GREEN HYDROGEN COALITION

HYBUILD LOS ANGELES™ PHASE 2 REPORT

Architecting the Green Hydrogen Ecosystem Vision For a Deeply Decarbonized LA

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1. EXECUTIVE SUMMARY AND KEY TAKEAWAYS

1.1 | INTRODUCTION

Green hydrogen (GH_2)[1] is an essential resource to mitigate climate change by decarbonizing hard-to-electrify sectors, such as maritime shipping, aviation, heavy-duty trucking, firm dispatchable power, high-heat industrial processes, and agriculture. In light of the current war in Ukraine and the surging fossil fuel energy prices around the world, GH_2 can also be a resource to support energy cost stability and greater global energy security. Moreover, GH_2 can support a just and equitable clean energy transition by helping to reduce environmental burdens, while creating family-sustaining job opportunities across sectors.

The United States has reached a pivotal moment for the GH_2 market. The federal government passed two landmark laws – the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA) – which together enable $479 billion in new climate and energy spending.[2] Near-term opportunities are driving swift action from the private and public sectors alike, including the $8 billion Department of Energy (DOE) funding opportunity for regional clean hydrogen (H_2) hubs. Beyond these near-term grants and incentives, driving a market for GH_2 production and use at scale will require unprecedented collaboration across sectors, innovation in technology and policy, new and expanded regulatory and permitting frameworks, and inclusivity.

HyBuild North America™ is the Green Hydrogen Coalition's (GHC) collaborative platform to architect mass-scale GH_2 hubs across the continent. Los Angeles was selected as the first focus region due to its abundance of large-scale offtakers, forward-thinking local leadership, robust decarbonization policies, and ample renewable energy resources for GH_2 production.

HyBuild Los Angeles™ brings together the GH_2 value chain and stakeholder ecosystem across the LA Basin, including GH_2 production, transport, storage, multi-sectoral offtakers, labor unions, environmental and environmental justice leaders, tribal nations, and other interested parties. The platform combines robust technical analysis and stakeholder engagement to facilitate alignment and identify key areas for action to advance a GH_2 economy at scale. Together, this collaborative group unlocked a vision to achieve $2.05/kilogram (kg) of delivered GH_2 by 2030, while identifying and maximizing community benefits from the clean energy transition.[3] Factoring in tax benefits from the recently enacted IRA, this delivered cost estimate is further reduced to $0.69/kg. This target is consistent with the DOE's Hydrogen Earthshot, which establishes a goal of achieving "$1 per 1 kilogram [$H_2$ produced] in 1 decade."[4]

HyBuild LA set out to determine if it is commercially and technically possible to create a mass-scale GH_2 ecosystem that displaces fossil fuels across multiple sectors.[5] The results of HyBuild LA represent a high-level vision and scenario, but the GHC recognizes that a variety of pathways may be pursued to achieve decarbonization in the future. The ultimate roadmap for LA and California will require significant additional research and stakeholder engagement with local communities.

1.2 | HYBUILD LOS ANGELES SCOPE

Over the past two years, HyBuild Los Angeles has focused on developing a mass-scale GH_2 ecosystem in the Los Angeles Basin. The GHC refers to "mass-scale" as the aggregation of a minimum of 0.3–0.5 million metric tons (MMT) GH_2 per year of multi-sectoral demand in targeted locations. Broader industry experience has demonstrated that these volumes are sufficient to take advantage of economies of scale – in particular, enabling establishment of dedicated (100%) GH_2 pipeline transport to significantly reduce the delivered costs for GH_2.[6] This demand would also significantly support the U.S. DOE's National Clean Hydrogen Strategy and Roadmap production target of 10 MMT per year by 2030, 20 MMT per year by 2040, and 50 MMT per year by 2050.[7]

1. The Green Hydrogen Coalition defines "green hydrogen" as hydrogen which is produced from non-fossil fuel feedstocks and has climate integrity. GHC supports a well-to-gate carbon intensity framework consistent with the International Partnership for Hydrgoen and Fuel Cells in the Economy to establish climate integrity.
2. Tom Baker, et al., "US Inflation Reduction Act: Clean Tech Growth Opportunities & Value Pools," Boston Consulting Group, October 2022.
3. This LCOH represents the estimated cost per kilogram delivered to the pipeline backbone. The cost includes electrolytic production of GH_2, wastewater treatment infrastructure, compression, transportation of GH_2 via dedicated (100%) GH_2 pipeline, and mass-scale storage.
4. Hydrogen and Fuel Cell Technologies Office, "Hydrogen Shot," Office of Energy Efficiency & Renewable Energy, Accessed February 8, 2023.
5. In HyBuild LA, technically feasible refers to only utilizing GH_2 production, transport, and storage technologies that are commercially available today.
6. Based on Corporate Value Associate's modeling and interviews with industry stakeholders, transport and distribution become significant cost drivers for GH_2 at delivery volumes under this threshold.
7. U.S. Department of Energy, "DOE National Clean Hydrogen Strategy and Roadmap," September 2022.

The platform focused on the following areas of GH_2 hub ecosystem development:

System Plan Design	• Establish an end-to-end system vision, including qualified annual demand, transportation, storage, and upstream production sources • Develop a levelized cost of GH_2 based on a mass-scale, full system cost • Perform a focused assessment on potential water resources for electrolytic GH_2 production
Community Impacts Analyses and Stakeholder Engagement	• Engage directly with key ecosystem stakeholders, including environmental justice groups, labor unions, and tribal representatives • Assess some of the impacts of a GH_2 economy at scale, including job creation potential and pollution reduction (for the entire South Coast Air Basin and specifically within Disadvantaged Communities)
Policy and Regulatory Innovation	• Develop a suite of policy and regulatory solutions that address key barriers to a scaled GH_2 hub, promote innovation, and reduce costs • Conduct a GH_2 "readiness assessment" of state and local H_2 regulation and oversight applicable to GH_2 systems in California
Contracts and Bankability	• Establish high-level contract terms and conditions to underpin large-scale investments

Due to funding and capacity constraints, the scope and scenarios evaluated in HyBuild LA were limited. For this reason, the analysis does not include the following topics:

- Non-electrolytic pathways for producing GH_2, such as organic waste-to-GH_2
- Environmental impacts related to construction of any portion of the ecosystem
- Potential for and impacts of fugitive H_2 leakage

Any infrastructure investments should be evaluated in accordance with federal, state, and local regulatory and permitting requirements, including a full evaluation of potential safety and environmental impacts, alongside meaningful engagement of communities that would be impacted.

