	54.76
2004	522.93	7.20	0.99	35.78
2005	438.94	8.16	0.35	68.27
2006	641.01	8.73	0.21	122.40
2007	977.04	8.49	1.20	102.70
2008	933.77	10.02	0.03	80.00
2009	1 054,53	13.40	4.21	79.88
2010	1 233,59	11.30	4.35	115.14
2011	1 679,73	20.03	0.39	151.00

Source: (Galeano 2013)

CHART 7.

APPARENT CONSUMPTION OF NITROGEN FERTILIZERS PER YEAR. PERIOD 2013-2019



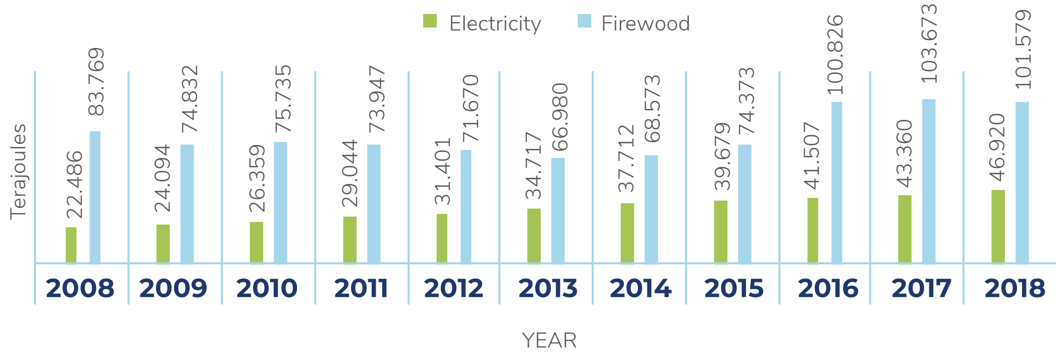
Source: National Plant and Seed Quality and Health Service.

Hydrogen could also replace or complement the use of biomass. Paraguay is a large consumer of firewood. As can be seen in Chart 8, from 2008 to 2018 the consumption of firewood in contrast to electricity has been over 50% without taking into account the other types of biomass.

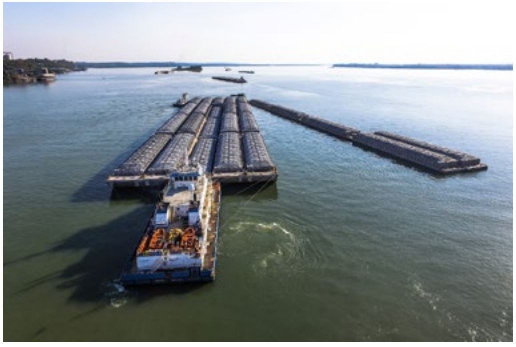
Firewood is currently used in high temperature industries. In 2018, it had a 48.7% share of the final energy consumption of the industrial sector (VMME 2019), mainly for generating heat. Firewood represents 99% of net energy consumption in steam and 84% of direct heat consumption in the industry as a whole, according to the Energy Outlook for Paraguay to 2040 (Itaipú Binacional, Fundación Parque Tecnológico Itaipú y Fundación Bariloche 2015). This study also suggests that firewood could be replaced immediately (in the short term without the need for major technological adjustments) by petroleum derivatives in the industrial sector to produce steam and direct heat, respectively by fuel oil and diesel, and also that as of 2030 the introduction of imported natural gas will gradually replace these sources for both cases. In this case, hydrogen could take part in this sector to replace these sources or complement a more sustainable use of biomass in the sector. Hydrogen has applications in high-temperature industries (IEA 2019), and indirectly could lead to the increased use of renewable electricity in industries.

CHART 8.

ENERGY CONSUMPTION OF ELECTRICITY AND FIREWOOD IN PARAGUAY



Source: Energy Resources Directorate of the Vice-Ministry of Mines and Energy.



07.

H_2 use experiences in the region

07.

H_2 USE EXPERIENCES IN THE REGION

7.1 COSTA RICA

Costa Rica is a great promoter of innovation and, like Paraguay, is one of the leading countries in the generation of energy from renewable sources. In addition, it has recently incorporated sustainable mobility into its government agenda, for which it has identified clean electricity and green hydrogen as indispensable resources to initiate a decarbonization process in the transportation sector. To this end, it is promoting initiatives that allow society to be exposed to these new types of technologies. Such is the case of the Hydrogen Experimental Plant in the province of Guanacaste, a project resulting from the alliance between Ad-Astra Rocket Company, an aerospace engineering company based in the United States, and RECOPE, a Costa Rican oil company, which launched an electrolysis hydrogen production plant in 2013, for use in a pilot of light vehicles and buses; in addition to putting into circulation the first Toyota Mirai in Latin America.

Juan Ignacio del Valle Gamboa, Operations Director of Ad Astra Rocket Company in Costa Rica, was interviewed to provide more details about this project, where they offer distributed renewable energy system solutions, one of which consists of the hydrogen energy cycle (production, storage and use). This company was the main promoter of the introduction of hydrogen as an energy vector in Costa Rica and is the company in charge of operating and maintaining the Experimental Plant. Here are the points that were discussed with the interviewee:

7.1.1 BACKGROUND

The hydrogen initiative in Costa Rica was mainly promoted by Ad Astra, when in 2010 they began a process of diversification towards renewable energy solutions, by then already incorporating these aspects, since the company had previous experience with respect to this energy vector in the framework of the space program in the United States, where the shuttles use hydrogen cells to produce water and electricity. Since then, they have had their sights set on hydrogen as a clean energy vector and a way to bring electricity not only to the transportation sector, but also to other sectors that are not so easy to electrify, such as the industrial sector, and also in the backup power sector.

In addition, an important stakeholder that allowed the development of the project was the Costa Rican oil company, RECOPE, with whom they worked together from 2011 to 2014, RECOPE was the first partnership that supported and financed the early part of the project.

7.1.2 TECHNICAL DETAILS OF THE PROJECT

Regarding hydrogen production, for feasibility demonstration purposes, a small-scale prototype of a low-cost system for hydrogen generation using solar and wind energy, consisting of a wind turbine and photovoltaic panels integrated with an electrolyzer, was manufactured, which allowed the storage of wind and solar energy in the form of hydrogen, generating a very small amount of hydrogen, initially approximately 2.5 kg per day. More production capacity and a dispenser for heavy-duty hydrogen vehicles were added later. Currently, there are two technologies in the hydrogen field, the pressure required by heavy-duty vehicles such as buses and trucks which is 350 atmospheres or H35, and the 700 bar technology commonly used for light-duty vehicles.

7.1.3 FINANCING AND PARTNERSHIPS

The first partner and investor in this project was the Costa Rican oil company, RECOPE, which financed the plant, which was basically the first practical and technical school of hydrogen generation, with respect to technical standards, safety aspects, operation of the systems, the handling of hydrogen at very high pressures, and its transportation and distribution. Together with RECOPE during the period 2011 - 2015 all the basic infrastructure and the school of technical skills needed to move forward were developed.

