CHAPTER 11

Green Energy: Latin America's Next Big Natural Resources Opportunity?

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In recent years, the race to develop the capacity of green energy production has picked up pace around the world as countries have announced and implemented increasingly ambitious carbon reduction targets. Out of these clean energies, the one that promises to revolutionise the market the most – outside of renewable electricity – is probably green hydrogen.

Among the countries leading the development of projects related to green hydrogen are Australia, the Netherlands, Germany, China, Saudi Arabia, Egypt, Morocco, Brazil and Chile. The United States has just announced hundreds of billions of dollars of tax credits intended to subsidise the development of a green hydrogen industry through its 2022 Inflation Reduction Act, leading the race to enter a new phase of momentum as countries compete for capital to invest in the exciting new economic opportunity.

Potential uses of hydrogen

Demand for energy worldwide continues to increase rapidly. It is estimated that since the first decades of the 20th century, energy consumption has increased 80-fold.[2]

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2 Apostolou, D; Xydis, G. 'A literature review on hydrogen refueling stations and infrastructure, Current status and future prospectus'. *Renew. Sustain. Energy Rev.* 2019, 113, 109292. Dincer, I; Acar, C. 'Smart energy solutions with hydrogen options'. *Int. J. Hydrog. Energy* 2018, 43, 8579–8599. Farias, CBB; Barreiros, RCS; da Silva, MF; Casazza, AA; Converti, A;

Today, almost 80 per cent of the total energy supply and nearly 65 per cent of electricity production depend on fossil fuels (oil, coal and natural gas). On the other hand, climate change has made the need to reduce carbon emissions greater and more urgent than ever, and there is constant debate about how to optimise energy efficiencies while incentivising the use of these clean energies to cover the growing needs of larger industries.[3]

Among the potential applications of hydrogen are:

- refining oil, producing fertilisers, treating metals, processing foods and mining applications;
- transportation, such as fuelling aircraft, trucks, cars and vessels;
- space exploration: the National Aeronautics and Space Administration (NASA) was one of the first to use hydrogen fuel cells to power the electrical systems on spacecraft; and
- electricity generation: electricity can be used as a power plant fuel (burning hydrogen) or in fuel cells power generators by combining hydrogen and oxygen atoms.[4]

The fundamental benefits of green hydrogen are that it:

- permits the decarbonisation of applications that require molecules (particularly steelmaking, refining, chemicals manufacture and heavy transport); and
- allows for the long-distance transportation of renewable energy, which is stored in the green hydrogen molecule, capable of being shipped around the world by vessel in liquefied form or by using ammonia as a carrier molecule, and can be converted back to electricity or other forms of energy at the receiving destination.

Sarubbo, LA. 'Use of Hydrogen as Fuel: A Trend of the 21st Century'. *Energies 2022*, 15, 311. https://doi.org/10.3390/en15010311.

3 Farias, CBB; Barreiros, RCS; da Silva, MF; Casazza, AA; Converti, A; Sarubbo, LA. 'Use of Hydrogen as Fuel: A Trend of the 21st Century'. *Energies 2022*, 15, 311. https://doi.org/10.3390/en15010311. Sharma, S; Agarwal, S; Jain, A. 'Significance of Hydrogen as Economic and Environmentally Friendly Fuel'. *Energies 2021*, 14, 7389. https://doi.org/10.3390/en14217389.

4 'Green hydrogen in Latin America: A new era has started. Hydrogen in tomorrow's world: Destination or aspiration?' Nicolas Borda and Karim Alhassan (2022).

In these ways, green hydrogen provides the 'missing link' of renewable energy: a way to transport it to countries that cannot generate it by themselves, and a way to reduce greenhouse gas emissions in applications that electrons cannot address alone.

Green hydrogen in Latin America: the Chilean case

Chile has been a regional leader in its commitment to increase green energy production.[5] During 2021, renewables generation represented 26.7 per cent of Chile's total electricity generation, having an installed capacity of 11,400 MW.[6]

In November 2020, the Chilean Ministry of Energy published its National Green Hydrogen Strategy, a road map that seeks to increase Chile's energy matrix while reducing greenhouse gas emissions.