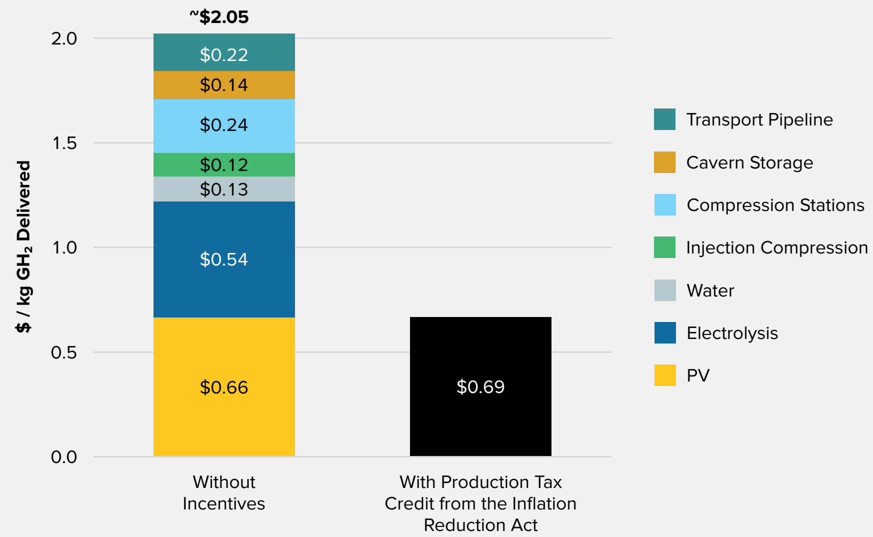
1.3 | KEY TAKEAWAYS

Los Angeles (LA) can achieve \$2.05/kg delivered GH_2 by 2030, even without incentives. With the tax benefits from the recently enacted IRA, LA's cost of delivered GH_2 can drop to \$0.69/kg.

Based on a total demand scenario of 1.4 million metric tons of annual GH_2 demand (roughly 3,836 tons/day), HyBuild LA finds that the LA Basin can achieve a cost of \$2.05/kg delivered by 2030 without financial incentives. This levelized cost of delivered hydrogen (LCOH) would make GH_2 competitive with fossil fuels, enabling cost-effective adoption across many hard-to-abate sectors.[8] For example, at this LCOH, the total cost of ownership for heavy duty fuel cell trucks would be cost-competitive with diesel trucks, even after factoring in incremental costs to establish local GH_2 fueling infrastructure.

8. The energy in 2.2 pounds (1 kilogram) of H_2 gas is about the same as the energy in 1 gallon (6.2 pounds, 2.8 kilograms) of gasoline. See: U.S. Department of Energy, "Hydrogen Basics," Alternative Fuels Data Center, Accessed February 8, 2023.

Figure 1 | HyBuild LA levelized cost ($/kg) of delivered GH_2 in 2030, broken down by value chain element. Based on a total estimated demand of 1.4 MMT annually.



Source: Corporate Value Associates Analysis for HyBuild LA, 2022

When factoring in the Clean H_2 Production Tax Credit (PTC) from the IRA, the levelized cost of GH_2 has the potential to reach $0.69/kg.[9] At this price, fuel cell trucks would be highly competitive with diesel alternatives as soon as 2026, substantially accelerating market uptake.

This levelized cost of GH_2 represents an end-to-end system vision for the LA region and includes the following system elements:

Figure 2 | Key infrastructure parameters of the HyBuild LA GH_2 system plan included in the levelized cost of GH_2.

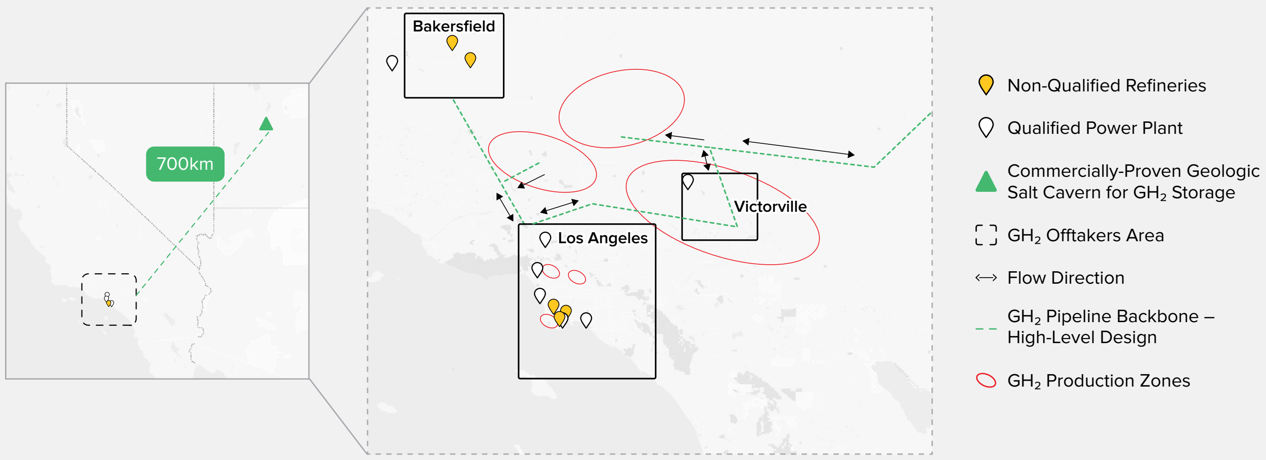
Upstream	**Solar PV Installations**	**28 GWp** – Combined plant capacity **75 TWh** – PV electricity produced per year
	Electrolyzers	**22 GWe** – Combined electrolyzer size **37%** – Average load factor **1.4Mt GH_2** – Annual production of GH_2
	Compression at Injection	**310 MW** – Cumulative compressor capacities **445t GH_2/h** – Max flow
Midstream	**Compressor Stations**	**620 MW** – Cumulative capacities of all compressor stations
	Underground Storage	**130kt GH_2** – Effective maximal capacity **1430M Nm^3** – Effective maximal volume
Downstream	**GH_2 Transport Pipelines**	**1,300 miles** – GH_2 pipeline backbone

9. This analysis assumed that all GH_2 producers would meet the workforce development and other relevant requirements need to receive the full tax credit of $3.00/kg GH_2.