Another public body that provided financial support was the Development Banking System between 2016 and 2017. This allowed the creation of a network of partnerships, due to the need to count on the support and participation of more stakeholders related to other sectors. International companies such as Air Liquide joined the project by providing equipment, tanks and the dispenser. Cummins Inc. provided other essential equipment, and several other companies provided some assistance both financially and in the form of equipment donations.

Later on, a tourist transportation company joined the project, whose role was to operate the vehicles that were part of the project. Finally, in 2017 the first demonstration of the use of a hydrogen bus in Costa Rica took place. In the same year, the Inter-American Development Bank participated in a first stage by providing consulting services for the improvement of business models regarding the use of hydrogen for the expansion of the project to 10 buses or 10 trucks. In a second stage, the IDB made a contribution of more than US$800 thousand to promote the development of technology in the country. However, the IDB's most important contribution was to build a partnership between companies interested in hydrogen development in Costa Rica, including international companies such as Siemens, Cummins and Linde, and public sector companies such as ICE and RECOPE.

In 2019, Toyota's national representative, the Costa Rican company Purdy Motors, joined the initiative and delivered 4 vehicles, the Toyota Mirai, which use hydrogen cells at 700 bar. However, vehicles are currently being charged at 350 bar with a 50% reduced range, since they do not yet have 700 bar dispensers, which are expected to be added by 2020.

7.1.4 LESSONS LEARNED

The correct scaling of the project is vital for success. In such a case, the scale should be adjusted, with at least a minimum return on investment in mind, to make it more viable.

However, projects such as these depend on several factors. It is very important to find the appropriate niche, since the general public, when talking about hydrogen in the transportation sector, often assumes that it is a proposal for all cars to become hydrogen cars, and while the technology certainly exists, it must be recognized that perhaps private mobility is not the niche where hydrogen will first be able to show its great advantages and strengths. Another important factor is that in the case of passenger transportation, it is necessary to properly think about and choose the bus routes, considering distances, frequency, or the number of units. Hydrogen also has an interesting element: the larger the scale, the easier it is today for the project to have a large financing network.

A balance must be found for the sustainability of the project, finding the right approach for the first step, getting to know the technology, knowing the risks, the technical aspects, but it is also evident that something too small is not the way to go.

7.2 BRAZIL

In Brazil, the use of hydrogen in the industrial sector is already consolidated, and like Paraguay, it has excellent conditions for the production of green hydrogen. However, a large percentage of the demand is met with gray hydrogen produced by reforming fossil fuels whose production involves CO_2 emissions (da Silva César et al. 2019).

In terms of policy initiatives for the promotion of hydrogen energy use in Brazil, since 2005 the Science, Technology and Innovation Program for the Hydrogen Economy ($PROH_2$) has allowed the promotion of research and development with great advances. On the other hand, the Ministry of Mines and Energy published The Guide for Infrastructure in the Hydrogen Economy in Brazil that same year, that establishes the promotion of green hydrogen and the development of technology for its incorporation in the energy matrix. One of the institutions actively participating in $PROH_2$ is the Federal University of Rio de Janeiro, which is involved in hydrogen production, and development of PEM and SOFC fuel cell technology. In order to gain more insight into the work they are doing within the framework of these programs, Dr. Paulo Emílio Valadão, a specialist in materials engineering and coordinator of the Hydrogen laboratory was interviewed.

7.2.1 BACKGROUND

In the case of Brazil, the initiative was promoted through research conducted in a laboratory dedicated to the study of hydrogen for 34 years, the Alberto Luiz Coimbra Institute of Post-Graduate Studies and Engineering Research of the Federal University of Rio de Janeiro (COPPE), Brazil, where there are two focuses, the energy application of hydrogen in the area of transportation, as well as a focus on solid oxide fuel cells (SOFC).

Through the research carried out in the area of transport, with technical cooperation for financing, they were able to develop a series of prototypes that were tested at different events. The series of prototypes developed by the Institute and the lessons learned allowed for the creation of companies that are dedicated exclusively to the development of electronic parts for the traction of vehicles with fuel cells on board.

With the consolidation of the prototypes and the technology produced in Brazil, a pre-commercial prototype is currently being developed, to be introduced later to the market.

7.2.2 TECHNICAL DETAILS OF THE PROJECT

The COPPE has been especially dedicated to the development and building of functional prototypes of heavy electric vehicles with fuel cells using hydrogen for the generation of electricity, specifically buses for the transport of passengers. The first prototype they presented was in 2010, then they presented a second prototype at the Rio+20 event in 2012, where the bus was put to the test. The third and final prototype was presented in 2016 at the Olympics.

The hydrogen supply was obtained through the purchase of an electrolytic hydrogen production plant.

THE ELECTROLYTIC PLANT HAS A PRODUCTION CAPACITY OF 6 KILOGRAMS OF HYDROGEN PER HOUR. ALSO, IN THE EVENT THAT MORE HYDROGEN IS REQUIRED, THEY TURN TO HYDROGEN GAS TRADING COMPANIES.

The know-how acquired in the development of these prototypes allowed COPPE to develop its own components for the vehicles' traction, consolidating the prototypes year after year. In the wake of the last prototype being presented, efforts are now directed towards the development of a pre-commercial prototype that will have real applications in society. Previously, in 2014, one of the prototypes circulated for an entire year in a university town.

They are also manufacturing and developing two riverboats, one of which is a ferry with a carrying capacity of 15 vehicles and 100 passengers. The other is a catamaran suitable for passenger transport with a capacity of 100 passengers. This ferry and the catamaran will be ready and demonstrated in 2022.

The testing of its prototypes allowed COPPE to gather a lot of useful data for future development. In terms of system efficiency, they claim that solid oxide fuel cells (SOFCs) achieve an energy conversion efficiency of about 60%. They also comment that, if they take advantage of the heat from the exothermic chemical reactions of the fuel cells, the overall efficiency of the system would be around 90%.

Among the most interesting information gathered is that the fuel cell manufactured and used in the bus prototypes consumes around 7 kilograms of H_2 per 100 kilometers traveled, thanks to a novel scheme that includes regeneration systems in braking with auxiliary batteries.

According to COPPE, the consumption of the cells they manufactured is considerably lower than those currently used in European vehicles, which fluctuate between 11 kilograms and 15 kilograms per 100 kilometers traveled.

7.2.3 FINANCING AND PARTNERSHIPS

The project has had several backers throughout the 15 years of operation of this specific project. In the past, they have formed technical cooperation and financing partnerships with FINEP (Financiadora de Estudos e Projetos), PetroBras (Petróleos Brasileiros S.A.), as well as other domestic companies. FURNAS, a company in the Brazilian electricity sector, is currently investing in the project through a partnership.

Throughout the project they also had government funding based on projects from national agencies, such as the National Petroleum Agency (ANP) and the National Electric Energy Agency (ANEEL) of Brazil.

