Hinicio

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Deliverable:
Study on the possibilities to produce, use and export "green" hydrogen in Costa Rica

Version 3
22nd April 2021

BRUSSELS • BOGOTA • BUENOS AIRES • PARIS • SANTIAGO • BEIJING

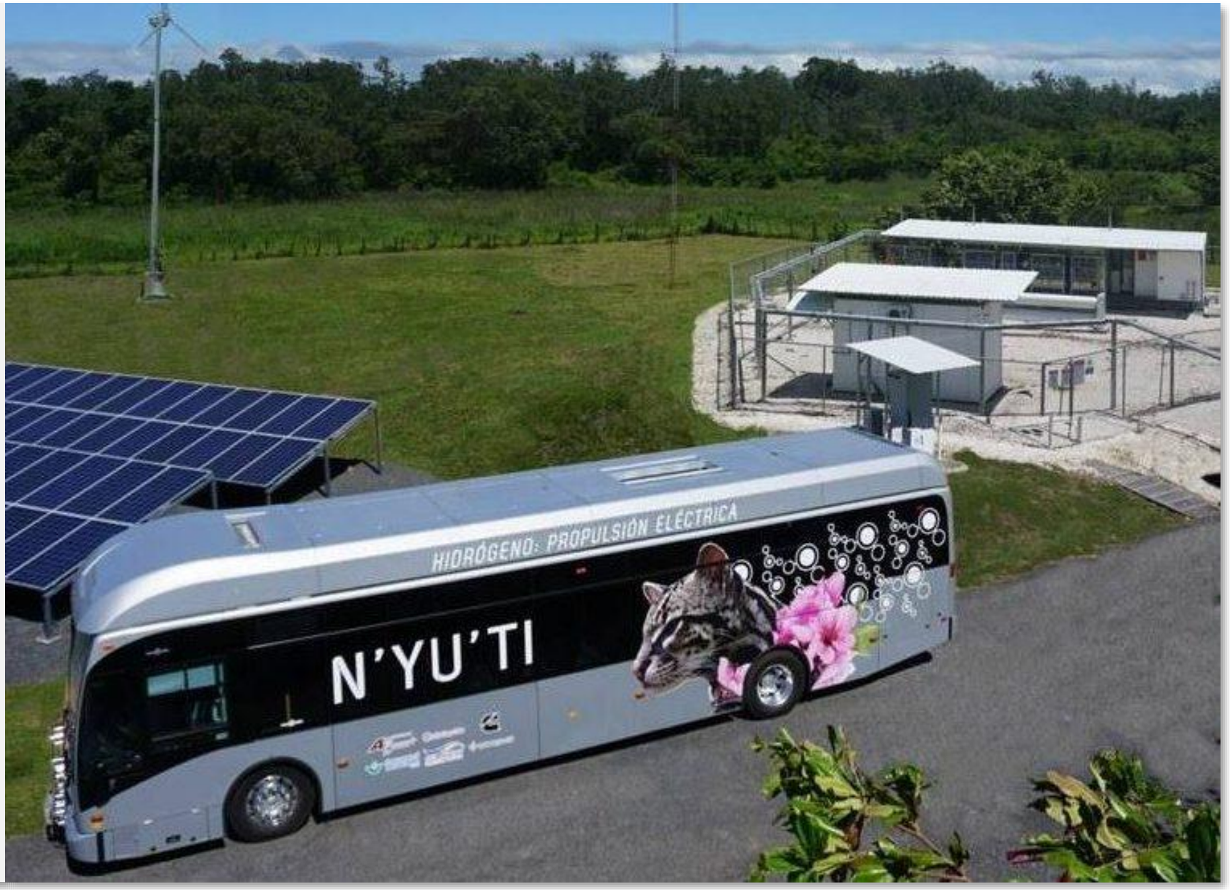
PROJECT SUMMARY

The **GIZ Innovation and Business Development** Hub (short: **InnoHub**) is a pilot initiative that seeks **to expand the impact of GIZ projects** in the region and to put innovation into action, with concrete, tangible and useful applications. In addition to innovation, the InnoHub also has a focus on business development for GIZ. The InnoHub is dedicated to the **creative and participatory development of new solutions** or projects on topics such as the problem of plastic waste in rivers, the safety of women in public transport, lightweight electric mobility and also on the potential for **hydrogen in Costa Rica.**

In this context, **GIZ in Costa Rica** has hired the services of the consulting firm **HINICIO SA** to develop the project **"Study on the possibilities to produce, use and export "green" hydrogen in Costa Rica"** with a duration of 8 weeks between February and March 2021.

Objectives of the project as per the Terms of Reference (ToR)

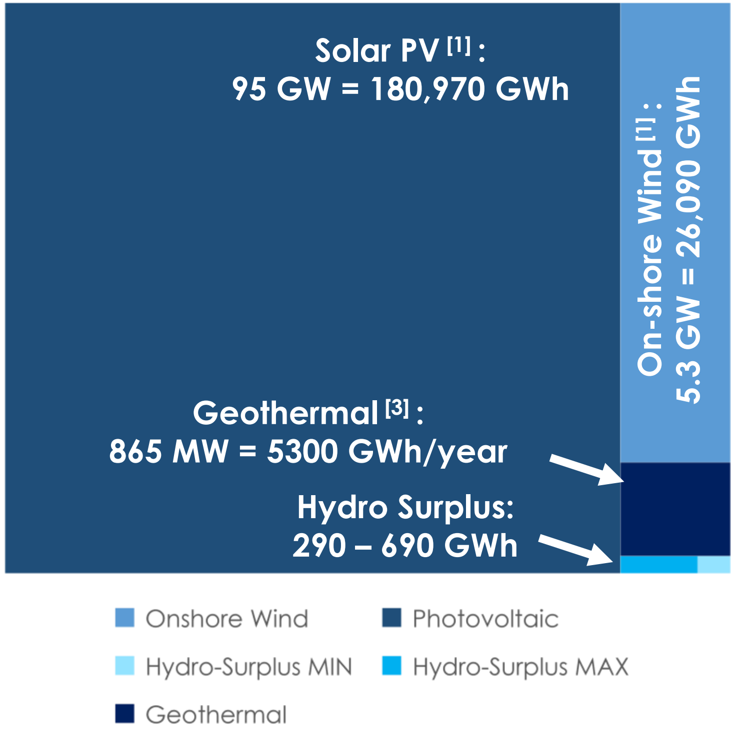
- To analyze the **current situation** regarding the potential to **produce, use and export hydrogen** in Costa Rica and to use hydrogen as a clean and sustainable energy source.
- To provide **recommendations** on the **convenience of promoting this technology** in Costa Rica.
- To provide **recommendations** for a proposed structure **for a future Costa Rica National Hydrogen Strategy**, and a **road map** for the development of such a strategy.



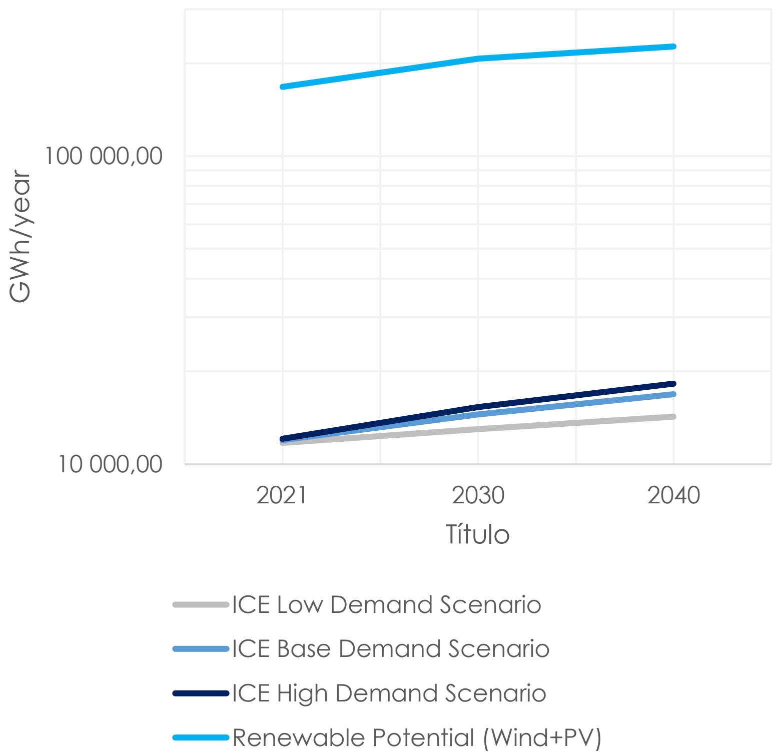
1 Technical and Financial - Economic Aspects

Costa Rica's renewable energy potential is 10x its forecasted electricity demand

Renewable Potential – 2030 [1, 3]



ICE Demand Scenarios & RE Potential for CR 2021-2040[2]*



KEY MESSAGES

- ✓ The difference between renewable potential and energy demand in Costa Rica leaves a **huge room for green hydrogen production**.
- ✓ By **2040**, the **renewable energy potential** could reach **231,900 GWh/year**, largely above the ICE's Costa Rican demand forecast of **18,237 GWh/year** (in the high scenario).
- ✓ **Geothermal** technical theoretical potential reported by ICE[3] is **865 MW,** which represents 5300 GWh annual generation, considering an average capacity factor of 69.7%[4]
- ✓ The hydropower energy **surplus seems small** compared to other renewable sources, however it is an **interesting resource** due to the low cost of energy that it could represent. Particularly **in early projects**.

* Due to the technological improvements in renewable power generation, the renewable energy potential of Costa Rica increases over time

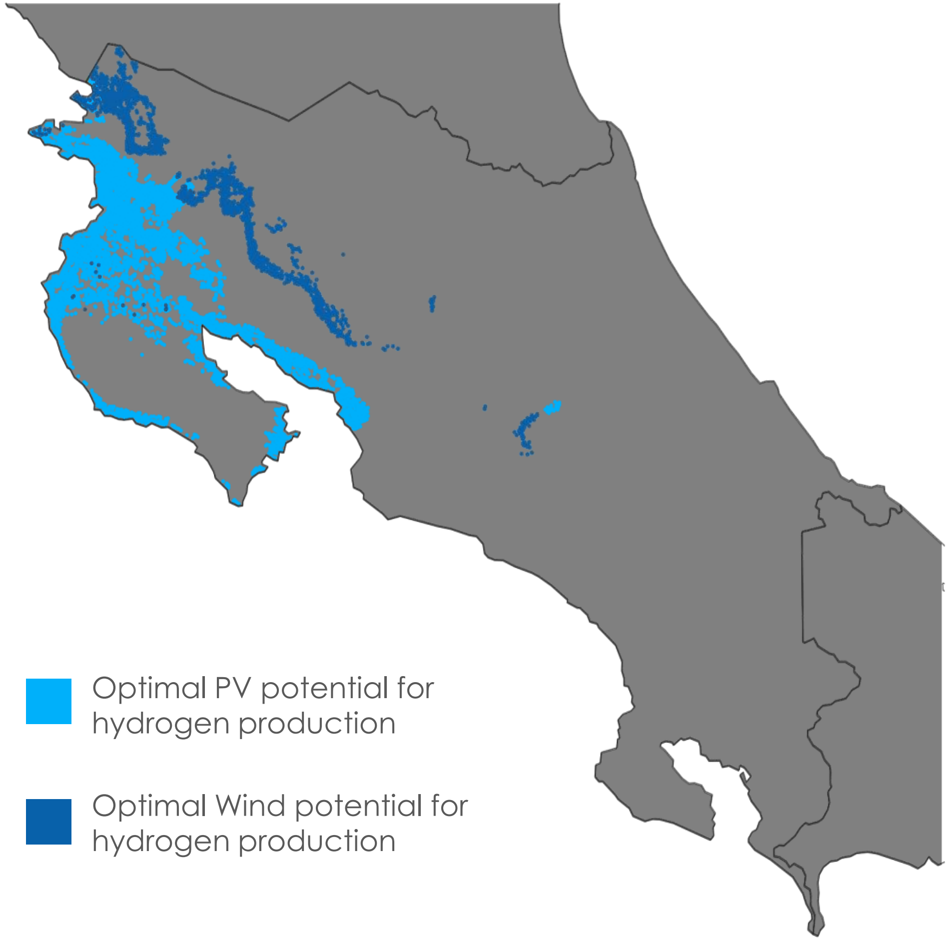
[1]: Hinicio, 2021 – Costa Rican Renewable Potential Assessment
[2]: Hinicio 2021 with information from ICE, 2018 (Plan de Expansión de la Generación Eléctrica)
[3]: ICE, 2016 – Plan Estratégico para la Promoción y Desarrollo de Fuentes de Energía Renovables no Convencionales
[4]: ICE, 2020 – Information provided by ICE to Hinicio on geothermal capacity factors 2019 and 2020

The combined solar PV and wind potential considered in this report as suitable for H2 production requires less than 10% of the CR territory

KEY MESSAGES

- ✓ The region with the **greatest renewable potential** to produce green hydrogen is to the **Northwest (Guanacaste, Alajuela, Puntarenas)**.
- ✓ The evaluation of renewable potential of solar photovoltaic and onshore wind sources was carried out by Hinicio through his proprietary model using information from NASA and the World Atlas of Renewable Sources, as well as **multiple restrictions on land eligibility.** The areas selected were only those that yield the best potential.
- ✓ The hydro and geothermal potential reported in this report come from public information from ICE reported in its Strategic Plan for the Promotion and Development of Non-conventional Renewable Energy Sources 2016-2035 (ICE, 2016.
- ✓ The theoretical geothermal potentials were taken from the document "Evaluation of the potential geothermal of Costa Rica ", (ICE, 1991). This report does not discriminate between potential within protected and non-protected areas.

Potential assessment for solar photovoltaic and wind power for hydrogen production in Costa Rica

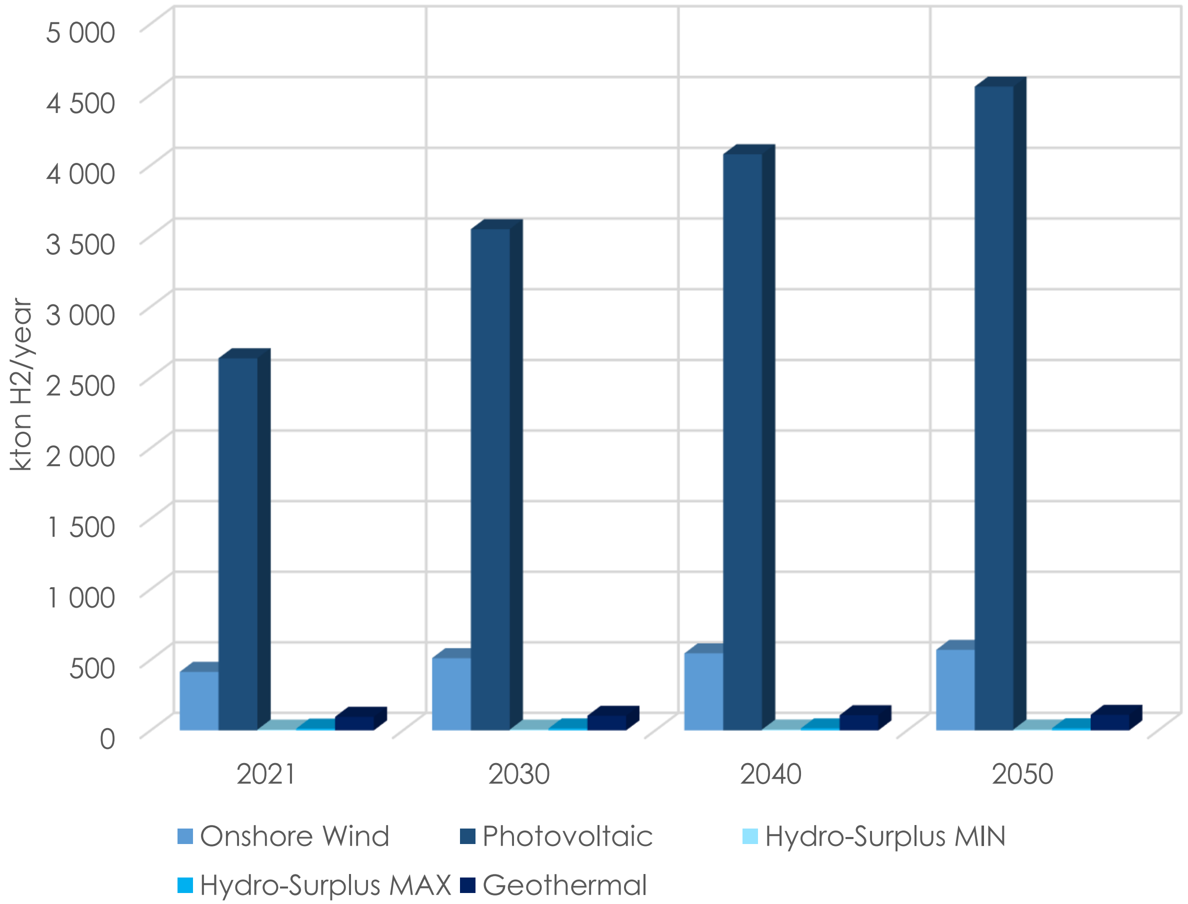


Costa Rica will be able to produce up to 4.5 million tons of green hydrogen by 2050

