Midwest Regional Hydrogen Economy Global Benchmarking

5.5.2022

AEG Chicago 21Q4 Hydrogen Hub Task Force

Milestone 2

Contributions by the following task force members: Ben Campbell, H.G. Chissell, Kyle Dolan, Jon Horek, Peter Kelly, Ted Krause, Antonio Krulas, Jessica Lang, Luis Montgomery, James O'Brien, Maya Rao, Megan Rhoades

AEG CHICAGO

Table of Contents

Section 1: Introduction

Section 2: Midwestern Hydrogen Economy Background

Section 3: The Americas

Section 4: Europe

Section 5: MENA

Section 6: Sub-Saharan Africa

Section 7: Asia

Section 8: Oceania

Section 9: Analysis and Recommendations

Section 10: Conclusion

Section 1: Introduction

Background

In December 2021, the Chicago chapter of Advanced Energy Group (AEG) convened a 1-year regional clean hydrogen economy task force to provide useful content for interested stakeholders. In March 2022, this task force issued its first deliverable, a white paper collecting relevant information that demonstrates the potential for a clean hydrogen supply chain ("Hydrogen Hub") centered in Chicago but extending hundreds of miles into all surrounding Midwestern states. The first white paper noted the locations of existing assets, projects currently under development, and policy discussions underway. In short, the previous paper consolidates multiple sources of information into a single document and provides baseline understanding of the key considerations.

Purpose of Current White Paper

The Hydrogen Council, a global initiative of 130+ energy, transport, industrial, and investment CEO's, has stated that the full global potential of hydrogen requires a direct investment of $700 billion USD by 2030. As of November 2021, $160 billion USD had been announced globally.[1] Bridging this gap will require both a clear regulatory framework and financial incentives to support scaleup in the early stages of the clean hydrogen sector. Regulations and incentives will undoubtedly vary by country, and will likely differ by specific regions, states, and cities.

The purpose of this current white paper is to benchmark a Chicago-centric hydrogen hub against other emerging US and international hydrogen hubs. This current paper intends to review, compare, and contrast best practices, innovations, and philosophies underpinning the projects and policies within the world's emerging hydrogen economies. Extensive work is underway throughout the entire world, with a wide variety of examples from which to draw. Our efforts will serve to inform local lawmakers and investors as they develop coordinated plans that can close these regulatory and funding gaps within Chicago, Illinois, and the broader Midwest.

Overview of Advanced Energy Group

Founded in 2016, Advanced Energy Group (AEG) works with leaders in Boston, Chicago, Washington D.C., New York, and the Caribbean to deliver systemic change on energy, equity and resilience. AEG works with multiple city governments, utilities, regulators, national energy labs and over 50 sponsoring organizations to overcome critical obstacles preventing systemic change on energy and equity impacting over 50 million people.

[1] https://hydrogencouncil.com/wp-content/uploads/2021/11/Hydrogen-Council_Policy-Toolbox.pdf

Working on a quarterly meeting schedule, AEG provides guided collaboration for leaders and organizations to make progress toward local decarbonization and resiliency goals. The outcome of each quarter is a volunteer task force dedicated to achieving quarterly milestones on the path toward a 1-year goal. This hydrogen economy task force was formed during the 2021Q4 Stakeholder dinner. AEG's framework has proven to be a successful way to address problems that are broader than any single stakeholder.

Geographic Focus of White Paper

Although national policy and funding initiatives are working to accelerate hubs across the world, this paper primarily intends to review the ways in which local decision-makers are developing hydrogen hubs. For historical and geographic reasons, certain regions such as Houston are capable of building the entire local supply chain, including a large local demand. Other regions such as Namibia are expected to have relatively low hydrogen consumption rates but will have large-scale production, leading to plans for clean hydrogen export in the form of hydrogen or ammonia. Finally, certain regions, such as those found within Japan, have very limited production capacity but have plans to consume large quantities of hydrogen. These will be heavily import-based hydrogen economies. Please note that this paper covers only a subset of current plans and projects. Additional efforts are ongoing throughout the world and can be reviewed through multiple current publications. There is activity on every continent.

Multiple potential hydrogen producers and offtakers exist within an approximately 350 mile radius around the Chicagoland area. Centered within greater Chicagoland and heavily industrial Northwest Indiana, this paper will also review various considerations throughout the rest of Illinois as well as portions of Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin. This is the Great Lakes region, with extensions more broadly into portions of adjacent Midwestern states that share common borders and interests with Illinois. These states operate largely within the MISO and PJM ISO territories.

This broader Great Lakes region of the Midwest is a true regional economy for large-scale production and consumption. Production is available from multiple feedstocks and power sources including nuclear. Large-scale underground hydrogen storage potential is available. Finally, heavy industry and heavy multimodal transport offtakers converge within the region. In short, this paper will review examples from all varieties of local hydrogen economies to determine whether the Midwest can incorporate any strategies, best practices, and lessons learned.

Section 2: Midwestern Hydrogen Economy Background

This section summarizes key findings from the previous white paper in order to provide a baseline understanding for comparison with other emerging and established regional hydrogen economies.

Clean hydrogen production opportunities

As noted in Figure 1 below, the Chicagoland area and surrounding states currently produce hydrogen primarily through Steam Methane Reforming (SMR) or as ammonia at a handful of sites. This capacity provides an existing baseline industrial market upon which to increase production capacity.

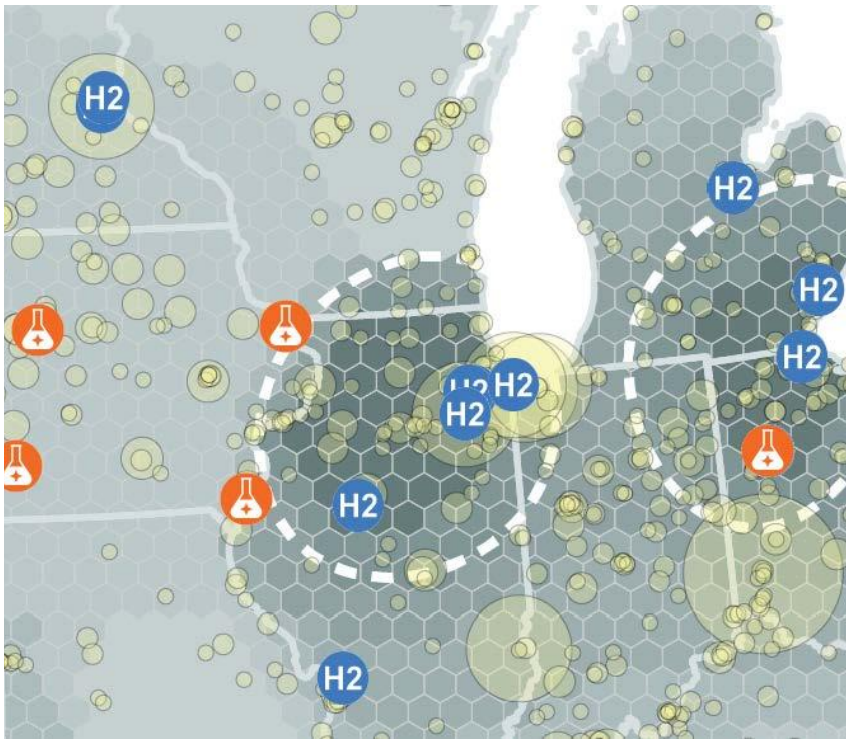

Figure 1 - Existing Hydrogen and Ammonia Production Facilities Within the Region[2]

One of the region's strengths is its diversity of production options:

- **Existing fossil facilities** as mapped above may have the option to add carbon capture and provide CO_2 for usage or sequestration (CCUS), providing "blue hydrogen," or "blue ammonia." As one of the world's leading agricultural regions, there is also high potential for development of renewable natural gas (RNG) projects that can replace natural gas supply to produce hydrogen from existing SMR's.

2 https://betterenergy.org/blog/gpi-carbon-and-hydrogen-hubs-atlas/

- **Renewables capacity** is increasing throughout the region, with wind and solar generation capacity increasing to 37 GW in 2021, the majority being solar+storage. In 2021, the Midwest Independent System Operator (MISO) announced a record 500 new interconnection queue applications, representing 77 GW of new projects, of which 56 GW were new solar and storage projects. For PJM, a record 1,223 new queue positions were filed in 2021, 100 times greater than the 123 applications filed in the 2017/2018 AD queue cycle.
- **Illinois's nuclear production capacity** is one unique advantage of the Great Lakes region. There are eleven nuclear reactors operating at six sites - Dresden, Clinton, LaSalle, Quad Cities, Braidwood, and Byron, all owned by Constellation (formerly Exelon), with a combined nameplate generating capacity of 11,500 MW. In 2020, Illinois nuclear power plants generated more than 100.2 TW-hr of electricity, 12.6% of the U.S. total nuclear electricity generated, which accounted for 58% of Illinois's in-state electricity generation.

Distribution and storage opportunities

Large-scale land-based hydrogen distribution will require use of an appropriate pipeline network. Beyond certain capacities and distances, truck delivery becomes uneconomical. Alternately, electric power purchase agreements to point-of-use electrolysis may become constrained by the regional electric transmission system. The challenge, typical of the "chicken and egg" nature of any new market, is that a pipeline network would not be expected to develop until the clean hydrogen market of producers and consumers gains large anchor participants. With an extensive inland waterway system and large multimodal ports such as the Illinois International Port District (IIPD) and Duluth Seaway Port Authority, long-distance water transport within the US or for international export is also an option.

The regional pipelines that do exist range from limited to extensive:

- **Hydrogen** - Approximately 15 miles of dedicated hydrogen piping exists between the local SMR's and hydrogen offtakers within industrial Northwest Indiana. Although this provides an anchor to expand a larger future network, this system is relatively small. In comparison, the largest existing regional hydrogen economy within the Texas/Louisiana Gulf region contains nearly 1000 miles of dedicated hydrogen pipeline.
- **Ammonia** - The dedicated NuStar pipeline extends throughout southern Illinois, Missouri, and Iowa, connecting Midwestern ammonia production and offtake sites with the ammonia production facilities along the Texas/Louisiana Gulf Coast. A similar pipeline owned by Magellan Midstream was recently decommissioned.

- **Natural Gas** - The Chicagoland region and Illinois more broadly possesses one of the nation's crossroads for natural gas transmission. The infrastructure is available if operators choose to procure clean hydrogen for blending into their networks
- **CO_2** - Large-scale pipelines do not yet exist but two have been proposed to run from Illinois into Iowa. The Midwest Carbon Express CO_2 pipeline, proposed by Iowa-based Summit Carbon, plans to sequester CO_2 from 31 Iowa Ethanol plants and transport west to North Dakota for sequestration. The Heartland Greenway Pipeline, developed by Dallas-based Navigator CO_2 ventures would also extend westward but would reach as far east as central Illinois.The pipelines would transport carbon dioxide captured from ethanol and other industrial emitters. Establishing future tie-ins with carbon capture from ammonia and hydrogen-production sites will be an important pathway to expand regional clean hydrogen supply.

Although storage of both hydrogen CO_2 and hydrogen has potential in the region, neither has been fully developed. Archer Daniels Midland and Schlumberger have operated a pilot sequestration facility near Decatur, IL over the past three years. Central Illinois currently contains well-characterized geological formation for underground sequestration of carbon dioxide, enabling the continued use of fossil fuels for hydrogen production. Hydrogen storage is proven and characterized within Michigan salt formations, but these have not yet been developed at scale. Much like pipeline development, coordination between producers and consumers must begin to gain traction for storage developers to consider investing in the local market.

Clean hydrogen consumers

Development of a clean hydrogen market requires that clean hydrogen compete for end consumer market share. Potential consumers occupy a wide variety of markets, from current fossil-based hydrogen consumers such as ammonia and methanol manufacturing, to potential emerging markets such as heavy trucking. In all cases, clean hydrogen must compete on three fronts - achieving cost parity and advantageous operating characteristics (i.e. - shorter fueling times) both against the status quo, against an existing fossil-based "grey hydrogen" option, and finally against multiple other decarbonized options. For example, clean hydrogen fuel cell heavy trucking must compete both against existing diesel-based trucking, electric vehicle trucking, and "grey hydrogen" trucking.

The Midwest contains a wide variety of potential offtakers across the full range of potential end-use markets. Particular end-use options are key advantages of the region:

- Sustainable Aviation Fuel (SAF) to supply O'Hare and Midway Airports
- Multimodal ports and their convergence with trucking, rail, and highways

- Warehouse vehicles, especially forklifts which often operate on hydrogen
- Heavy industrial production of oil, steel, and chemicals, including ammonia

Midwestern Policy and Incentives

Illinois in particular has made policy commitments that lay the groundwork for further hydrogen projects:

- The Illinois Climate and Equitable Jobs (CEJA) passed in late 2021, with targets that provide a decarbonization roadmap. Illinois CEJA targets 40% of electricity being provided by renewable energy by 2030, 50% by 2040 and 100% from carbon-free sources by 2050.
- SB-3613 "The Hydrogen Economy Act" was introduced in January 2022 and passed both chambers in early April 2022. The act establishes a state-level task force and may provide a greater level of statewide coordination and marketing of regional plans.
- The Rebuild Illinois capital plan will invest $45 billion worth of investments, with some funded projects going towards hydrogen fuel cell demonstration transportation projects. The Illinois Downstate Assistance program has also supported hydrogen transportation projects such as the Champaign-Urbana Mass Transit District's fuel cell bus depot with 1 MW onsite hydrogen production.

Federal Policy and Incentives

Two key federal initiatives provide a backdrop for regional developments:

- The Department of Energy's "Hydrogen Hub FOA," or Funding Opportunity Announcement. DOE plans for a mid-May release of the initial phase for what will eventually become an $8B funding opportunity to seed multiple hydrogen economies across the United States. Over the past year, states, cities, and the private sector have all been positioning and planning in anticipation of the FOA release.
- The 45X hydrogen production tax credit of up to $3/kg was included in the "Build Back Better" (BBB) plan. Although the full BBB seems unlikely, it is possible that 45X may be passed through alternate means.

Even as we review specific regions of the US and elsewhere, it is important to consider federal plans. Other regions of the world are nearly always operating with national-level support, even for seemingly local initiatives.

Section 3: The Americas

Houston / The Gulf Coast (United States)

The Houston Gulf Coast region is currently home to the world's leading hydrogen system, which services the region's oil refining and petrochemical industries. Plans are underway to expand and decarbonize this system.

Major operating or announced projects

Local and global decarbonization goals are driving the region to develop a coordinated hydrogen hub expansion plan. Along the Gulf Coast, 48 hydrogen production plants produce approximately one-third of the 10 million tons of hydrogen produced annually in the U.S. There are more than 900 miles of dedicated hydrogen pipelines in the region, which is more than half of the U.S. total and nearly one-third of the global total. The eastern portion of the region's current hydrogen system overlays the Denbury carbon capture and sequestration (CCS) field, which was developed to utilize CO_2 for enhanced oil recovery (EOR). Developed salt caverns have enabled large-scale storage of hydrogen since the 1980's, the region is home to 3 of the world's 6 developed hydrogen salt storage caverns. See Figure 2 for a pictorial representation of the existing Gulf Coast regional hydrogen hub infrastructure.