Shared, scaled infrastructure – namely, a dedicated GH_2 pipeline connected to a geologic salt cavern storage resource – is essential to achieving low delivered cost and widespread GH_2 adoption.

A key driver to achieving low delivered cost of GH_2 is shared infrastructure, including transportation via a dedicated (100%) GH_2 pipeline and access to underground geologic salt cavern storage.[10] The HyBuild LA scenario includes a bidirectional transmission pipeline connection with the closest commercially proven salt caverns to California, located in central Utah.[11,12]

Figure 3 | HyBuild Los Angeles Illustrative System Plan.



Note: Electrolytic GH_2 can be produced in Southern California and along the pipeline route. This map is illustrative and does not include all potential offtakers. Refineries and power plants are shown as sample potential offtakers.
Source: Corporate Value Associates Analysis for HyBuild LA, 2021

The end-to-end system vision from HyBuild LA – including the infrastructure required to produce, transport, store, and deliver mass-scale GH_2, and the local liquefaction and fueling infrastructure needed for mobility applications – is estimated to cost about $34 billion over 10 years. It is expected that this infrastructure investment will be stimulated by regional and federal government investment alongside significant private sector investment, helping to support regional economic growth.

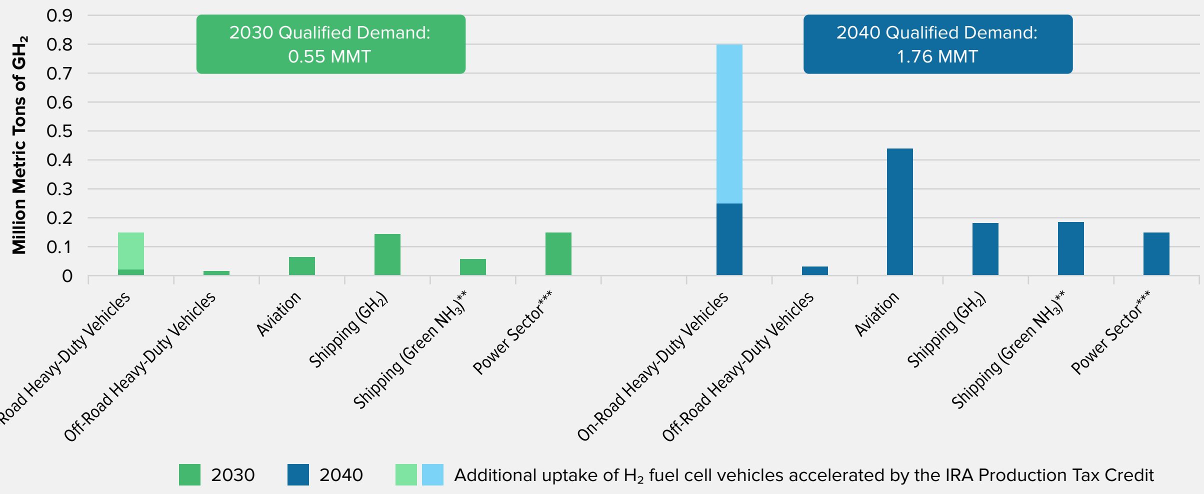
The power sector's use of GH_2 as a clean, firm dispatchable power resource is a strategically important step to jumpstart a GH_2 economy in LA.

Los Angeles is home to a variety of industries that can utilize large quantities of GH_2, including a maritime shipping sector that serves the largest port in the nation, a significant transportation sector for heavy-duty vehicles (e.g., heavy-duty trucks, long-distance coach buses), and a power sector with demand for a clean, firm dispatchable resource to support local electric reliability.

In total, HyBuild LA identified 0.54 MMT of "qualified demand" in 2030.[13] Importantly, this demand is part of a larger, system-wide demand forecast of 1.4 MMT of GH_2 per year in 2030. The 1.4 MMT total demand estimate includes potential "unqualified demand" of 0.85 MMT of GH_2 per year in refineries, which assumes that a portion of fossil-fuel derived H_2 utilized today would be replaced with GH_2.[14]

10. An appropriate tracking and accounting system will need to be established to ensure the carbon intensity of GH_2 in the pipeline system.
11. Aces Delta, "Advanced Clean Energy Storage Hub," Accessed February 8, 2023.
12. Multiple underground salt caverns for H_2 storage are already operational in United States, such as the Linde facility which has been operating for over a decade in Texas. See: Linde Hydrogen, "Storing Hydrogen in Underground Salt Caverns," Accessed February 8, 2023.
13. "Qualified demand" refers to potential demand that was validated through industry interviews or public announcements confirming a future interest or intention to purchase GH_2 if it becomes cost-competitive with existing fuels.
14. HyBuild LA outreached to multiple oil refineries in the LA Basin and were not able to obtain confirmation of plans to switch from grey to green H_2.

Figure 4 | Qualified GH_2 demand in the LA Basin projected for 2030 and 2040, by sector.*



*Potential refinery demand has not been qualified, but may represent up to 0.85 million metric tons of demand annually.
**Due to safety concerns, green NH_3 is unlikely to be produced in the LA Basin from local GH_2 feedstocks.
***2040 Power sector demand was not formally analyzed. However, it is not expected to grow at the same rate as mobility applications.
Source: Corporate Value Associates and American Bureau of Shipping Analysis for HyBuild LA, 2022

Most of the end uses shown in Figure 4 will require an assured, consistent supply of low-cost GH_2 throughout the year. As noted in section 1.3.2, HyBuild LA found that shared infrastructure (transportation via a dedicated GH_2 pipeline and mass-scale underground geologic salt cavern storage) provides the most cost-effective pathway to achieve a stable supply of GH_2 at a low-delivered cost.

To jumpstart the ecosystem and attract the necessary capital investments for shared infrastructure, LA will need visibility into bankable, large-scale offtakers. As a point of reference, the world's largest clean H_2 hub in Europe was enabled by offtake commitments from steel and fertilizer makers, which can utilize large volumes of GH_2 in the near-term. HyBuild LA interviewed and researched a variety of potential "first-movers," and a number of industrial end users.