KEY MESSAGES

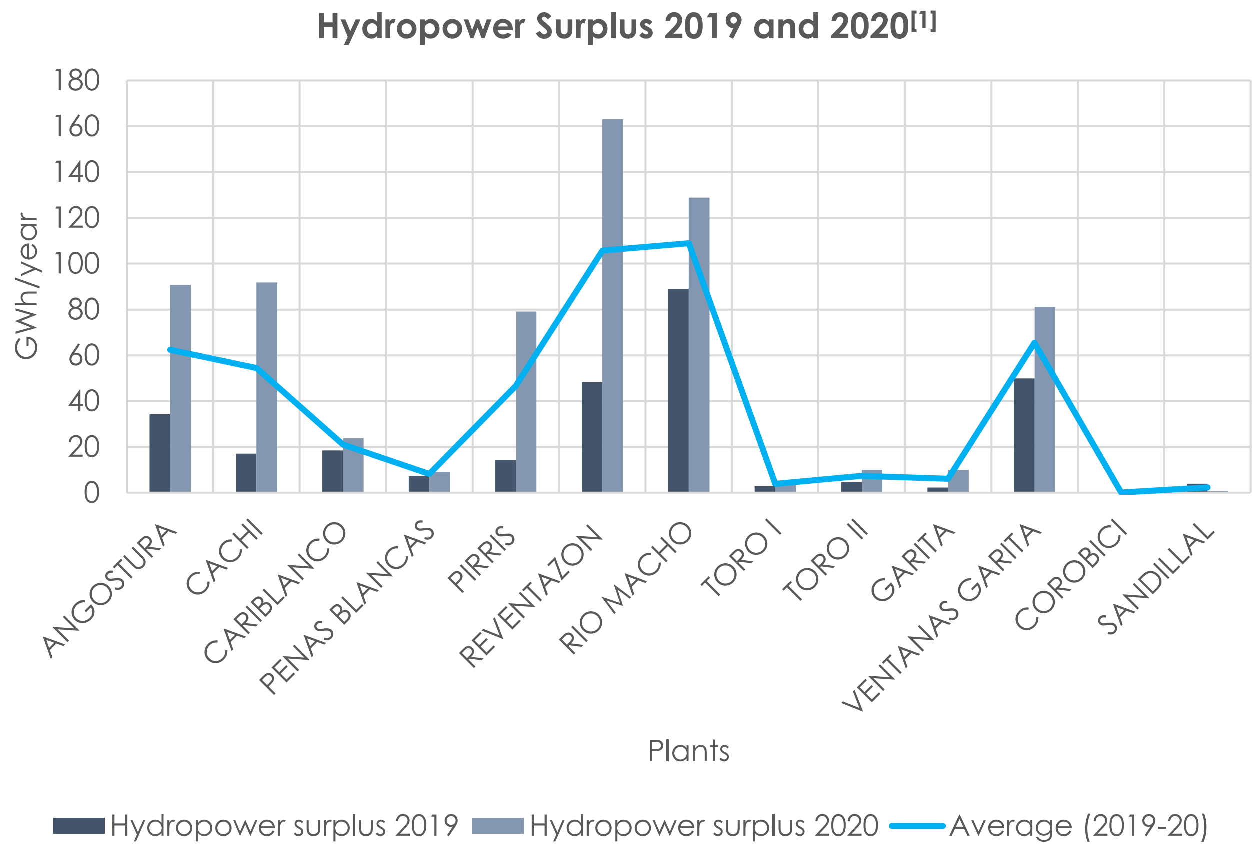
- ✓ By **2050**, the renewable hydrogen production potential of CR could reach **5.2 million tons of H2 per year**.
- ✓ Comparatively: the **United States** (a highly industrialized country) consumed **11.4 million tons of H2 in 2020** and the **Hydrogen Council** estimates that in **2050** the world demand for hydrogen will be just over **600 million tons of H_2.**
- ✓ The **largest volumes** of green hydrogen come from **solar PV**, however **wind power** is an attractive option due to its **higher capacity factors which translate into lower production costs**
- ✓ Due to the **technological (energy efficiency) improvements** of both, renewable power generation and electrolysis equipment, **the potential for hydrogen production increases** over the time.

Green hydrogen potential production in Costa Rica [1]



[1]: Hinicio, 2021 with information from ICE, 2021 (Interviews and bilaterally shared information)

A few hydro plants have surplus to produce H2, which could help early market development. However, volumes won’t be enough in the long-run



KEY MESSAGES

- ✓ The annual volumes of hydro surplus are unpredictable. The data provided by ICE shows large deviations between 2019 and 2020. Therefore, Hinicio established a range using 2019 as a minimum data point, and 2020 as a maximum. Hinicio is requesting data from other years and will update the analysis if able to get it.
- ✓ The **minimum** potential for hydrogen production using surplus hydro is around **5.3 kton / year**.
- ✓ The **maximum** potential for hydrogen production using surplus hydro is around **12.6 kton / year**.
- ✓ The hydro plants with the best potential for hydrogen production through surpluses are: **Reventazón** (2.97 kton H_2/year), **Rio Macho** (2.34 kton H_2/year), **Ventanas Garita** (1.47 kton H_2/year)
- ✓ The only source of electricity with surplus in Costa Rica is hydropower. Geothermal energy is a preferential dispatch power source with no real surpluses in Costa Rica (source: Interviews with ICE)

[1]: Hinicio, 2021 with information from ICE, 2021 (Interviews and bilateral shared information)

Geothermal energy have much potential to produce green hydrogen in Costa Rica

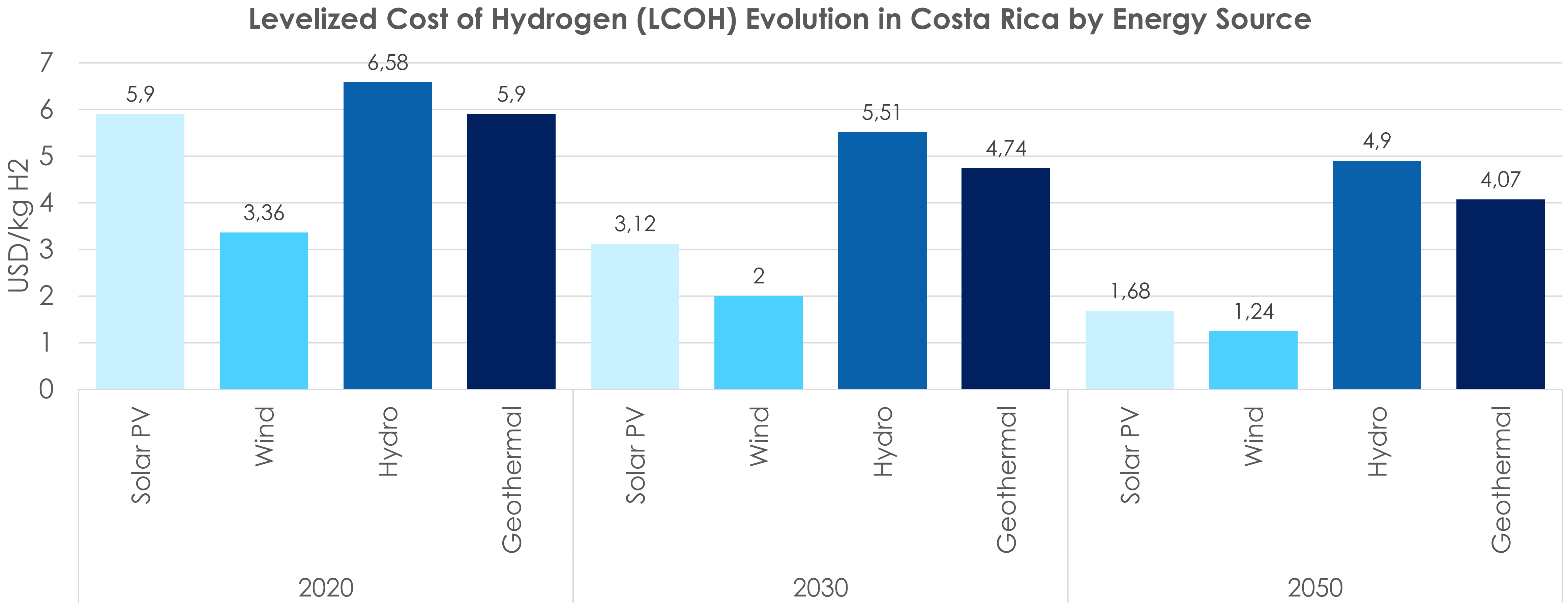
KEY MESSAGES

Despite the very well-known advantages that Geothermal energy has for the production of hydrogen, such as providing base-load power to maximize electrolyzer load factors, the conditions in Costa Rica are not favorable due to the following reasons:

- ✓ The **theoretical technical potential** of geothermal energy in Costa Rica **is low**. With only 865 MW (ICE data) against 95 GW of solar energy and the more than 5.3 GW of on-shore wind power (Hinicio RE potential assessment)
- ✓ There are important regulatory constraints for the production of green hydrogen via geothermal power in Costa Rica
  - ✓ ICE cannot use geothermal power to produce hydrogen:
    - ✓ Geothermal power has **priority electrical dispatch** in Costa Rica: according to ICE, geothermal plants are used to buffer the variability that run-of-river plants and variable renewables (wind and solar PV) represent for the system.
    - ✓ **There are no surplus** of geothermal energy that ICE could tap into. It is an easily storable energy source (steam can be kept underground by closing the outlet valve) when the electricity demand decreases.
    - ✓ ICE is not allowed (by law) to commercialize hydrogen, so investing into dedicated geothermal plants for hydrogen production is not an option.
  - ✓ Only ICE can tap into Geothermal resources (no private intervention allowed)
- ✓ **Geothermal production is not cost competitive against other sources for hydrogen production**. Due to its exploration costs and the infrastructure for the extraction of underground heat and transportation to the generation plant, this energy reports levelized costs of electricity between 50 and 100 USD / MWh worldwide (IRENA).

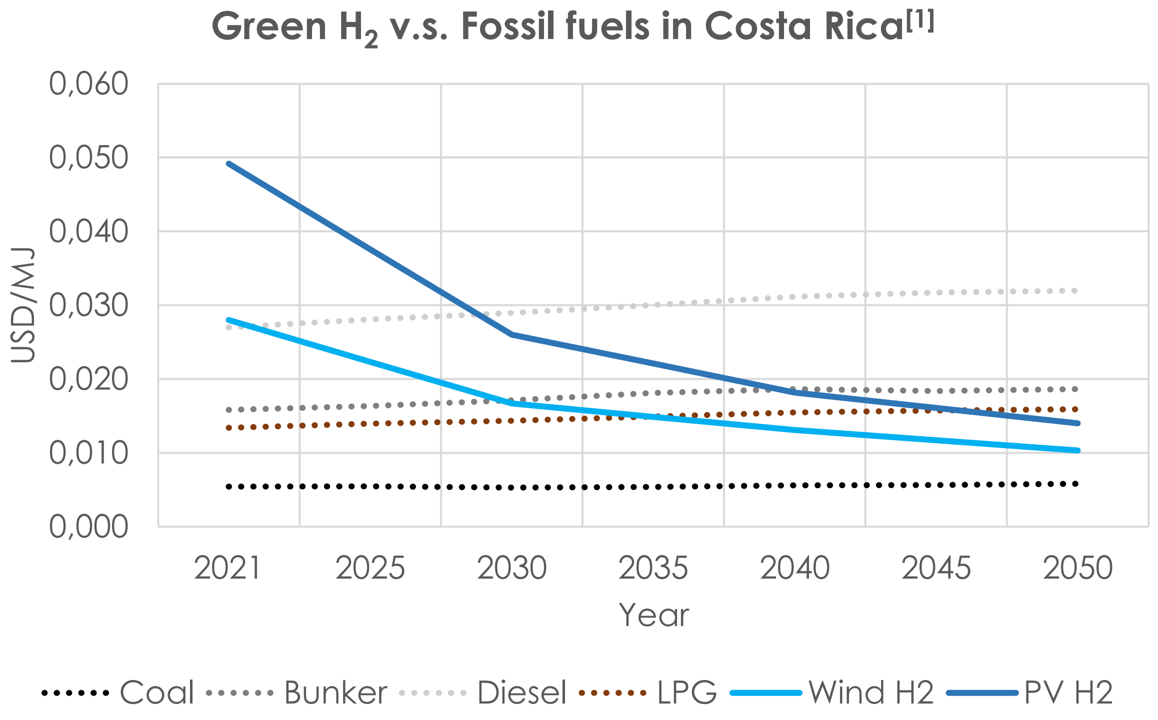
Image: ThinkGeoEnergy, 2010

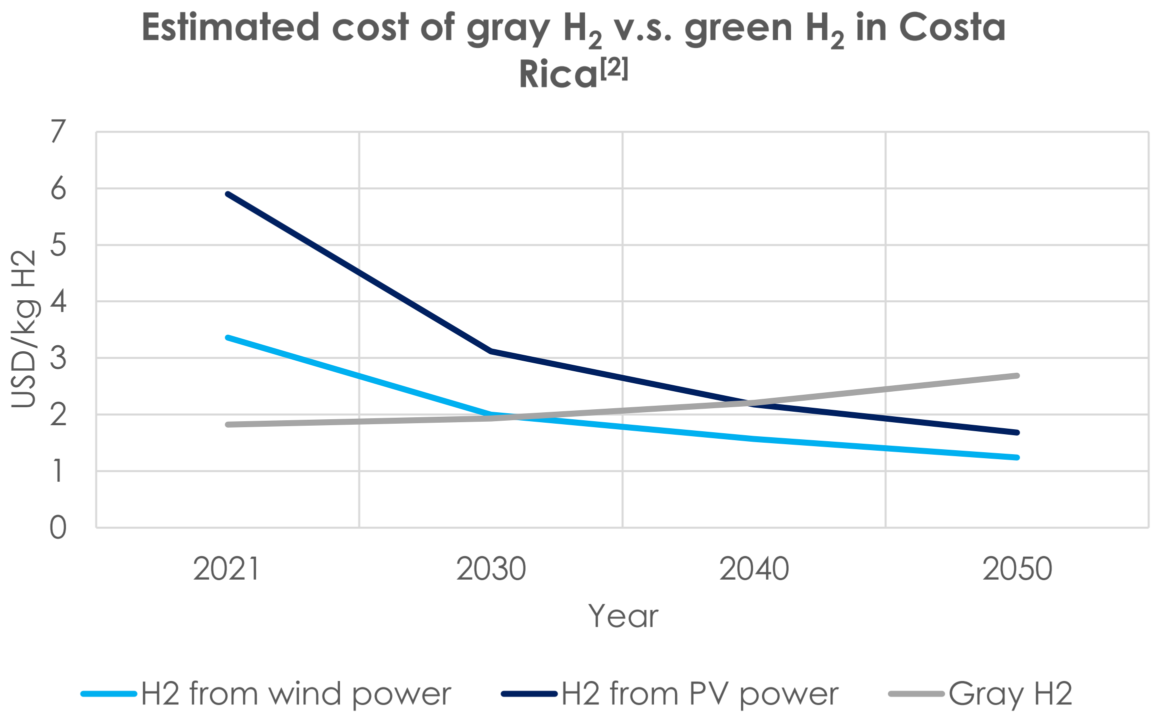
Hydro (at regulated tariffs) is the most expensive source to produce H2 in CR. Wind will be most competitive in the long run