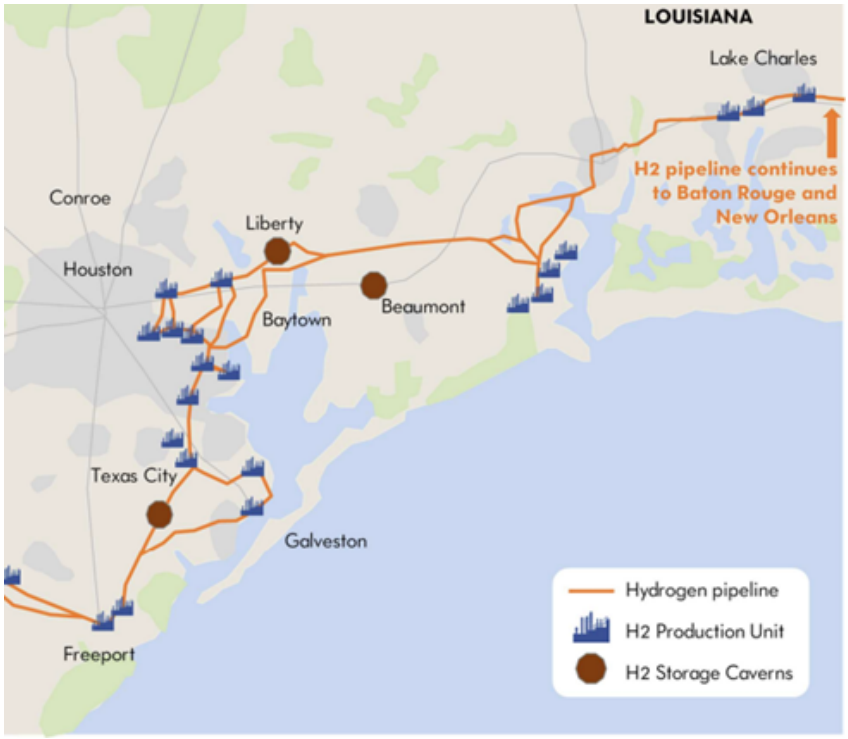

Figure 2 - Gulf Coast Existing Hydrogen Infrastructure[3]

[3] Center for Houston's Hydrogen Future - https://www.centerforhoustonsfuture.org/h2houstonhub

The Center for Houston's Future (CHF), the University of Houston, and other regional stakeholders initiated a study in 2020 to develop a vision for a Houston hydrogen economy. See Figure 3 for the general layout of Houston's vision for the Gulf Region. The study describes Houston's role not only as the center of a self-sufficient regional hydrogen hub but also as a global hydrogen export hub.

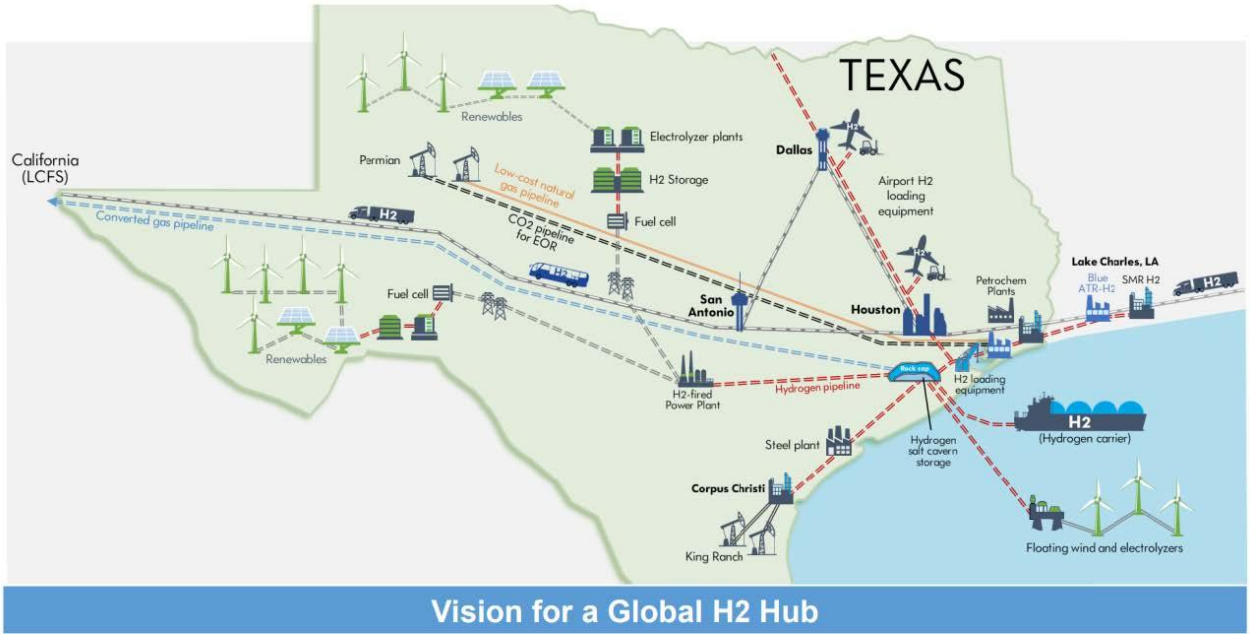

Figure 3 - Vision for Buildout of Gulf Coast Clean Hydrogen Hub[4]

The 2020 study evaluated various market opportunities for hydrogen, prioritizing the markets based on: (1) minimizing new infrastructure, (2) the competitiveness of hydrogen over existing fuels for a given market, and (3) relative emissions reductions. The study concluded that leveraging existing opportunities for grey and blue hydrogen would accelerate decarbonization efforts while allowing the value chain for green hydrogen to develop.

Four key initiatives were therefore identified to initiate development of the hub:

1. Launch a heavy-duty trucking pilot
2. Expand existing SMR plants to utilize carbon capture and connect to the existing carbon sequestration network.
3. Pilot seasonal storage of hydrogen within existing salt caverns

[4] Center for Houston's Hydrogen Future - https://www.centerforhoustonsfuture.org/h2houstonhub

4. Advance additional long-duration hydrogen storage opportunities across the Texas electrical grid.

Heavy-duty trucking was identified as the initial priority since it would require limited new infrastructure. Additionally, hydrogen fuel competes relatively strongly with diesel fuel on a cost basis. Therefore, switching heavy trucking to hydrogen fueling should be an immediate priority for the Gulf Coast region. The study notes several high concentration trucking markets as potential opportunities, including the Houston port area, the I-45 corridor connecting Houston and Dallas, and the I-10 corridor connecting Houston with San Antonio.

Houston's study views blue hydrogen as critical for capturing the full value from new emerging hydrogen markets while growing out the green hydrogen value chain. Given the region's existing SMR infrastructure, low-cost natural gas, and existing CCS infrastructure, producing blue hydrogen is significantly cheaper than green hydrogen at the present time. A phased approach is envisioned for expansion of the blue hydrogen market - first equipping existing SMR plants in the Houston area with CCS and then connecting them to the existing Denbury pipeline for CO_2 sequestration. New hydrogen plants using alternative natural gas-based technologies, such as autothermal reforming (ATR), would also be built. Additional CO_2 pipelines will be required in order to increase blue hydrogen production capacity.

As blue hydrogen capacity expands, developing the green hydrogen value chain will also take advantage of Texas's significant deployment of wind power and growing deployment of solar power. Texas is the number one wind-producing state in the country with more than 33,000 MWh of installed capacity. Wind energy currently supplies ~21% of the Texas Electrical Grid.[5] A key regional advantage is the low price of Texas wind, with 90% of generating hours producing at less than $.035/kwh. The availability of large salt caverns for storing hydrogen will further reduce prices by enabling production during periods of lowest electricity costs. Flexible salt storage is a key driver to enable a low cost clean hydrogen economy.

Mid-term opportunities would target exporting blue and green hydrogen both to domestic and international markets. For example, Houston views domestic exports to California as an early opportunity to take advantage of California's Low Carbon Fuel Standard incentive, while Germany, the Netherlands, and Japan are viewed as potential global export destinations.

[5] https://windexchange.energy.gov/states/tx

Policy and Incentive Programs

Despite regional infrastructure being owned and operated by the private sector, both government and business have jointly led the push for the region's clean hydrogen hub. The Center for Houston's Future, a public/private partnership which has coordinated regional initiatives since 1992, led the 2019 economic viability study that assessed Houston's long-term economic outlook. The study concluded that Houston's economic growth had historically outperformed peer cities, but that region's growth was falling behind that of peer cities after the 2014 decline in oil prices. The study found that oil and gas jobs lost due to the price decline were high-multiplier jobs, and that subsequent job creation had a lower multiplier factor, leading to slower economic growth.

The CHF regional study concluded that Houston could not rely on the oil and gas industry for economic growth, and that the region would require economic diversification to sustain a growth rate greater than its peer cities. A hydrogen economy was identified as one of the options that could result in new high-multiplier jobs and would leverage the region's existing infrastructure, skills, and capabilities.

The 2019 economic study led to the 2020 hydrogen hub planning study that has been described herein. The regional hydrogen hub study estimates that building out the four key pillars of a regional hydrogen hub would cost $565 million over a 10-year period, with appropriate policy changes and public funding to help defray the costs. This publicly-stated regional cost estimate is of critical importance, and regional-level planning beyond any single public or private entity is necessary to achieve the alignment required.

Los Angeles / Southern California (United States)

Southern California is home to ambitious city and statewide decarbonization goals, as well as committed regional stakeholders with large-scale potential to convert their existing fossil-based assets to hydrogen fuel.

Major operating or announced projects

Along with Houston, Los Angeles was the United States' early regional adopter of the hydrogen hub concept. The Green Hydrogen Coalition (GHC) formed as a 501(c)3 in 2019 to coordinate the region's stakeholders. GHC began working with HyDeal North America, the North American project of HyDeal Ambition, a European platform to align hydrogen economy stakeholders around the key supply chain issues - production, distribution, offtake, financing, and policy. After launching HyDeal España in Europe, HyDeal launched

HyDeal Los Angeles in order to align regional stakeholders behind a $2/kg delivered green hydrogen target within the LA basin.[6]

Coordination between the LA region's stakeholders has led to major project announcements and commitments from the "anchor institutions" and companies that can form the basis of a regional hydrogen hub:

- Although located remotely from Los Angeles, Utah's Intermountain Power Plant sends the majority of its electricity to Los Angeles. Los Angeles Department of Water and Power (LADWP) operates the plant and is currently converting the 840 MW station to run initially with a 30% hydrogen blend. The project targets 100% clean hydrogen operation by 2045 and is building a large underground salt cavern for hydrogen storage.
- LADWP plans to follow the Intermountain Project with hydrogen blend conversions of the Los Angeles regional natural gas power plants - Harbor, Haynes, Scattergood, and Valley - with potential to eventually run them all on 100% hydrogen.
- From 2022 to 2026, the Port of Los Angeles is working with Toyota Tsusho to demonstrate the use of hydrogen in forklifts, drayage trucks, and other material handling equipment to evaluate the benefit of rapid refueling times.[7]
- SoCalGas Angeles Link - The region's gas utility has committed to building a dedicated hydrogen pipeline supplying green hydrogen produced from renewables sourced in the Central Valley, Mojave Desert, and/or Blythe area near the Arizona border.[8] By connecting into the demand centers of the LADWP plants, the Ports, and other potential offtakers, a regional pipeline provides surety that a local market is under development.

Policy and incentive programs

The region has activity at the state and local level:

- State Senate Bill SB-18 defines green hydrogen, states that it is a valid option for California's clean energy goals, and directs the California PUC to include green hydrogen as an energy storage option in future energy storage directives for resource adequacy planning.
- NREL produced the LA100 study showing that LA could run on 100% "clean energy" by 2035. Hydrogen is a key part of this strategy, and LA city council approved a 100% clean energy target by 2035.
- The California Low carbon fuel standard (LCFS) provides credits for low carbon fuels, including hydrogen fuel cell vehicles.

[6] https://www.ghcoalition.org/hydeal-la
[7] https://www.toyota-tsusho.com/english/press/detail/211221_004955.html
[8] https://www.socalgas.com/sustainability/hydrogen/angeles-link

New York (United States)

The NY/NJ region is already one of the busiest ports and heavy industrial / chemical centers of the United States. The region is building on this legacy for transition to clean hydrogen.

Major operating or announced projects

Several projects have been announced regarding the clean hydrogen value chain.

- Generation:
    - Offshore wind generation in NY, with hydrogen use case for post-2027 offshore wind production following NY Bight auction in 2021
    - Significant operating onshore wind, solar generation in NYISO, with multiple GW's worth of NYSERDA PPA's ensuring sufficient onshore wind is viable in near-term
    - Hydroelectric power is prominent in the Niagara Falls area, which is being used to power the 120 MW Plug Power green hydrogen production facility.
- Electrolyzers: Plug Power located its hydrogen fuel cell component R&D and manufacturing in upstate NY.
- Hydrogen transportation: Williams, which operates 30% of natural gas pipelines in the US, is reviewing its local NY/NJ regional infrastructure for hydrogen blending.
- Off Takers: The region has multiple end users supporting hydrogen-based use case for energy and storage, including:
    - Long duration storage - hydrogen for peak shaving for National Grid on Long Island as a supplement for their battery storage projects
    - Power generation - In July 2021, NY provided $8.5m to retrofit a NYPA natural gas power plant to run on 30% green hydrogen
    - Commercial fleet applications - Plug Power is offering hydrogen fuel cells for long-haul trucks, heavy payloads, and extreme temperatures where EV's fall short

Policy and incentive programs

Policies and incentives are available and ongoing in order to provide focus:

- Ongoing efforts by state to be carbon free by 2040 with large scale procurements in offshore, onshore, wind, solar, and storage technologies via NYSERDA, NYPA, and Long Island Power Authority (LIPA)
- March 2022 NY State announced coordination between CT, MA, NJ + interstate agencies (NYSERDA, NYPA, Empire State Development Cooperation) to develop a regional hydrogen hub proposal
- The Multi-state hydrogen hub FOA teaming agreement includes 40 public and private partners with a blueprint that outlines additional non federal support to supplement federal funding, including $27m in hydrogen pilots to derisk new

technologies for following hydrogen use cases, including creation of a Green Hydrogen Prize for innovations in end use of hydrogen;

- Heating / cooling;
- Expanding on existing hydrogen use cases (chip fabrication, methanol production, warehouse material handling)
- Microgrids in underserved areas where backup power is critical - clean hydrogen fuel cells replace generators

Additionally, NYC has banned natural gas hookups in new buildings as of 2021. This will likely lead to a large-scale push toward heat pumps and building electrification rather than hydrogen within buildings, but this policy illustrates the region's serious push toward decarbonization within all sectors.

Alberta (Canada)

Alberta has one of the world's largest proven oil reserves and is one of the world's leading oil producers. With massive petroleum infrastructure as well as an existing large-scale CCUS pipeline, Alberta plans to become a major blue hydrogen hub.

Major operating or announced projects

Canada already produces 3 megatons per year of grey hydrogen, with Alberta producing 60% of the country's output.[9] According to Edmonton Global, Alberta hydrogen is the second lowest cost in the world. Alberta also hosts more than 50 km (31 miles) of pipeline for hydrogen transportation shown in Figure 4.[10] The Wolf CCUS pipeline also operates in the Edmonton region, connecting carbon dioxide production, offtake, and sequestration.