7.2.4 LESSONS LEARNED

Among the most significant points that can serve as a reference for the implementation of a hydrogen production and energy use project in Paraguay, the following stand out:

- The need to formalize technical cooperation partnerships with both the public and private sectors.
- The development and elaboration of proprietary technology for prototypes brings great benefits with respect to investment and operating costs.
- Take advantage of Paraguay’s geographical location for hydrogen production.
- A possible route for cargo and passenger transport would be from Asunción to the Brazilian border, where interesting new routes could be opened up.
- Directing a great deal of effort to estimating project costs in order to obtain investors, which is one of the most important parts of the project.
- An important niche for the implementation of the project is the private transportation companies that could benefit from the technological transition.

08.

SWOT analysis: H_2 economy development

08. SWOT ANALYSIS: H_2 ECONOMY DEVELOPMENT

The tasks of national assessment with a view to promoting the use of hydrogen in Paraguay's energy transition are completed with an organized vision of relevant stakeholders, which will allow the outlining of national strategies within the framework of this transition.

Thus, a SWOT analysis was carried out to evaluate and compare the benefits and obstacles in the use of hydrogen for freight and long-distance passenger transportation. The results are shown in the table below.

TABLE 4.

SWOT ANALYSIS FOR THE DEVELOPMENT OF THE GREEN H_2 ECONOMY IN PARAGUAY

Strengths		Weaknesses	
S1	Natural resources for generating electricity are abundant and renewable - in particular, hydroelectric generation.	W1	A lack of specific standards and regulations for hydrogen as an energy carrier.
S2	State-owned electricity supplier with capacity, competitive electricity rates and usable electricity surpluses.	W2	Limited technical capacity of human resources.
S3	National infrastructure conditions exist for land transportation between cities.	W3	A lack of adequate business models for hydrogen development.
S4	Law establishing the import tax exemption for electric vehicles in effect.	W4	Infrastructure for hydrogen distribution to the user does not exist (public or private).
S5	The country is part of one of the main waterways in South America (the Paraguay-Paraná waterway) for the transportation of cargo at competitive costs.	W5	Regulatory framework regarding tax treatment for the import of conventional vehicles.
S6	There are studies on the feasibility of hydrogen at regional and national level.	W6	Articulating and coordinating organizations in the transportation sector and in the energy sector of limited capacity.
S7	PETROPAR's strategic physical space for the installation of a hydrogen plant.		

Opportunities		Threats	
O1	Government and private sector support and interest in electric mobility.	T1	Erroneous perception of hydrogen and resistance to the adoption of new technologies.
O2	Technical cooperation and investors interested in hydrogen production projects in the country.	T2	Uncertainty in oil price projections may inhibit incentives for green hydrogen production.
O3	Renewal and transition of fleets in the cargo and passenger transportation sector.	T3	A lack of incentives for the private sector.
O4	Significant fleet of river barges and tugboats operating in the Paraguay-Paraná waterway	T4	High CAPEX and OPEX
O5	Hydrogen market potential in the international market in the medium term.		
O6	International environmental commitments.		
O7	Use of natural resources for greater production of electricity.		
O8	Hydrogen as last mile transportation.		
O9	Positioning the country as an energy HUB.		
O10	Technology implemented in local industry.		
O11	Resources allow the formation of stable and predictable prices.		

8.1 OVERVIEW

The description of the elements mentioned in the matrix is developed in the order shown[26].

8.1.1 STRENGTHS

S1: The country's natural resources would enable the option of producing green hydrogen[27], i.e. derived from a renewable resource. Paraguay is an exporter of electricity and less than 1% comes from non-renewable energy sources only. In Paraguay there is a significant availability of water resources, with relatively easy access to water practically all year round, particularly surface watercourses.

26 The order will be sorted according to importance after validation.
27 Renewable energy sources can produce hydrogen, be they water, solar photovoltaic (PV), waste, wind, sustainable small hydro, geothermal, and even wave energy, among others. These "green" resources, together with the environmentally friendly technologies that are available today, are increasingly being used to produce electricity. This electricity, in turn, can be used through the electrolysis process to split water into hydrogen and oxygen. (Clark, W. & Rifkin, J., 2006)

S2: ANDE has an enabling legal framework to implement incentives, as well as electric capacity and surpluses that can be used. Electricity rates in the country are among the lowest in the region. Followed by capital costs, one of the main components of the price structure in hydrogen production is the electricity cost.

S3: The cities -Ciudad del Este, Asunción and Encarnación- with the highest passenger and freight transport flow are connected by permanent road infrastructure, which would mean that only a technological transition would be necessary.

S4: A law is in force that exempts electric vehicles from import taxes until 2024.

S5: The country is part of a hydrographic basin (the La Plata Basin) where the important Paraguay-Parana waterway connects Paraguay to the rest of the world in terms of cost-competitive transportation compared to long-distance land transportation.

S6: The Itaipu Technological Park and other researchers have already developed numerous research projects on alternatives and the feasibility of hydrogen.

S7: PETROPAR has the physical space to implement a pilot plant for electrolytic hydrogen production.

8.1.2 WEAKNESSES

W1: The legal and regulatory framework in Paraguay directly related to hydrogen is very limited. Mainly, there is a shortage of technical regulations linked to the different aspects of hydrogen, such as safety and storage.

W2: As a consequence of the novelty of this technology, there is also the limited technical capacity of human resources.

W3: The novelty of hydrogen results in the fact that there are still no adequate business models in the country, nor established rates for hydrogen, nor for the service to be offered.

W4: The novelty of this technology also influences the infrastructure. Hydrogen is still confined to private factories (captive production).

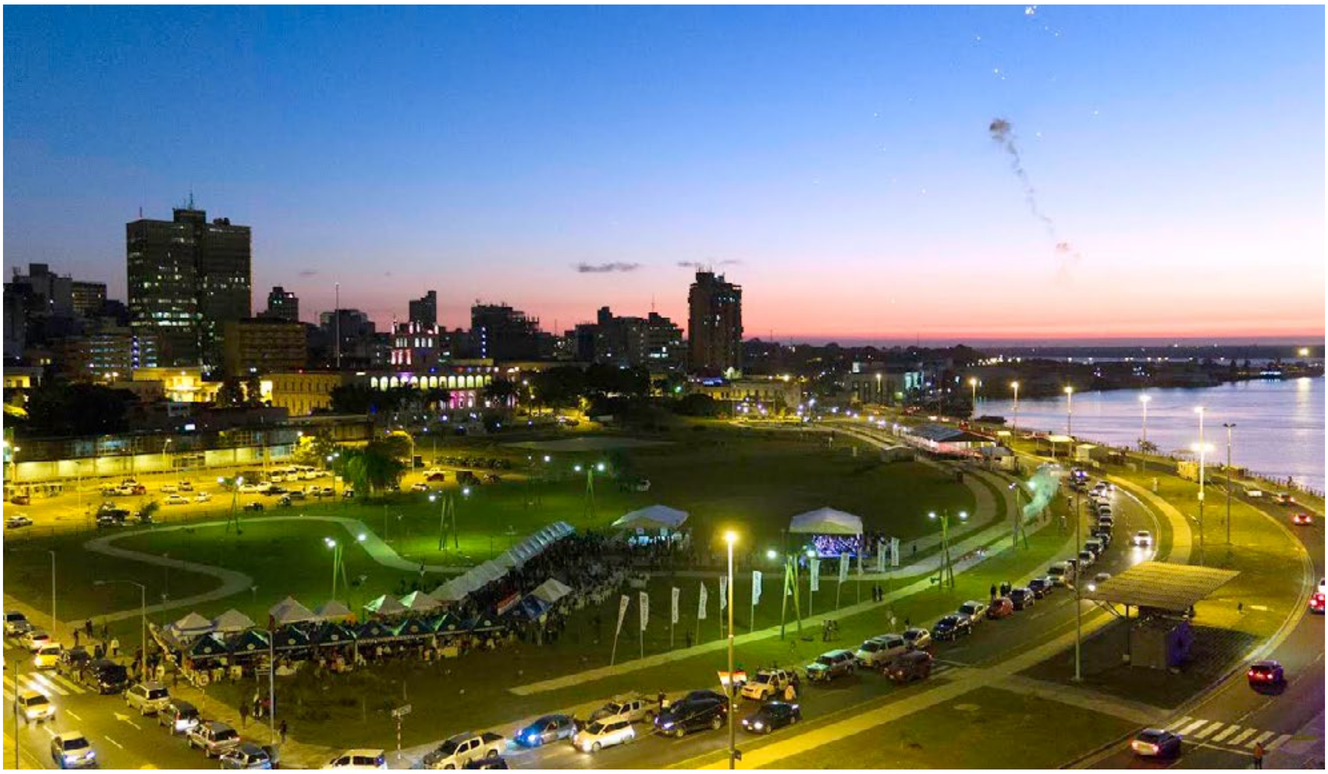
W5: The lack of incentives for the use of clean energy or penalization of the use of polluting energy sources is considered a weakness for the transition to this new technology.