Sources: Hinicio´s study for the CRUSA Foundation and BID Lab "Análisis del mercado global de hidrógeno verde: el potencial de participación de Costa Rica " (2021) and IRENA – Renewable Power Generation Costs in 2019. (Geothermal LCOE for the calculation of LCOH)

Costa Rican green hydrogen could be competitive* to replace diesel, bunker and LPG in less than a decade





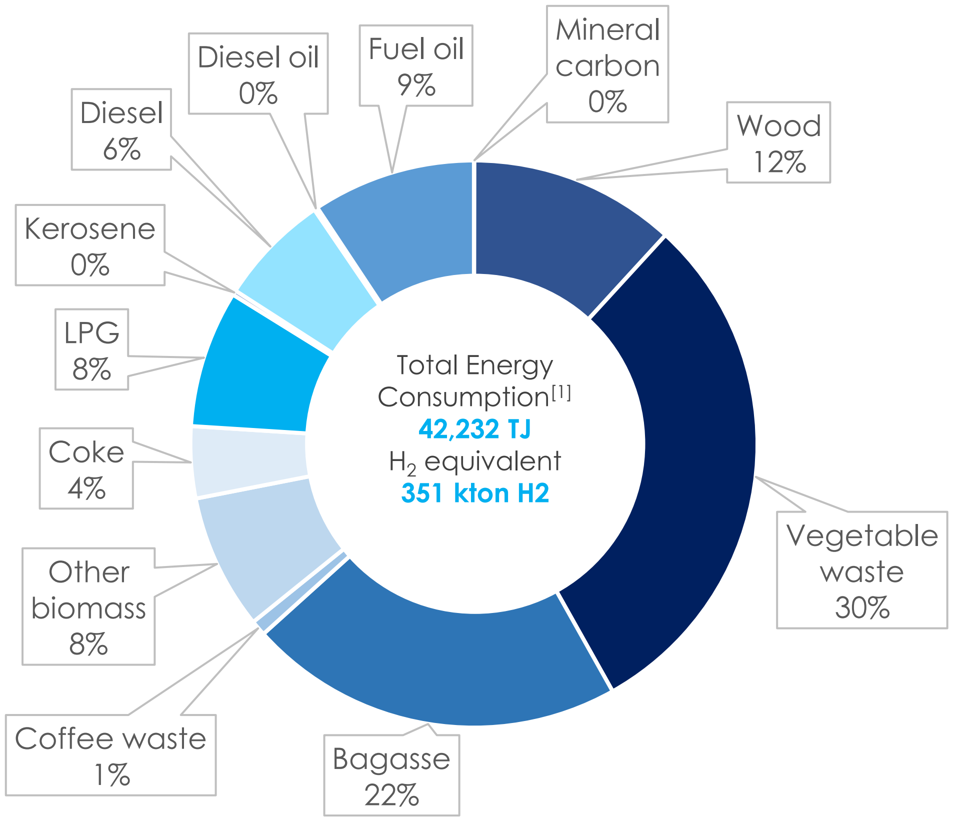
1) **Green hydrogen** from wind power will be **competitive with diesel in less than a decade**.*
2) **Gray hydrogen would not be an option for Costa Rica.** Hinicio did not identify existing gray H2 plants in Costa Rica. Green hydrogen from wind power could be competitive before methane reforming projects get constructed and operative.

[1]: Hinicio, 2021 with information from ICE, 2018 (Plan de Expansión de la Generación Eléctrica)
[2]: Hinicio calculations with information from ICE 2018 for the hypothetical natural gas price in Costa Rica.
Further information on the LCOH parameters considered on Annex 1 - Methodology

* This cost competitiveness is based on a MJ-to-MJ comparison. Therefore, a more comprehensive analysis considering TCO (i.e. capex for technology replacement) is needed to reach more robust and detailed conclusions on cost competitiveness.

Adding 94kton of GH2, the energy consumption of the industrial sector could be 99% renewable

Industrial energy consumption -Costa Rica, 2019



[1]: SEPSE, 2020 – Energy Balance Costa Rica 2019

KEY MESSAGES

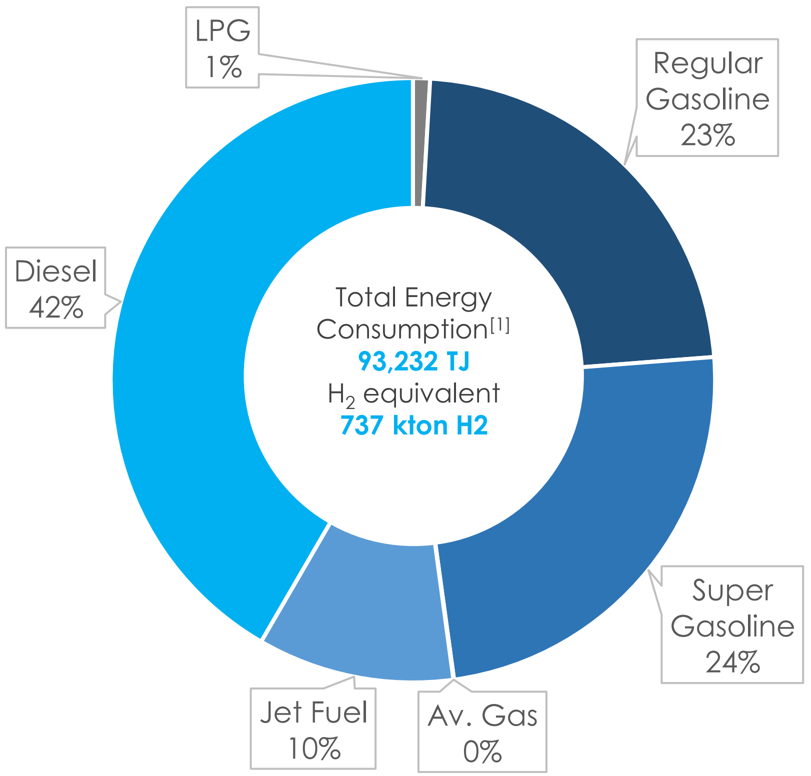
- ✓ More than 70% of the industrial energy consumption in Costa Rica comes from biomass and waste. Even if they produce GHG during combustion processes, they would be considered carbon neutral.
- ✓ The biggest opportunities of green hydrogen to replace fossil fuels in industrial uses are:
  - **LPG**: the easiest replaceable fuel from the technical point of view. Consumer equipment of LPG would be easily adapted to receive hydrogen – LPG blends. **Theoretical potential for H2: 28 kton H_2 /year (270 MW electrolysis)**
  - **Diesel**: H_2 can be mixed with hydrogen in certain equipment, while other should be replaced by hydrogen burners. Green hydrogen will be cost competitive with diesel in the short term. **Theoretical potential for H2: 21 kton H_2 /year (202 MW electrolysis)**
  - **Fuel oil and coke**: mainly used for thermal applications, they are two of the top pollutant fossil fuels, however, important modifications for the infrastructure are needed to replace them with H2. **Theoretical potential for H2: 45 kton H_2 /year (433 MW electrolysis)**

Diesel is the most consumed fossil fuel in the transport sector, used mostly in heavy duty vehicles where hydrogen is the most technically viable zero emissions technology (ranges and refuelling times)

KEY MESSAGES

- ✓ The transport sector is key for the decarbonization in Costa Rica: It consumes **more than twice** the energy volume of the industry.
- ✓ **Diesel has the biggest share** of fossil fuel consumption in the transport sector. Diesel is mostly consumed **by heavy duty mobility segments** for both: passenger and freight transport (51.2% of the diesel consumption in the transport sector)[1].
- ✓ Hydrogen technologies are foreseen as a competitive option in the heavy segments, so **the potential for diesel replacement by green hydrogen in transportation is high**. **Theoretical potential for H2 in CR: 310 kton H_2 /year (2.98 GW electrolysis)**
- ✓ Hydrogen has a smaller replacement potential for gasolines. This sector would be decarbonized by the adoption of hybrid, plug-hybrid and battery electric vehicles; however, a small market share of the passenger vehicles would be for fuel cell in niche uses where fast-refueling time, extended ranges and high availability rates are crucial. **Theoretical potential for H2 in CR: 346 kton H_2/year (3.33 GW electrolysis)**

Transport energy consumption -Costa Rica, 2019*

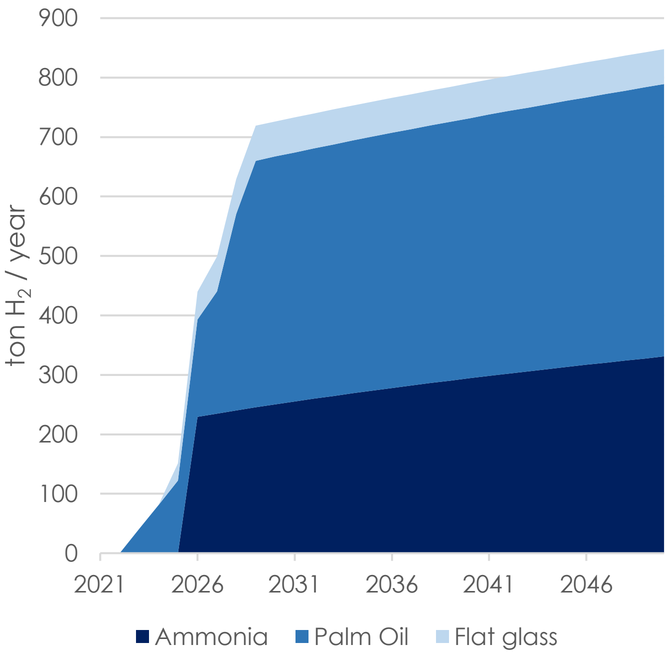


* Includes: Ground, public transport (taxis, buses and mini buses, Freight, Special Equipment, Rail, Aero and Maritime transport.

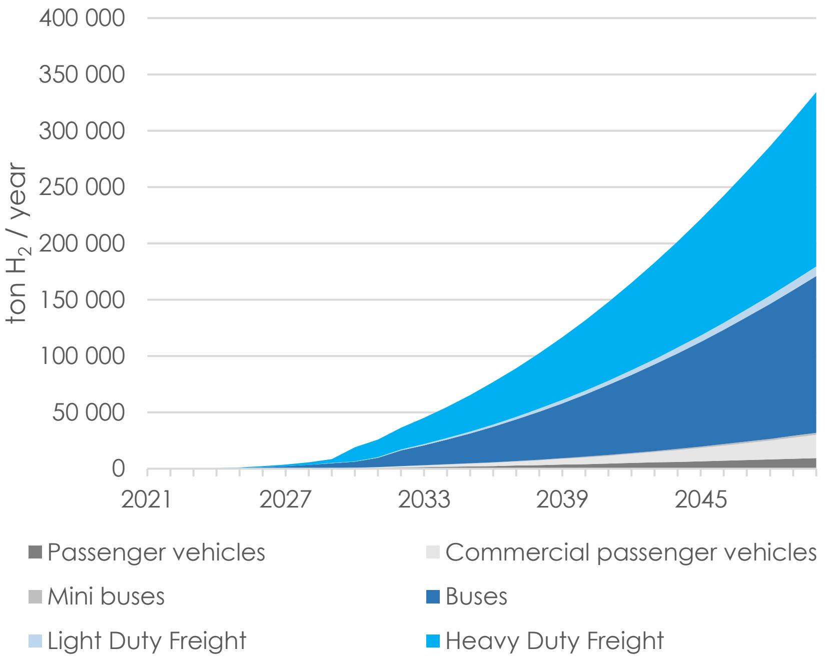
[1]: SEPSE, 2020 – Energy Balance Costa Rica 2019

The largest volumes of hydrogen in Costa Rica will be demanded in the transport sector

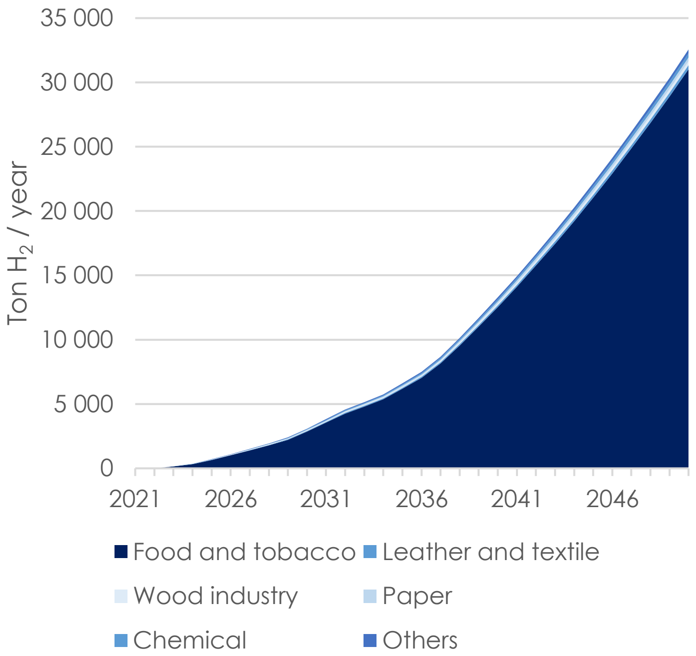
Industrial Use



Transport



Heat for industry

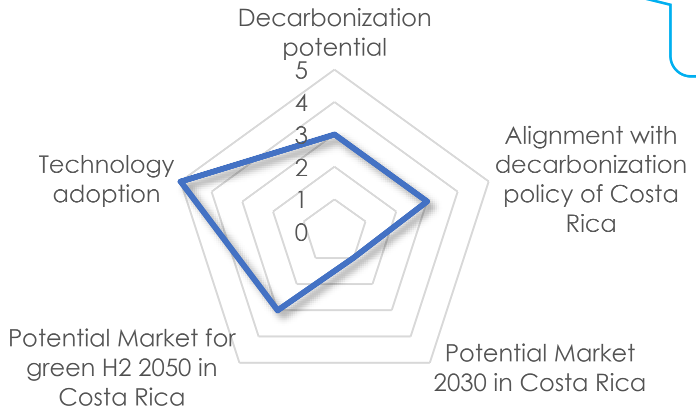


- The **industrial sector** has the **lowest** forecasted hydrogen demand. Costa Rica could meet its own needs with only a few electrolysis plants (**approximately 8 MW**)
- The **ground transport sector** could have the **highest hydrogen consumption** in Costa Rica. According to the adoption projections reported by (Hinicio 2020), demand for hydrogen for mobility could reach **19 kton H2 in 2030 (183 MW electrolysis)** and up to **335 kton in 2050 (3.2 GW electrolysis).** Other transport segments like maritime and rail transport were not considered due to their negligible contribution to energy consumption in CR (less than 1%). For Air Transport, further analysis of synthetic fuels is required.
- Regarding **heat applications**, hydrogen could be adopted as **a replacement for LPG** in pilot and demonstration projects from now until 2035, when green hydrogen reaches its breakeven point with the fossil fuel. **From 2035 to 2050**, hydrogen has a **replacement potential of up to 100% of LPG.**

(Hinicio 2020): Creación de condiciones habilitadoras del ecosistema hidrógeno en aplicaciones de movilidad eléctrica. Fundación Crusa y BID Lab

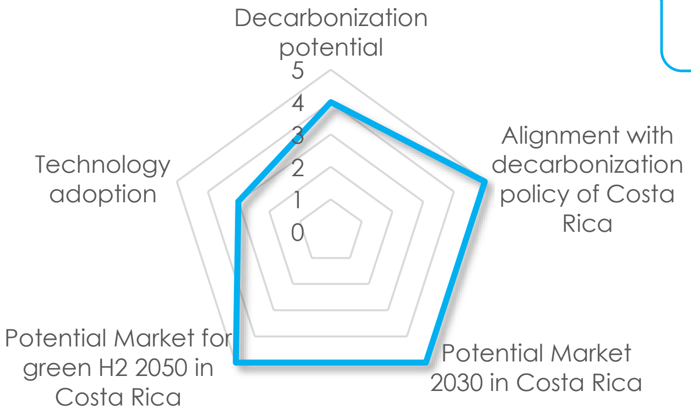
Costa Rica should focus its efforts to develop hydrogen in the transport sector. H2 for industrial applications (feedstock) and industrial heat has some good potential. Hydrogen energy storage should not be prioritized.