[9] https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen%20Strategy%20for%20Canada%20Dec%2015%202200%20clean_low_accessible.pdf

[10] https://edmontonglobal.ca/hydrogen-economy/

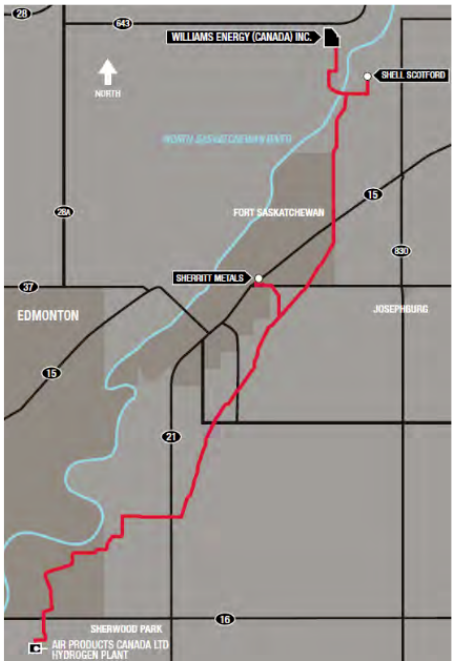

Figure 4 - Air Products Hydrogen Pipeline, Courtesy of Canada H_2 Roadmap Report[11]

Building on this momentum, Canada's hydrogen strategy identified the potential to produce 30% of end-use energy with Hydrogen by 2050. This percentage of hydrogen availability could reduce CO2e by 190 megatonnes. The Hydrogen Strategy for Canada has identified a potential market of up to CA$50 billion for a domestic hydrogen sector creating 350,000 jobs throughout Canada.[12] In Figure 5, the Hydrogen Strategy for Canada report details current hydrogen production costs and projected costs for 2030 and 2050.

[11] Center for Houston's Hydrogen Future - https://www.centerforhoustonsfuture.org/h2houstonhub

[12] https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen%20Strategy%20for%20Canada%20Dec%2015%202200%20clean_low_accessible.pdf

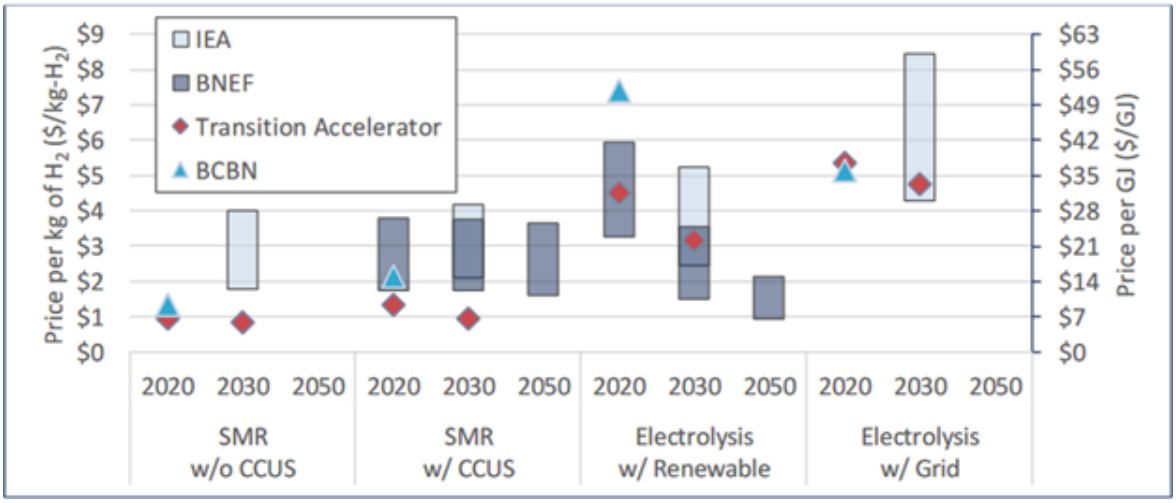

Figure 5 - Comparison of Hydrogen Production Pathway Costs 2020, 2030, and 2050 [13]

As the historic center of Canada's energy industry, Alberta has focused closely on executing these national aspirations. Alberta's Edmonton Region Hydrogen HUB has identified more than 25 projects currently in development for hydrogen production, transportation, and end use.[14] Emissions Reduction Alberta, through the Natural Gas Challenge, has provided CA$2.8 million of a total CA$5.7 million project cost towards an ATCO trial blending 5% hydrogen in their natural gas pipelines.[15]

Policy and incentive programs

Alberta is taking a 7-pillar approach to develop its hydrogen strategy:

- Create new market demand
- Enable carbon capture
- Reduce investment risk
- Encourage technology innovation
- Establish regulatory codes and standards
- Build alliances
- Create export opportunities.[16]

A wide variety of funding sources and Emissions Reduction Alberta offered CA$500,000 in funding for R+D to generate green methanol with carbon capture[17] in addition to the

---

[13] https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen%20Strategy%20for%20Canada%20Dec%2015%202200%20clean_low_accessible.pdf

[14] https://erh2.ca/

[15] https://eralberta.ca/story/atco-project-blends-hydrogen-with-natural-gas-to-reduce-emissions/

[16] https://open.alberta.ca/dataset/d7749512-25dc-43a5-86f1-e8b5aaec7db4/resource/538a7827-9d13-4b06-9d1d-d52b851c8a2a/download/energy-alberta-hydrogen-roadmap-2021.pdf

[17] https://eralberta.ca/projects/details/green-methanol-carbon-dioxide-renewable-hydrogen-methanol/

CA$2.8 million funded towards the ATCO 5% hydrogen blending in existing natural gas pipelines. The Canadian Federal Government plans to invest CA$319 million in carbon capture technologies over a 7-year period.[18] The Western Economic Diversification of Canada, Alberta's Industrial Heartland Association, and the Emissions Reduction Alberta have also provided CA$2 million for creation of the Edmonton Region Hydrogen HUB. CA$1.2 million was provided from the Western Economic Diversification Canada (WD), CA$600,000 from Alberta's Industrial Heartland Association, and CA$450,000 from the Province of Alberta through Emissions Reduction Alberta.[19] The Transition Accelerator has the Transition Pathways Research Funding Opportunity offered in 2022 for universities, research institutions, and think tanks to develop pathways to carbon neutrality and will select three proposals for a maximum CA$20,000 of funding.

In addition to directly funding hydrogen projects, the Canadian Revenue Agency has also implemented the Greenhouse Gas Pollution Pricing Act. The act sets fuel charge rates to reflect a carbon pollution price of $20/tonne of CO2e emissions in 2019, increasing by $10/tonne annually until it reaches $50/tonne CO2e by 2022.[20] Canadian provinces have the option to set more stringent fuel charge rates but they must meet the federal standard.

Northeastern Brazil Atlantic Coast

Brazil's Northeast coast is the nearest South American port to Europe. With plentiful renewable resources available, the country plans to become a major clean hydrogen exporter. With relative proximity to South America's largest industrial center, São Paulo, Brazil also has a potential large-scale domestic offtake center.

Major operating or announced projects

Brazil has a number of hydrogen projects planned, mostly focused on the country's northeast region. Major projects have been announced in the state of Ceará at the port of Pecém, where twelve projects have signed up for the announced Green Hydrogen Hub. Five additional projects have been announced in the adjacent states - three in Rio Grande do Norte, and two in Pernambuco's Port of Suape.

Brazilian hydrogen production is primarily focused on export, capitalizing on the significant percentage of renewables on the grid. As noted in Figure 6, upwards of 83% of electricity

[18] https://www.jdsupra.com/legalnews/the-alberta-hydrogen-roadmap-5317545/

[19] https://transitionaccelerator.ca/news-release-canadas-first-hydrogen-hub-launches-in-the-edmonton-region-backed-by-over-2-million-in-funding-from-three-levels-of-government/

[20] https://www.canada.ca/en/revenue-agency/services/forms-publications/publications/fcrates/fuel-charge-rates.html

production in Brazil is currently renewable, with hydropower comprising 62% of the overall generation mix.

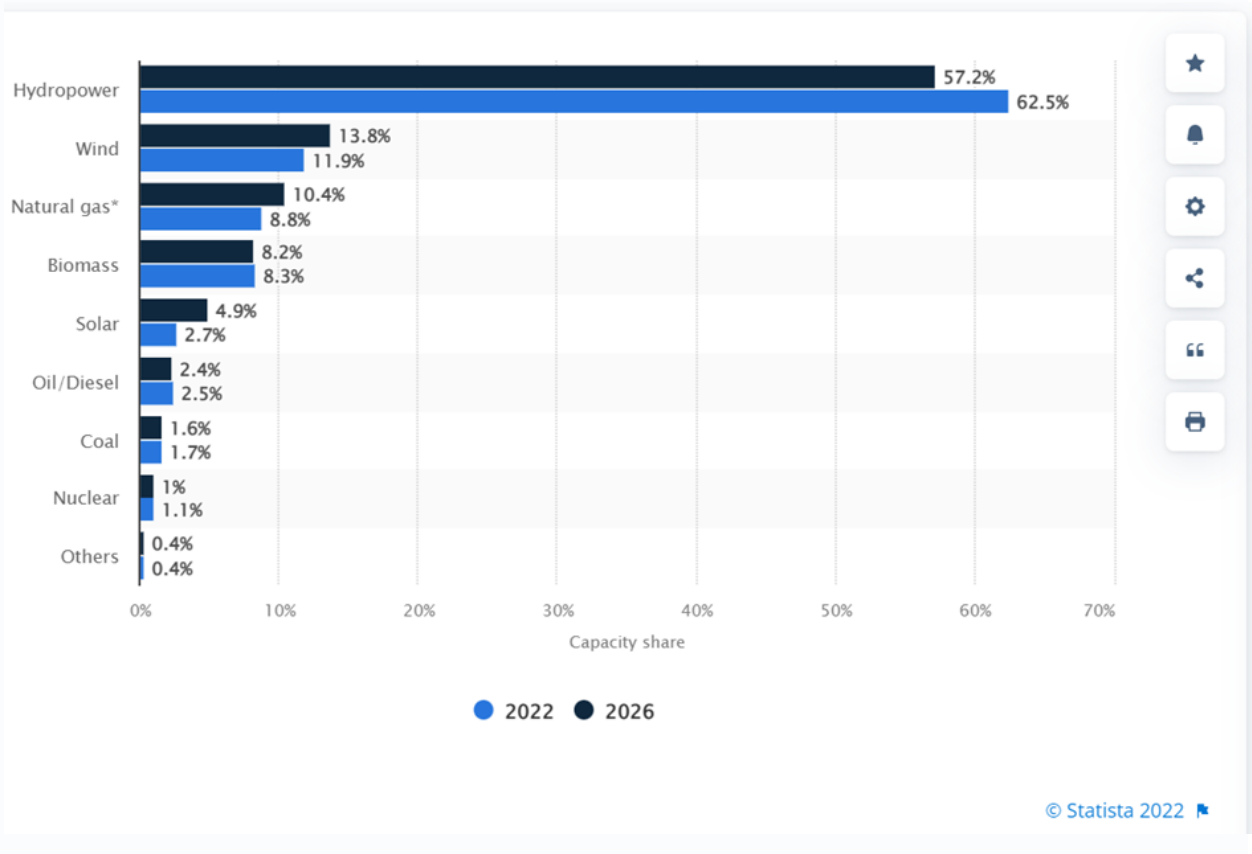

Figure 6 - Brazil electricity generation capacity by source, courtesy of Statista

Ceará Green Hydrogen Hub

The Ceará Green Hydrogen Hub initiative was launched in February, by the state government, the Federation of Industries of Ceará (FIEC), and the Federal University of Ceará (UFC). The Hydrogen hub will be located at the Port Complex of Pecém (CIPP) and has already attracted 12 memoranda of understanding (MOU) from key multinational participants including EDP, Enegix, Fortescue, MingYing, Linde, Engie, Iberdrola, and others. The Ceará port is particularly attractive for H_2 export as it is the closest South American port to Europe and is partially owned (30%) by the Port of Rotterdam. Rotterdam plans to become a major green hydrogen importer, especially through its partnerships with the Northeastern Brazilian export hubs.

Pernambuco and Rio Grande do Norte

The states adjacent to Ceará are also seeking to participate and contribute to a Northeastern regional hydrogen economy. Rio Grande do Norte is already the leading wind energy producer in Brazil, and green hydrogen projects are planned to harness this production. Additional projects are planned by Iberdrola and Qair Brazil in the adjacent state of Pernambuco.

See Figure 7 for a listing of current planned clean hydrogen projects throughout Brazil, including the green ammonia plant proposed by Australia's Fortescue. The majority of focus is within the Northeastern coastal states and their strategic Dutch partnership for exporting to the Port of Rotterdam.

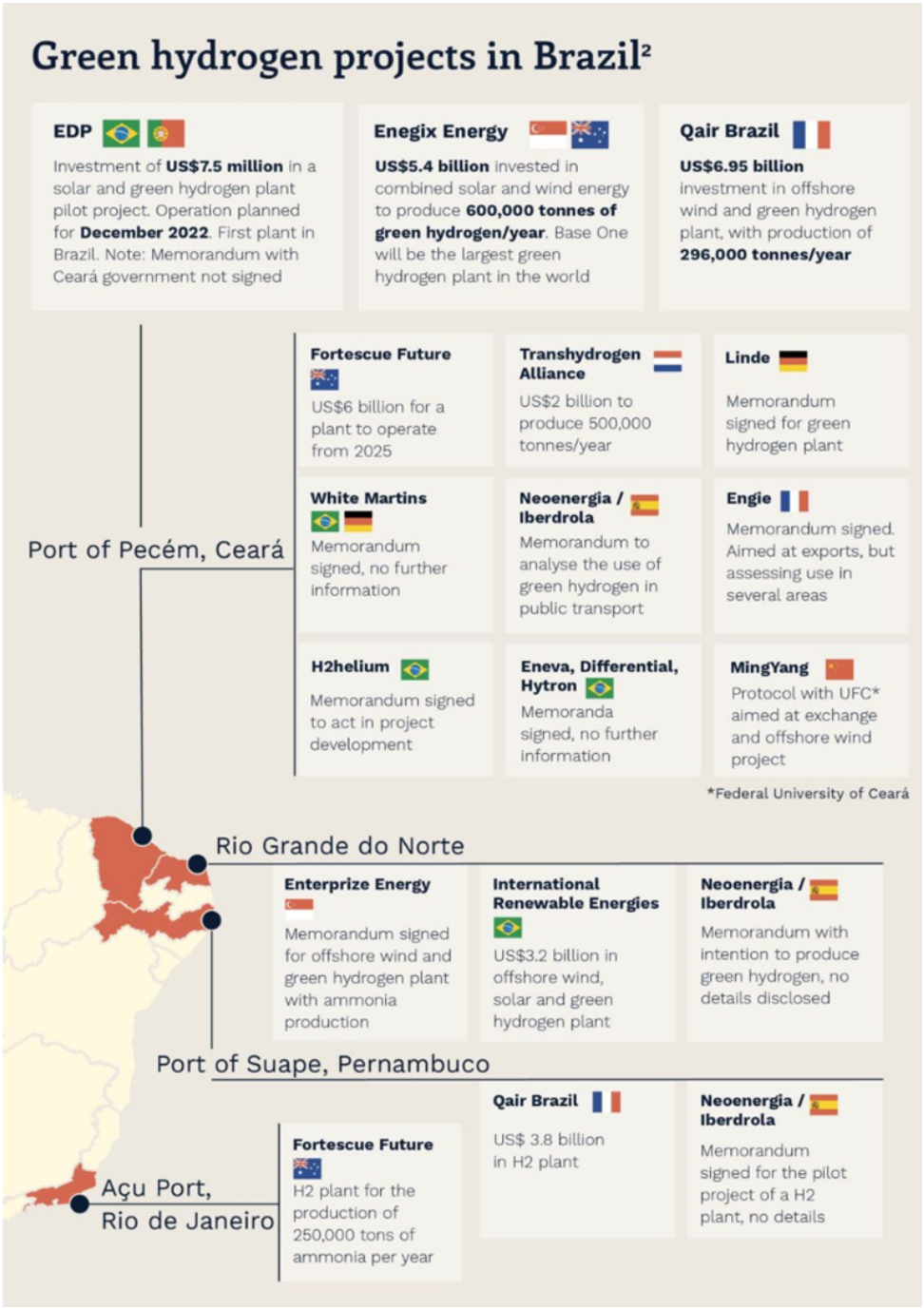

Figure 7 - Brazilian Clean Hydrogen Projects

Policy and incentive programs

The state Government of Ceará is actively leading development of the Northeastern regional hydrogen economy. Seeking means to both increase economic activity and reduce emissions, local leadership has noted that the region's renewable resources and strategic port location provide a strategic advantage.