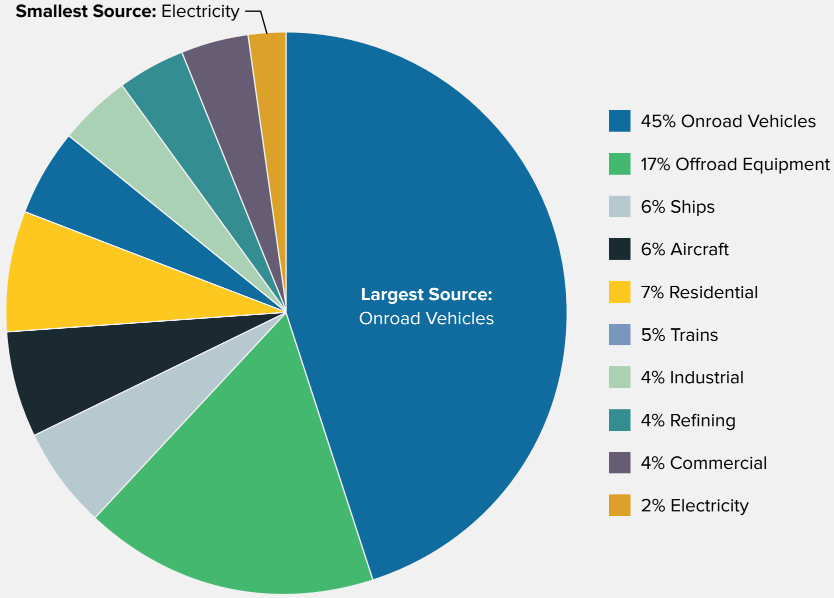
Among those potential applications evaluated, the power sector's need for clean, firm power resources was identified as a key application that requires large quantities of GH_2 near-term, satisfying the City of LA's mandate to achieve 100% renewable energy in the power sector by 2035. Modernization of existing power plants needed for grid reliability (i.e., converting natural gas turbines to greenhouse gas-free GH_2-fueled turbines) enables development of scaled GH_2 supply infrastructure while reusing existing power sector infrastructure, helping the LA Basin to achieve 100% affordable, resilient, and reliable clean energy.

Stable, low-cost supply of GH_2 will enable nearby mobility sectors – which are still heavily reliant on fossil fuels – to transition to GH_2-fueled equipment. Displacing fossil fuels for hard-to-electrify mobility end uses is critical to improve air quality in the region, as combustion of fossil fuels from these sectors (i.e., on-road mobility, materials handling, maritime shipping, and aviation) is collectively responsible for more than 75% of total NOx emissions in Southern California.[15] Interviews from HyBuild LA indicated that fleet owners and operators will not transition to fuel cell equipment until mass-scale, lower cost GH_2 is available. In this regard, power sector applications are highly strategic to launching LA's scaled GH_2 economy to achieve economy-wide decarbonization and pollution reduction.

Although the power sector represents a relatively small share of the region's total nitrogen oxides (NOx) emissions today (<2%), it is critically important that any power plant conversion from natural gas to GHG-free GH_2 combustion undergo environmental review and permitting. This should include permitting that requires NOx emissions from GH_2 combustion to remain at or below all applicable state and local emissions requirements for power plants.

15. California Air Resources Board, "Emissions Projections by Summary Category."

Figure 5 | Existing Southern California NOx emissions by source.

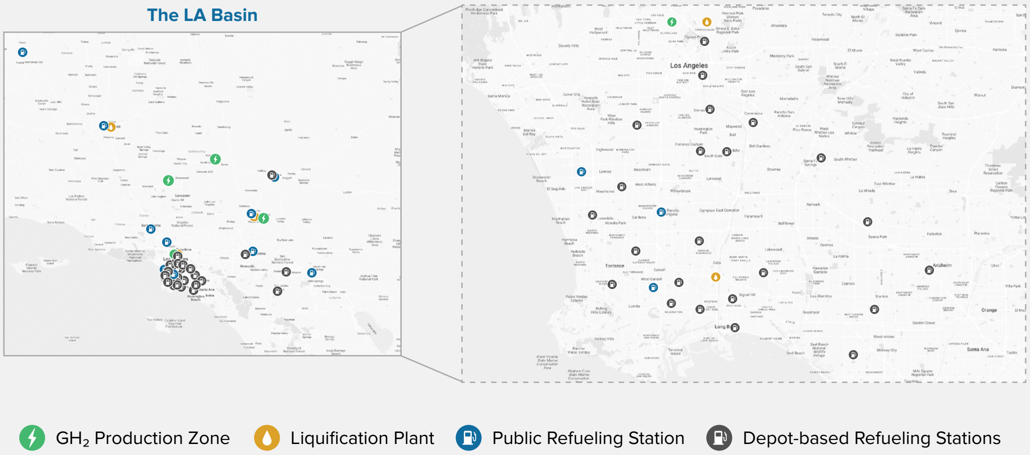


Source: California Air Resources Board.

Serving heavy-duty mobility end uses in the LA Basin will require additional infrastructure, such as local GH_2 compression and liquefaction. Additionally, aviation and maritime shipping sectors will require infrastructure for the production of GH_2 derivative fuels. GH_2 is key to displacing fossil fuels in a variety of difficult-to-electrify mobility sectors such as heavy-duty trucking, offroad equipment with long duty cycles, maritime shipping, and aviation. To ensure a realistic GH_2 adoption scenario, the HyBuild LA demand assessment only considered end uses where GH_2 was considered more cost-effective than alternate decarbonization pathways, such as battery electric options.

By 2040, heavy-duty mobility (including drayage trucks and long-distance buses) is projected to require close to 0.8 million tons of GH_2 per year. To meet this demand, GH_2 fueling stations that are not located near a pipeline are predicted to be served with liquid GH_2 via truck delivery. Liquid GH_2 was selected for the system plan due to its volumetric density for efficient delivery and the maturity of related technologies.