Industrial uses



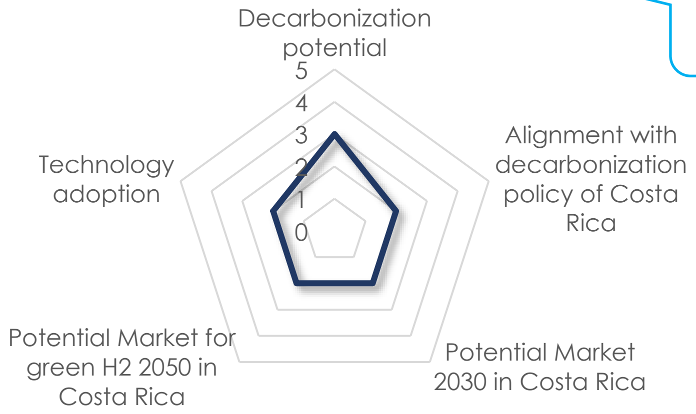
Overall Score:
3.1/5
★★★

Transport



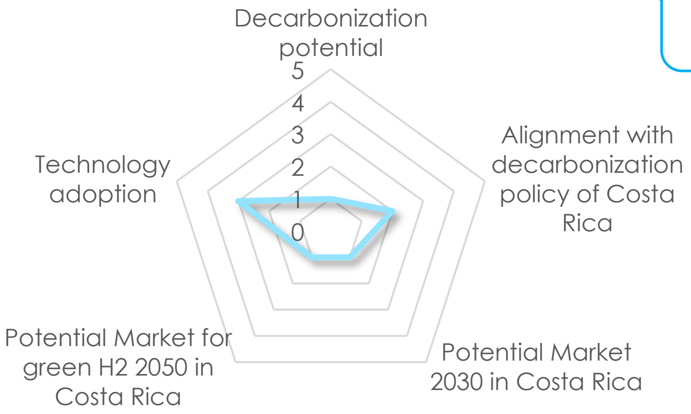
Overall Score:
4.95/5
★★★★★

Industrial heat applications



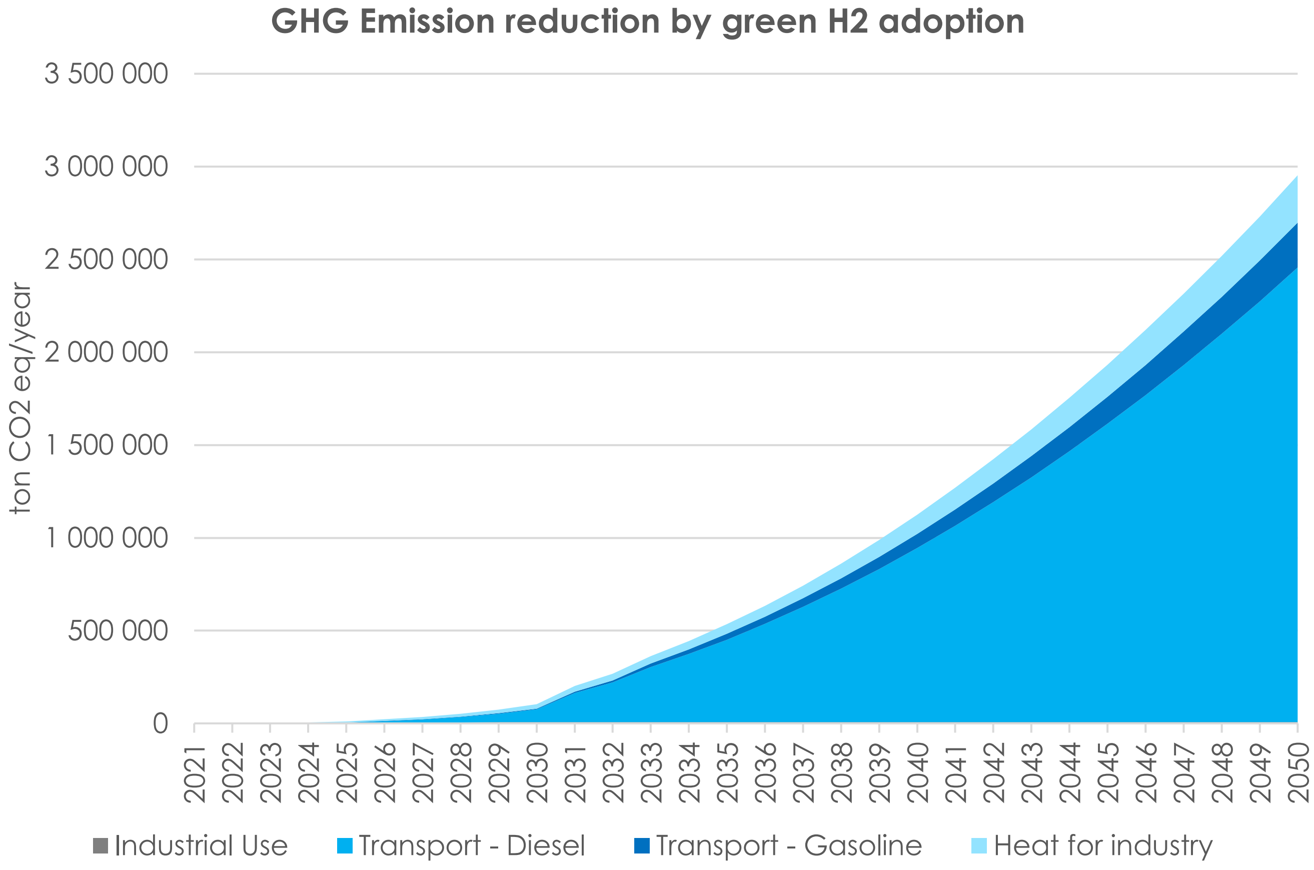
Overall Score:
2.55/5

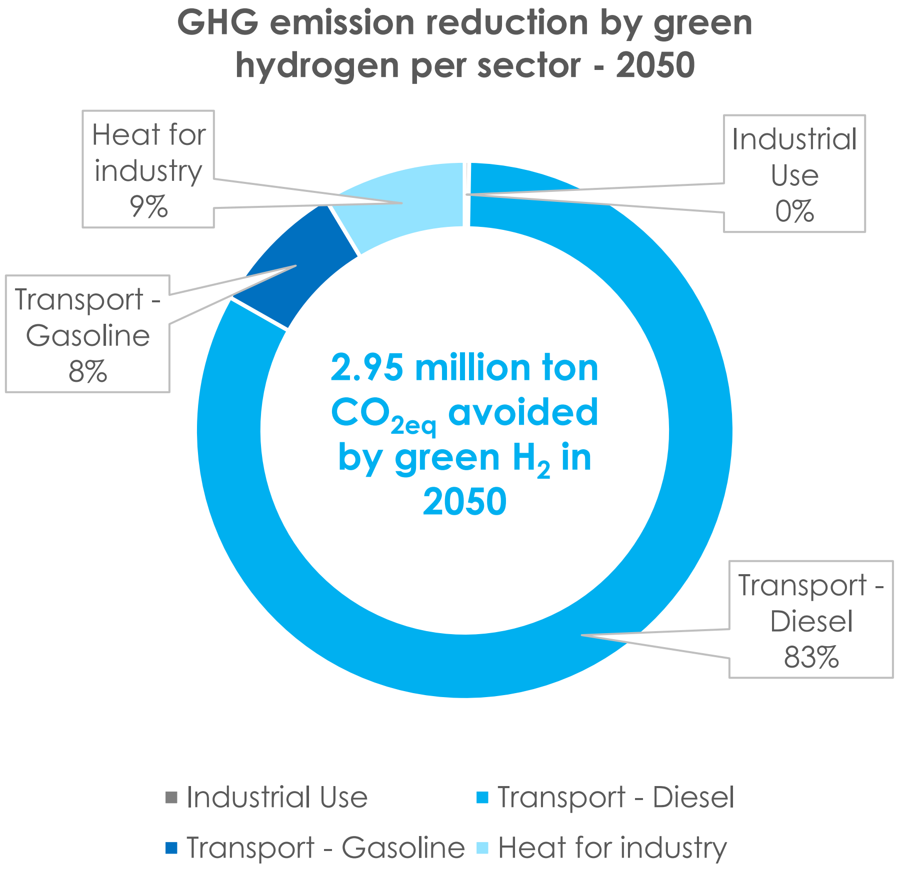
Energy storage



Overall Score:
1.60/5

Decarbonizing the transport sector using green hydrogen in Fuel Cell Electric Vehicles (FCEV) could save Costa Rica 2.68 million ton of CO_{2eq} in 2050





Transport encompasses 3 out of 10 axes of the Costa Rican decarbonization plan where H2 can make a direct contribution

1. Develop a public transport system (buses, taxis and passenger train) and safe shared mobility, powered by clean energy.

H_2 Contribution: Direct contribution
Impact: High impact
Technology: Fuel cell (FC) buses

2. Progressively transform the country's vehicle fleet from fossil-combustion light cars to zero-emission vehicles and promote autonomous shared car business models.

H_2 Contribution: Direct contribution
Impact: Medium impact
Technology: Passenger FC vehicles

3. Reduce the environmental impact of freight transport in the country by favoring the adoption of energy efficient technologies and low-carbon vehicles.

H_2 Contribution: Direct contribution
Impact: High impact
Technology: FC Heavy Duty Trucks

4. Consolidate a national electricity system capable of supplying and managing renewable energy at a competitive cost for users.

H_2 Contribution: Direct contribution
Impact: Low impact
Technology: Power to Power Systems

5. Develop buildings for commercial, residential and institutional use under high efficiency and low emission standards.

H_2 Contribution: Direct contribution
Impact: Low impact
Technology: FC heat &power systems

6. Modernize the industrial sector through the application of electrical, sustainable and more efficient processes.

H_2 Contribution: Indirect contribution
Impact: Medium impact
Technology: H_2 turbines and fuel cells

7. Develop an integrated waste management system based on the separation, reuse, revaluation and final disposal of maximum efficiency and low emissions.

H_2 Contribution: No identified
Impact: No impact identified
Technology: No technology identified

8. Support the adoption of efficient and low-carbon food technology that generates goods for export and also for local consumption.

H_2 Contribution: Direct contribution
Impact: Low impact
Technology: Hydrogenated fats

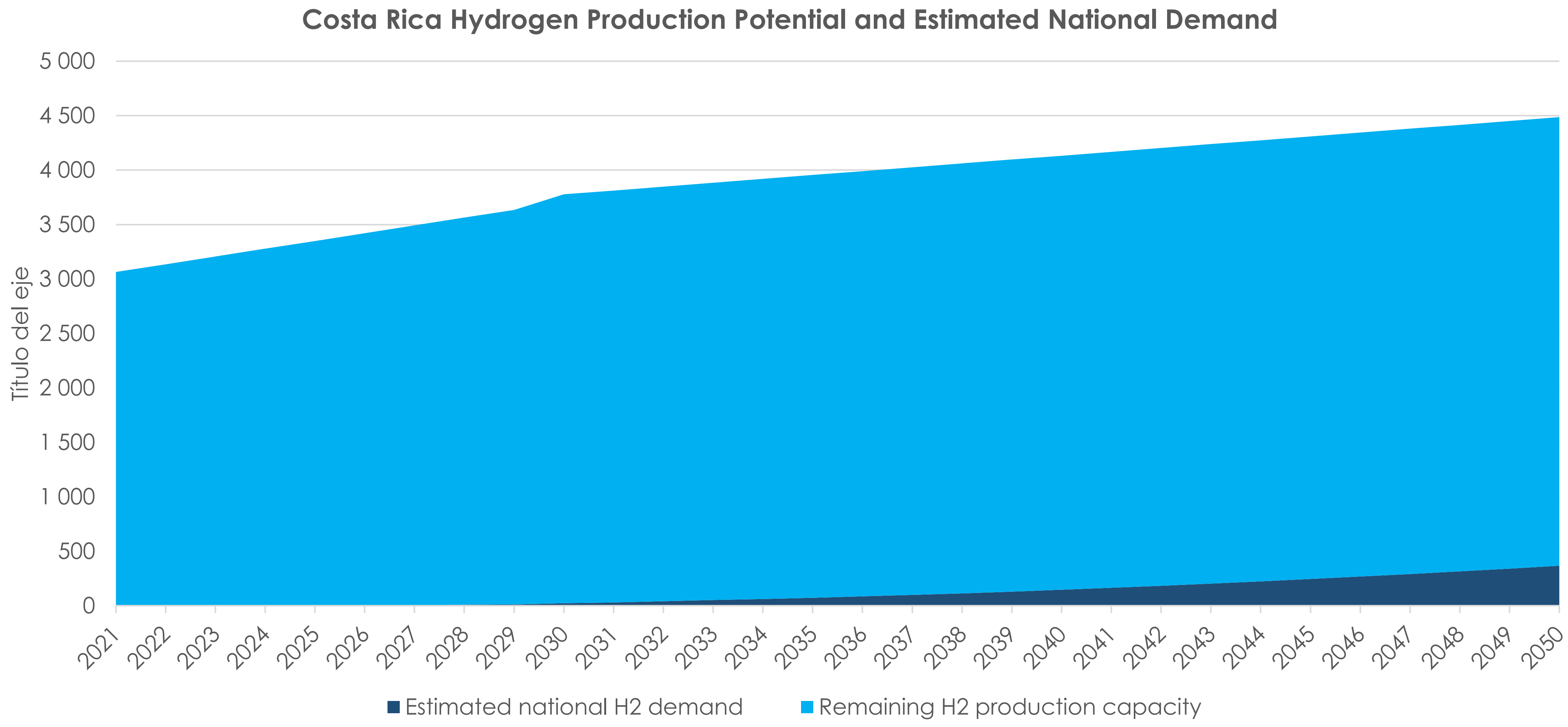
9. Consolidate livestock models based on productive efficiency and reduction of greenhouse gases.

H_2 Contribution: No identified
Impact: No impact identified
Technology: No technology identified

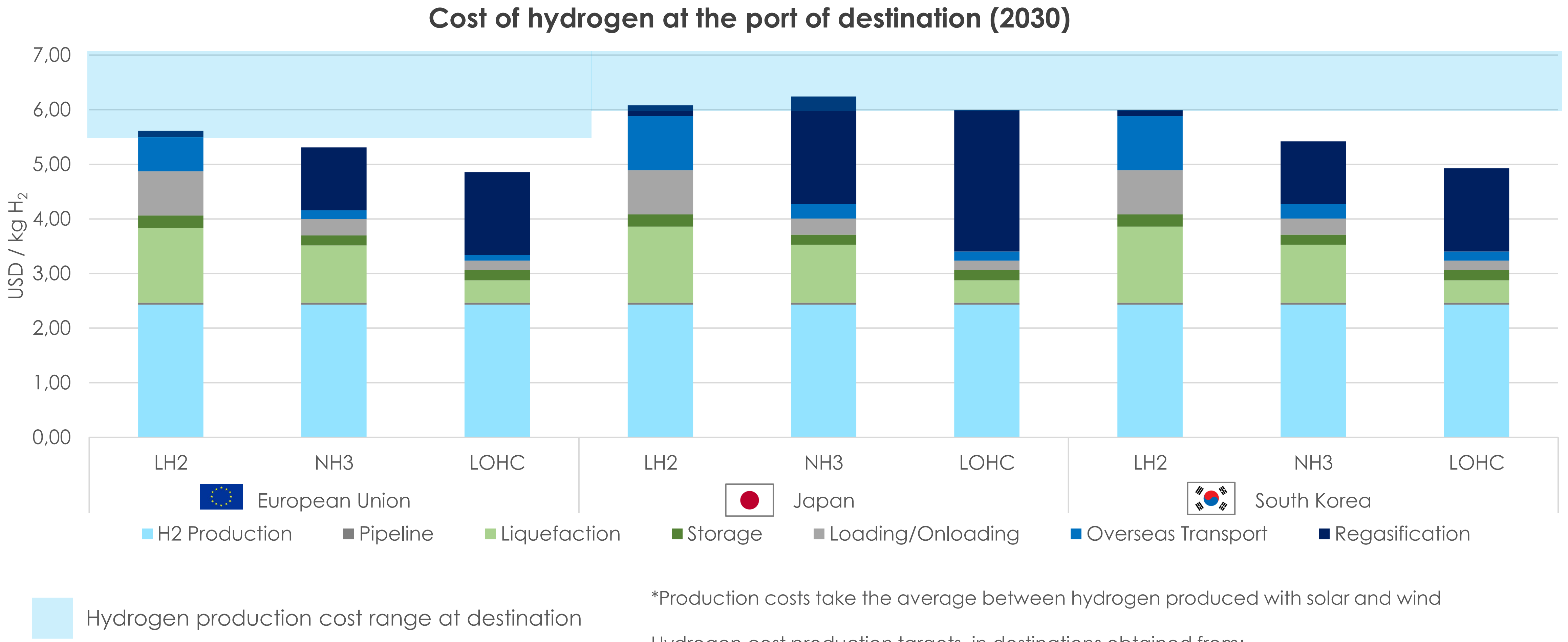
10. Consolidation of a management model for rural, urban and coastal territories that facilitates the protection of biodiversity and the increase of forest cover.