Chilean Pacific Coast

Using its large wind and solar resources, Chile plans to become one of the world's lowest cost producers of green hydrogen and a Pacific-based exporter to the world.

Major operating or announced projects

Chile Green Hydrogen Program - the Chilean government has developed a Green Hydrogen Program in order to incentivize new developments, and six (6) projects were selected from twelve (12) that were submitted.[21] The program was designed to attract major energy and industrial gas multinationals to work with large local Chilean companies. The program has attracted the participation of global hydrogen leaders - Linde, Air Liquide, Engie, and ENEL - as well as major Chilean industrial concerns - LNG operator GNL Quintero and steel producer CAP SA.

Brief summaries of the 6 specific projects are listed below, with the participating seed funding available from the Chilean government.

1. **Faro del Sur:** This Enel Green Power project located in Magallanes has a planned production of 25,000 tonnes of green hydrogen per year using 240 MW of wind-powered electrolysis. The H_2 offtake will be provided to renewable fuels producer HIF Chile for fuel production and export.
   Chilean government funding: $16.9m USD awarded
2. **Antofagasta Mining Energy Renewable (AMER):** This Air Liquide project located in Antofagasta plans to utilize 80 MW electrolysis to produce green hydrogen and captured CO_2 as feedstock for 60,000 tons per year of renewable methanol production. *Chilean government funding: $11m USD awarded*
3. **HyEx - Producción Hidrogeno Verde:** This Engie pilot project in Antofagasta plans to install 26 MW of electrolyzers and will initially produce 3,200 tonnes of green H_2 per year, sent to offtaker Enaex for conversion to green ammonia.
   Chilean government funding: $9.5m USD Awarded

---

21 https://renewablesnow.com/news/six-green-h2-projects-in-chile-to-split-usd-50m-in-state-funds-767487/

4. **Quintero Bay Green Hydrogen:** This GNL Quintero project located in Valparaiso plans to install 10 MW of electrolyzers and produce 430 tonnes of green hydrogen per year for regional industrial use. *Chile government funding: $5.7m USD awarded*
5. **H2V CAP:** This CAP SA project located in Biobio plans to use 20 MW of electrolyzers to produce 1,550 tonnes of green hydrogen per year for use in steel making. *Chilean government funding: $3.6m USD awarded*
6. **HyPro Aconcagua:** This Linde project located in Valparaiso plans 20 MW electrolyzers to produce 3,000 tonnes of green hydrogen per year. This supply will replace a portion of the grey hydrogen currently used at ENAP's oil refinery in Aconcagua. *Chile government funding: $2.4m USD awarded*

Total Eren Hydrogen Magallanes Complex

In addition to the 6 projects that have received seed funding from the Chilean government, French Independent Power Producer Total Eren is developing a green hydrogen megaproject within Magallanes. The Magallanes complex plans for 10 GW of wind power feeding 8 GW of electrolysis in addition to a seawater desalination and ammonia production plant. The site plan includes a data center and a substation for power export, as well as port facilities for ammonia and hydrogen export. This project is being developed without government funding. See Figure 8 for the conceptual layout.

Figure 8 - Total Eren's H2 Magallanes project

Policy and incentive programs

The Chilean government committed $50 million USD to funding the six green hydrogen projects listed above. This funding is intended to promote Chile as a center of global hydrogen production and export using the country's substantial renewable capacity. Projects required a minimum of 10MW electrolyzers and an operational date no later than December 2025.

One may note that the specific funding dedicated to each project is rather small relative to typical project cost. This funding is intended to function as an incentive to lower project risk and funding requirements for outside investors, attracting and "crowding in" outside investment. The Chilean government expects this seed money to have a multiplier effect, resulting in total project investments of approximately $1B USD for the six projects.

Section 4: Europe

Rotterdam (The Netherlands)

As home to the world's largest seaport outside of China and a gateway for EU energy, Rotterdam plans to leverage its local heavy industrial activity while acting as a key global importer of clean hydrogen and ammonia to distribute throughout Europe.

Major operating or announced projects

The Port of Rotterdam, located in and near the city of Rotterdam in the Netherlands, is the largest seaport in Europe.[22] From 1962 until 2004, it was the world's busiest port based on annual cargo tonnage, and it is currently the world's largest seaport outside of China. Nearly three times the total energy consumption of the Netherlands is delivered to Rotterdam every year, mostly as crude oil. The amount of energy passing through Rotterdam equates to 13 percent of the European Union's total energy needs. The majority of this energy is transported to Germany and the rest of Europe.

The conception of the Port of Rotterdam as a Hydrogen Hub is tied to the 2019 Dutch Climate Agreement which perceives hydrogen "as a robust solution in the end result of a CO_2-free energy and feedstock system."[23] The Dutch government acknowledges that it is strategically important for the Port to maintain its leadership in international energy flows as clean hydrogen becomes a globally-traded energy commodity.

---

22 https://www.portofrotterdam.com/en/port-future/energy-transition/ongoing-projects/hydrogen-rotterdam

23 https://www.portofrotterdam.com/sites/default/files/2021-06/hydrogen-vision-port-of-rotterdam-authority-may-2020.pdf

Today, approximately 0.4 million metric tons of hydrogen is used in the Port area, primarily for oil refining including desulfurization of heavy crudes and hydrocracking to produce light products. The 0.4 million metric ton represents half of current hydrogen demand in the Netherlands. The Port serves as a major source of energy imports for Germany. Current hydrogen demand is 1.6 million metric tons for Germany.

The Port of Rotterdam has both 2030 and 2050 goals. For 2030, the Port is targeting production of 1.16 million metric tons of hydrogen. To achieve this goal, the Port plans to produce 800,000 metric tons SMR equipped with carbon capture and sequestration utilizing both existing and new SMR capacity. It is projected that 5-6 million metric tons of CO_2 will have to be captured and sequestered. An additional 360,000 metric tons will be produced by electrolysis using offshore wind power, which will require installing an additional 4 GW of wind capacity.

By 2050, it is projected that 20 million metric tons of hydrogen will pass through the Port of Rotterdam. Seven million of these metric tons are targeted for domestic use, providing approximately half of the projected 13.6 million metric tons of hydrogen required for the Netherlands to be climate neutral by 2050. As an existing industrial hub, clean hydrogen will also be used for process heating as well as feedstock to transportation fuel and chemical production. Approximately eight million metric tons will be sent to Germany, or 1/3 of the projected 24 million metric tons of hydrogen that Germany will have to import in order to be climate neutral in 2050).

Dutch renewable production capacity, while large, is insufficient to meet these goals. There is approximately 1 GW of wind capacity currently installed in the North Sea. Offshore wind capacity is projected to grow to 60-70 GW by 2050 but will be well below the projected 200 GW of installed capacity needed to produce 20 million tons of hydrogen by 2050. The 200 GW of installed capacity assumes that about half of the electricity generated by the 60-70 GW of Dutch offshore wind power available in 2050 will be used for producing hydrogen and the remainder will be placed on the electric grid.

Most of the hydrogen passing through the port will be imported from regions of the world with much larger and cheaper renewable energy production capacity than the Netherlands. The Port anticipates importing green hydrogen in various forms including as liquid hydrogen, ammonia, liquid organic hydrogen carriers, and as synthetic methane. Bunkering capacity to store these various forms of hydrogen will be required.

There are several projects either under consideration or in the planning stages:

- **A consortium of the Port of Rotterdam, EBN, and Gasunie**, operating under the name of Prothos, is developing the infrastructure for carbon capture and sequestration. It is projected that up to 2-3 metric tons of CO_2 could be captured and sequestered each year from existing hydrogen production facilities in the region. The CO_2 would be stored in an empty gas field under the North Sea about 12 miles (20 kilometers) from the coastline.
- **Shell** is planning to build a 200 MW green hydrogen plant with electricity coming from offshore wind farm Hollandse Kust (Noord). Shell has contracted Thyssenkrupp to engineer, procure and fabricate a 200 MW electrolysis plant based on their large-scale 20 MW alkaline water electrolysis module. Construction work for the electrolyzers will likely begin in Spring 2022 with the plant expected to be operational in 2024. The hydrogen will be transported through a 40 km pipeline that will run from the plant to Shell's Energy and Chemicals Park in Rotterdam.[24]
- **Air Liquide and the Port of Rotterdam Authority** have announced the launch of an initiative to enable 1,000 hydrogen-powered zero-emission trucks on the roads connecting the Netherlands, Belgium, and West Germany by 2025. More than half the trucks are expected to operate in the Port of Rotterdam. At least 25 hydrogen fueling stations located throughout the Netherlands, Belgium and Germany are envisioned to support the truck operations.[25]
- **The Delta Corridor** project is a pipeline project consisting of four different but bundled pipelines transporting hydrogen, CO_2, LPG, and propylene between the Port of Rotterdam and the German Rhineland region. The project was conceived by the Port of Rotterdam Authority and a cross-sector of industry partners including Shell, BP, RWE, thyssenkrupp, LyondellBasell, HeidelbergCement, Attero and Chemelot. If approved, operation of the pipelines is expected to begin in 2026.[26]

Policy and incentive programs

In the Netherlands, "Stimulation of sustainable energy production and climate transition" (SDE++) is an operating subsidy provided by the Netherlands Enterprise Agency for climate-friendly technologies. The SDE++ subsidizes the excess cost for utilizing a cleaner technology. For example, an electric boiler program may be subsidized to cover the excess

---

24 https://www.offshore-energy.biz/shell-and-thyssenkrupp-join-in-on-port-of-rotterdam-hydrogen-facility/

25 https://www.portofrotterdam.com/en/news-and-press-releases/air-liquide-and-port-rotterdam-authority-hydrogen-road-transport

26 https://www.portofrotterdam.com/en/news-and-press-releases/broad-industry-support-for-delta-corridor-project

cost of steam produced utilizing renewables to power the new electric boiler, relative to the cost of steam produced from natural gas fueling an existing fossil boiler. It is the main government subsidy mechanism to support the goals of the Climate Agreement.

The program was launched in 2011 under the name of SDE+ and was originally designed for large-scale roll out of renewables. Consequently, the funds went to solar and wind power for generating electricity. In 2020, the program was expanded (and renamed SDE++) to support technologies that reduce CO_2 or other greenhouse gas emissions. This opened the door for SDE++ funding of CCUS projects.

United Kingdom - City and Regional Hydrogen Clusters

As a leading champion among major economies for taking action on climate change, the UK is looking to hydrogen as a key piece of its decarbonization roadmap. Backed by both public and private investments, hydrogen projects are emerging across the UK. Through its hydrogen ambitions, the UK aims to secure low-carbon economic growth and create green jobs, helping to "level up" its industrial heartlands.

Major operating or announced projects

Hydrogen is set to have a major role in delivering the UK's legally binding national target of net zero emissions by 2050.[27] Advantages for the development of a hydrogen economy in the UK include:

- Diverse energy production sector including oil and gas, offshore wind and tidal, nuclear energy
- Major investments to develop and deploy CCUS, which will enable blue hydrogen production
- Extensive assets for natural gas which can be repurposed for hydrogen
- Storage capacity in disused oil and gas fields, as well as salt caverns
- World-leading hydrogen technology companies including Johnson Matthey, ITM Power, Ceres Power, Doosan

In England, nascent hydrogen hubs are forming in the industrial regions of the North. HyNet is an initiative to decarbonise the North West, including the Liverpool City Region, Greater Manchester, and Cheshire, along with the northern part of neighboring Wales. See Figure 9.[28] Last year, HyNet was named as one of two industrial decarbonisation cluster projects selected for additional support from the UK Government.[29] The project aims to set

---

[27] https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law

[28] https://hynet.co.uk

[29] https://hynet.co.uk/hynet-selected-by-government-as-track-1-industry-cluster/

up a blue hydrogen production facility by the mid-2020's, linked to new infrastructure for CCUS which will be co-developed by the consortium. Future phases will increase hydrogen production via renewables, in particular offshore wind and solar. Hydrogen will be blended into the natural gas pipelines in the area. HyNet partner, Cadent Gas, also plans to build dedicated hydrogen pipelines. The hydrogen will be used for transport, home heating, and by industrial manufacturers in the region. Hydrogen can also be stored underground in salt caverns in Cheshire.

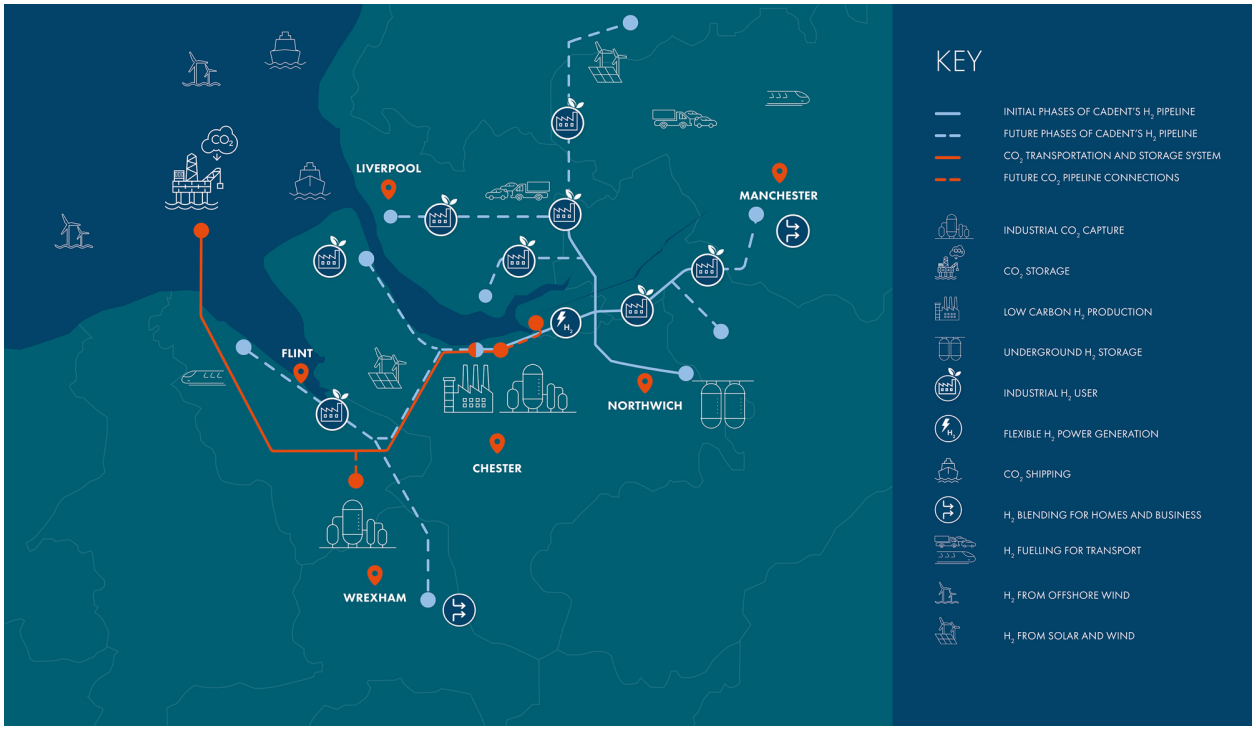

Figure 9 - Diagram of the Proposed HyNet cluster in North West England / North Wales

A second hydrogen cluster is developing in the Tees Valley of the North East, which accounts for nearly 6% of the UK's industrial emissions. Here, the UK government has invested £3 million for the development of a freight-centric hydrogen hub. Industrial support is coming from BP, which plans to develop 1 GW of blue hydrogen capacity by 2027 through its H_2 Teesside project, and recently announced a green hydrogen project in the region (HyGreen Teesside).[30]

Scotland has also emerged as a focal point for UK hydrogen development, building on a strong base of energy infrastructure and diverse opportunities for hydrogen consumption. The largest project announced to date is 'Green Hydrogen for Glasgow', which received a

30 https://www.bp.com/en/global/corporate/what-we-do/gas-and-low-carbon-energy/h2teesside.html

Government investment of £9.4 million in November 2021.[31] [32] The project, a partnership between ScottishPower, ITM and BOC UK & Ireland, will deliver 20MW of green hydrogen when completed. To generate this hydrogen, a PEM electrolyser manufactured by Sheffield electrolyzer manufacturer ITM will be installed at Whitelee, the UK's largest onshore wind farm (capacity 539MW), based just outside the city. Solar assets will be added to complement the existing wind assets and provide additional generation capacity, and a hydrogen storage facility will also be constructed on the site. Hydrogen from Whitelee will initially be used to decarbonise the city's public transit system; as production expands, it is expected that hydrogen could be used as fuel for heavy transport and to aid Glasgow industries' low-carbon transition.