The geographical characteristics of Chile create unique opportunities for green energy production. Chile's northern territories have some of the highest solar radiation levels on the planet, facilitating the production of solar energy. Its southern regions are ideal for the generation of wind energy. Combining these natural endowments, the country is seeking to have 5 GW of electrolysis capacity under development by 2025, to produce the cheapest green hydrogen on the planet by 2030 and to be among the three main global exporters by 2040.[7]

In early 2021, the Chilean Ministry of Energy approved a guide to support applications for green hydrogen projects. There are also several working groups focused on enacting a Hydrogen Law and Hydrogen Facility Safety Regulations in Chile. These regulations would regulate the installation, design, construction, operation, maintenance, inspection and final closure of operations in Chile.

At the time of writing, there are more than 60 green hydrogen projects in Chile. A quarter of them have announced intentions to start operating and producing green hydrogen before 2030.

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5 'What the Mining Industry can learn from Chile's shift to Green Hydrogen', José Ignacio Morán and Jaime Cruzat.

6 Report by 'Chilean Association of Renewable Energy and Storage AG (ACERA)'. Renewable Energy Generation Sector. December 2021. See more in https://acera.cl/wp-content/uploads/2022/01/2021-12-Bolet%C3%ADn-Estad%C3%ADsticas-ACERA.pdf.

7 National Green Hydrogen Strategy. Ministry of Energy, Government of Chile. November 2020. See more in https://energia.gob.cl/sites/default/files/estrategia_nacional_de_hidrogeno_verde_-_chile.pdf.

Green hydrogen in the rest of Latin America

Although Chile has arguably led the way, other Latin American countries are planning on becoming major players in the global production of green hydrogen. Having significant comparative advantages over other regions of the world, Latin America has the potential to produce cheap, excess renewable energy, which in turn should help to produce green hydrogen more cheaply than competitors.[8]

In addition to Chile, Colombia, Costa Rica, Uruguay, Mexico, Argentina, Peru and Brazil aspire to be leaders in the global green hydrogen market, including as exporters to Europe and Asia. Although not all these countries have yet issued national strategies for the development of green hydrogen, they are all working on legal frameworks and policies to reach their goals, and there are several projects and partnerships underway to move their plans forward.[9]

In this regard, according to the latest study by the International Renewable Energy Agency (IRENA), Chile and Colombia are among the five countries, along with Morocco, Australia and Mexico, that will be able to generate the cheapest green hydrogen in the long term.[10]

It is expected that several factors will encourage the use of hydrogen by global players, creating a demand that Latin America will be keen to satisfy. Such factors include reliability of supply, including price, the fight against climate change and the need for energy security in regions such as Europe.[11]

Hydrogen applied in mining

Given the importance of mining in Latin America, decarbonisation of this sector will be essential to the reduction in carbon emissions across regional economies.[12]

Several applications have been found by the mining industry for green hydrogen, including the manufacturing of low-emission explosives, the moving of ore by high tonnage trucks and subway mining, metallurgical processes, backup

8 'Green hydrogen in Latin America: A new era has started. Hydrogen in tomorrow's world: Destination or aspiration?' Nicolas Borda and Karim Alhassan (2022).

9 The US company MMEX Resources Corporation, through a technology agreement with Siemens Energy, will invest US$500 million to produce green hydrogen in Tierra del Fuego with the aim of generating between 120 and 190 million exports per year from its entry into operation in 2025.

10 IRENA (2022), *Global hydrogen trade to meet the 1.5°C climate goal: Part III – Green Hydrogen Cost and Potential*, International Renewable Energy Agency, Abu Dhabi.

11 'Green hydrogen in Latin America: A new era has started. Hydrogen in tomorrow's world: Destination or aspiration?' Nicolas Borda and Karim Alhassan (2022).

12 'What the Mining Industry can learn from Chile's shift to Green Hydrogen', José Ignacio Morán and Jaime Cruzat.

power generation, the transportation of personnel and supplies to the mine, and the sustainable export of ore.[13] None of these can be completely achieved with renewable electricity alone.

A number of factors that have made the industry's growth increasingly challenging have driven changes in the Latin American mining industry. The mining sector has an increasing impact on the environment, and the industry faces a threat related to climate change and land transformation. The decrease in ore grades, changes in environmental conditions, the significant decrease in productivity and the increase in costs are some of the challenges that are affecting the mining countries in Latin America.[14]

In the case of Peru, Brazil, Chile and Argentina, where the mining industry is a fundamental pillar of their economies, the use of clean energy can result in a considerable reduction of CO_2 as well as potential cost reductions.