W6: The limited capabilities of the articulating bodies in the energy and transportation sector restrict the possibility of creating policies that benefit the process of adaptation to new technologies such as hydrogen.

8.1.3 OPPORTUNITIES

O1: The government supported the Electromobility Strategy and the Guide for the Standardization of Electric Mobility. In addition, the Minister of Public Works expressed his interest in the transition to clean mobility. ANDE will analyze the possibility of using hydrogen as a backup during peak load times. The Ministry of Industry and Commerce (MIC) will analyze the possibility of using hydrogen in industrial and productive processes, in order to replace the unsustainable use of Biomass.

O2: There is interest from different organizations with funds available for



cooperation with developing countries. These include the IDB, IRENA's Climate Investment Platform (CIP). (IRENA, N. D.). Likewise, foreign investors are also interested in the installation of hydrogen production plants in the country. These include: Omega Green and "Seven Seas Energy Limited", an Israeli company. (MRE, 2020) (Paraguayan Information Agency [IP], N.D.)

O3: The market for fossil fuel-powered bus and truck ground transportation is established and presents an opportunity to transition to another technology. Currently, the bus fleet has had several years of service life, an appropriate time for entrepreneurs to make the transition to a new technology.

O4: The market for fossil fuel-powered river transport by barge is established and presents an opportunity to transition to another technology.

O5: There is a potential hydrogen market in the medium term as progress is made in the different countries of the region and the world.

O6: With regard to the environment, there is a set of commitments assumed through various conventions aimed at reducing pollution caused, among other things, by transportation.

O7: The country's abundant natural resources could be harnessed for increased electricity production.

O8: Last mile transport represents a large share of the total percentage of urban vehicles. The application of hydrogen as a propellant could mean a significant reduction in emissions in the transport sector.

O9: Due to the country's geographical position and the natural resources available for renewable energy production, Paraguay could become a clean energy HUB.

O10: The implementation of this technology in a local industry could facilitate learning and implementation in other industries and sectors.

O11: Because of the resources available in the country, there is an advantage for the establishment of stable and predictable prices.

8.1.4 THREATS

T1: Because of the limited awareness concerning this technology, driven by its novelty, there is a misperception regarding hydrogen and its safety.

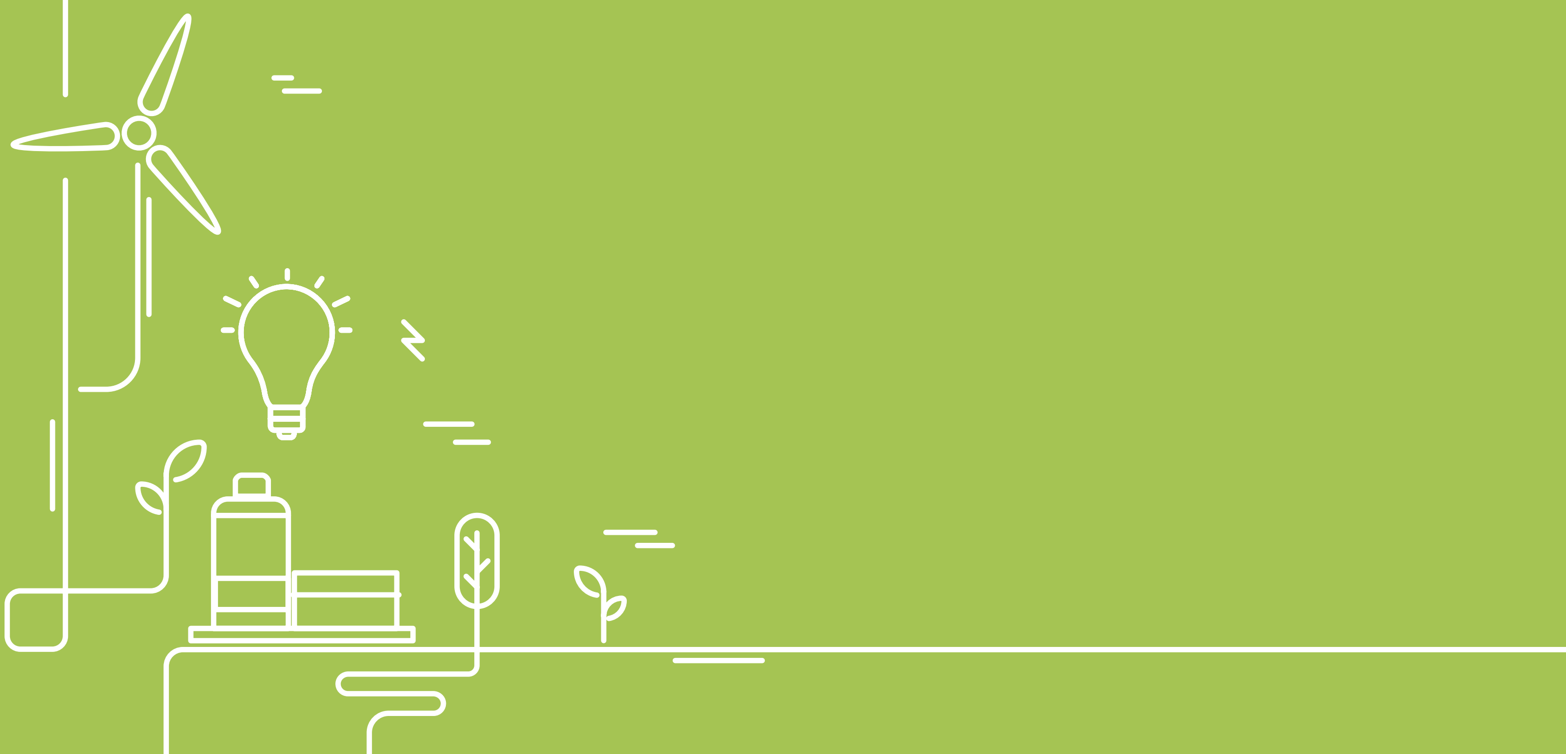
T2: Uncertainty in oil prices threatens green hydrogen production.