More recently, BP and the city of Aberdeen in Scotland agreed a joint venture to develop a hydrogen hub, with BP committing £3 million toward the project.[33] The first phase of the project aims to produce hydrogen from solar-powered electrolyzers, as a fuel source for Aberdeen's existing fleet of hydrogen fuel-cell vehicles such as buses and garbage trucks. Future phases would expand availability for off-takers in Aberdeen's shipping and logistics industry (rail, marine), as well as use of hydrogen for home heating.

Feasibility studies have also been conducted for hubs in the Scottish Highlands (Cromarty Firth) and the Shetland archipelago.[34] [35] [36] In each case, common features include energy assets which can be leveraged for low-carbon hydrogen production - oil and gas assets for blue hydrogen; wind, solar and tidal energy for green hydrogen - and a diverse array of potential end users, including energy and transport industries as well as more specialized businesses such as distilleries, aquaculture farms, and spaceports.

Policy and incentive programs

The UK Government released a National Hydrogen Strategy[37] in August 2021, which set a target of 5GW of low-carbon hydrogen production by 2030; this target has recently been

---

31 https://www.gov.uk/government/news/glasgow-to-be-home-to-first-of-a-kind-hydrogen-storage-project

32 https://www.scottishpower.com/news/pages/investment_secured_for_whitelee_green_hydrogen_facility.aspx

33 https://www.bp.com/en/global/corporate/news-and-insights/press-releases/aberdeen-city-council-and-bp-sign-joint-venture-agreement-to-develop-city-hydrogen-hub.html

34 https://pocf.co.uk/hydrogen/

35 https://www.scottishpower.com/news/pages/green_hydrogen_potential_in_cromarty_firth.aspx

36 https://www.orioncleanenergy.com

37 https://www.gov.uk/government/publications/uk-hydrogen-strategy/uk-hydrogen-strategy-accessible-html-version#full-list-of-commitments

doubled to 10GW within the same timeframe as part of the UK's plans to strengthen its energy security.[38] A central plank of the Hydrogen Strategy is the Net Zero Hydrogen Fund, which will provide up to £240 million between 2022-25 for commercial deployment of low-carbon hydrogen production.[39] The UK Government is also developing a Low Carbon Hydrogen Standard to provide regulatory certainty for hydrogen producers.[40]

The deployment of energy technologies to produce various forms of low-carbon hydrogen (blue, green, pink) forms an additional foundation for policy support of the hydrogen economy. The UK has recently committed to 2050 targets of 24 GW new nuclear and 50 GW offshore wind, which will boost the availability of inputs needed for low-carbon hydrogen generation.[41] The UK has also announced a £1 billion Carbon Capture and Storage Infrastructure Fund, to enable the development of up to four industrial CCUS clusters across the UK by 2030. The HyNet North West and Teesside clusters mentioned above have been named as finalists in the first phase of this programme.

Cities and regions in the UK likewise provide support and direction for hydrogen hub development. The HyNet North West project has received backing from the combined authorities (roughly parallel to US county government) of the Liverpool City Region, Greater Manchester, and Cheshire West as an integral partner to deliver the region's net zero transition. The city of Aberdeen's hydrogen strategy[42] dates back to 2015, when the city committed to replacing its fossil fuel-powered fleet with vehicles powered by hydrogen fuel cells. Hydrogen strategies are currently being drafted by the devolved governments of Scotland and Wales.[43] [44]

Within the UK, the HyNet project provides a leading example of cross-border collaborations, as it is currently the only proposed hub spanning two of the country's constituent nations (England and Wales). Internationally, the UK is also developing partnerships to support its hydrogen ambitions. Through the global clean energy initiative, Mission Innovation, the UK is leading a multinational effort (along with the US, EU, Australia

---

[38] https://www.gov.uk/government/publications/british-energy-security-strategy

[39] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067275/nzhf-consultation-government-response.pdf

[40] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067392/low-carbon-hydrogen-standard-guidance.pdf

[41] https://www.gov.uk/government/publications/british-energy-security-strategy

[42] http://archive.northsearegion.eu/files/repository/20150918111637_AberdeenHydrogenStrategy_March2015.pdf

[43] https://www.gov.scot/publications/draft-hydrogen-action-plan/

[44] https://gov.wales/developing-hydrogen-energy-sector-wales

and Chile) to reduce clean hydrogen costs to $2 per kg by 2030, by creating at least 100 hydrogen hubs worldwide, generating economies of scale and accelerating hydrogen R&D and knowledge exchange.[45] At the regional level, the Scottish Government funds an R&D scheme through the Royal Society of Edinburgh to encourage Scottish and German researchers to collaborate on hydrogen projects.[46]

Spain

Spain is home to Hydeal España, the first industrial implementation of the HyDeal Ambition platform, recently ranked by the International Renewable Energy Agency (IRENA) as the world's largest integrated renewable hydrogen project.

Major operating or announced projects

According to the International Renewable Energy Agency (IRENA) HyDeal España is the largest worldwide renewable hydrogen project implemented by industry. ArcelorMittal, Enagás, Grupo Fertiberia and DH2 Energy are the anchor sponsors with a total installed capacity expected to reach 9.5 GW of solar power and 7.4 GW of electrolyzers by 2030. Production of hydrogen is expected to occur by 2025.

The hub region, located in northern Spain, was selected given the available water resources and plentiful solar power. The hub-innovative approach was set as a disruptive model based on an aggregation of industries with dedicated hydrogen pipelines.

The offtakers are looking to purchase 6.6 million tons of renewable hydrogen over 20 years, which will result in a 4% reduction of CO_2 from the current emissions and a 5% replacement of current natural gas demands, contributing to Spain's energy independence. The project will cover the full lifecycle of hydrogen: production, transportation, distribution and financing. The Industrial offtakers willing to commit to the clean hydrogen alternative will produce green steel, green ammonia, green fertilizers and other low carbon products.

Policy and incentive programs

HyDeal is fully aligned with Europe's Fit for 55 agenda. This will mean that the platform will contribute to the 55% European Union reduction by 2030 at a 1.5 €/kg market price. The plan has a total of 21 initiatives and a €1.6B investment. The recently approved PERTE (Recovery, Transformation and Resiliency Plan) funding will continue to support Hydrogen, renewables and storage, with the intent to continue to develop and reinforce H_2 in Spain, in alignment with the Hydrogen roadmap set in 2020. This illustrates the importance not only

[45] http://mission-innovation.net/missions/hydrogen/
[46] https://rse.org.uk/over-97k-is-awarded-in-rse-scotland-germany-hydrogen-research-scheme/

of aligning stakeholders around common targets, but also providing the funding to meet those targets.

France

As one of the world's largest producers and consumers of nuclear power, France provides considerations for Illinois, which leads the United States in nuclear production and consumption.

Major operating or announced projects

In 2021, nuclear power accounted for 69% of France's electricity generation. Renewables accounted for nearly 20%. Fossil fuels including natural gas and coal accounted for 6.2 and 1.1%, respectively.[47] CO_2 emissions for the French electric grid were 57.3 g of CO_2 per kWh generated in 2020,[48] resulting in France having one of the lowest CO_2 emissions per capita for electric power generation globally.[49] In comparison, Illinois generated 57.98% of its electricity from nuclear power in 2020. Coal and natural gas accounted for 17.9 and 14.0%, respectively. Wind accounted for 9.9% and other renewables accounted for 0.6%.[50] CO_2 emissions for the Illinois electric grid were 273 g of CO_2 per kWh generated in 2020.[51]

Nevertheless, France has targeted a reduction of dependence on nuclear energy, with a target of 50% of its electricity being generated by nuclear power in 2035 as stipulated in the 2019 Energy and Climate Law. It is expected that as many as 14 nuclear reactors will be decommissioned over the next 15 years.[52]

Currently, France produces 1.2 million metric tons of hydrogen annually. The two major industrial consumers of hydrogen are petroleum refining and ammonia/fertilizer production which accounts for 60 and 25%, respectively, of the hydrogen consumed. Chemical production, metallurgy, and other uses account for the remaining 15% of the

---

47 https://www.statista.com/statistics/1235410/france-distribution-of-electricity-production-by-source/

48 https://www.statista.com/statistics/1190067/carbon-intensity-outlook-of-france/#:~:text=The%20power%20sector%20in%20France,its%20use%20of%20nuclear%20power.

49 Rte, "The transition to low-carbon hydrogen in France – Opportunities and challenges for the power system by 2030-2035."

50 https://www.nei.org/resources/statistics/state-electricity-generation-fuel-shares

51 https://www.eia.gov/electricity/state/illinois/

52 Rte, "The transition to low-carbon hydrogen in France – Opportunities and challenges for the power system by 2030-2035." January 2020, Available at https://assets.rte-france.com/prod/public/2021-03/Hydrogen%20report_0.pdf

hydrogen consumed. Hydrogen production results in emissions of 10 MtCO2/year, representing about 2-3% of the total French emissions.[53]

France views low-carbon hydrogen as a means to decarbonize existing hydrogen usage in industry. It views low-carbon hydrogen as having the potential to decarbonize heavy transportation, and within certain limits, supplying the existing gas network as a substitute for natural gas.[54] In the long-term (2050), France views grid level energy storage via hydrogen including power-to-gas-to-power as a critical technology for increasing the amount of renewable energy on the power grid despite its low overall energy efficiency of 25-35%.[55]

Electrolysis is viewed as the main option for developing low carbon hydrogen in France. To meet the National Low-Carbon Strategy would require 7 GW of installed electrolyzer capacity and an additional 30 TWh of electricity consumption in 2035 to produce 630,000 metric tons of hydrogen and by as much as 50 TWh by 2050.[56,57] Carbon capture and sequestration is not considered a primary focus for France to achieve its low-carbon hydrogen goals. However, it is estimated that steam methane reforming with carbon capture and sequestration will produce about 130,000 metric tons of hydrogen in 2030.[58]

It is estimated that France will have to invest up to 24 billion euros through 2030 to meet its targets with the government providing 6.7 billion euros and other financial support of 3.6 billion euros in addition to industry spending.[59]

Policy and incentive programs

The French National Hydrogen Strategy has three goals for 2030:

1. Develop a French electrolyzer industry and install enough electrolyzers to make a significant contribution to decarbonize the French economy. The target is 6.5 GW of electrolyzer capacity.

---

[53] Rte, "The transition to low-carbon hydrogen in France – Opportunities and challenges for the power system by 2030-2035." January 2020, Available at https://assets.rte-france.com/prod/public/2021-03/Hydrogen%20report_0.pdf
[54] Ibid.
[55] Ibid.
[56] Rte, "The transition to low-carbon hydrogen in France – Opportunities and challenges for the power system by 2030-2035." January 2020, Available at https://assets.rte-france.com/prod/public/2021-03/Hydrogen%20report_0.pdf
[57] France Hydrogène "The Hydrogen sector's proposals for the development of a renewable and low-carbon hydrogen industry in France," https://www.iphe.net/_files/ugd/45185a_243e896f130d4fb3b8e78e571afdca04.pdf
[58] Ibid.
[59] France Hydrogène "The Hydrogen sector's proposals for the development of a renewable and low-carbon hydrogen industry in France," https://www.iphe.net/_files/ugd/45185a_243e896f130d4fb3b8e78e571afdca04.pdf

2. Develop clean mobility for heavy-duty transportation including focus on shipping and aviation in addition to rail and trucking.
3. Support research and development including workforce development.

French energy-climate law and the draft Multi-Annual Energy Plan and Low-Carbon strategy defines targets for decarbonizing the French hydrogen industry. The target calls for 10% of the hydrogen consumed in 2023 to be low-carbon hydrogen, increasing to 20-40% by 2030.[60] The Energy and Climate Law targets that renewable energy will account for 40% of France's electricity production by 2030. However, there is concern that France will not meet its renewable energy target due to very long permitting processes due to burdensome authorization requirements and the lack of available land.[61]

The French government will provide €7billion toward these goals, with €3billion being provided between 2020-2023.

Section 5: MENA

Saudi Arabia

Capitalizing on its large renewable resource base, Saudi Arabia seeks to diversify beyond its massive oil and gas industries.

Major operating or announced projects

In 2020, Air Products, ACWA Power, and the greenfield city of NEOM agreed to an MOU with Saudi Arabia to build a new green ammonia plant. The facility will produce 237,000 tonnes per year of green hydrogen while being powered by 4 GW of wind and solar.[62] The project is estimated to start exporting hydrogen fuel by 2026 and will cost $5 billion.[63]

State-controlled Saudi Aramco and Hong Kong's InterContinental Energy have also reached an agreement to build a new hydrogen and ammonia plant in Saudi Arabia. Since the initial

---

[60] Idib.

[61] IEA France 2020 – Energy Policy Review available at https://iea.blob.core.windows.net/assets/7b3b4b9d-6db3-4dcf-a0a5-a9993d7dd1d6/France2021.pdf

[62] https://ieefa.org/wp-content/uploads/2020/08/Asia_Australia_Europe-Lead-Green-Hydrogen-Economy_August-2020.pdf

[63] https://www.bloomberg.com/news/articles/2022-03-17/saudi-arabia-to-start-building-green-hydrogen-plant-in-neom

announcement of the project in late October of 2021, details such as the size or location of the project remain unclear.[64]

Policy & Incentive Programs

Saudi Arabia has pledged to achieve net-zero GHG emissions by 2060.[65] As part of the country's climate goals, Saudi Arabia intends to produce and export an estimated four million tons of hydrogen per year by 2030.[66] A comprehensive hydrogen production strategy is currently being prepared by the country's government.[67] The kingdom is also actively pursuing strategic planning partnerships with other leading nations. For example, Germany has opened a "hydrogen diplomacy office" to provide expertise and foster a strategic partnership between the two nations.[68]

United Arab Emirates (UAE)

Similar to Saudi Arabia, the large petrostate seeks to use clean hydrogen to diversify its economy away from oil and gas. In the process, UAE hopes to grow state-owned company Masdar into one of the world's leading renewables developers.