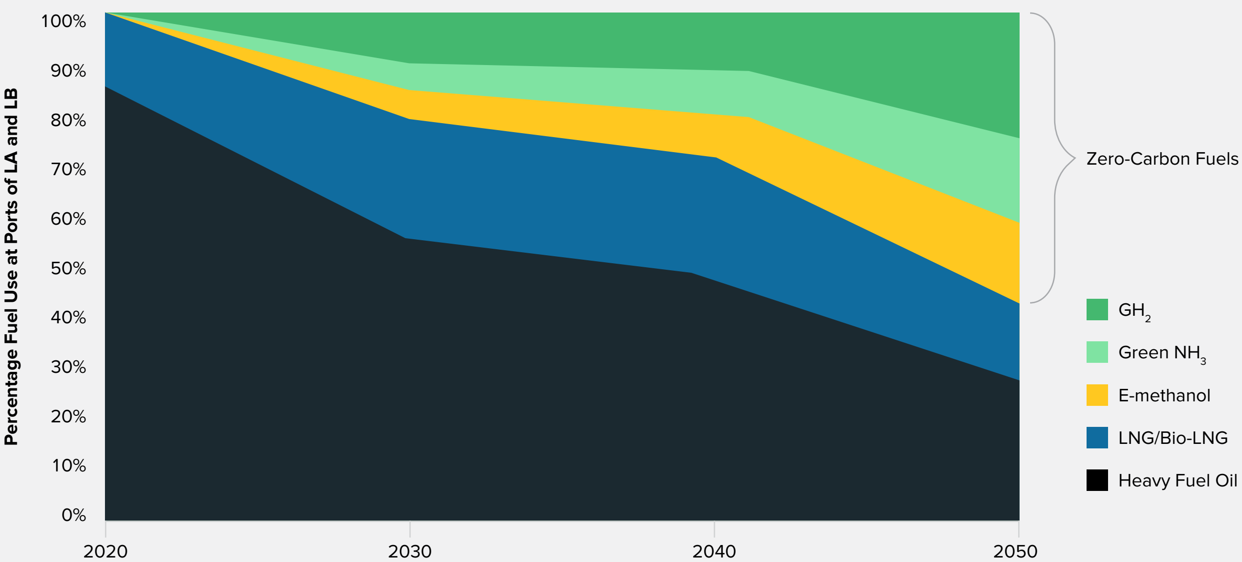
Figure 6 | Illustrative high-level GH_2 system design for mobility applications in 2030.



Note: This map is illustrative. Final location of liquefaction stations and other infrastructure may be impacted by final location of pipeline infrstructure.
Source: Source: Corporate Value Associates for HyBuild LA, 2022

By 2050, over half of the ships entering into the Ports of LA and Long Beach will be powered by zero-carbon fuels, according to the American Bureau of Shipping's analysis for HyBuild LA. GH_2 will play a crucial role in the overall fuel mix, both as a direct fuel and a decarbonized resource to create green ammonia (NH_3) and e-methanol. This transition will be accelerated by already enacted resolutions from both the Cities of Los Angeles and Long Beach, calling on major importers to commit to achieving 100% zero-emissions shipping by 2030.[16]

Figure 7 | Potential adoption of zero carbon fuels in the maritime shipping sector by percentage of total fuel use at the ports of Los Angeles and Long Beach.



Source: American Bureau of Shipping Analysis for HyBuild LA, 2022

16. Ship It Zero Coalition "Setting Sail on a Zero-emissions Shipping Industry by 2030," Accessed February 8, 2023.

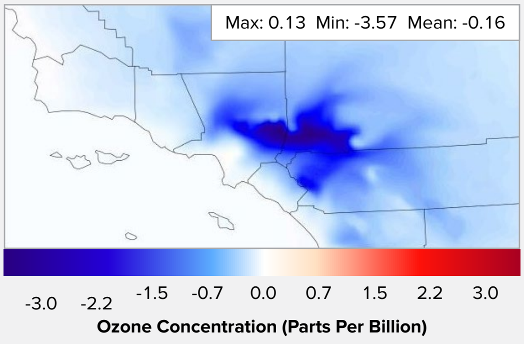
By 2040, aviation will represent the second-largest sector of demand in the LA Basin. GH_2 will primarily be utilized to produce sustainable aviation fuel (SAF) for domestic and international flights departing from Los Angeles International Airport (LAX). SAF is a drop-in fuel for low-carbon aviation that can be blended into fossil jet fuel. Direct use of GH_2 to power short-range flights via fuel cells or combustion may also begin as early as 2035,[17,18] although industry stakeholders expect that this application of GH_2 will ramp up post-2040.

GH_2 use in mobility and materials handling applications will yield significant air quality improvements, resulting in measurable public health benefits.

The use of GH_2 in fuel cells can directly displace fossil fuel use in many hard-to-electrify applications that cause significant pollution (e.g., heavy-duty trucking, port operations equipment with long duty-cycles, and aviation). Since the only emission from GH_2 usage in fuel cells is water vapor, the adoption of GH_2 fuel cell equipment can greatly reduce harmful local pollutants such as NOx and dramatically improve air quality for residents of LA and the greater South Coast Air Basin.

HyBuild LA evaluated the impacts of using GH_2 fuel cell technology in place of diesel combustion equipment for specific hard-to-electrify end uses (heavy-duty trucks, drayage trucks, port equipment forklifts with long duty cycles, and long-distance buses) via an atmospheric modeling study with the University of California, Irvine (UCI). It should be noted that the air quality analysis only modeled emissions reductions associated with mobility use cases where GH_2 in fuel cells was found to be more competitive on a total cost of ownership basis than battery electrification. The figure below demonstrates that the substantial impact the GH_2 adoption scenario (in place of fossil fuel combustion) can have to reduce pollution from these end uses regionally, resulting in benefits such as improvements in ground-level ozone, a pollutant which is caused by NOx and is a key component in smog. The improvements shown in Figure 8 can reduce 23% of ozone non-compliance events with state and federal clean air standards, which is significant given that portions of the region studied (Los Angeles-Long Beach; Bakersfield) experience some of the worst ozone pollution in the United States.[19]

Figure 8 | Improvements in maximum daily 8-hour average ozone (ppb) in July 2045 due to the GH_2 deployment scenario analyzed.



Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

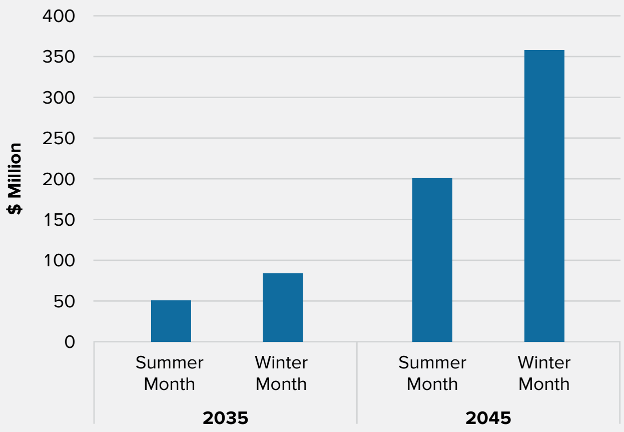
17. Airbus, “ZEROe: Towards the world’s first zero-emission commercial aircraft,” Accessed February 8, 2023.
18. Some technology providers, such as Zeroavia, have indicated potential for this technology to be commercialized sooner. See: ZeroAvia, “About us,” Accessed February 8, 2023.
19. American Lung Association, “Most Polluted Cities,” Accessed February 8, 2023.