T3: There are still no incentives for the private sector to invest in hydrogen.

A4: As hydrogen is a new energy vector with a short time of implementation and study, in the stage of learning and experimental prototypes in the world, it has high capital costs that will be reduced with mass production (large scale). This is also true in the investment and operation area, where maintenance costs are high.

09.

Case study: costs for H_2 production and use in Paraguay



09. CASE STUDY: COSTS FOR H_2 PRODUCTION AND USE IN PARAGUAY

9.1 GREEN HYDROGEN PRODUCTION BY ELECTROLYSIS

Electrolysis is a chemical process by which electricity is used to separate water molecules into hydrogen and oxygen. This chemical process is carried out by means of equipment called an electrolyzer, which basically consists of two electrodes (an anode and a cathode) separated by a membrane submerged in water. In a reverse process to electrolysis, which is carried out for example in a fuel cell, it is possible to obtain electrical energy with high efficiencies of around 50% to 70% (Dawood, Anda y Shafiullah 2020).

CURRENTLY, THERE ARE SEVERAL TYPES OF TECHNOLOGIES IN TERMS OF ELECTROLYZERS AND THE TYPE OF MATERIAL USED.

The following are some of them: Alkaline (AC); and; Polymeric (PEM), which operate at temperatures between 50°C and 80°C; and; Solid Oxide (SOEC), which operate at temperatures between 700°C and 800°C (Bagheri 2017). These are the three types of electrolyzer units available on an industrial scale. However, the first two are the most commonly used. In terms of technological maturity, alkaline electrolyzers are more established and may even be cheaper and have a longer service life compared to the other types. They are also more adapted to work connected to the electrical grid. However, PEM-type electrolyzers produce hydrogen of high purity, with less sensitivity to water quality; they are smaller, respond more quickly to variations in the quantity produced and can produce pressurized electrolytic hydrogen, which reduces the need for compression. The cost of alkaline and PEM type electrolyzers are fairly close as can be seen in Table 5. However, **the service life of alkaline electrolyzers is around 90,000 hours (10 years operating 24 hours)** as opposed to 50,000 hours for PEM technology (IRENA 2018), which would have a significant impact on the project's cash flow in the long term. In a favorable scenario, the CAPEX of alkaline electrolyzers is expected to be reduced significantly in the coming decades (Deutsch y Andreas 2019).

PEM type electrolyzers may be more suitable for stations with on-site production as they are more compact and require less physical space. According to (Hecht y Pratt 2017) accommodating the components needed for alkaline electrolysis from 100 kgH_2/day to 300 kgH_2/day could be a challenge in a 20-foot ISO container. However, for PEM electrolysis, the components should fit in this container and possibly even smaller containers. In addition, PEM technology permits working directly coupled to an intermittent renewable source such as a photovoltaic or wind power plant by better supporting power fluctuations in the battery power supply, whereas, in alkaline batteries, alkaline electrolyzers have less elastic working regimes and do not allow for rapid fluctuations. That is why the alkaline option is recommended if it is fed directly from the grid where the power supply is assumed to be stable.

TABLE 5.

COST AND CHARACTERISTICS OF THE MAIN ELECTROLYSIS TECHNOLOGIES.

CAPEX 2019[28]	Water electrolysis technology		
USD/kW	Alkaline	PEM	SOEC
Min.	500	1.100	2.800
Max	1.400	1.800	5.600
Average range	**950**	**1.450**	**4.200**

Source: (IEA 2019; Deutsch y Andreas 2019)

As for the **electricity consumption of the electrolyzers**, it is estimated to be around **5.0 kWh/Nm3$_{H2}$ = 55.7[29] kWh/Kg$_{H2}$** This may vary depending on the efficiency of the equipment produced by different manufacturers. On the other hand, **water consumption** is estimated considering not only the electrolysis process with the losses in purification, but also the water required for the cooling and refrigeration systems in the order of **26.4 L$_{H2O}$/kg$_{H2}$**. This estimate was made by the NREL(Hecht y Pratt 2017) . For the **treatment of water[30]** entering the electrolyzer using SWRO technology as reference, (Sommariva 2010) a **CAPEX** of around **1,570 USD/(m^3/day) to 2,095 USD/[m^3/day]** is estimated[31]. In addition, electrical installation (5%), civil engineering and others (10%) are considered on the capital. Electricity consumption amounts to about 5 kWh/m^3.

Initially, considering that the supply of renewable electric energy will come via the electrical grid and that its origin will be hydraulic, the use of alkaline electrolyzer technology is the most recommended.

9.2 STORAGE

If hydrogen consumption and supply are carried out at the same production site, in order to ensure a certain level of hydrogen storage and to guarantee supply in case of production stoppage, on-site storage equipment is required.

Tanks that store compressed or liquefied hydrogen have high discharge rates and efficiencies of around 99%, making them suitable for smaller scale applications where a local stock of fuel or feedstock needs to be readily available.

28 European forecasts in their new programs already foresee and promise a 10% decrease in these figures for alkaline electrolyzers and even higher percentages for other technologies due to the productivity boom in the sector, as well as advances in technology.
29 Europe is already working with 50kWh/KgKg50 kWh/kg H_2, 10% less.
30 Water treatment will be required. In the case of the Villa Elisa Plant, PETROPAR has two sources of water, one comes from the river through pipes, the second is chlorinated well water.
31 Adjusted costs from 2010 to 2020 based on https://www.bls.gov/data/inflation_calculator.htm.

Two pressure requirements arise because hydrogen refueling is different for large vehicles than it is for cars. The latter possibility requires the inclusion of storage at 700 bar. Storage costs vary depending on the required pressure conditions as shown in Table 6.

TABLE 6.

STORAGE EQUIPMENT COSTS

Components	Cost (USD/kg)
H_2 storage at 450 bar	2.680
H_2 storage at 700 bar	4.070

Source: (IEA 2019)

9.3

HYDROGEN STATION

For the use of hydrogen in the transport sector, in addition to storage equipment, adequate infrastructure is required for the supply of H_2. For this purpose, the Hydrogen Stations[32]- Recharging Stations fulfill the task. A hydrogen station is a facility designed to provide a vehicle with hydrogen fuel. It consists of a basic storage and dispensing unit, or a basic unit plus a production unit, if the hydrogen is produced on site. The basic unit includes at least one high pressure storage system and one or more dispensers.