Major operating or announced projects

In May 2021, UAE kicked off a Dubai-based project described as the "first industrial scale, solar-driven green hydrogen facility in the Middle East and North Africa." [69] The pilot project is a collaboration between Siemens Energy, the Dubai Electricity and Water Authority (DEWA), and Expo 2020 Dubai. The hydrogen facility with a currently unspecified capacity, will be affiliated with the DEWA solar facility, which continues to grow and is expected to produce 5 GW by 2030. Seven projects are underway throughout the country, a mix of both green and blue hydrogen.

---

64 https://www.argusmedia.com/en/news/2267651-saudi-aramco-plans-new-green-hydrogen-ammonia-project

65 https://www.npr.org/2021/10/23/1048655294/saudi-arabia-zero-emissions-climate-change-2060

66 https://www.reuters.com/business/energy/saudi-arabia-wants-be-top-supplier-hydrogen-energy-minister-2021-10-24/

67 https://www.worldenergy.org/assets/downloads/Working_Paper_-_National_Hydrogen_Strategies_-_September_2021.pdf

68 https://www.giz.de/en/worldwide/104041.html

69 https://www.cnbc.com/2021/05/20/dubai-launches-regions-first-industrial-scale-green-hydrogen-plant.html

Policy & Incentive Programs

UAE is the first MENA nation to have set a net zero carbon emissions target, with 2050.[70] The country has announced a goal of capturing 25% of the global hydrogen market by 2030, although no national production target has been announced.[71]

Section 6: Sub-Saharan Africa

Namibia

With sunshine over 300 days of the year and significant wind energy stemming from a nearly 1,000-mile coast, Namibia has plans to export clean hydrogen globally.

Major operating or announced projects

Hyphen Hydrogen Energy Ltd. has been awarded preferred bidder status for two sites, which will cost an estimated $9.4 billion to construct.[72] Hyphen is funded by European partners seeking to provide the necessary capital for Namibia to harness its resources. For comparison, Namibia's entire GDP was $10.7 billion in 2020. By 2030, the projects aim to produce 300,000 metric tons of green hydrogen annually from 5 GW of renewables and 3 GW electrolyser capacity. Hyphen will have rights to the project for forty years.[73] Currently, export agreements are signed with Germany, Belgium, and the Netherlands.[74]

Policy & Incentive Programs

Namibia has allocated over $45 million towards green hydrogen feasibility studies and pilot projects.[75] The German government has helped provide funding for the initiatives and believes Namibia's natural advantages could help it produce the world's cheapest green

---

70 https://u.ae/en/information-and-services/environment-and-energy/climate-change/theuaesresponsetoclimatechange/uae-net-zero-2050

71 https://www.wam.ae/en/details/1395302988986

72 https://hyphenafrica.com/

73 https://www.wsj.com/articles/the-worldwantsgreen-hydrogen-namibiasays-it-can-deliver-11639823404

74 https://www.bbc.com/news/business-59722297

75 https://www.wsj.com/articles/the-worldwantsgreen-hydrogen-namibiasays-it-can-deliver-11639823404

hydrogen. The focus on hydrogen stems from President Hage Geingob's desire to "craft an economic recovery plan that is responsive, globally relevant, and systemic in nature."[76]

South Africa

As the most heavily industrialized country in Africa and home to one of the world's leading mining industries, South Africa has a large potential to both self-produce and consume clean hydrogen throughout its economy.

Major operating or announced projects

South Africa is well positioned to be a leader on production of clean hydrogen and its byproducts. The country has major production capacity for critical minerals, including 75% of the global reserves of platinum group metals that are required for production of green hydrogen), and deep expertise in the Fischer-Tropsch process used in the production of power fuels. Three projects provide examples of the local production/consumption hydrogen hub nature of South Africa's approach to the industry.

- **Platinum Valley Initiative (PVI)**
    - The PVI will focus on creating a "hydrogen valley" to connect three key areas spanning the industrial, mobility, and building sectors - mining in Mogalakwena/Limpopo, industry in Johannesburg, and the port of Durban. See Figure 10 below for illustration of the production and consumption centers within the PVI.
    - This initiative intends to realize cost savings through shared infrastructure investments, improve cost competitiveness through economies of scale, enable a rapid ramp up of production, and create an incubator for new hydrogen pilot projects. This hub-based approach helps de-risk investments by identifying diversified sets of off-takers across many sectors, ensure long-term commitments across stakeholders, and creates a framework for applying for project funding.
    - The next steps to accelerate PVI implementation center on pilot projects in the industrial (ammonia, chemicals), mobility (mining trucks, buses), and buildings (fuel-cell power) sectors. Currently, several projects are earmarked for the PVI: development of ethylene and ammonia from green hydrogen, green steel production, switching paper mills from natural gas to hydrogen, deployment of fuel cell vehicles from forklifts at ports to buses and heavy
    - duty trucks, powering office buildings via fuel cells, and stationary fuel cell power.

[76] https://www.bbc.com/news/business-59722297

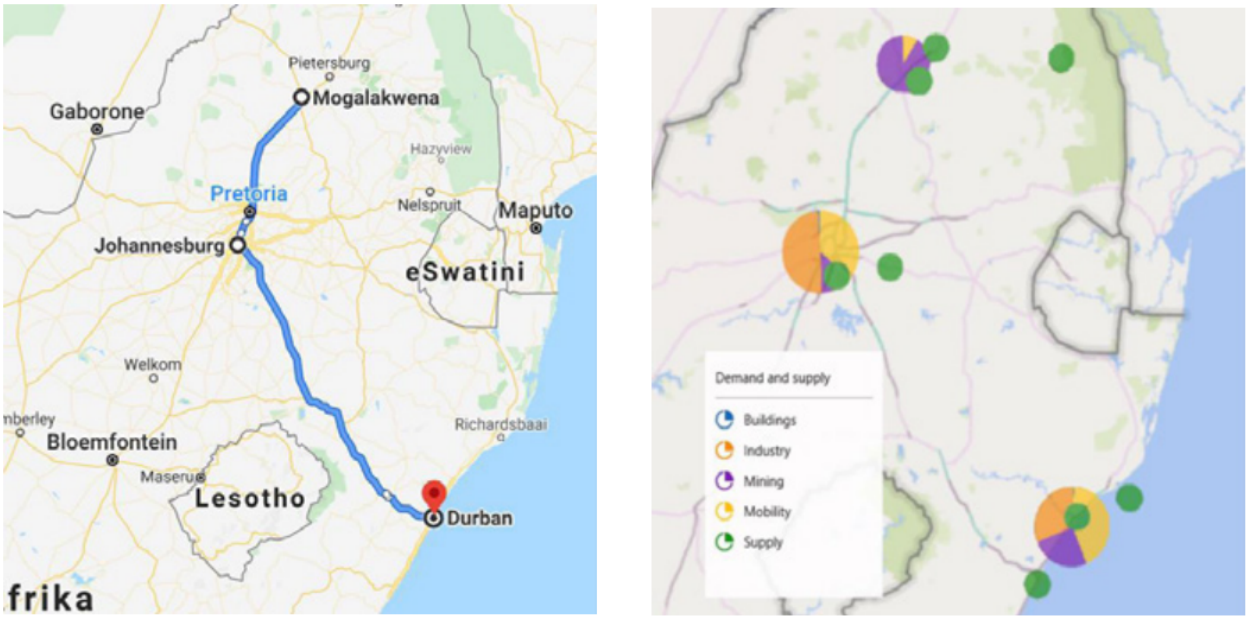

Figure 10 - Layout of the Platinum Valley Hydrogen Supply and Demand Centers

- **CoalCO2 -X Project**
    - The Coal CO2 -X Program is a pilot to use green hydrogen and coal-fired boiler flue gas to produce value-added products supporting a decarbonization transition. Value-added products include green ammonia, fertilizers, and sulfuric acid, which will help increase local demand for green hydrogen. The government's Science and Innovation Department is providing R60M ($3M) in seed funding over three years. The overall goal is to demonstrate that coal-fired power plants can be transformed into zero emissions chemical factories, as shown in the Figure 11 process flow diagram below.

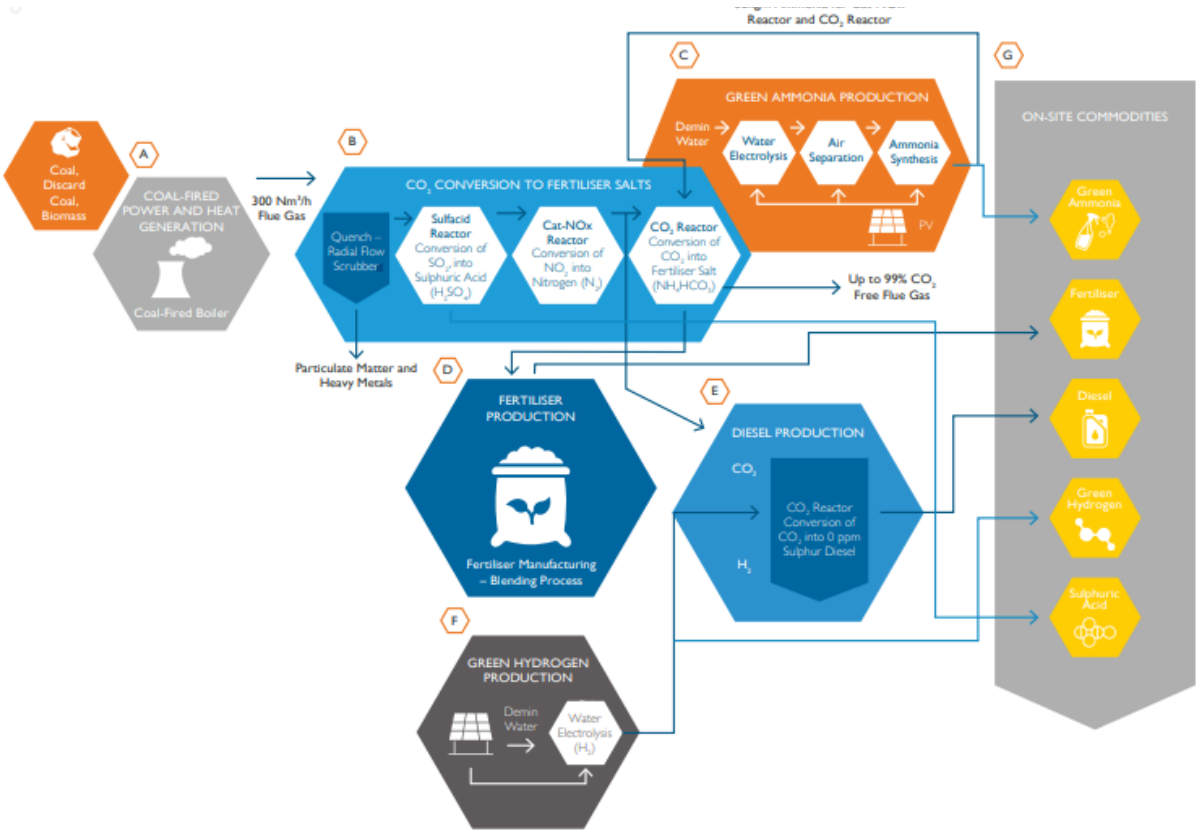

Figure 11 - Power Plant Conversion to Produce Chemicals from Coal and Clean Hydrogen Boegoebaai Special Economic Zone (BSEZ)

The BSEZ a large industrial zone that will host seven key facilities:

1. An electrolyser park
2. Desalination plant
3. Green ammonia (NH_3) production plant
4. Storage facility
5. Solar, wind, and battery park
6. Supplier park for common components, and
7. Gigafactory to ramp up production of electrolysers.

The BSEZ already has an established hydrogen production plan. If the project is fully realized, it will add an estimated 6,000 jobs and create up to 400,000 tonnes of green hydrogen annually, allowing South Africa to produce clean hydrogen for mass export. As shown in Figure 12 below, the BSEZ also plans to supply internally to South African offtakers, including the converted coal-fired power plants and the PVI.

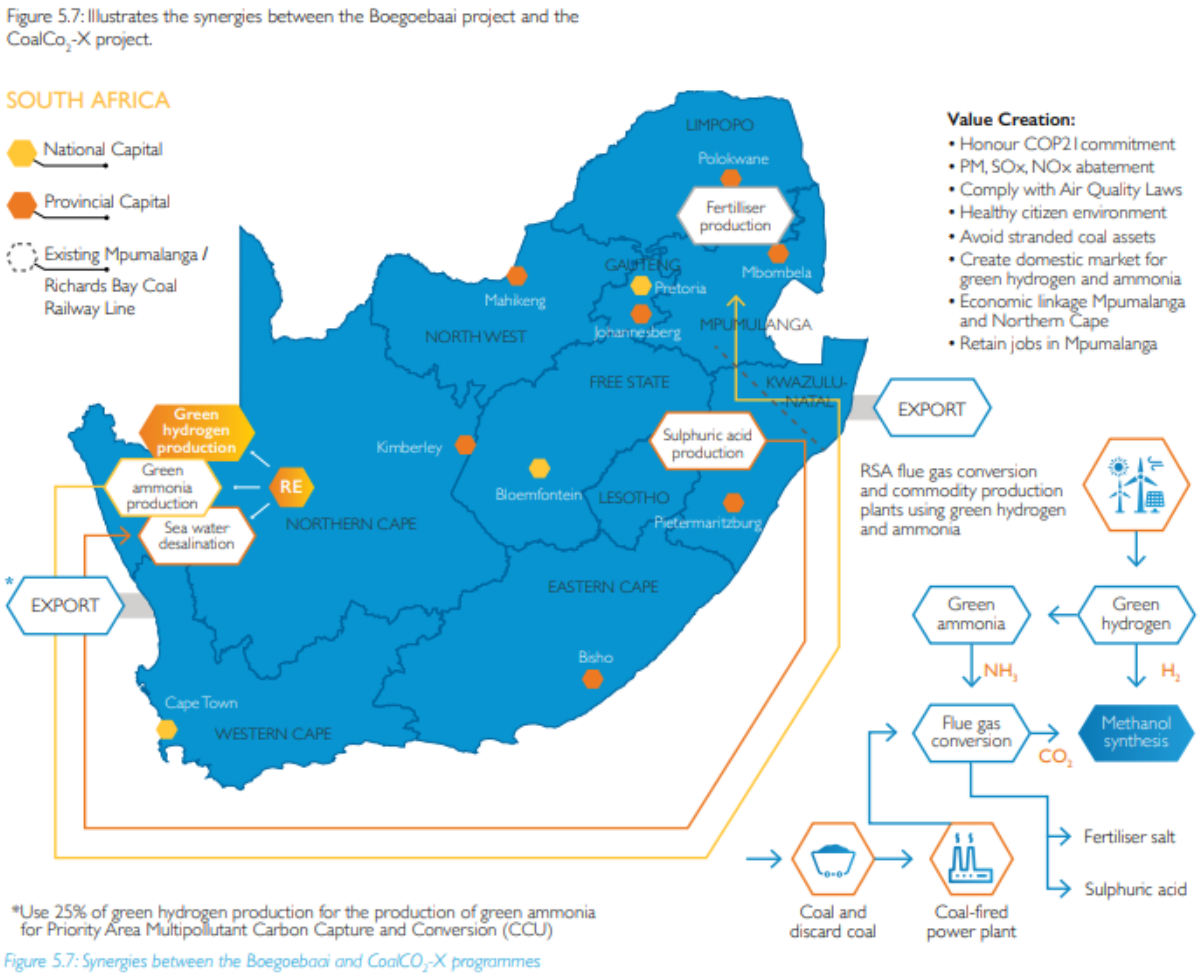

Figure 5.7: Synergies between the Boegoebaai and CoalCO2-X programmes

Figure 12 - Synergies Between Green H_2/NH_3 from BSEZ and the Coal CO2-X Program

Policy & Incentive Programs

To maximize these advantages, South Africa released its Hydrogen Society Roadmap for South Africa 2021 (HSRM), which serves as a national coordinating framework to facilitate integration of hydrogen-related technologies.[77]

The HSRM was developed by South Africa's Department of Science and Innovation and more than 50 stakeholder organizations. Its goals are to decarbonize heavy transportation and energy-intensive industries, enhance the green power sector, and create an export market for green hydrogen. The HSRM intends to double South Africa's current share of global hydrogen production from 2% to 4 by 2050. A recent report by South Africa's National Business Initiative (NBI) estimates that the country may produce green hydrogen for less than $1.60 per kg by 2030, which would be one of the lowest costs worldwide. In particular, the HSRM focuses on four major catalyst projects described above. By 2030, the

[77] https://www.dst.gov.za/images/South_African_Hydrogen_Society_RoadmapV1.pdf

four flagship projects are estimated to produce 500,000 tons of hydrogen and create at least 20,000 jobs annually with a projected GDP contribution of at least $5B by 2050.[78]

Section 7: Asia

Shanghai (China)

As the world's leading country in multiple categories - largest renewables producer, largest port (Shanghai), largest population, and more - China plans to become both a leading consumer and producer of hydrogen for the sake of self-sufficiency rather than export capacity.