Mining in Chile and Peru represents around 12 per cent and 14 per cent of gross domestic product (GDP) respectively, and 60 per cent of the exports from Chile.[15]

As an example of the development of applications of hydrogen in mining countries of Latin America, in August 2021, a hydrogen station generated the first molecule of green hydrogen for powering mining vehicles in Santiago. The station specifically dispenses fuel powering a forklift used at a mine site.

However, the most advantageous implementation of hydrogen relates to the powering of mining trucks, used both in underground and open pit mines, with fuel cells or dual combustion, resulting in reduced CO_2 emissions. For example, a well-known British mining company managed to power a mining truck with green hydrogen, with the truck's engine powering 2 MW of energy (enough to supply approximately 1,000 homes) and containing eight parallel fuel cells and seven large lithium batteries. The engine is expected to be used to power a mining truck at an open-pit platinum mine in South Africa.[16]

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13 Report of Chilean Green Hydrogen Association (H2 Chile, November 2021). https://h2chile.cl/wp-content/uploads/2021/11/20211118_H2V_Mineria-4-1.pdf.

14 'Productive Development Policies in the Mining Value Chain: Policy Opportunity and Alignment'. Prepared for the Inter-American Development Bank by Guendalina Anzoli, December 2021.

15 Information obtained from the Chilean Copper Commission (COCHILCO) database. 'Gross Domestic Product (GDP) by class of economic activity and sectoral participation.' 'Annual Foreign Trade Report', prepared by the Research Department of the National Customs Service of Chile (2021).

16 Global Hydrogen Review 2021, International Energy Agency (IEA).

These technological developments are expected to be implemented on a large scale during this decade, with strong government incentives to promote investment and innovation in mining.

Legal and regulatory challenges and opportunities[17]

Hydrogen development in any country also comes with its fair share of complications and obstacles, which may include:

- Development of government regulations and legal certainty: as mentioned above, Latin American countries are slowly establishing regulatory frameworks for hydrogen with the aim of developing road maps and regulate the entire hydrogen value chain: production, conditioning, storage, transportation, distribution and consumption.
- The construction and development of adequate infrastructure and technical safety for hydrogen handling: this includes either altering existing infrastructure or building new infrastructure altogether to develop each stage of the value chain, from production to consumption. Hydrogen is difficult to store and transport, which is different from other energies such as electricity or batteries, representing a major challenge.[18]

For example, in Chile some studies have shown that, depending on the tolerance of the pipeline, up to 20 per cent of hydrogen can be injected into existing natural gas networks.[19] One project, H2GN, currently in the design stage in Chile, will incorporate hydrogen into the country's gas networks.[20]

The use of water in electrolysis for the generation of green hydrogen presents other challenges. For example, it is estimated that between nine and 12 litres of water are needed to generate 1 kilogram of hydrogen. This consumption may

17 'What the Mining Industry can learn from Chile's shift to Green Hydrogen', José Ignacio Morán and Jaime Cruzat.

18 IRENA (2022), *Global hydrogen trade to meet the 1.5°C climate goal: Part III – Green Hydrogen Cost and Potential*, International Renewable Energy Agency, Abu Dhabi.

19 Study, 'Hydrogen injection in natural gas networks'. Publication prepared on behalf of the Project 'Decarbonization of the Energy Sector in Chile' implemented by the Ministry of Energy of Chile and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in the framework of the intergovernmental cooperation between Chile and Germany. Santiago de Chile, 3 August 2021.

20 See more at: https://www.gasvalpo.cl/noticiavisor.aspx?4,Pionero_en_Am%C3%A9rica_Latina:__ANUNCIAN_PRIMER_PROYECTO_DE_CHILE_QUE_INYECTAR%C3%81_HIDR%C3%93GENO_VERDE_EN_REDES_DE_GAS_.

increase due to the amount of demineralised water required for the process.[21] However, over the past decade, Peru and Chile have suffered considerable droughts, which has prompted the development of seawater desalination plants linked to mining projects. Eight desalination plants are currently in operation in Chile, and there are 15 new initiatives, which should be completed in the next few years. It is projected that by 2031, 47 per cent of the water to be used in mining will come from seawater.[22]

The development of an appropriate market to commercialise hydrogen at a competitive price: in Latin America, developing a regulatory framework for hydrogen production requires active and effective commercial relations and cooperation agreements, in order to ensure the correct balance between supply and demand.