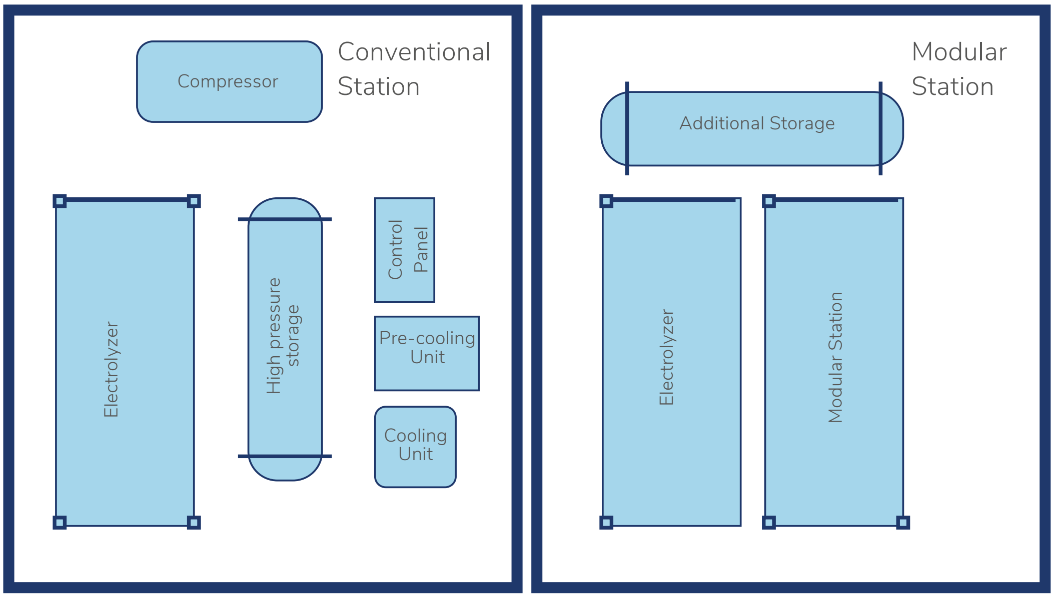
If H_2 is produced on site or delivered to the station at an intermediate pressure or in a liquid state, the basic unit also requires intermediate storage (based on gaseous or liquid hydrogen technology) and a compression system. Certain technical components are required for the construction of a hydrogen station. For all refueling stations, these include compressors that bring the hydrogen to the desired gas pressure level, a pre-cooling system and dispensers to deliver the fuel, in addition to properly sized hydrogen storage facilities.

Currently, there are two alternatives for the installation of hydrogen stations (See Chart 9). The first consists in installing a conventional station, where the components (compression, storage and auxiliary equipment) are installed independently. The second alternative is the direct acquisition of Modular Stations. Chart 9 is illustrative and does not include the location of the dispenser, which may or may not be located in the vicinity of the plant. In both cases the dispenser must be purchased as a stand-alone unit.

32 The term hydrogen station refers to a hydrogen refueling station for subsequent use, usually for transportation applications.

CHART 9.

CONVENTIONAL STATION (LEFT) AND MODULAR STATION (RIGHT)



Source: Author's own work based on (Hecht y Pratt 2017)

It is known that hydrogen, used in the transportation sector, is employed at different pressures. At 350 bar, it is used by trucks, buses and other heavy vehicles, at 700 bar it is mainly used by light vehicles such as sedans or SUVs. This duality has led manufacturers (sera GmbH; McPhy; Powertech) to offer dispensers which within the same unit, supply two hoses (See Chart 10), one for 350 bar and the other for 700 bar(Parks et al. 2014; Pratt et al. 2015; Hecht y Pratt 2017). To accompany this, modular station manufacturers also offer units capable of supplying hydrogen at both 350 and 700 bar as shown in Table 7.

TABLE 7.

SOME COMMERCIALLY AVAILABLE MODULAR HYDROGEN STATION MODELS[33]

Manufacturer and Model	Maximum Capacity	Dispenser connections	Dispenser options
Nel SM[34]	65 kg/h @ 70 MPa[35]	2 (adjacent)	70 MPa and 35 MPa
Sera M	74 kg/h @ 90 MPa	2 (adjacent)	70 MPa and 35 MPa
McPhy McFilling 200-DP	35 kg/h @ 70 MPa	2 (adjacent)	70 MPa and 35 MPa

Source: https://nelhydrogen.com/product/h2station/, https://www.sera-web.com/hydrogen

33 There are other manufacturers that claim to have this type of technology, such as Hydrogenics or ITM Power. In addition, the dispensers are equipped with double hoses.
34 Nel only has independent dispensers.
35 1 Mega Pascal is equivalent to 10 bar.

CHART 10.

FUEL DISPENSER H70/35, WITH 350 AND 700 BAR HOSES

Fuente: https://www.truezero.com

Both modular and conventional stations must be paired with a dispenser. The dispenser includes valves, high pressure switches, hoses, nozzles, flow meters, control electronics and a customer interface (point-of-sale system). Some stations supply hydrogen at **350 and 700 bar** as shown in Chart 10, thus requiring additional piping and control systems. **Dispensing units** range in price from approximately **$155k-$370k USD**[36], depending on capacities and operating regimes.

In a comparison study of conventional versus modular hydrogen stations conducted by the National Renewable Energy Laboratory (NREL) in conjunction with Sandia National Laboratories in the USA, it was found that the estimated capital investment for modular stations with capacities of 200 to 400 kg/day is in the range of 790k USD to 1.6M USD[37] depending on the manufacturer and whether or not a dispenser is offered with the unit. This estimate was made based on surveys and consultations with different manufacturers and users. In addition, they conducted a review of the total equipment costs required for the installation of a **conventional station**, which is in the range of 950k USD to 1.3M USD[38], without installation costs. In the same study they assert that the costs are approximate. However, the main difference is found when considering the installation cost, which for a conventional station is estimated at **35% of the investment** capital, in contrast to that of a **modular station**, at less than **5% of the capital.**

Both types of stations have advantages and disadvantages in economic terms. On the one hand, as already mentioned, the main benefit of modular stations is the cost of installation, which is much lower than that of conventional stations. In addition, modular stations are easier to install. On the other hand, manufacturers produce modules with fixed capacities (e.g. 60kg/h, 100kg/h, 200kg/h and so on), so there could be no savings resulting from adjusting the capacities of certain components, and there could be drawbacks for capacity expansion.

9.3.1 INSTALLATION COSTS

For a **modular electrolyzer** with a production of 100 - 300 KgH_2/day, **installation costs** were estimated at **65k USD**, based on (Pratt et al. 2015) estimates from

36 Adjusted costs from 2017 to 2020 based on https://www.bls.gov/data/inflation_calculator.htm.
37 Same as above.
38 Same as above.

discussions with several companies[39]. In line with the above, the installation of a **water treatment** plant to supply water to the electrolyzer and cooling systems would cost around **US$1,570 to US$2,095/[m^3/day]**[40] **plus 15%** of the capital for installation (see section 9.1).

Finally, for the installation of the **hydrogen station, 35% of the capital** would be invested in the case of **conventional stations**, and less than **5% in the case of modular** stations, as mentioned in the section above. These ratios include dispenser installation.