H_2 Contribution: Indirect contribution
Impact: Low impact
Technology: H_2 power: isolated grids

Costa Rica will be able to produce 11 times as much H_2 as it will potentially consume in 2050



Costa Rican hydrogen won't compete against hydrogen produced locally in the EU and Japan

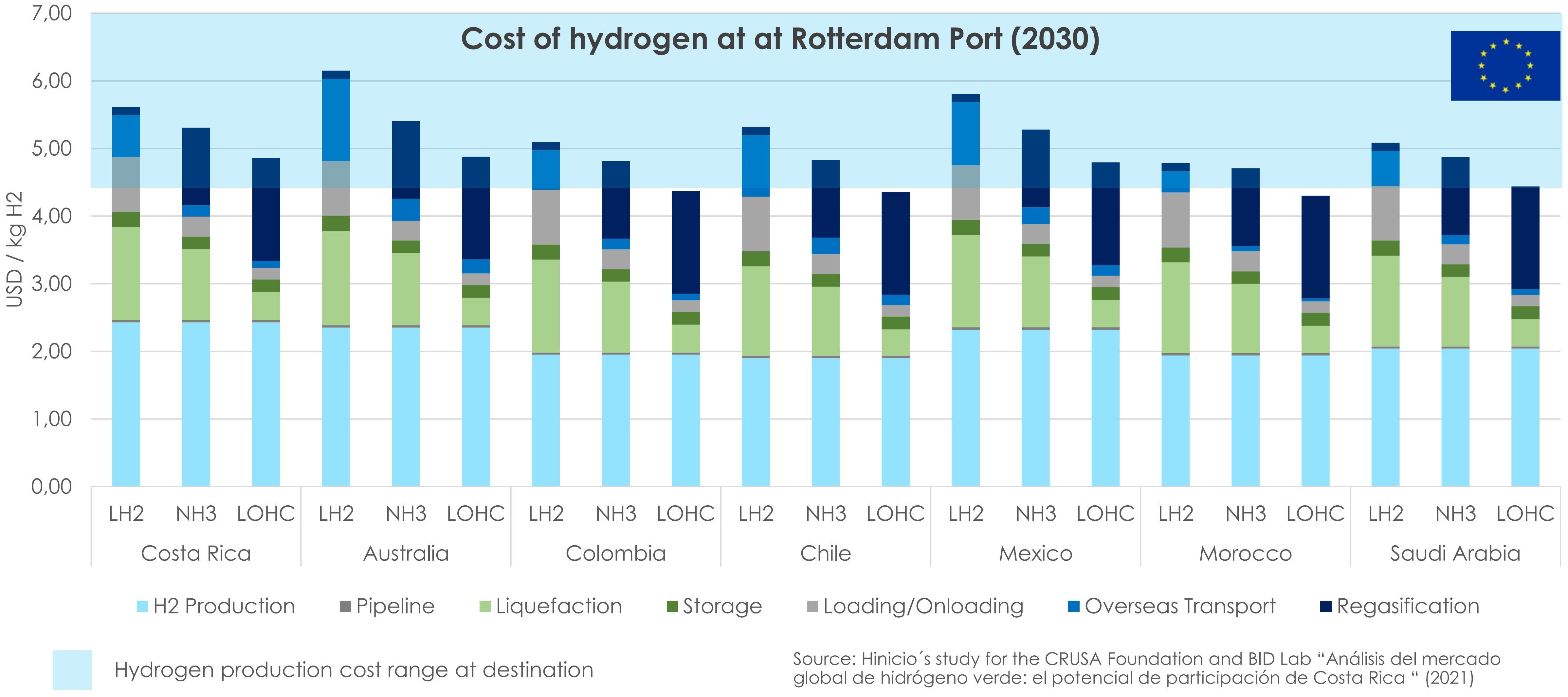


LH2: Liquefied hydrogen
NH3: Ammonia
LOHC: Liquid organic hydrogen Carriers

*Production costs take the average between hydrogen produced with solar and wind

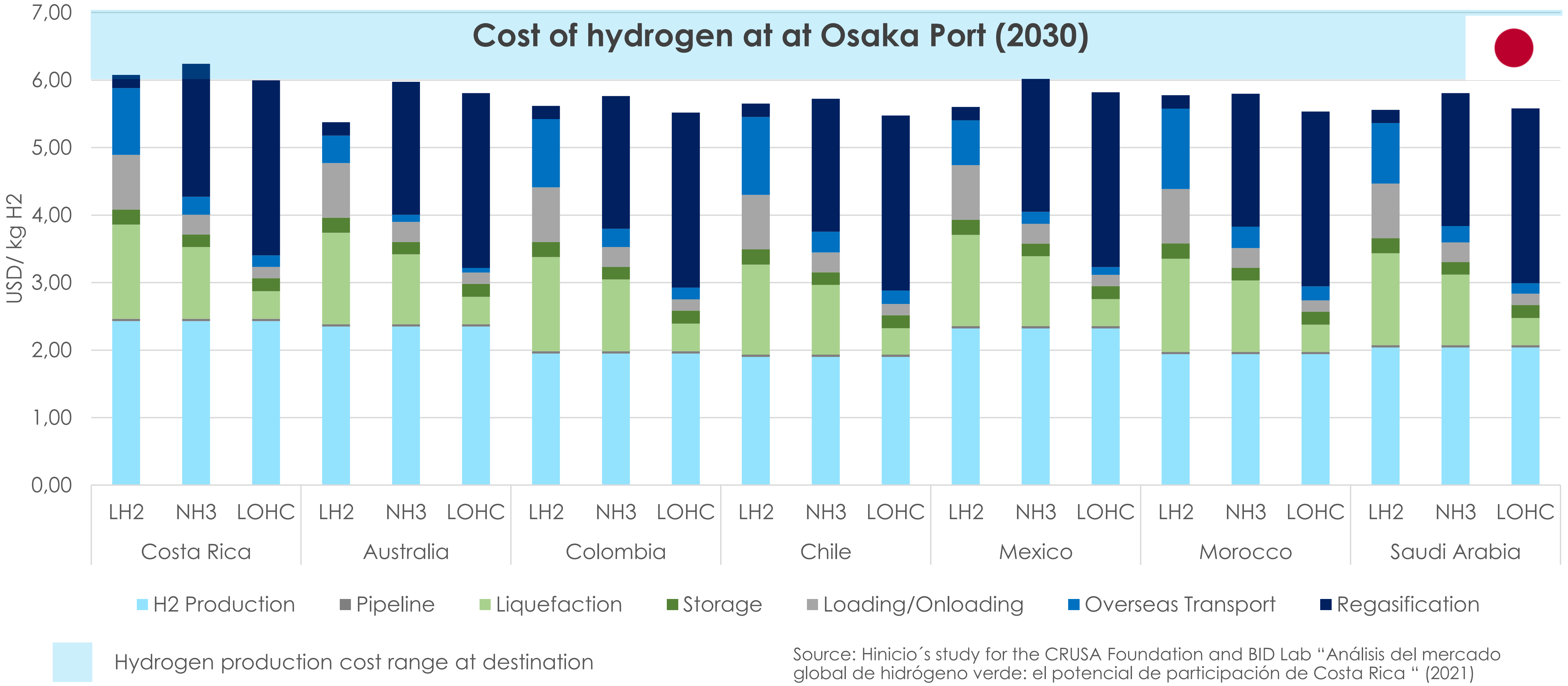
Hydrogen cost production targets in destinations obtained from:
EU: Hydrogen Roadmap Europe. FCH JU. January 2019
JP: Crolius, Stephan. On the Ground in Japan: Mid-Term Prospects for the Hydrogen Society. June 2017
SK: Hydrogen Economy Roadmap of Korea. South Korean Government. January 2019

Costa Rican hydrogen won't compete in the EU against H2 produced in Colombia or Chile



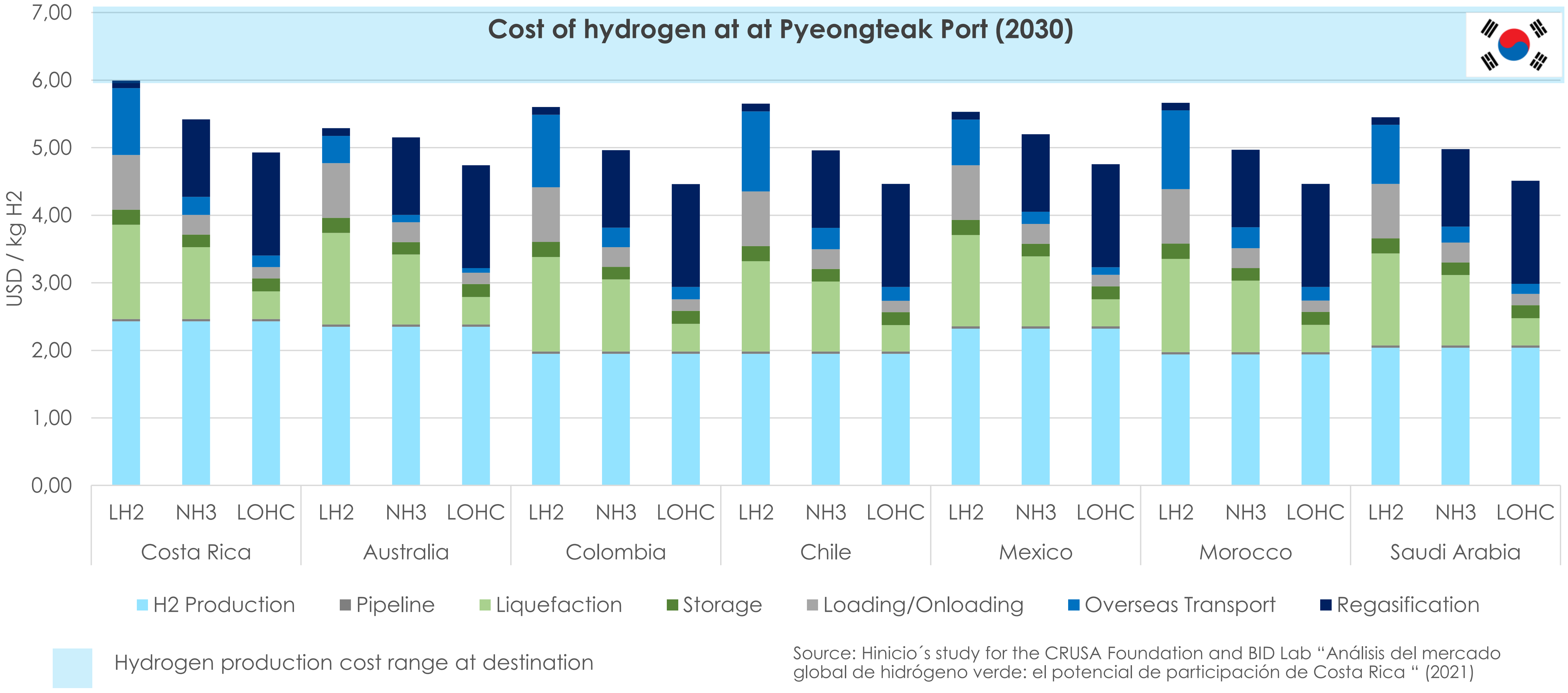
Source: Hinicio´s study for the CRUSA Foundation and BID Lab "Análisis del mercado global de hidrógeno verde: el potencial de participación de Costa Rica " (2021)

Costa Rican Hydrogen in Japan is more expensive than other countries' in all three carriers



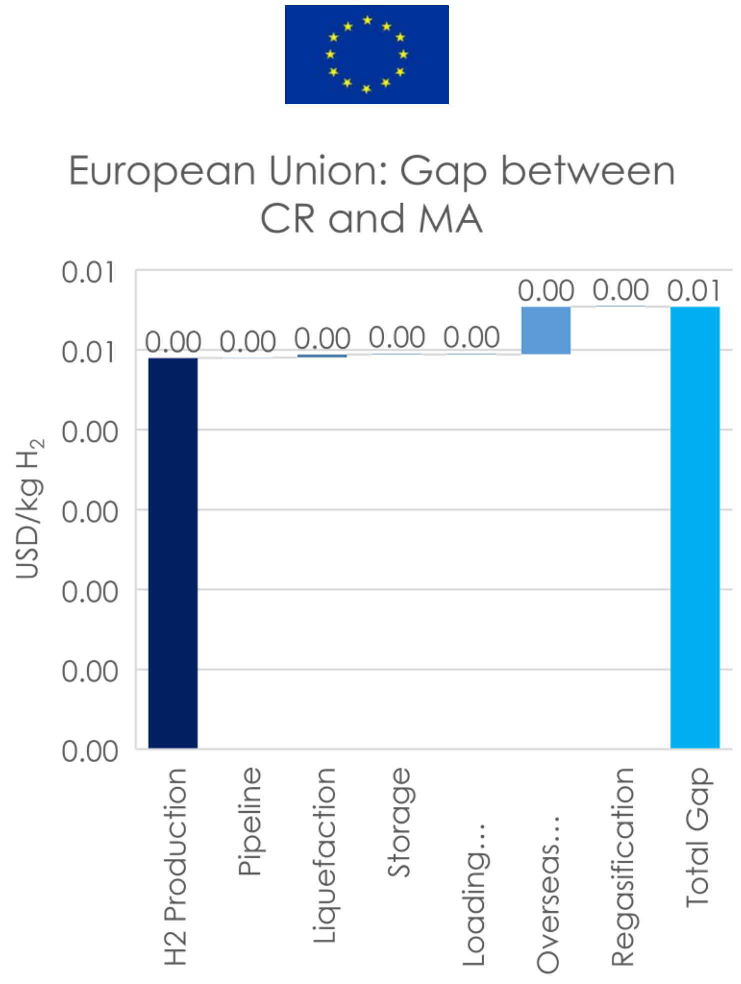
Source: Hinicio´s study for the CRUSA Foundation and BID Lab "Análisis del mercado global de hidrógeno verde: el potencial de participación de Costa Rica " (2021)