Last year, the Economic Commission for Latin America and the Caribbean (ECLAC), the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the Euroclima+ Program, the World Bank and the Alliance for Green Hydrogen in LatAm launched 'H2LAC', a collaborative platform that seeks to promote the development of green hydrogen in Latin America and the Caribbean, bringing together representatives from more than 19 countries.

Additionally, international agreements are being signed to support the evolution of a hydrogen market. Chile has signed several commercial agreements, such as the 'Energy Partnership Chile-Germany', as well as memorandums of understanding with European ports (Rotterdam, Antwerp and Zeebrugge) and with Asian countries (Singapore and South Korea).

Compared with other regions, which only have the potential to produce grey or blue hydrogen (in the former case, a very high-carbon form of energy, and in the latter a lower carbon form that some say may be fundamentally challenged from a carbon reduction technology perspective), some countries in Latin America hold significant advantages as potential producers of green hydrogen, given their availability of renewable energies, which should allow them to offer competitive prices. Studies indicate that the cost of hydrogen could be US$2.50 per kilogram at the beginning of this decade and could reach US$1.20 per kilogram in 2030.[23]

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21 'Wells to wheels: water consumption for transportation fuels in the United States'. Energy & Environmental Science. David J Lampert, Hao Cai and Amgad Elgowainy.

22 'Projection of water consumption in copper mining 2020-2031'. Directorate of Studies and Public Policies. Chilean Copper Commission (COCHILCO).

23 'Path to hydrogen competitiveness. A cost perspective.' Hydrogen Council. (2020).

Opportunities for export of green hydrogen from Latin America

Although the international green hydrogen market is currently non-existent, it is expected that it will grow into a dynamic market over time. The global green hydrogen market is expected to grow at a compound annual rate of 39.5 per cent between 2022 and 2030, reaching US$60.56 billion by 2030.[24]

According to data from the Observatory of Economic Complexity, in 2020, grey hydrogen was the world's 327th most traded product, with a total trade value of US$9.3 billion. The top exporters in 2020 were China (US$1.44 billion), the United States (US$1.41 billion), Germany (US$1.01 billion), Qatar (US$615 million) and Norway (US$472 million). On the other hand, in 2020, the top importers of hydrogen were China (US$1.41 billion), Japan (US$1.12 billion), Germany (US$975 million), South Korea (US$639 million) and the United States (US$549 million). [25]

Current status of the hydrogen market in Latin America

Argentina, Brazil, Chile, Colombia and Mexico are the largest economies in Latin America, and they are responsible, along with Trinidad and Tobago, for almost 90 per cent of the demand for hydrogen in the region. Trinidad and Tobago alone represents 40 per cent of total hydrogen demand in Latin America for use in the chemical industry, producing large quantities of ammonia, methanol and urea for export.[26,27]

In Brazil, refined oil accounts for 80 per cent of local energy demand, while in Mexico this figure is 60 per cent. In Argentina, hydrogen is used for three industrial uses (oil refining, ammonia and methanol production, and direct iron reduction for steel production). Finally, Chile and Colombia together account for about 10 per cent of Latin America's total hydrogen demand.[28]

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24 Green Hydrogen Market Size, Share & Trends Analysis Report By Technology (PEM Electrolyzer, Alkaline Electrolyzer), By Application (Power Generation, Transportation), By Distribution Channel, By Region, And Segment Forecasts, 2022–2030.

25 https://oec.world/en/profile/hs/hydrogen.

26 'Green hydrogen in Latin America: A new era has started. Hydrogen in tomorrow's world: Destination or aspiration?' Nicolas Borda and Karim Alhassan (2022).

27 International Energy Agency (IEA): Hydrogen in Latin America From near-term opportunities to large-scale deployment (2021).

28 'Green hydrogen in Latin America: A new era has started. Hydrogen in tomorrow's world: Destination or aspiration?' Nicolas Borda and Karim Alhassan (2022).