9.3.2
CAPITAL INVESTMENT, OPERATION AND MAINTENANCE

To estimate the Investment Capital, commercially available electrolyzers were considered, whose characteristics are shown in Table 11 of the Attachment. The data given in Table 12 of the Attachment were used to estimate station costs (H70/35 dual pressure dispenser included), assuming that the conventional and modular stations differ only in installation costs. Likewise, to estimate the cost of a water treatment plant, the information given in the previous section was considered. In the case of installation at the PETROPAR plant located in Villa Elisa, Asunción, it was considered appropriate to include additional storage to that estimated for the station (40kg at 945 bar) at 450 bar with a capacity of approximately 100kgH_2.

Regarding operation and maintenance costs, the process and the considerations taken are shown in section 4 of the Attachments. Finally, Table 8 summarizes the analysis results for Conventional Plants (CP) with conventional stations and for Modular Plants (MP) with Modular Stations, with a capacity to produce 60 and 200 kg/day.

TABLE 8.

SUMMARY OF CAPEX AND OPEX ESTIMATES FOR PILOT PLANTS

Units in USD	PC60	PM60	PC200	PM200
Initial Capital[41]	1.388.300	1.318.524	2.003.092	1.969.189
Annual O&M	119,444	114,644	22,140	224,256
Cost of Hydrogen (USD/kg)	5.4	5.2	3.1	3.0

Source: Author's calculation.

9.4
TRANSPORT

Hydrogen has always been seen as a potential fuel for the decarbonization of the transportation sector, either through its direct use in technology or in the production of synthetic fuels. Some of the possible applications for the land transport sector include private mobility such as light vehicles and vans, passenger transport such as buses, and cargo transport such as trucks.

39 This amount will not undergo major variations over the years since it includes civil projects, electrical installations and other types of services whose prices are not subject to the electrolyzer technologies.
40 This depends on the origin of the water and its content of organic matter and mineral salts. Manufacturers normally provide the system for water treatment.
41These costs and their expected changes are not a cause of increased mobility costs.

Currently, the leading manufacturers of FCEVs, Toyota and Hyundai produce around 3,000 vehicles annually with ambitious targets to increase units in the coming years (IEA 2019). If we look at the intercity passenger transportation segment, there is greater competition from manufacturers in the United States, Europe and Asia. The technology for this segment is at more mature levels(IEA 2019). On the other hand, an important niche whose development is in its initial stages is long-distance freight transport with several manufacturers developing models (Nikola, Hyundai, Scania, Toyota, Volkswagen, Daimler and Groupe PSA) with delivery expectations from 2025 onwards (IEA 2019).

TABLE 9.

COST AND DETAILS FOR DIFFERENT TYPES OF GROUND TRANSPORTATION.

Type of transport	Range	Tank capacity	Refueling time	Passenger traffic	Tank pressure	Manufacturer and model	CAPEX (USD)
Intercity buses (passengers)		37.5 kg	<5min	80	350 bar	Solaris Urbino 12 hydrogen	710,000
	350 Km	40 kg		81	350 bar	Van Hool A330 FC	965,000
Goods trucks	400 Km	33 kg	7 min	-	350 bar	Hyundai H_2 XCIENT FC truck	160,000
Cars	500 Km	5Kg	3 min	-	700 bar	Toyota Mirai	90.000
	756 Km	6,3Kg		-	700 bar	Hyundai NEXO	79.000

Source: manufacturers list price

10.
Attachments

10.
ATTACHMENTS

TABLE 10.

POWER GENERATION PROJECTS PLANNED IN ANDE’S MASTER PLAN

System	Type	Name of the project	Capacity	Units
Central System	Hydroelectric Plant	Paraguay River Hydroelectric Power Plant A	72	MW
	Hydroelectric Plant	Paraguay River Hydroelectric Power Plant B	72	MW
	Small Hydroelectric Plant	Jejui Small Hydroelectric Plant	5.4	MW
	Small Hydroelectric Plant	Jejui Small Hydroelectric Plant	10	MW
	Small Hydroelectric Plant	Jejui Small Hydroelectric Plant	7	MW
Eastern System	Small Hydroelectric Plant	Ñacunday Small Hydroelectric Power Plant	34	MW
	Small Hydroelectric Plant	Carapá Small Hydroelectric Power Plant	4.3	MW
	Small Hydroelectric Plant	Ñacunday Small Hydroelectric Power Plant	8	MW
	Small Hydroelectric Plant	Carapá Small Hydroelectric Power Plant	19	MW
	Small Hydroelectric Plant	Itambey Small Hydroelectric Plant	5	MW
	Small Hydroelectric Plant	Ñacunday Small Hydroelectric Power Plant	54	MW
Northern System	Small Hydroelectric Plant	Ypané Small Hydroelectric Plant	5	MW
	Small Hydroelectric Plant	Ypané Small Hydroelectric Plant	4.2	MW
	Small Hydroelectric Plant	Ypané Small Hydroelectric Plant	4.2	MW
	Small Hydroelectric Plant	Ypané Small Hydroelectric Plant	4.3	MW
	Small Hydroelectric Plant	Ypané Small Hydroelectric Plant	3.2	MW
Western System	Photovoltaic	Bahía Negra Solar Park-Toro Pampa	0.5	MW
	DIESEL	Bahía Negra Solar Park-Toro Pampa	0.99	MVA
	Photovoltaic	Bahía Negra Solar Park-Toro Pampa	0.5	MW
	DIESEL	Bahía Negra Solar Park-Toro Pampa	0.99	MVA
	Photovoltaic	Bahía Negra Solar Park-Toro Pampa	0.5	MW
	DIESEL	Bahía Negra Solar Park-Toro Pampa	0.99	MVA
	Photovoltaic	Bahía Negra Solar Park-Toro Pampa	0.5	MW
	DIESEL	Bahía Negra Solar Park-Toro Pampa	0.99	MVA
	Photovoltaic	Loma Plata Solar Park	10	MW
Southern System	Small Hydroelectric Plant	Tembey Small Hydroelectric Plant	3.6	MW
	Small Hydroelectric Plant	Capiibary Small Hydroelectric Plant	5.6	MW
	Small Hydroelectric Plant	Tembey Small Hydroelectric Plant	3	MW
	Small Hydroelectric Plant	Tembey Small Hydroelectric Plant	11	MW
		Pirajui Small Hydroelectric Plant	8.6	MW

Source:(ANDE 2016). Power Generation and Transmission Master Plan 2016-2025.

TABLE 11.

CHARACTERISTICS OF COMMERCIALLY AVAILABLE ELECTROLYZERS UNDER CONSIDERATION

Model	A30	A90
Production capacity kg/h	2.70	8.10
Production capacity Nm3/h	30	90
Rated power (kW)	250	430
Water consumption (l/Nm_3 H_2)	0.90	0.90
Power consumption (kWh/kg H_2)	51.44	53.70
Output pressure (bar)	35	35
CAPEX (USD)[42]	142,500	427,500

**Includes: Container; water treatment system; connection to water and electricity; and 2 years of service and maintenance.*

TABLE 12.