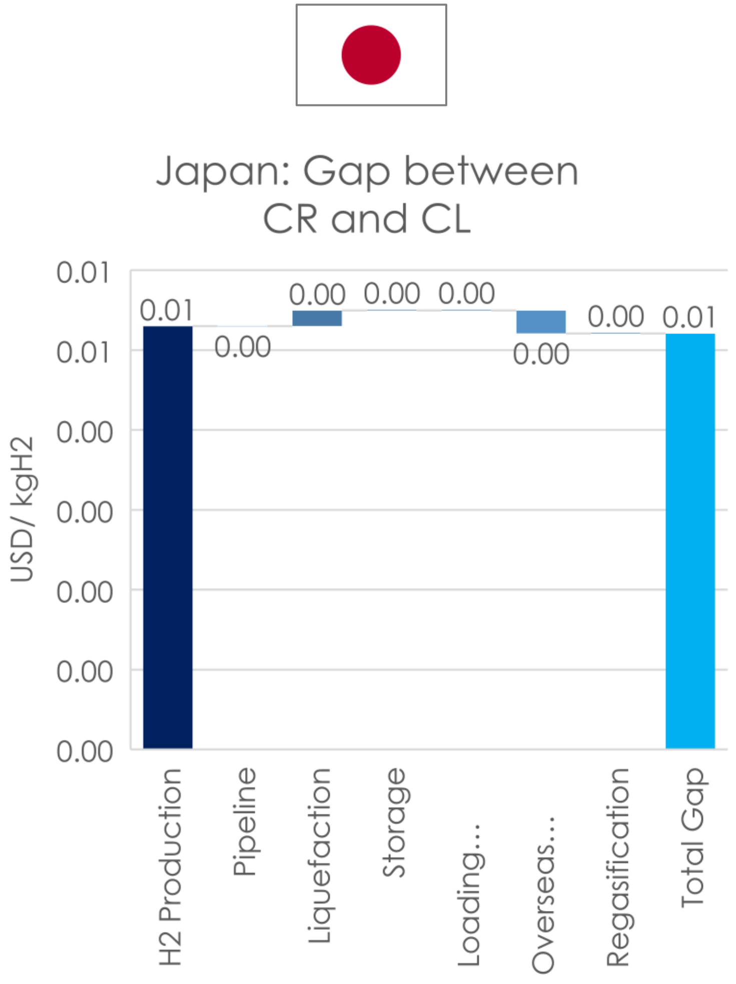
Even if Costa Rican H2 will be cheaper than locally produced H2 in South Korea, other countries will be more competitive

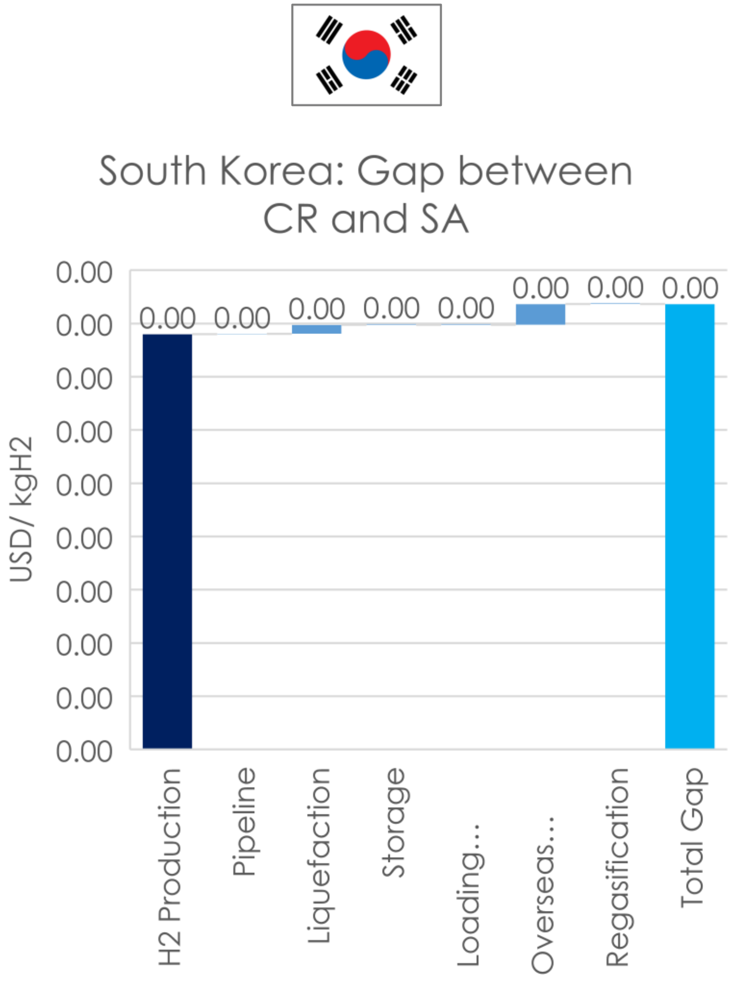


Source: Hinicio´s study for the CRUSA Foundation and BID Lab "Análisis del mercado global de hidrógeno verde: el potencial de participación de Costa Rica " (2021)

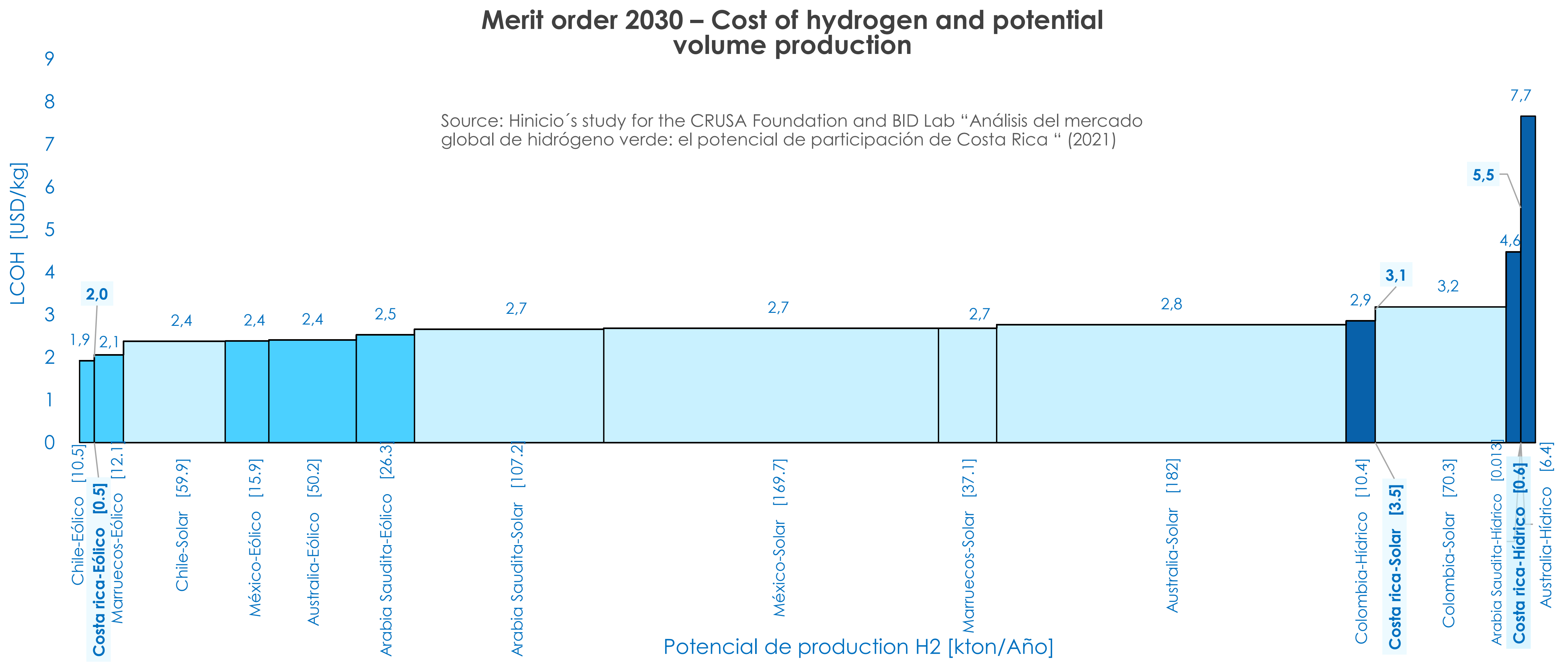
The biggest obstacle for Costa Rica to be competitive in the exports market is not the distance to destinations, but its energy costs, which are strongly linked to its renewable potential



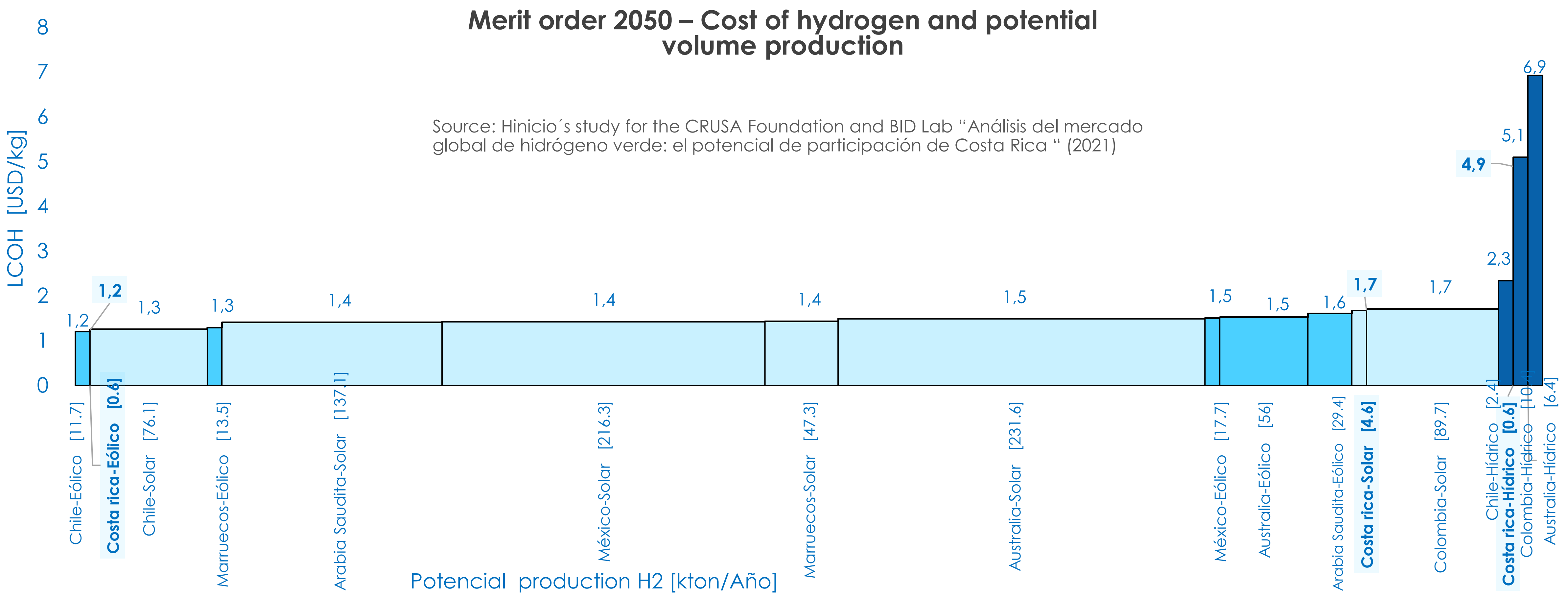




2030 volumes of hydrogen produced in Costa Rica will be minor compared to potential exporting countries



Even with LCOHs closer other countries' in 2050, Costa Rican H2 volumes remain minor



Conclusions of the Technical, Economic and Financial aspects (1)

- **Efforts for hydrogen development in Costa Rica should focus on its domestic market, and not on exports**
  - Volumes of hydrogen for exports will be minor compared to other countries' potential production. This implies Costa Rica will not be attractive enough for investors and will not be able to optimize its H2 maritime transport supply chain.
  - The cost of Costa Rican hydrogen at the port of destination in the main future importing markets (EU, Korea, Japan) are above those of other potential exporters. Even when there could emerge new hydrogen economies demanding imported hydrogen, today it is unpredictable.

- **Costa Rica should focus its efforts to develop hydrogen for the decarbonization of its transport sector**
  - Transportation is the sector with the highest energy consumption in Costa Rica, and therefore the largest emitter of CO_2
  - Decarbonizing the transport sector using green hydrogen in FCEV could save Costa Rica 2.68 million ton of CO2eq in 2050
  - The heavy-duty segment, which accounts for the largest consumption of fossil fuels in the transport sector in Costa Rica, is also the segment where fuel cell vehicles perform better against other zero emissions technologies like batteries due to their long ranges and short refueling times.
  - Potential hydrogen volumes in the transport sector in Costa Rica are the largest among all the sectors analyzed. This large volumes will allow for demand aggregation and costs optimization in the short-medium term.

- **The hydropower surplus that exist in Costa Rica could help steer the early market adoption. However, it will fall short in the long-term.**
  - Surpluses of hydropower are scattered among 13 plants around the country. The 3 with the highest volumes Reventazón, Rio Macho, and Pirris
  - The maximum theoretical potential to produce green hydrogen from hydro surpluses is 12.6 kton/year. This is 70% of the expected demand of green hydrogen in the transport sector in 2030, therefore relying on surplus hydro for hydrogen production in Costa Rica won't be sustainable in the long-run.
  - It is important to bear in mind that today ICE is not allowed to sell electricity at prices below the ARESEP regulated tariffs, therefore ICE is not able to use its hydro surpluses to produce cost-competitive hydrogen. Nor is it allowed to commercialize hydrogen under the current legislation. The possibility for a special tariff regime for the production of hydrogen is under discussions (Proyecto de Ley 22392 del 2021). Possibilities for ICE to form alliances with private companies to commercialize hydrogen under Law 8660 should be analyzed.

Conclusions of the Technical, Economic and Financial aspects (2)

- **Hydrogen has a good potential to replace fossil fuels in Costa Rica in the transport and industrial sectors, particularly diesel and LPG**
  - Hydrogen will reach MJ-to-MJ cost competitiveness* in the next 15 years with LPG, bunker and diesel
  - More than 70% of the industrial energy consumption in Costa Rica comes from biomass and waste, which are considered carbon neutral when there is a strong reforestation program in place. Adding 94kton of green H_2 (905 MW of electrolysis), the Costa Rican industrial sector would be 99% renewable-based (2019 figures)

- **Costa Rica has a high potential for renewable generation, so its internal demand for electricity in the next 30 years will not be compromised by the production of green hydrogen**
  - Costa Rica's renewable energy potential is 10x its forecasted electricity demand
  - Profound changes in policy are needed in Costa Rica to significantly increase (aprox 2-fold) the renewables installed capacity in the country to produce hydrogen to decarbonize its economy.

- **E-fuels production could be a niche application to supply international flights and maritime ships connecting with Costa Rica,** thus contributing to international decarbonization efforts. (Interview with Alexander Mahler, GIZ-DE)

- **Energy storage using hydrogen has a low potential in Costa Rica as ICE projects low capacities of variable renewable energies, for which geothermal and hydro will provide enough buffer**
  - Hydrogen could play a role for energy storage as a niche application for isolated microgrids

* This cost competitiveness is based on a MJ-to-MJ comparison. Therefore, a more comprehensive analysis considering TCO (i.e. capex for technology replacement) is needed to reach more robust and detailed conclusions on cost competitiveness.

2 Policy and governance

The role of CR stakeholders in the H_2 economy

Across three stages of hydrogen development in Costa Rica

1. Market preparation

Preparing policy and creating technical and commercial regulations for hydrogen. Developing the first pilot/demonstration projects.

2. Early market development

More projects are developed, and more actors get involved with hydrogen. Ecosystem is strengthened to maintain the impetus for H2 developments.

3. Mature market

Hydrogen has reached sufficient technical and commercial maturity. Its adoption is no longer actively promoted, but an atmosphere of competitiveness on the subject must be maintained.

Strategic Action Line	Objective
Policy and regulation	Establish the highest-level guidelines for the development of the hydrogen economy in Costa Rica. They are the main lines of action from which all stakeholders plan their activities.
Market development	These are actions that promote the commercial development of green hydrogen technologies. Includes activities indirectly related to market development but necessary to promote it.
Funding and investments	Actions for the strategic financing of initiatives and projects for the accelerated adoption of hydrogen technologies, as well as incentives that favor technological change.