In total, the improvements in air quality from reduction of the pollutants modeled (ozone and $PM_{2.5}$) would result in measurable public health benefits. Due to computational limitations of the atmospheric model, the UCI analysis measured the impacts during four sample months, one winter month and one summer month in 2035 and 2045.[20] The modeled data for only these four months found that communities in the South Coast Air Basin would experience public health improvements, including:

- 27 fewer premature deaths
- 964 fewer hospitalizations for respiratory and cardiovascular illness
- 7,500 fewer work loss days

For the months modeled, these quality-of-life improvements translate into values exceeding $689 million.

Figure 9 | Estimated value of health benefits for one summer and one winter month associated with the GH_2 adoption scenario modeled in 2035 and 2045.



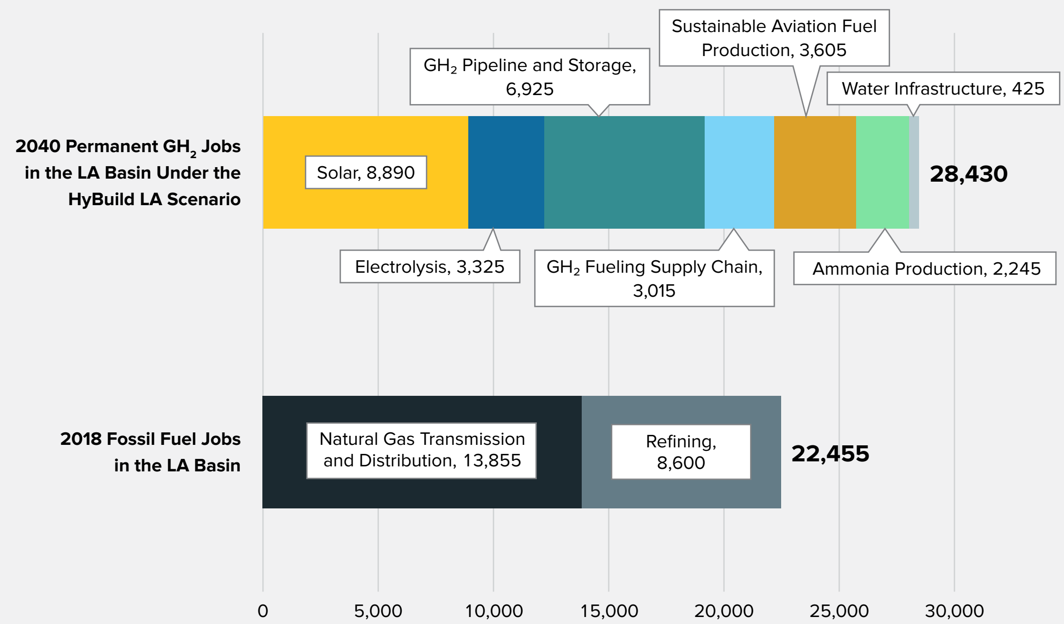
Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

The GH_2 economy will generate diversely skilled jobs, exceeding the quantity of jobs from the incumbent fossil fuel industries in Southern California.

The vision established in HyBuild LA has the potential to create over 28,430 high-quality, full-time jobs to support the range of activities across the value chain needed to serve the LA Basin's GH_2 demand.

20. Given the highly computational nature of these models, the study evaluates one summer month (July) and one winter month (January) for both 2035 and 2045 to demonstrate the effect of seasonal variation.

Figure 10 | 2040 full-time employment in the LA Basin resulting from the HyBuild LA system plan scenario.



Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

More than 65% of these jobs will be in sectors requiring similar skills to incumbent fossil energy jobs,[21] which will create opportunities for workers to transition into the clean energy economy. With the incumbent fossil fuel industry providing over 22,400 jobs in 2040 – many of which are family-sustaining, union jobs – the GH_2 industry can provide meaningful preservation and creation of high-quality jobs and economic development.

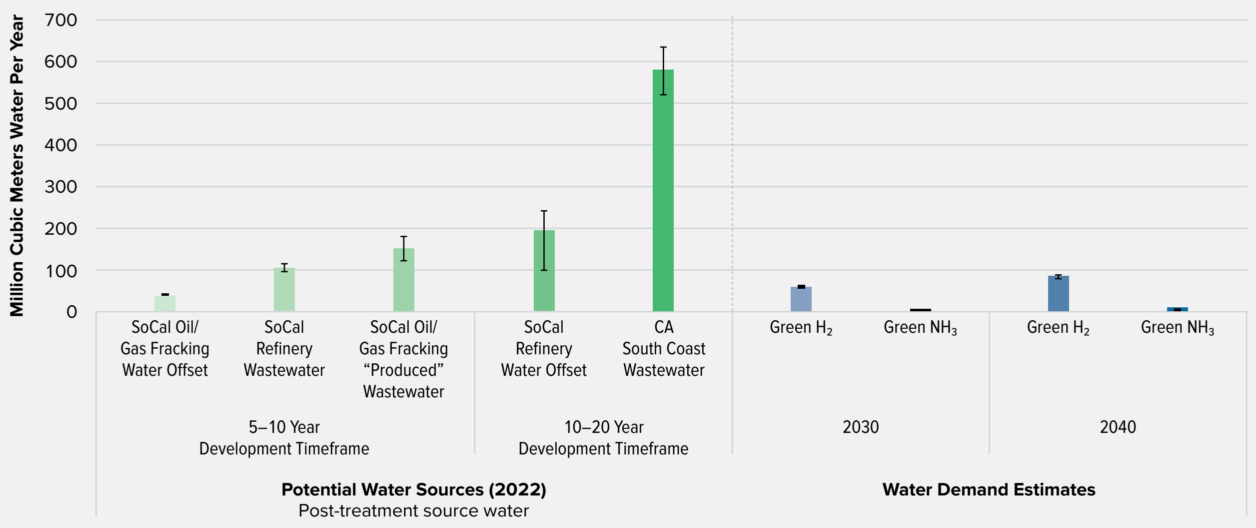
> **"GH_2 is a key technology for both deep decarbonization and the preservation and creation of high-quality, family-sustaining jobs. H_2 can reduce emissions while leveraging both our existing infrastructure and the skills that exist in the current workforce."**
>
> **Brad Markell**
> Executive Director,
> AFL-CIO

21. Jobs considered similar include: GH_2 pipeline and storage; GH_2 derivative fuel production (i.e., green NH_3, e-methanol, SAF); GH_2 fueling supply chain; water infrastructure.