Major operating or announced projects

Shanghai is an international business hub. In 2021, it was one of the first cities selected as a demonstration district, or a government-supported hub for China's burgeoning hydrogen economy. Other regions of China have hydrogen activity as well, but Shanghai - a global city with extensive industrial and multimodal capabilities - provides a good case study for comparison with Chicago. By 2023, Shanghai alone is projected to have at least 100 hydrogen fueling stations and has vast potential for hydrogen fueling of vehicles at the port of Shanghai, the world's busiest port. As Shanghai has a vast market for both commercial and industrial hydrogen fuel cell vehicles, much of its investment has gone towards creating technology that will lower the cost of hydrogen production and increase the efficiency of hydrogen vehicles.

Multiple hydrogen projects are underway within Shanghai:

- **Jiading Hydrogen Park**
    - Jiading Hydrogen Park has received a total investment of over RMB 10 billion (USD 1.5 billion) as of January 2022. This investment is in the form of over 50 hydrogen energy and intelligent automobile industrial projects from companies like Toyota, Great Wall Motor, Horiba, etc. The Jiading Hydrogen Park is also partnered with nearby Tongji University for scientific and technological expertise.[79]
- **Shanghai Chemical Industry Park**
    - In March 2022, Air Liquide China, Shenergy and SCIP Investment Co. announced a joint investment of over RMB 180 million (USD 26.2 million) in Shanghai Chemical Industry Park.

---

78 https://www.nbi.org.za/wp-content/uploads/2021/08/NBI-Transition-Chapter-Decarbonising-SA-power-11-Aug-2021.pdf

79 http://english.jiading.gov.cn/2022-01/28/content_37549850.htm

- This venture's goal is to accelerate the distribution of hydrogen energy in Shanghai and surrounding areas. In particular, it also aims to build Shanghai's largest-scale filling center to date. In the first phase, the goal of the filling center is a capacity of 24 tonnes/day. This investment also furthers the city's goal of peaking its carbon emissions in 2025, five years earlier than the national goal laid out in China's 14th Five Year Plan.[80]

Policy & Incentive Programs

In China, national level plans play a major role in guiding regional activity. China's 14th Five Year Plan is an official national outline for the nation's goals across multiple sectors. This plan, which covers 2021 to 2025, identifies hydrogen energy as key for its clean energy goals. Despite targets for lowering CO_2 emissions and increasing non-fossil fuel consumption, no explicit quota is provided regarding hydrogen production, storage, transport, or consumption.[81]

China's strategy is for the national leadership to select certain provinces as hubs of its growing hydrogen economy. Provinces that reach their individual production quotas will receive an RMB 1.7 billion (USD 226.7 million) fiscal bonus.[82] Since 2019, China has created more than 30 individual hydrogen projects in this fashion.[83] See Figure 13 below for relative hydrogen progress across all of China's provinces.

---

[80] https://hydrogen-central.com/air-liquide-shenergy-shanghai-chemical-industry-park-hydrogen-energy/

[81] https://www.carbonbrief.org/china-briefing-24-march-2022-14fyp-energy-plan-more-plans-on-energy-storage-and-hydrogen-chinas-emissions-analysis

[82] https://asia.nikkei.com/Spotlight/Caixin/China-s-hydrogen-roadmap-4-things-to-know

[83] https://energycentral.com/news/shanghai-electric-signs-agreement-launch-pem-hydrogen-production-technology-rd-center

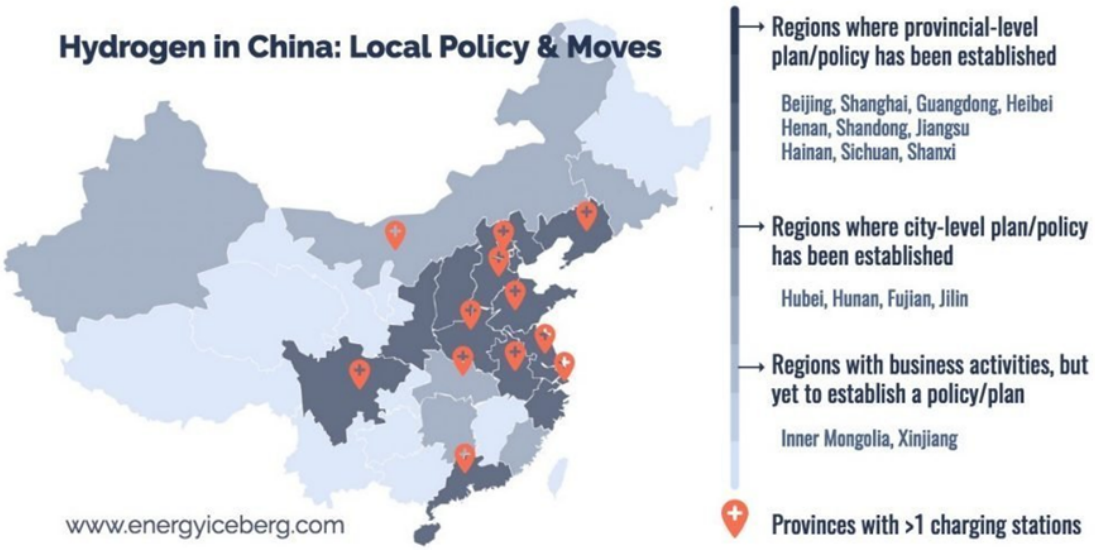

Figure 13 - Regional Chinese Hydrogen Policy, figure courtesy of Energy Iceberg

The advantage of this strategy is the creation of self-sufficient, highly individualized hydrogen economies across the country. For example, in the northern province of Inner Mongolia, the private company Shanghai Electric has established a "Source-grid-load-storage-hydrogen" project. This project uses Inner Mongolia's natural abundance of wind and solar energy to feed an entire chain of hydrogen production, storage, and consumption. This example points to the potential for the Chinese hydrogen economy to be insular – one expert noted in March 2022 that "China would become neither an exporter nor an importer of hydrogen," a true set of local circular economies.[84]

Japan

Japan was the first country in the world to draw up a national hydrogen strategy, but it is very limited on self-production capacity. Japan sees itself as a major global importer of clean hydrogen and ammonia from around the world.

Major operating or announced projects

A large focus of Japan's hydrogen economy is buildout of infrastructure for fuel cell vehicles. Japan currently has more hydrogen vehicle fueling stations than any other country, approximately 160 as of June 2021, with plans to increase to 1,000 by 2030.[85] Most of Japan's project efforts are in fact abroad, with co-ownership and development in other

[84] https://asia.nikkei.com/Spotlight/Caixin/China-s-hydrogen-roadmap-4-things-to-know

[85] https://www.lexology.com/commentary/energy-natural-resources/japan/nishimura-asahi/hydrogen-update-and-outlook-in-japan-2022

resource rich countries for shipment back to Japan. The largest hydrogen production plant within Japan is currently the 10 MW renewable-powered Fukushima Hydrogen Energy Research Center. Japan is actively developing larger projects in Canada, Australia, and New Zealand. Key highlights include the following:

- **The "Desert Bloom" project,** a joint venture with Osaka Gas and Australia in the Australian outback, is a USD 10.75 billion green hydrogen project to condense water from air and send it through electrolyzers to produce green hydrogen. The project is targeting 410,000 tonnes per year, with export back to Japan at a target cost of less than $2/kg , and to export hydrogen at an internationally competitive cost (less than $2/kg).[86]
- **The Suiso Frontier,** the world's first liquefied hydrogen carrier vessel, docked in Victoria, Australia during January 2022 in order to demonstrate the transport of liquefied hydrogen from Australia to Japan. The Port of Kobe has been modified to accept liquid hydrogen deliveries.
- **Japan's liquified natural gas (LNG) infrastructure,** accounting for 37% of Japan's energy mix, is currently under modification to flexibly handle import of either large-scale hydrogen or ammonia in addition to LNG.

Policy & Incentive Programs

In 2017, Japan became the first country to adopt a national hydrogen framework, and has always been a major participant in the global hydrogen economy. In 2019, the Japanese government released a detailed hydrogen roadmap which identified four key benefits for increased hydrogen investment:

1. Increasing energy self-sufficiency
2. Furthering decarbonization
3. Strengthening industrial competitiveness
4. Positioning Japan as a major fuel cell exporter while also utilizing fuel cells at home

The major challenge facing Japan's hydrogen industry is its severe lack of feedstock. Given this limitation, Japan has focused its public funds into the "research, development, demonstration, and deployment" of hydrogen technologies.[87] Along with its domestic projects, Japan notably focuses on collaborative investment to remain a leader in fuel cell technology. One example of this strategy is Toyota's joint ventures to produce fuel cell vehicles in China.

---

86 https://www.reuters.com/world/asia-pacific/japans-osaka-gas-backs-11-bln-green-hydrogen-project-australia-2022-04-12/

87 https://www.csis.org/analysis/japans-hydrogen-industrial-strategy

Section 8: Oceania

Queensland (Australia)

Australia plays a strategically central role in the Pacific, actively seeking international partnerships for clean hydrogen development and export while developing hydrogen hubs to produce and consume within its industrial and mining sectors.

Major operating or announced projects

Australia has many examples of hydrogen hubs throughout the country, but Queensland is the first known State-level government in the world to appoint a Minister of Hydrogen. The Queensland government named Mick de Brenni as Australia's first dedicated minister for hydrogen in November 2020. The Australian Hydrogen Council (AHC) welcomed the appointment of a dedicated minister for hydrogen. The AHC CEO, Final Simon, said: "Even before today's announcement, Queensland has one of the more mature approaches to the hydrogen industry including a Queensland Hydrogen Industry Strategy, development fund, prospectus, investor toolkit and guidance for local governments on hydrogen developments."

Part of Queensland's strategy to promote clean hydrogen development was to release the "Queensland Hydrogen Investor Toolkit" in January 2022. The purpose of the toolkit is to provide two specific actions from the Queensland Hydrogen Industry Strategy (QHIS):

1. **Action 2.1** of the QHIS is to 'Prepare an investor toolkit to assist private sector proponents with information on developing projects in Queensland' and
2. **Action 2.2** of the QHIS is to 'Provide project facilitation services, including investment facilitation and the application of the powers of the Coordinator-General, to eligible project proponents.

Queensland has developed State Development Areas (SDA) with one of the following typical characteristics:

- Industrial hubs for large-scale, heavy industry - mainly located on the coast of Queensland, close to ports, rail and major road networks
- Multi-user infrastructure corridors - for the co-location of infrastructure such as rail lines, water and gas pipelines, and electricity transmission lines
- Major public infrastructure sites

Figure 14 below illustrates these SDA's which are favored for hydrogen project development.

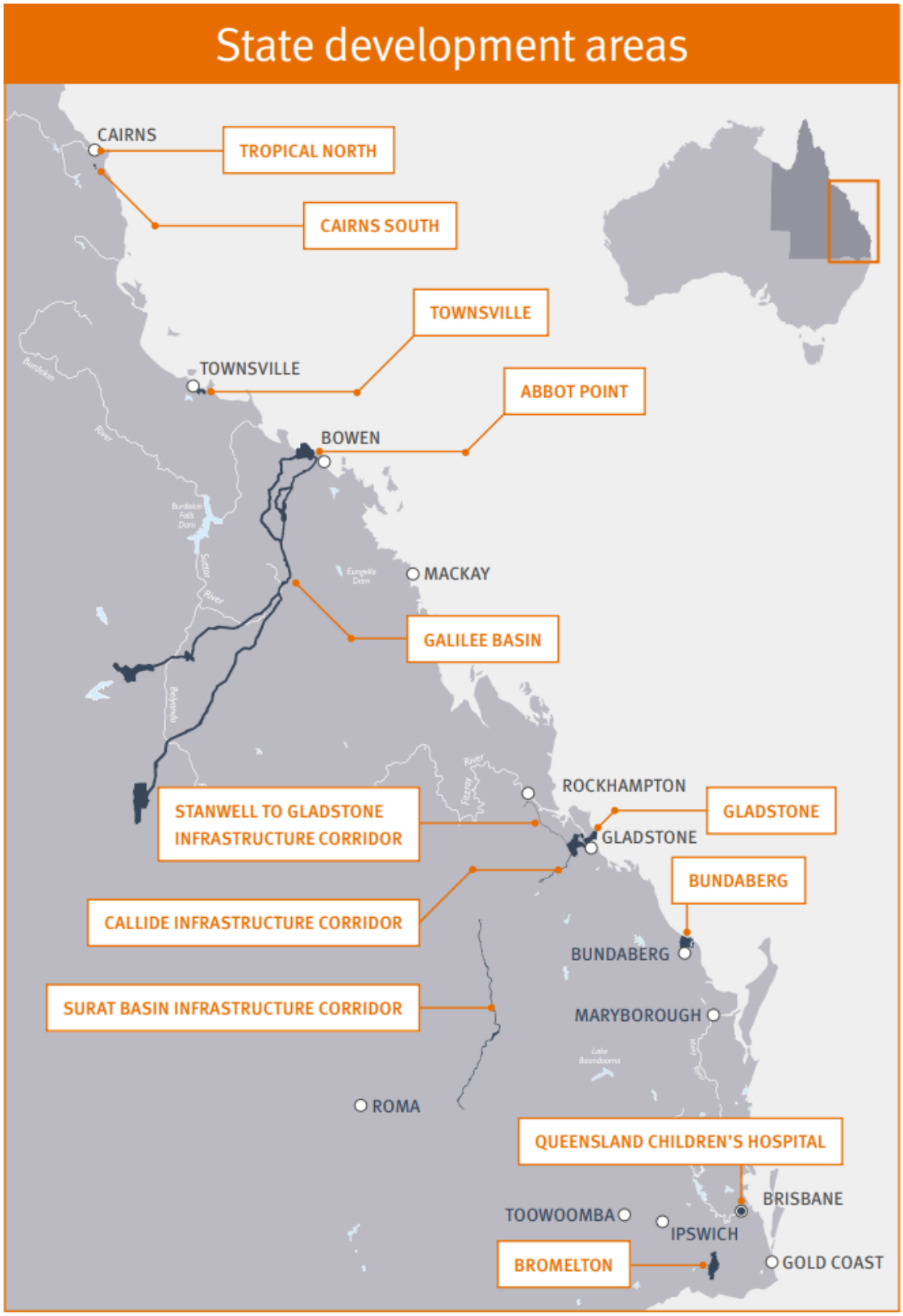

Figure 14 - Map of Queensland State Development Areas (SDA)

Policy and incentive programs

In Australia's National Hydrogen Strategy, Australia's Chief Scientist Dr. Allen Finkel quotes science fiction author Jules Verne (1874) in his opening message:

> "*Water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable. Someday the coal-rooms of steamers and the tenders of locomotives will, instead of coal, be stored with these two condensed gases, which will burn in the furnaces with enormous calorific power.*"

The Council of Australian Governments Energy Council established a Hydrogen Working Group in December 2018 with Dr. Allen Finkel as chair. The goal was to develop a National Hydrogen Strategy that would "set a vision for a clean, innovative, safe and competitive hydrogen industry that benefits all Australians and is a major global player by 2030."[88]

The Executive Summary outlines Australia's advantages, benefits, and pathways to achieving the National Hydrogen Strategy. Australia believes itself to have the resources and experience to capitalize upon hydrogen as its next major energy export, with potential economic growth and emissions reduction through 2050.