Total hydrogen demand in Latin America was 4.1 million tonnes of hydrogen in 2019 and 90 million tonnes of hydrogen in 2020. As hydrogen has not been traded internationally within Latin America, demand is estimated to be equal to supply in all countries.[29]

To date, hydrogen production has almost exclusively been obtained from fossil fuels without storage of the resulting CO_2 emissions. The main feedstock to obtain hydrogen is natural gas, which in 2019 was used to produce 91 per cent of the total production of hydrogen. It is estimated that this use of natural gas without carbon capture, utilisation and storage (CCUS) caused at least 32.5 million tonnes of CO_2 emissions in 2019, more than the total emissions from transport in Chile.[30]

Water electrolysis, which is the means by which green hydrogen is produced, represented only 0.2 per cent of total hydrogen produced in 2019.[31]

Projections of the hydrogen demand in Latin America

In addition to decarbonising local industries, demand for Latin American low-carbon hydrogen will come from international markets outside Latin America (mainly Europe and Asia). To this end, the region should work together to develop competitive low-carbon hydrogen production to supply domestic demand in the first phase and implement internationally recognised certification processes capable of increasing low-carbon hydrogen production.[32]

However, Latin America is not the only region in the world with the potential to develop this fuel, as it could be produced at low cost in remote desert areas such as the Middle East and North Africa, which are closer than Latin America to European and Asian markets.[33]

In this regard, there are studies that support that the pipeline projects announced in northwest Europe may not to be enough to meet the expected hydrogen demand for 2030, which will result in the need to import 10 million

29 International Energy Agency (IEA): Hydrogen in Latin America From near-term opportunities to large-scale deployment (2021).

30 ibid.

31 International Energy Agency (IEA): Hydrogen in Latin America From near-term opportunities to large-scale deployment (2021).

32 ibid.

33 Farias, CBB; Barreiros, RCS; da Silva, MF; Casazza, AA; Converti, A; Sarubbo, LA. 'Use of Hydrogen as Fuel: A Trend of the 21st Century'. Energies 2022, 15, 311. https://doi.org/10.3390/en15010311.

tonnes of hydrogen a year by 2030.[34] On the other hand, Japan's 'Hydrogen Roadmap' estimates that the country will need about 300,000 tonnes of hydrogen imports per year by 2030. [35]

Given its renewable resources, Latin America could become a global hydrogen producer by 2050. Although several parts of the region may offer competitive prices by then, the cheapest production costs could be located in southern Patagonia (Argentina and Chile) and in the Atacama region (Argentina, Chile, Bolivia and Peru), as well as in northwestern Mexico and northeastern Brazil. In terms of area, it is estimated that Latin America could have more than 800,000 km^2 in which the levelised cost of hydrogen by electrolysis is less than US$1/kg using a hybrid energy supply. Then, the challenge will be to increase the supply infrastructure needed to increase production of hydrogen, given the remoteness of Latin America production areas from the current centres of demand.[36]

Conclusions

Green energy sources are essential for the reduction of the global economy's carbon footprint and green hydrogen is a critical part of achieving this goal.

Latin America has the opportunity to play a lead role, having excellent conditions for green hydrogen production, alongside other areas of the planet that will compete.

While the case of Chile has been emblematic, becoming a pioneer and leader in the area, Latin American countries such as Colombia, Costa Rica, Uruguay, Mexico, Argentina, Peru and Brazil can make an important difference in this market.

Hydrogen applications are varied and given the importance of mining in Latin America, the application of hydrogen is essential in its various processes, and the decarbonisation of this sector is low-hanging fruit for the emerging green hydrogen economy.

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34 International Energy Agency (IEA): Hydrogen in North-Western Europe: A vision towards 2030 (2021).

35 International Energy Agency (IEA): Hydrogen in Latin America: From near-term opportunities to large-scale deployment (2021).

36 International Energy Agency (IEA): Hydrogen in Latin America From near-term opportunities to large-scale deployment (2021).

Projections regarding the supply and demand of this fuel point to the fact that, with adequate regulation and incentives, its production cost will be increasingly lower, allowing some Latin American countries to cover the demand not only of the entire region, but also of all those countries where production does not meet the demand, such as Europe and Asia.

This, however, should not be taken for granted, since the green hydrogen race presents several challenges such as regulation, the need for adequate infrastructure, efficient use of water, technological innovation and human capital, among others. This is why the coming decades will test Latin America's ability and willingness to overcome all these obstacles and – eventually – become the main source of green hydrogen in the world.