Water needs for electrolytic GH_2 production in the LA Basin can be fully met from wastewater sources for approximately $0.07 – 0.13/kg of GH_2. Demand for recycled or repurposed water for GH_2 production can help accelerate needed investments in wastewater treatment infrastructure.

Considering the severe drought conditions across the Western United States, HyBuild LA modeled the feasibility of utilizing recycled or repurposed water for electrolytic GH_2 production to meet anticipated demand in the LA Basin. The study, conducted by Pacific Northwest National Labs (PNNL), found ample potential sources for recycled wastewater and repurposed water for GH_2 production. Further, the infrastructure required to supply recycled wastewater will only marginally impact delivered GH_2 delivered cost (total water and associated infrastructure costs amount to $0.07–$0.13/kg).[22]

Figure 11 | Potential sources of recycled or repurposed water compared to the water demand of the HyBuild LA scenario.



Note: Error bars represent ranges in model inputs from data sources.
Source: Pacific Northwest National Laboratory for HyBuild LA, 2022

Looking forward, growing demands for recycled wastewater for GH_2 production can help drive private sector investment in water infrastructure that can benefit all Angelenos. It will be critical to further evaluate how water infrastructure needs identified in the water analysis can be supportive of the City of LA's existing plans to recycle 100% of its wastewater by 2035 to reduce reliance on imported water.[23] Notably, any private sector investments from the GH_2 sector into wastewater infrastructure may effectively reduce the cost burden on customers/ratepayers of meeting recycled wastewater goals.

22. Municipal water costs were estimated based on an average of residential rates in California during HyBuild LA Phase 1, which was calculated to be around 3.70 USD / cubic meter (~$10.00 per 100 cubic feet). See: UNC School of Government, “California Small Water Systems Rates Dashboard,” July 1, 2020. The incremental cost of utilizing wastewater would increase costs by $0.04 - $0.10/kg GH_2.

23. Los Angeles Department of Water and Power, “Mayor Garcetti: Los Angeles Will Recycle 100% of City's Wastewater by 2035,” February 2019.

Expanding the HyBuild LA vision to serve demand in Northern California yields important statewide system benefits. HyBuild LA analyzed a scenario that extends its Southern California GH_2 system vision to serve large-scale demand for GH_2 in Northern California. The analysis identified key synergies that may be realized from a dedicated GH_2 pipeline that connects Southern and Northern California. This system:

- **Enables Northern California to connect to out-of-state geologic salt cavern resources for storage**
  Direct connection to out-of-state geologic salt caverns from Northern California is likely infeasible, as the route would cross the national forests in the Sierra Nevada Mountains. By following existing rights-of-way to establish a connection with Southern California, Northern California can share the link to out-of-state storage resource needed for system balancing.

- **Lowers the cost of electrolytic GH_2 in Northern California by taking advantage of Southern California's solar resources**
  If connected to GH_2 supply from Southern California, Northern California can access its high-yield solar resources, lowering the upstream costs of electrolytic GH_2 by around 15%.

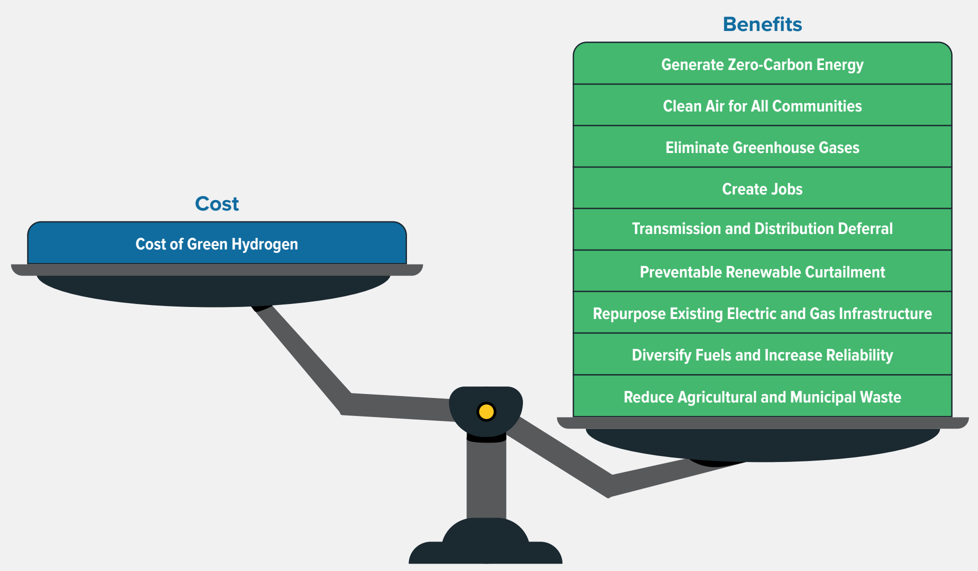
  This connective infrastructure may also unlock potential GH_2 production from organic waste sources throughout the Central Valley. Waste-to-GH_2 pathways, such as gasification of agricultural waste via pyrolysis, can reroute waste streams that have historically been open burned, a process that contributes significantly to local pollution and will be banned by 2025.[24]

- **Enables cost-competitive production of green ammonia (NH_3) for decarbonized shipping and agriculture**
  Once connected to stable GH_2 supply via access to geologic salt cavern storage, green NH_3 can be produced in Northern California and utilized to eliminate the carbon footprint of the fertilizer industry, reduce reliance on NH_3 imports, and power the clean maritime shipping industry.

1.4 | NEXT STEPS: POLICY & REGULATORY INNOVATION

California must accelerate state policy and regulatory innovation to remove implementation barriers and make California the model market for GH_2. Significant policy and regulatory actions are needed to enable private sector investments and jumpstart the state's GH_2 economy.

Figure 12 | Valuing stacked benefits of GH_2.



24. San Joaquin Valley Air Pollution Control District, "Agricultural Burning," Accessed February 8, 2023.

The GHC has developed a suite of policy and regulatory solutions that address barriers to a mass-scale GH_2 hub, promote innovation, and drive down the cost of GH_2 in recognition of its benefits. While the recommendations are written from a California perspective, many are applicable in jurisdictions throughout the United States.