Hinicio prepared the stakeholder map and validated it with MINAE, MIDEPLAN, ICE and RECOPE

Acronyms of main stakeholders to get involved on H2 developments in Costa Rica

Acronym	Logo	Institution name (Spanish)	Institution name (English)
ANE		Agencia Nacional de Empleo	National Employment Agency
ARESEP		Autoridad Reguladora de los Servicios Públicos	Regulatory Authority of Public Services
CNC		Consejo Nacional de Concesiones	National Council of Concessions
CINDE		Agencia Costarricense de Promoción de Inversiones	Costa Rican Investment Promotion Agency
Com.Ex		Ministerio de Comercio Exterior	Ministry of Foreign Trade
CONASSIF		Consejo Nacional de Supervisión del Sistema Financiero	National Council for the Supervision of the Financial System
ICE		Instituto Costarricense de Electricidad	Costa Rican Institute of Electricity
INA		Instituto Nacional de Aprendizaje	National Institute of Learning
INEC		Instituto Nacional de Estadística de Costa Rica	National Institute of Statistics of Costa Rica
INTECO		Instituto de Normas Técnicas de Costa Rica	Institute of Technical Standards of Costa Rica
MEIC		Ministerio de Economía, Industria y Comercio	Ministry of Economy, Industry and Commerce
MICITT		Ministerio de Ciencia, Tecnología y Telecomunicaciones	Ministry of Science, Technology and Telecommunications

Acronyms of main stakeholders to get involved on H2 developments in Costa Rica

Acronym	Logo	Institution name (Spanish)	Institution name (English)
MOPT		Ministerio de Obras Públicas y Transportes	Ministry of Public Works and Transport
MIDEPLAN		Ministerio de Planificación Nacional y Política Económica	Ministry of National Planning and Economic Policy
MINAE		Ministerio de Ambiente y Energía	Ministry of Environment and Energy
MREC		Ministerio de Relaciones Exteriores y Culto	Ministry of Foreign Affairs and Worship
PROCOMER		Promotora del Comercio Exterior de Costa Rica	Promoter of Foreign Trade of Costa Rica
SBD		Sistema de Banca para el Desarrollo	Development Banking System
SNC		Sistema Nacional para la Calidad	National System for the Quality
SUGEVAL		Superintendencia General de Valores	General Superintendence of Stocks
MH		Ministerio de Hacienda	Ministry of Treasure
Pres.Home		Casa presidencial	Presidential home
RECOPE		Refinadora Costarricense de Petróleo	Costa Rican Oil Refinery

1. Market preparation

Strategic Action Line	Action	Responsible	Role	Priority
Policy and regulation	Communicate and spread the knowledge on hydrogen technologies	MINAE MICITT[1]	Promotor Executor	●●●
	Promote the accelerated deployment of hydrogen production	MINAE	Promoter	●●●
	Formulate a National Strategy or Roadmap for Hydrogen	Presidential home + MINAE MINAE + MIDEPLAN MINAE + MEIC + Other ministries	Promoter Developer Executors	●●●
	Establish the regulatory framework of the hydrogen market and its uses as energy and feedstock	MINAE[2] + MEIC	Developers and executors	●●●
	Provide tax or import benefits for goods directly and indirectly related to the hydrogen value chain	MIANE MH +Com.Ex	Promoter Executor	●●○
	Stimulate the continuous development of renewable energy	MIDEPLAN MINAE ICE + Companies	Promoter Developers Executors	●●○
	Elaborate technical standards (at least) for hydrogen production and handling	MINAE SNC	Developer Executor	●●●
Market development	Identify and quantify country's potential for hydrogen production and consumption	MINAE + MEIC	Executors	●●●
	Stimulate the development of demonstrative and pilot projects and oversee developers during their execution	MICITT + MINAE Companies	Promoters and co-funder Co-funders and executor	●●●
	Promote the public-private partnerships	CNC CINDE ICE + Companies	Promoter Developer Executors	●●○
	Create Mission Driven Innovation Programs	MICITT Companies + Universities + Research Centres	Promoter and Developer Executors	●●○

[1] : The scientific and R&D aspects of the hydrogen economy could be addressed both by MICITT or the recently approved Costa Rican of Innovation and Research
[2]: …and ARESEP in case of hydrogen become a public service in Costa Rica

1. Market preparation

Strategic Action Line	Action	Responsible	Role	Priority
Funding and investments	Co-fund demonstrative and pilot projects (public-private funding)	MICITT MEIC Private Sector MINAE	Co-funders International financing manager	●●●
	Create specific funds for supporting activities and studies to assess the national H2 market	MICITT Universities International Cooperation	Co-funders	●●●
	Provide funding for innovation and R&D programs	MICITT Universities	Funders	●●●

2. Early market development

Strategic Action Line	Action	Responsible	Role	Priority
Policy and regulation	Fiscal or tax support for green hydrogen. Reduction of VAT or other taxes, accelerated depreciation or deductibility of green hydrogen equipment	MINAE MH	Promoter Executor	●●●
	Create non-economic stimuli for the adoption of certified green hydrogen	MINAE MOPT Com.EX	Promoter Developers and executors	●●●
	Formulate a "Green Tax Reform" for the switch from fossil to alternative fuels	MINAE MH	Promotor Executor	●●●
	Create of regional (Central America) and international cooperation to accelerate hydrogen commercialization and learning processes by exchanging experiences	Presidential home MINAE + MIDEPLAN MREC + Sectorial Ministries	Promoter Developer Executors	●●●
	Implement a continuous policy for measuring progress and updating goals	MIDEPLAN MINAE Sectorial Ministries	Promoter Developer Executors	●●●
Market development	Create of national "hydrogen hubs" or "hydrogen corridors"	MINAE + MICITT + PROCOMER CINDE Private Sector	Promoter Developer Executors	●●●
	Establish Guarantee of Origin Schemes for green hydrogen	MINAE + PROCOMER + Com.Ex INTECO	Developers Executor	●●●
	Create sectorial action plans for the development of green hydrogen	MIDEPLAN MINAE + MEIC + MOPT + Com.Ex	Promoter Developers and executors	●●●
	Establish alliances with industrial chambers to promote hydrogen technologies and measure the progress of their affiliates.	PROCOMER + Alianza H2 Industrial chambers Private companies	Developer Executor Participants	●●●
	Setting international codes and standards for every single hydrogen application or use.	MINAE INTECO	Developer Executor	●●●
	Continuous preparation of personnel and human resources trained in green hydrogen value chains.	MICITT Universities + INA + Private companies	Promotor and developer Executors	●●●

2. Early market development

Strategic Action Line	Action	Responsible	Role	Priority
Funding and investments	Provide loans, grants or dedicated funds for identified priority sectors for hydrogen	SBD + International Cooperation + Sectorial Ministries	Funders	●●●
	Create financing mechanisms with preferential interest rates for the development of green hydrogen projects	Public and private banking		●●●

3. Mature Market

Strategic Action Line	Action	Responsible	Role	Priority
Policy and regulation	Policy for the deep decarbonization of the economy	MIDEPLAN MINAE + MEIC + MICITT	Promoter Developers	●●●
	Establish a carbon border tax for imported goods.	Presidential home MINAE + Com.Ex MH	Promoter Developers Executor	●●●
	Generation of mechanisms that facilitate international private investment.	Com.Ex + CINDE + PROCOMER MH	Promoters Executor	●●●
	Evaluation and continuous updating of the regulatory framework around the commercial activities of green hydrogen.	MIDEPLAN MINAE + MEIC + ARESEP[1]	Promoter Developers and executors	●●●
Market development	Secure a private investment ecosystem	MINAE + MH + Com.Ex CONASSIF / SUGEVAL	Promoter Executors	●●●
	Promotion of synthetic fuels (liquid and gaseous) for the decarbonization of sectors that still need to use hydrocarbons.	MINAE / RECOPE Companies + Major consumers	Promoter Executors	●●○
	Identifying economic growth and evaluation of cobenefits obtained so far (job creation, GHG emission mitigation, etc.)	MINAE + MEIC Com.Ex + PROCOMER ANE (National Employment System)	Promoter Developers Executor	●●○
Funding and investments	Fair financing for mature hydrogen applications and preferential rates for applications still under development.	National and International Private and public banking institutions	Executors	●●○

[1] : ...and ARESEP in case of hydrogen become a public service in Costa Rica

International lessons learned for the successful development of a hydrogen market (1)

	Topic	Learned from:	Lesson
1	Promotion of renewable energy to ensure the parallel development of green hydrogen	European Union	New projects for the production of hydrogen through electrolysis on a GW scale go along with the development of new renewable electricity generation plants. For example: in the North Sea the NorthH2 project plans to install 10 GW off-shore wind power by 2040 for the production of green hydrogen.
2	Extensive base of stakeholders	Chile	Countries with a large number of stakeholders around the hydrogen economy development generate plans and execute projects in a more agile way. An example is Chile, who convened roundtables with public and private actors and even international cooperation organizations for the planning of its National H2 Strategy.
3	Importance of a strategy / roadmap as a guideline for actions at the national level around hydrogen	Chile and Japan	A National Strategy or Roadmap for hydrogen establishes guidelines for the development of projects by stakeholders in the countries. An example of this are Chile and Japan. Japan has a clearly focused roadmap on the development and adoption of hydrogen consuming technologies. Japan envisions itself as an H2 importer. Chile positions itself as an exporter of hydrogen and its derivatives on its H2 strategy. As a consequence, it has already attracted investments for 4 large projects of e-fuels production in less than 2 years.
4	Establishment of explicit hydrogen adoption goals.	Japan	Japan has a hydrogen strategy with a large number of quantitative goals. Japan's goals are set as numbers of FC vehicles or buses, number of residential combined heat & power systems, or electricity generated in large power plants by 2025, 2030 or 2050. This establishes a commitment for adoption and allows predicting the volumes of hydrogen required to satisfy the Japanese market.

International lessons learned for the successful development of a hydrogen market (2)

	Topic	Learned from:	Lesson
5	Creation of hydrogen hubs to aggregate demand and accelerate the adoption of higher volumes of hydrogen in concentrated areas.	European Union	The European Union has identified seaports as potential hubs for the adoption of green hydrogen. Seaports gather a high volume of cargo truck traffic, heavy industries and thermal power plants installed in their vicinity and have preferential access to off-shore renewable energy and international shipments of hydrogen and its derivatives. The aforementioned characteristics allow ports to group multiple hydrogen off takers, while having the potential to produce the required hydrogen in a semi-centralized way. This concept of hydrogen hubs can be transferred to centers of accumulated H_2 demand inland as well.
6	International collaboration at the regional level to increase leverage towards equipment providers when aggregating demand	Uruguay	Throughout more than 5 years developing projects for the Latin American region, Hinicio has seen the need to generate push for aggregating regional demand for equipment to attract technology providers and promote the local installation of aftersales service centers. Sometimes a single project does not demand the necessary volumes of equipment (for example: FC buses) for a manufacturer to establish after-sales services in Latin American countries, particularly the smaller ones like Costa Rica.
7	Creation/adoption of green hydrogen guarantee of origin schemes in the early stages of the adoption	European Union	Green hydrogen Guarantee of Origin schemes were proposed for the first time in Europe, being CertifHy the most important. This scheme helps create market pull for Green and Low-carbon hydrogen, EU-wide, independently from production sites. It improves the business case and ensures transparency & consumer empowerment
8	Provide financial incentives to reduce the cost gap between hydrogen and fossil fuel applications	United States	Financial incentives that reduce the cost gap between fossil technologies and the hydrogen alternative allow the consumer to make decisions oriented not only by price. In California, for example, FCEV buyers can get a rebate of up to $ 4,500. Other forms of financial incentives may be tax discounts, subsidies, or benefits for the importation of hydrogen equipment.

Conclusions of the policy and governance aspects

- There are actions to be taken by the public sector during the whole course of development of the hydrogen market, and not only at its infancy
- MINAE has a prominent role in the development of the hydrogen market in Costa Rica. Nonetheless, the contribution of other ministries and government agencies is crucial to build the national hydrogen ecosystem
- It is of paramount importance to develop the regulatory framework for hydrogen in the short term, so as to assign roles and responsibilities in the subsequent market development stages to the different entities
- Hinicio did a preliminary validation of the stakeholder map with MINAE, MIDEPLAN, ICE and RECOPE. However further discussions with them, as well as with other stakeholders seems necessary to consolidate a unified vision and engage all actors
- Dialogue with the public and private sector agents developing hydrogen successfully in other countries and regions is important to gather lessons learn that help steer developments in Costa Rica in the most agile and practical ways.

Hinicio

YOUR KNOWLEDGE PARTNERS FOR HYDROGEN PROJECTS AND STRATEGIES

Contact

WeWork, Sint-Lazaruslaan, 4 - 10
B-1210 Brussels, BELGIUM

+32 (0)2/211 34 14 (Belgium)

http://www.hinicio.com

/company/hinicio

info@hinicio.com

HinicioSA

Annex 1 - Methodology

List of people/entities interviewed by Hinicio in Costa Rica to gather information and validate results

Name	Organization / Institution	Date
Juan Guillermo Murillo	CRUSA Fundación Costa Rica - Estados Unidos para la Cooperación	12-March-2021
Arturo Molina	minae Ministerio de Ambiente y Energía	18-March-2021
Yariela Webb	RECOPE	21-March-2021
José Olegario Saenz	mideplan Ministerio de Planificación Nacional y Política Económica	21-March-2021
Laura Lizano	minae Ministerio de Ambiente y Energía	23-March-2021
Alejandro Zuñiga Luna	ice	25-March-2021

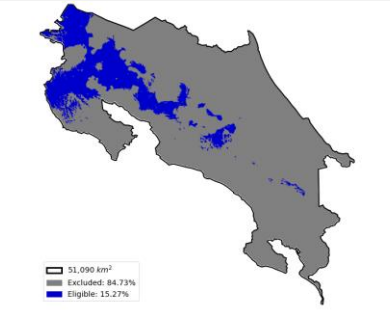
Costa Rican hydrogen production potential

Methodology

1 Assessment definition

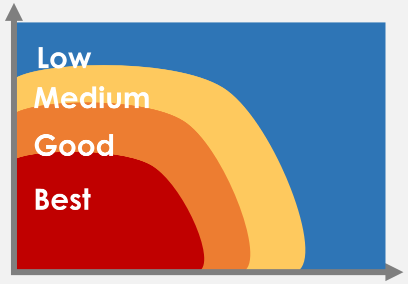
- Costa Rican territory
- Onshore wind, solar PV, and Green H_2

2 Geospatial Analysis



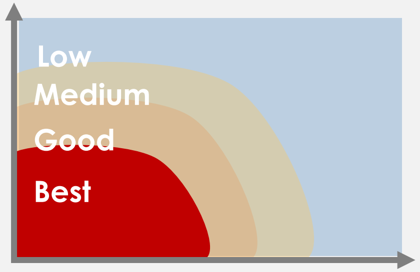
- Total land available for the installation of solar PV or on-shore wind power plants.
- +50 constrains on land eligibility: natural protected areas, distance to highways, human settlements, etc.