EQUIPMENT FOR A CONVENTIONAL HYDROGEN REFUELING STATION, AND ESTIMATED COSTS

Overview	Amount	Cost[43]	Sub Total
Tanks [13 kg each, 945 bar MAWP , Type II].	3	48.444	145.332
Pressure transducer and gauge	6	1.211	7.268
Block and bleed valve	6	605	3.631
Pneumatic valve	6	2.423	14.535
Solenoid pilot valve	7	61	424
Manual isolation valve	12	605	7.261
Check valve	3	484	1.452
Coolant pump	1	1.453	1.453
Water cooler	2	4.844	9.688
Coolant filter	1	61	61
Instrument air compressor	1	1.211	1.211
Air dryer for instruments and filter	1	3.088	3.088
Hydrogen compressor [2 stages, 950 bar output]		0	
100 kg/day - 6 kg/h, 25 kW Station		201.520	
200 kg/day - 14 kg/h, 60 kW Station	1	349.026	349.026
300 kg/day - 23 kg/h, 100 kW Station		480.915	
Hydrogen dispenser [(1) 350 bar and (1) 700 bar hose]	1	265.400	265.400
H_2 pre-cooling/cooling unit	1	159.240	159.240
IR flame Detector	2	1.816	3.633
Hydrogen filter	1	3.028	3.028
PLC	1	6.055	6.055
Pipes and connections	-	42.389	42.389
Electrical installations	-	60.555	60.555
Fencing and posts	-	12.110	12.110
Total (100kg/day Station)			**949,335**
Total (200kg/day Station)			**1.096.841**
Total (300kg/day Station)			**1.228.730**

Source: *(Hecht y Pratt 2017)*

42 Calculated on the basis of the maximum for alkaline electrolyzers given in Table 5
43 Adjusted costs from 2017 to 2020 based on https://www.bls.gov/data/inflation_calculator.htm.

TABLE 13.

CAPEX CALCULATION FOR HYDROGEN STATIONS WITH ON-SITE PRODUCTION

	With Conventional Station						With Modular Station					
Overview	Investment		Installation		Sub Total		Investment		Installation		Sub Total	
Villa Elisa-PETROPAR 200 kg/day												
200 kgH_2/d Alkaline electrolyzer	427,500	USD	65.000	USD	492,500	USD	427,500	USD	65.000	USD	492,500	USD
250 lH_2O/h Water treatment	8.290	USD	1.243	USD	9.533	USD	8.290	USD	1.243	USD	9.533	USD
Storage at 450 bar	268,000	USD	26.800	USD	294,800	USD	268,000	USD	26.800	USD	294,800	USD
Hydrogen station	949,335	USD	113,920	USD	1.063.255	USD	949,335	USD	47.467	USD	996,801	USD
Sub Total					1.860.088	USD					1.793.635	USD
Freight and import					50.000	USD					50.000	USD
Planning (5%)					55.803	USD					89.682	USD
Contingency (2%)					37.202	USD					35.873	USD
Total					**2.003.092**	**USD**					**1.969.189**	**USD**
Hernandarias-Acaray 60 kg / day												
60 kgH_2/d Alkaline electrolyzer	142,500	USD	65.000	USD	207,500	USD	142,500	USD	65.000	USD	207,500	USD
70 lH_2O/h Water treatment	3.318	USD	498	USD	3.816	USD	3.318	USD	498	USD	3.816	USD
Hydrogen station	949,335	USD	113,920	USD	1.063.255	USD	949,335	USD	47.467	USD	996,801	USD
Sub Total					1.274.571	USD					1.208.118	USD
Freight and import					50.000	USD					50.000	USD
Planning (3%)					38.237	USD					36.244	USD
Contingency (2%)					25.491	USD					24.162	USD
Total					**1.388.300**	**USD**					1.318.524	**USD**

Source: Author's calculation.

TABLE 14.

OPEX CALCULATION FOR HYDROGEN STATIONS WITH ON-SITE PRODUCTION

	Abbreviation	Formula			Uni
Principales Supuestos					
Reserved Power				41.126	Gs/kW
Peak Energy				331.93	Gs/kWh
Off-Peak Energy	s			144.83	Gs/kWh
Water fee	wk			3.324	Gs/m3
Interest rate	i			3%	-
Depreciation period	T			15	años
Annuity Factor	a	i*(1+i)**T /(((1+i)**T)-1)		8,3767%	-
Water consumption	w			1	L/Nm3H_2
Annual working hours	v			8.760	h/a
Exchange rate	xr			6.900	Gs/USD
Basic Data	**Abbreviation**	**Formula**	**E60+**	**E200**	**Unidades**
Reserved Monthly Power			150	450	kW
Power Required by the Electrolyzer	P	5kWh*H_2m^3 [per hour]	150	450	kW
Annual Electricity Consumption	m	v*P	1.314.000	3.942.000	kWh/a
Annual On-Peak Electricity Consumption	Pke	v*P*(4/24)	219,000	657,000	kWh/a
Annual Off-Peak Electricity Consumption	OPke	v*P*(20/24)	1.095.000	3.285.000	kWh/a
Annual water quantity	wm	w*EH_2 [Nm^3]/1000	282	846	m3/a
Electrolyzer Efficiency	n			0.74	-
H_2 Secondary energy quantity - Annual	EH_2[Nm3]	m*n/3.45	281,843	845,530	Nm3/a
H_2 secondary energy content - Annual	EH_2[KWh]	m*n	972,360	2.917.080	kWh/a
Seed Capital (Donation)	cs	P/ Conventional Station	559,107	940,893	USD
		P/ Modular Station	535,744	964,256	
CAPEX	I	With Conventional Station	1.388.300	2.003.092	USD
		With Modular Station	1.420.672	1.969.189	
Annual Costs	**Abbreviation**	**Formula**	**E60+**	**E200**	**Unidades**
Capacity cost	AN = (I-cs)*a	With Conventional Station	69.459	88.977	USD/a
		With Modular Station	65.571	84.180	
Cost of Electric Power	S	s*m	34.413	103,239	USD/a
HR Costs	HR		14.600	14.600	USD/a
Water cost	WK	wk*wm	136	407	USD/a
Cost for Service and Maintenance	W	EH_2[Nm^3] * 0,009648 USD	2.719	8.158	USD/a
Miscellaneous costs (equipment, other)	SK	EH_2[Nm^3] * 0,009648 USD	2.719	8.158	USD/a
Total cost of Operation	BK	S+ HR + WK + W + SK	54.587	134,562	USD/a
Total Annual Cost	K = AN + BK	**With Conventional Station**	**124,046**	**223,539**	USD/a
		With Modular Station	**120,158**	**218,742**	

Source: Author's calculation.

TABLE 15.

COORDINATES OF ALTERNATIVE LOCATIONS FOR THE PLANT IN VILLA ELISA

Alternative	Coordinates	
A	25°23'04.7"S	57°36'21.1"W
B	25°23'19.3"S	57°36'18.2"W
C	25°23'26.4"S	57°36'27.7"W

Source: Author's calculation.

11.
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11.

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