The key element of Australia's approach is to create hydrogen hubs, clusters of large-scale demand and production. The development of a National Hydrogen Strategy has provided a blueprint and impetus for state governments to establish regional and local hydrogen strategies, including New South Wales, Northern Territory, Queensland, South Australia, Tasmania, and Victoria. This policy support has attracted outside investment and development from other nations such as Japan, which is working to co-develop Australian projects for hydrogen export for use in meeting its own hydrogen consumption goals.

New Zealand

With plentiful renewable resources and advanced social goals around equity and human development, New Zealand provides a model for a self-sufficient hydrogen economy.

Major operating or announced projects

The New Zealand Hydrogen Council (NZHC) NZHC is promoting over twenty projects throughout the country. The clean hydrogen generation projects are powered by solar and geothermal, while consumption projects are especially focused on transport and shipping. Several projects are aimed at developing infrastructure to deliver hydrogen from

[88] https://www.industry.gov.au/data-and-publications/australias-national-hydrogen-strategy

generation nodes to consumers. The entire country is working towards a Hydrogen Hub, with opportunities to export additional clean hydrogen.[89] See Figure 15 below for a map of NZ's hydrogen projects.

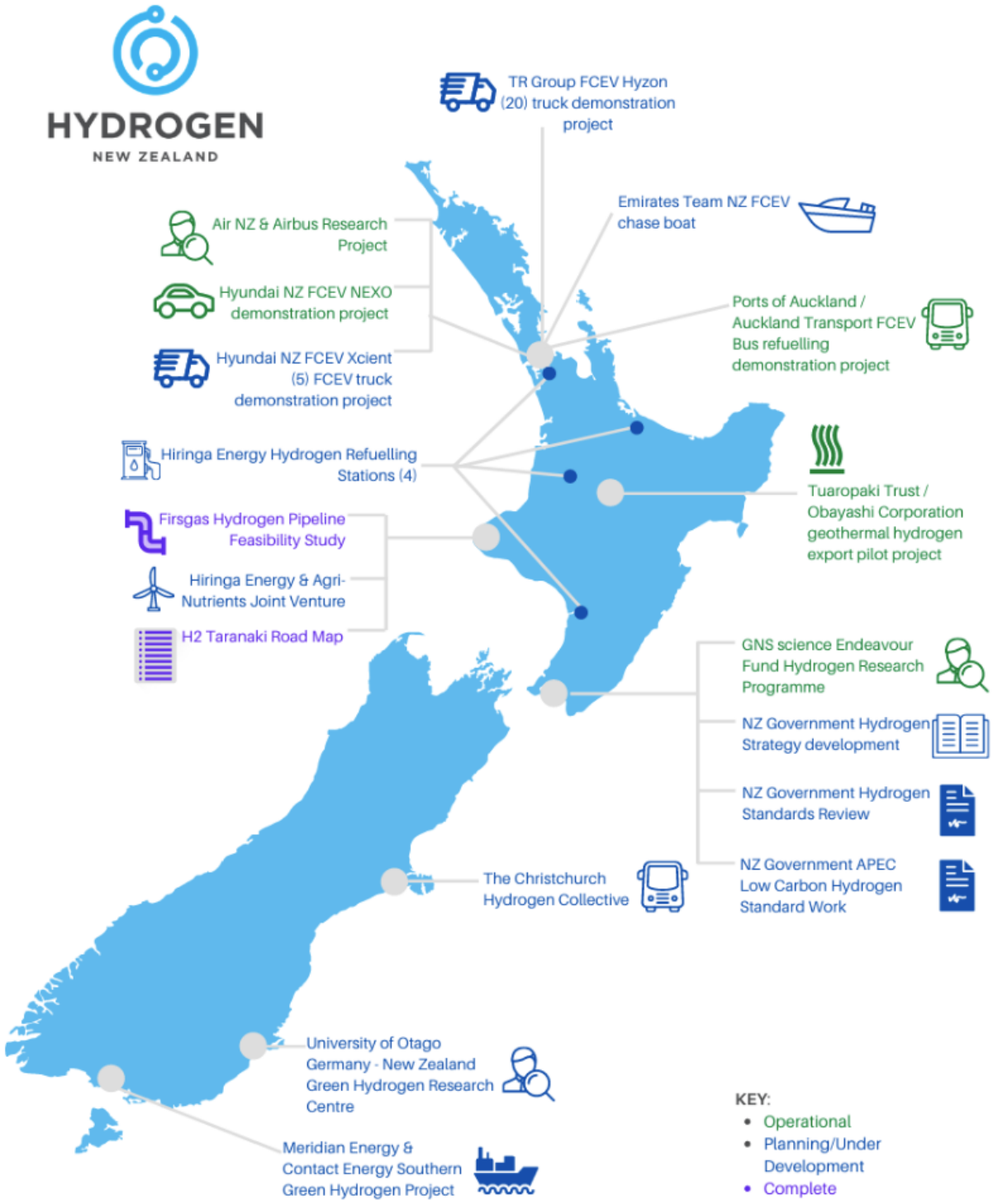

Figure 15 - Current Hydrogen Projects in New Zealand

[89] https://www.nzhydrogen.org/nz-hydrogen-projects

Policy and incentive programs

The New Zealand Hydrogen Council (NZHC) was formed in September 2018 to support the progression and uptake of low emission clean hydrogen in New Zealand. The NZHC has five (5) aims for the production, delivery, and consumption of low emission hydrogen:

1. Facilitate collaboration and cooperation with national and international governmental, institutional and private sector agencies to advance the commercialisation and uptake of low emission hydrogen for use in New Zealand and for export.
2. Support and promote the development and adoption of effective policy and internationally recognised codes, standards and regulatory frameworks for efficient and effective use of low emission hydrogen infrastructure and associated technologies.
3. Deliver and facilitate the collection and dissemination of national and international hydrogen related information and resources.
4. Enable the realization of business opportunities in low emission hydrogen through linkages with technology developers, service providers, research capability, operational partners and financiers in New Zealand and worldwide.
5. Provide thought leadership in order to advance the development of a low emission hydrogen economy in New Zealand.

The New Zealand Government released a "Green Paper" entitled "A Vision for Hydrogen in New Zealand" in September 2019. The Green Paper presents the New Zealand Government's vision to harness the hydrogen opportunity for a sustainable and resilient energy future for New Zealand. The Government aims to achieve a net zero carbon economy by 2050.

Section 9: Analysis and Recommendations

The Hydrogen Council produced a 2021 analysis entitled "Policy Toolbox for Low Carbon and Renewable Hydrogen," in which it stated six key "Pillars of Efficient Policy Design":[90]

1. Make use of local strengths and benefit from cross-border cooperation
2. Create certainty through targets and commitments
3. Provide hydrogen-specific support across the value chain
4. Support robust carbon pricing
5. Adopt harmonized certification schemes
6. Factor in societal value and values

[90] https://hydrogencouncil.com/wp-content/uploads/2021/11/Hydrogen-Council_Policy-Toolbox.pdf

A review of the regions noted above provides examples for all of these pillars. We highlight specific examples from three of these recommendations below for consideration. Benchmarking against these other example regions highlights particular ways in which the Chicagoland area, the state of Illinois, and the broader Midwest are both achieving and not achieving the goals listed in the Hydrogen Council's policy toolbox.

Local strengths and cross-border cooperation

Houston, Texas

Houston regional stakeholders actively studied the role of Hydrogen beginning in 2019-2020 because it built upon the region's existing strengths. Regional leaders felt that a potential shift away from oil would leave existing infrastructure and jobs underutilized. Cross-border discussions with Louisiana were necessary to develop a coherent vision beyond the existing Gulf Coast hydrogen ecosystem. A strong analogy exists within Chicago / Northwest Indiana. The Great Lakes Compact, an agreement between US and Canadian member states to coordinate Great Lakes water withdrawals, also provides at least an initial framework for discussing regional water supply to clean hydrogen projects.

United Kingdom (UK)

The Hynet hydrogen hub within the UK illustrates a similar successful cross-border collaboration model in which Liverpool/Manchester worked across the border with North Wales to develop a shared vision for their region.

New York, Connecticut, Massachusetts, New Jersey

Governor-level support is often necessary to advance interstate initiatives. In March 2022, NY State announced coordination between CT, MA, NJ and several interstate agencies to begin a framework for their regional response to the DOE's hydrogen hub funding announcement. This Governor-level cross-border collaboration provides regional strength. Illinois and its neighboring states have not made any similar cross-border public commitments.

Alberta, Canada

Alberta, Canada intentionally built upon its fossil fuel legacy and extensive grey hydrogen production, which it claims can be fitted with carbon capture to produce the second cheapest clean hydrogen in the world. The Midwest has multiple leading strengths, including the largest nuclear capacity in the US, extensive renewables, and one of the largest freshwater sources in the world. Regional leaders must align priorities to recognize and favor these assets as a global competitive advantage.

Ceará, Brazil

The Brazilian state of Ceará, in Northeastern Brazil, recognized its physical position as the closest South American port to Europe. Building on this advantage, it sought European investment and partnerships and is developing multiple projects for exporting clean hydrogen to Europe. As the historic crossroads of the United States, with convergence of air, rail, highways, and water, the leadership of Chicago in particular should recognize that it is uniquely situated both to fuel hydrogen heavy transport vehicles and export clean hydrogen to the world.

Spain

Spain's HyDeal España, the first program of HyDeal Ambition, was led from the bottom up by large industrial companies and major private investors. Their success illustrates that a successful hydrogen hub requires the leadership of the business community to provide definitive projects that can gain the support of national and state governments.

Certainty through targets and commitments

Houston, Texas

In its 2020 regional hydrogen hub study, Houston identified that building out a Gulf Coast clean hydrogen hub would cost $565M over 10 years. Whether or not public and private sector commitments have been made is a separate discussion. Regardless, the funding target provides a number for discussion and planning. No local studies of regional hydrogen infrastructure cost buildout have been published within the greater Midwestern region, but this is a critical next step.

Los Angeles, California

Through the HyDeal LA program and Green Hydrogen Coalition, Los Angeles is telling a coherent story of its commitments with simple public messaging. A single organization coordinating public messaging of key asset owners helps to attract investment. A single regional voice signals that supply, distribution, and offtake leaders are developing synergies between their individual project plans. Consistent messaging provides certainty that each piece of the local hydrogen supply chain will in fact have partners willing to complete the ecosystem. The recent January 2022 Illinois Senate Bill SB3613, which passed both chambers in early April, provides for creation of an Illinois Hydrogen Economy Task Force. This bill at least provides high-level support for creating an organization to coordinate target and commitment messaging.

In Los Angeles, clear public commitments by major offtakers have provided certainty for supply and distribution organizations. Los Angeles Department of Water and Power (LADWP) has committed to converting its existing large natural gas power plants to

hydrogen blending. Having a large publicly committed anchor customer is likely a key reason that SoCalGas announced it will develop the Angeles Link, a new dedicated green hydrogen pipeline bringing hydrogen to the LA Basin from more rural regions of the state. There are no visibly public offtake commitments in the Chicagoland region. If large anchor customers provided commitment, this could signal the need for expansion of the region's relatively small existing hydrogen pipeline.

Finally, Los Angeles illustrates the ways in which broad energy targets play a role. The Los Angeles city council approved 100% clean energy commitment by 2035, which specifically led to LADWP's plan for hydrogen fueling at its existing LA Basin power plants. The Illinois Climate and Equitable Jobs Act (CEJA) targets 40% of electricity being provided by renewable energy by 2030, 50% by 2040 and 100% from carbon-free sources by 2050. The ambitious targets of CEJA signed into law by Governor Pritzker provide a strong basis for clean hydrogen seasonal storage and use as a power generation fuel.

Chile

Chile demonstrates that governmental funding commitments are important even when they provide only a small fraction of a project's total funding needs. Chile has recently awarded $50M to six hydrogen projects, seed funding that has attracted energy multinationals to further develop green H_2 supply. These awards provide capital to derisk the investments of the private sector, encouraging them to provide multiples of additional funding. One of two new Illinois green banks, the Climate Bank housed within the Illinois Finance Authority, should consider a similar targeted support to encourage private sector funding of Illinois hydrogen projects.[91]

Factor in Societal Value and Values

United Kingdom (UK)

The UK is demonstrating that a net zero transition actually aids in economic growth. These are industrially intensive areas (akin to the US Rust Belt) requiring decarbonization but also needing further job growth. Hydrogen developers in the UK also see themselves as contributing toward the national targets outlined in the Government's vision for a net-zero society, thereby providing civic and environmental benefits. For example, HyNet North West claims that it will be able to produce nearly 50% of the UK's hydrogen target, and single-handedly meet 80% of the UK's target for clean power in transport, homes and industry by 2030. Similar concerns arise throughout the more rural regions of Illinois and other Midwestern states, where the idea of a "just transition" away from coal requires creative options to create jobs and maintain communities. For example, retiring coal plants

[91] https://coalitionforgreencapital.com/illinois-gets-two-new-green-banks-in-historic-climate-bill/

may be repurposed for hydrogen production and potentially for clean hydrogen sales to nearby rural ammonia plants or other chemical facilities.

Section 10: Conclusions

Over the past 3 years, regions across the US and around the world have developed and begun implementing clean hydrogen strategies. In fact, nearly every region claims that it will be the lowest cost producer of clean hydrogen in the entire world. Some regions are clearly intending to import for use, others plan to export, and others may be essentially self-sufficient on their own. The Midwest has all of the assets required to be a fully self-sufficient region and may be capable of using its logistical position to export excess hydrogen outside the region. Continued review of policies, incentives, and partnerships from around the world is a critical next step. The Chicagoland area, Illinois, and the broader Midwest must develop and execute a hydrogen strategy capable of establishing this region as a strong center within the emerging global clean hydrogen sector.