3 Potential assessment



- Installable capacity [MW]
- Generation potential [GWh/year]
- Capacity factors for each technology [%]
- Levelized cost of electricity [USD/kWh]

4 H_2 cost-minimization



- Usable renewable energy capacity [MW]
- Solar PV: best 10 statistical percentiles
- Wind power: best 10 statistical percentiles under 60% of capacity factor
- Levelized cost of hydrogen [USD/kg H_2]

Levelized Cost of Hydrogen

Inputs for LCOH calculation

	Solar PV		On-shore Wind		Hydropower		Electrolysis characteristics****					
	LCOE [USD/MWh] *	Electrolyzer load factor [%]**	LCOE [USD/MWh] *	Electrolyzer load factor [%]**	LCOE [USD/MWh] ***	Electrolyzer load factor [%]**	Electrolyzer efficiency [kWh/kg H2]	Electrolyzer Size [MW]	Electrolyzer technology	Electrolyzer CAPEX [USD/kW]	Stack Lifetime [Hours]	Water consumpti on [L/kgH2]
2021	47.78	26.62%	31.91	60.47%	90	53%	55	10	PEM	1090	40,000	16
2030	23.89	26.62%	21.65	60.47%	90	53%	51	10	PEM	650	70,000	13
2040	19.91	26.62%	19.37	60.47%	90	53%	49	10	PEM	450	85,000	12
2050	15.93	26.62%	17.09	60.47%	90	53%	48	10	PEM	300	90,000	11

* LCOE for solar PV and the on-shore wind was calculated by Hinicio
** A 1.25X ratio between Powerplant capacity / Electrolyzer capacity were considered for the three technologies
*** LCOE obtained from Renewable Power Generation Costs 2019 – IRENA for Central America and the Caribbean region.
**** Electrolysis parameters are a compilation made by Hinicio based on information from IEA, the US Department of Energy, and OEMs public forecasts for the technology development

Potential green hydrogen adoption by sector

Findings and assumptions for the studied hydrogen uses,

Sectors	Sub-sectors	Findings	Assumptions
Industrial use	Refining	• Costa Rica does not have refineries. Plans by RECOPE to build a refinery of 65,000 bpd did not materialize. [1]	• Considering Costa Rica's decarbonization plans: we assume that there will be no refineries in the country.
	Ammonia	• Costa Rica imports approximately 1000 ton of ammonia per year[2]	• Ammonia demand growth will follow the historic trend (2015-2020). • Costa Rica aims for self sufficiency in ammonia production by 2030
	Hydrogenated food fats	• The largest production of hydrogenatable oils in Costa Rica is palm oil (295,800 ton/year)[3]	• Palm oil production will grow following historic trends. • Costa Rica aims to hydrogenate all palm oil produced at home (maximum theoretical potential)
	Glass production	• Grupo Vical produces 430 tons of glass per day in Costa Rica. Of this volume of glass, 1.5 million bottles for beverages are produced.[4]	• We assume that the bottles produced are 12 oz. • By mass difference with respect to the volume of glass processed daily: we estimate that Vical could produce up to 142 tons / day of flat glass
	Mineral ore reduction	• No reducible mineral ore production was identified in Costa Rica (focus on iron and copper)	• No reduction of mineral ores in Costa Rica.
Transport	Light Duty Segments	• Passenger vehicles: up to 5% share of FCEV by 2050 • Public passenger vehicles (taxis): 12% share of FCEV by 2050	• Hinicio's fuel cell vehicles adoption estimates from the 2020 study "Estudios Técnico – Económicos – Financieros para la creación de condiciones habilitadoras del Ecosistema del Hidrógeno en Aplicaciones de Movilidad Eléctrica" [5]
	Heavy Duty Segments	• Buses: up to 25% penetration by 2050 • Freight trucks: up to 31% penetration by 2050	
Heat for industry	Industrial Sectors	• 42,232 TJ of energy consumption by the industrial sector in Costa Rica [6]	• Fossil fuel of main interest for replacement with hydrogen: liquefied petroleum gas (LPG).
Energy Storage	Variable Renewable Energy Storage	• ICE's forecast for variable renewable energy adoption of 805 MW (Solar PV + Wind) by 2034.[7]	• Hydropower and geothermal sources will be enough a buffer for the VRES in Costa Rica until 2050.

[1]:, ENER-Data world refinery data base 2020
[2]: tradeconomy.com – Costa Rica Imports (March 2021)
[3]: Informe Monitoreo: Estado de la Palma Aceitera 2018_2020. (COnARE, 2020)
[4]: https://grupovical.com/vidrieras/vicesa-planta-en-costa-rica/
[5]:, https://h2lac.org/portfolio-items/creacion-de-condiciones-del-ecosistema-del-hidrogeno-en-aplicaciones-de-movilidad-electrica-en-costa-rica/
[6]: https://sepse.go.cr/ciena/balances-energeticos/
[7]: Plan de Expansión de la Generación Eléctrica 2018 – 2034 (ICE, 2018)

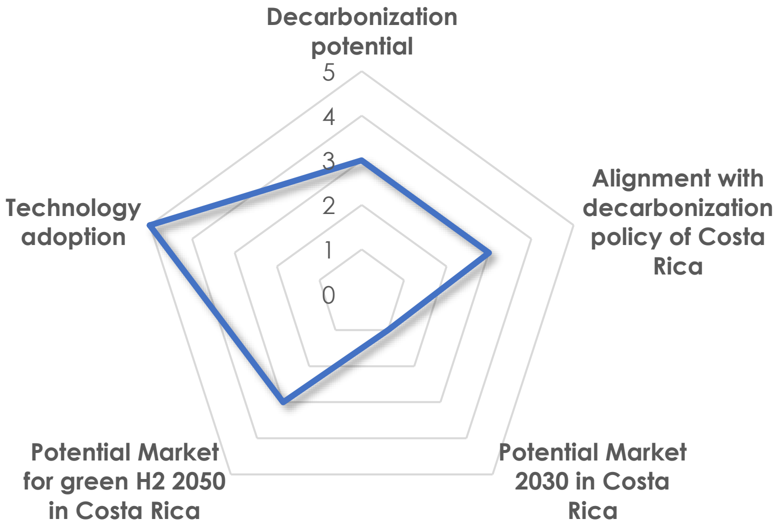
Annex 2 – Sectorial hydrogen adoption evaluation

Sectorial evaluation for the use of green H_2 in CR

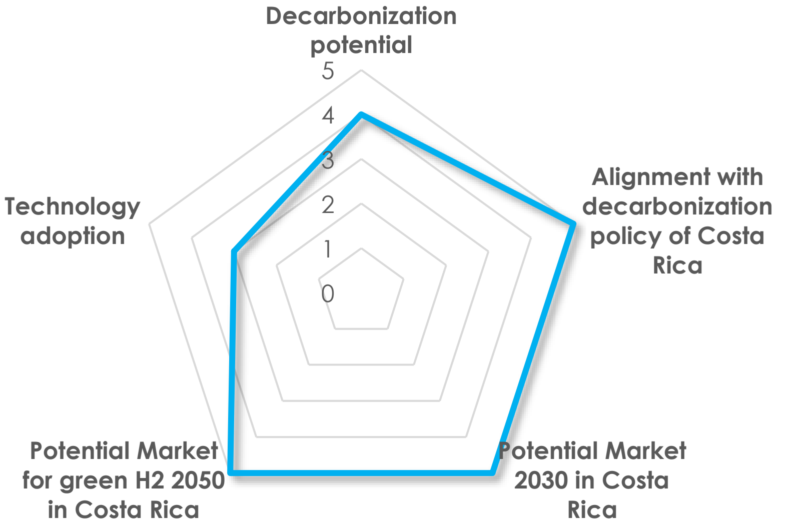
	Weighing	1	2	3	4	5
Decarbonization potential	35.0%	Potential to decarbonize between 1 - 4 kg CO2/kg H2 used	Potential to decarbonize between 5 - 8 kg CO2/kg H2 used	Potential to decarbonize between 9 - 12 kg CO2/kg H2 used	Potential to decarbonize between 13 - 16 kg CO2/kg H2 used	Potential to decarbonize between 17 - 20 kg CO2/kg H2 used
Alignment with decarbonization policy of Costa Rica	30.0%	Segment indirectly impacts some of the 10 axes of the Decarbonization Plan.	Segment is explicit as one of the 10 axes of the Decarbonization Plan. Hydrogen has a technology that indirectly contributes to meeting the goals	Segment is explicit as one of the 10 axes of the Decarbonization Plan. Hydrogen has a technology that contributes directly to meeting the goal with an impact of less than 10% of the 2050 goals	Segment is explicit as one of the 10 axes of the Decarbonization Plan. Hydrogen has a technology that contributes directly to meeting the goal with an impact of 10 to 20% of the 2050 goals	Segment is explicit as one of the 10 axes of the Decarbonization Plan. Hydrogen has a technology that contributes directly to meeting the goal with an impact of more than 20% of the 2050 goals
Potential Market for green H2 2030 in Costa Rica	20.0%	Annual market below 1 kton green H2/year in 2030	Annual market between 1 - 5 kton green H2/year in 2030	Annual market between 5 -10 kton green H2/year in 2030	Annual market between 10 - 15 kton green H2/year in 2030	Annual market greater than 15 kton green H2/year in 2030
Potential Market for green H2 2050 in Costa Rica	15.0%	Annual market below 10 kton green H2/year in 2050	Annual market between 10 - 100 kton green H2/year in 2050	Annual market between 100 - 200 kton green H2/year in 2050	Annual market between 200 - 300 kton green H2/year in 2050	Annual market greater than 300 kton green H2/year in 2050
Technology maturity as of 2021	10.0%	The technology is under development with a TRL 7 or higher with expected market arrival in more than 5 years	The technology is under development with a TRL 7 or higher with an expected market arrival in less than 5 years	The technology is in early stages of use in real working conditions (Pilot or demonstration projects)	The technology has been used in real working conditions for more than 5 years	The technology has been used in real working conditions for more than 10 years

Potential H_2 use for: Industrial Use

Industrial Use			
Scope: Use of green hydrogen as: - Replacement of gray hydrogen in applications such as ammonia production, production of food fats and float glass. - Hydrogen as a feedstock			
Criteria	**Score**	**Argument**	**Source**
Decarbonization potential	3	Average SMR produces 9.26 kg CO2/kg H2	- https://greet.es.anl.gov/publication-smr_h2_2019
Alignment with decarbonization policy of Costa Rica	3	Strategic Axis 6: Industrial sector modernization. Strategic Axis 8: Low carbon food technology Hydrogen is one of lots of technologies that would contribute for those strategic axis	- Plan Nacional de Descarbonización Costa Rica - Hinicio Desk Research
Potential Market 2030 in Costa Rica	1	Potential market 2030: 0.73 kton/year	- Hinicio estimate
Potential Market for green H2 2050 in Costa Rica	3	Potential market 2050: 0.85 kton/year	- Hinicio estimate
Technology adoption	5	Hydrogen has been used as a feedstock for decades, primarily by the chemical and refining industries	- https://wha-international.com/hydrogen-in-industry/
Weighted Rating: 3.1/5			



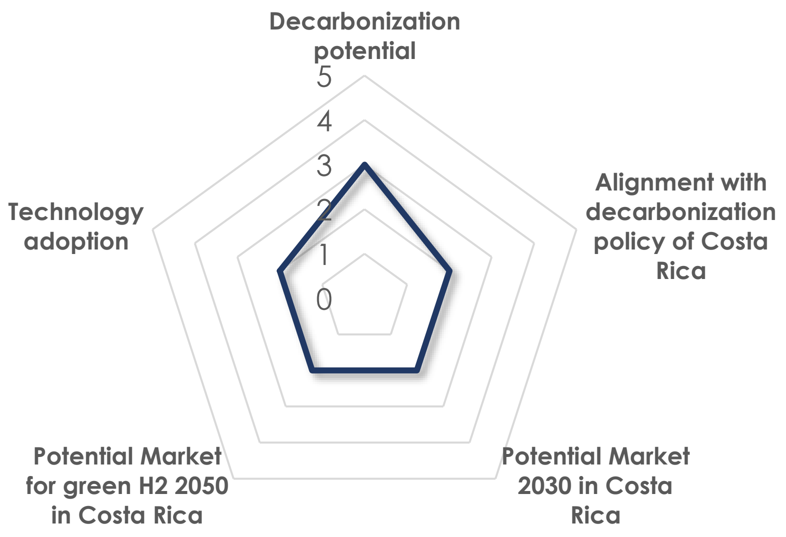
Potential H_2 use for: Transportation



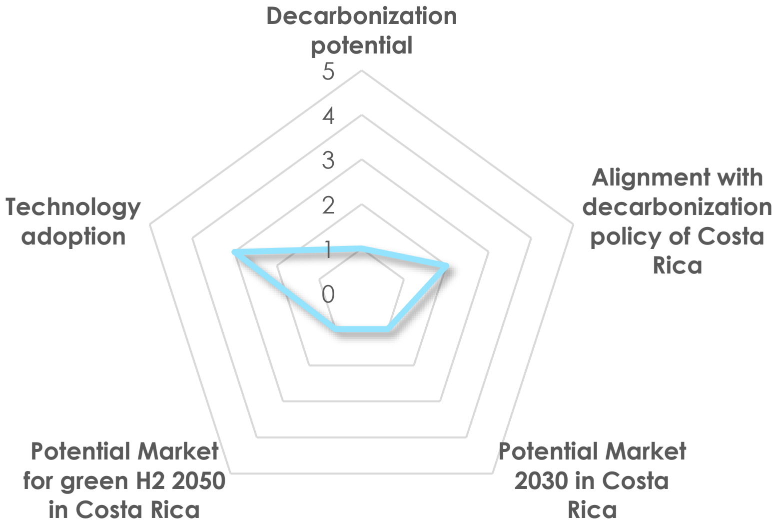
Transport			
Scope: Use of green hydrogen in Fuel Cell Vehicles in 6 diferent segments: a) passenger vehicles (private), b) taxis, c) mini buses, d) buses, e) light duty vehicles, f) heavy duty vehicles			
Criteria	**Score**	**Argument**	**Source**
Decarbonization potential	4	Decarbonization potential for FCEV goes from 11.54 (LDV) to 19.17 (HDV) kgCO2 avoided per kg H2 used	- Hinicio calculation with FCEV and ICEV car manufacturers information
Alignment with decarbonization policy of Costa Rica	5	- FCEV would directly contribute to decarbonization goals on Strategic Axis 1, 2, and 3	- Plan Nacional de Descarbonización - Hinicio Desk Research
Potential Market 2030 in Costa Rica	5	Potential Market 2030: 18.9 kton H2	- Hinicio estimation based on Alianza H2 H2 mobility study 2020
Potential Market for green H2 2050 in Costa Rica	5	Potential Market 2050: 334 kton H2	- Hinicio estimation based on Alianza H2 H2 mobility study 2021
Technology adoption	3	- Passenger vehicles and buses have been on the road for more than 5 years, however, the light and heavy-duty vehicles are still in early commercialization steps	- Hinicio desk research
Weighted Rating: 4.95/5			

Potential H_2 use for: Industrial Heat

Heat for industry			
Scope: Hydrogen as a replacement for fossil fuels in thermal industrial applications. Focus on the replacement of liquefied petroleum gas (LPG)			
Criteria	**Score**	**Argument**	**Source**
Decarbonization potential	3	Decarbonization potential for hydrogen heating goes from 8.8 to 12.8 kgCO2 avoided per kg H2 used, depending on the industrial subsector	- Hinicio estimation with information from SEPSE - Energy Balance Costa Rica
Alignment with decarbonization policy of Costa Rica	2	The Decarbonization Plan only speaks of the modernization of the industry and the use of less polluting sources in 2050. No numerical goals are presented and the industrial hydrogen heat will be one more option among many to fulfill the strategic axis 6	- Plan Nacional de Descarbonización - Hinicio Desk Research
Potential Market 2030 in Costa Rica	2	Potential Market 2030: 3 kton/y	- Hinicio estimation
Potential Market for green H2 2050 in Costa Rica	2	Potential Market 2050: 3 kton/y	- Hinicio estimation
Technology adoption	2	Hydrogen combustion technology is still under development and only some sites with hydrogen as a by-product consume low volumes for thermal applications.	- https://global.toyota/en/newsroom/corporate/25260001.html#:~:text=The%20burner%20will%20be%20used,hydrogen%20burners%20has%20proved%20challenging. - Hinicio desk reserach
Weighted Rating: 2.55/5			



Potential H_2 use for: Energy Storage



Energy Storage

Scope: Hydrogen as variable renewable energy storage (solar photovoltaic and wind).

Criteria	Score	Argument	Source
Decarbonization potential	1	Due to the low carbon content of Costa Rica's energy matrix, each kg of H2 would only contribute to reducing 4.15 kg of CO2	http://cglobal.imn.ac.cr/documentos/publicaciones/factoresemision/factoresemision2018/offline/download.pdf
Alignment with decarbonization policy of Costa Rica	2	Hydrogen will indirectly contribute to the decarbonisation of the Costa Rican electricity grid, however variable sources (photovoltaic - wind) will not be a priority. Hydropower and geothermal energy could buffer the intermittancy of VRES.	- Plan Nacional de Descarbonización - NREL - Hydrogen in Energy Storage, 2019 - Hinicio Desk Research
Potential Market 2030 in Costa Rica	1	Potential Market 2030: 10 - 11 ton/year H2	- Hinicio estimation
Potential Market for green H2 2050 in Costa Rica	1	Potential Market 2030: < 100 ton/year H3	- NREL - Hydrogen in Energy Storage, 2019 - Hinicio Desk Research
Technology adoption	3	Hydrogen storage for energy storage purposes and conversion to electricity is in the pilot and demonstration project stage	- Hinicio World Project Database
Weighted Rating: 1.6/5			