To support the HyBuild LA vision, the GHC recommends the following enabling actions:

Policy and Regulatory Objective	Motivation	Key Actions
Adopt a Statewide Green or Renewable H_2 Definition	Today, each relevant California agency utilizes a different definition for green and/or renewable H_2. Without a common, established definition, it is challenging to establish GH_2 eligibility for compliance with existing state policy and programs. It is also challenging to make efficient, coordinated progress on the development of needed policies and programs to accelerate progress.	Direct state agencies to adopt a universal definition of "renewable H_2" so that eligibility for existing and future state programs, incentives, mandates, and procurement opportunities is clear. The GHC also recommends adopting an internationally recognized well-to-gate lifecycle carbon intensity (CI) framework for green and renewable H_2, which will enable consistency with federal CI requirements for tax incentive eligibility.[25]
Clarify GH_2 Infrastructure Permitting and Siting	The development of GH_2 infrastructure (e.g., production, storage, transport, and dispensing facilities) in California is challenging as a result of complex state and local permitting requirements, differing requirements across local jurisdictions, and insufficient opportunities for community engagement with respect to implementing new infrastructure. Limited understanding of existing standards for GH_2, along with complex permitting and siting requirements, will increase project costs and the timelines required for development.	Direct state agencies to jointly develop a permitting guidebook for the GH_2 supply chain (e.g., production, storage, transport, dispensing, facilities) to help stakeholders – including municipalities – responsibly navigate and safely implement GH_2 projects and infrastructure. As H_2 is already a globally traded commodity, this guidebook may also compile existing safety guidance and best practices from around the world. This guidebook should include optimal locations for permitting and siting GH_2 infrastructure based on: existing local, state, and federal regulation, and the lowest possible burden and risk to local communities.
Conduct a Water Regulation Assessment for GH_2 Production	There is not yet a sufficient understanding of water use regulations by local jurisdiction across the state, particularly for electrolytic GH_2 production. Lack of such knowledge could impact the ability to optimize GH_2 production facility siting.	Assess water use regulations and identify the pros, cons, and implications of using different water resources (e.g., municipal and industrial recycled waste water) for GH_2 production in different regions of the state, based on existing regulations. Publish and clarify findings for all stakeholders.
Certify Technology-Agnostic Renewable H_2 Eligibility in California's Renewable Portfolio Standard (RPS)	Currently, fuel cells are the only RPS-eligible technology that utilize renewable H_2. As a result, California's RPS Eligibility Guidebook does not allow other commercially available and environmentally responsible renewable H_2 technologies – such as combustion turbines and linear generators – to participate in the RPS program.[26] Such technologies can provide clean, firm dispatchable power for grid reliability and resiliency benefits.	Modify the RPS Eligibility Guidebook to ensure all environmentally responsible renewable H_2-capable technologies can participate in the RPS program.[27] Ensure that if the facility uses a combustion process to generate electricity, the combustion process must be appropriately controlled and regulated to meet all required emissions requirements.
Develop A Vision For A 100% GH_2 Pipeline Network in California, WhichWould Eventually Be Interconnected with Other Hubs Emerging Through DOE's Regional Clean H_2 Hubs Program	Coordinated planning is essential to accelerate the development of needed GH_2 infrastructure for California and the broader U.S. Without a plan for a statewide 100% GH_2 pipeline backbone and distribution network, GH_2 transportation will have to occur via truck or rail, which would dramatically increase the final delivered cost of GH_2 and limit scalability. Additionally, the lack of a statewide long-term gas planning strategy prevents important discussions – regarding, for example, the appropriate way to repurpose pipelines – which will impede GH_2 pipeline development.	Require state agencies to jointly develop a statewide vision for establishing a regionally-interconnected California GH_2 backbone. This vision would augment long-term gas system planning to include the evaluation and development of a transition plan to retrofit or replace existing natural gas pipelines with a 100% dedicated GH_2 pipeline backbone and distribution network, analogous to what is being done in Europe via the European H_2 Backbone Initiative.[28]

25. Green Hydrogen Coalition, et al., "IIJA 'Clean Hydrogen' Carbon Intensity Framework," March 14, 2022.
26. Lin, Janice, "RPS Eligibility of Renewable Hydrogen Gas Turbines," The Green Hydrogen Coalition, October 5, 2021.
27. Ibid.
28. European Hydrogen Backbone, "The EHB initiative," Accessed February 8, 2023.

Clarify Jurisdictional Authority for Interstate Dedicated GH_2 Pipelines	Ambiguity exists regarding the entity that has interstate regulatory authority over 100% dedicated GH_2 pipelines. If left unresolved, uncertainty around jurisdictional authority will impede project development, regional pipeline infrastructure progress, access to out-of-state geologic salt caverns for GH_2 storage, and California's ability to achieve mass-scale GH_2 at low delivered cost.	Collaborate with neighboring states and other regional/national institutions to develop the appropriate regulatory or legislative pathways. This is needed to clarify the appropriate regulatory authority to approve and regulate interstate 100% dedicated GH_2 pipelines.
Establish a Safe GH_2 Blending Standard in the Natural Gas Network	Today, transporting GH_2 via truck and rail makes delivered GH_2 unnecessarily expensive. The most cost-effective way to transport GH_2 is via pipeline. While it is estimated to take several years to develop and deploy dedicated GH_2 pipelines, existing natural gas pipeline infrastructure may be able to catalyze progress by storing and transporting GH_2 at certain blending percentages. However, current policy does not allow for this opportunity, from the recent UC Riverside Study, which demonstrated that GH_2 can be safely blended into the existing natural gas grid at fractions at or below 5%.[29]	Establish an interim GH_2 blending standard at a volume fraction of 5% to begin moving GH_2 molecules through California's natural gas pipeline network to catalyze market development in the near-term. The standard should prioritize blending GH_2 into the natural gas system for hard-to-electrify sectors that require an alternative to electrification. While the GHC supports blending as a near-term solution to catalyze the GH_2 ecosystem, blending alone will not achieve the mass-scale vision established by HyBuild LA. Because of the scale, this vision requires dedicated 100% GH_2 pipeline infrastructure connected to out-of-state underground GH_2 storage in commercially-proven geologic salt caverns.
Expand California's Renewable Gas Mandate to Include GH_2	The CPUC, under the direction of Senate Bill 1440 (2017-2018),[30] approved biomethane procurement targets (72.8 billion cubic feet of biomethane by 2030) for gas utilities to meet the broader goal of reducing methane and other short-lived climate pollutants (SLCP) by 40% by the end of the decade.[31] However, GH_2 is not explicitly included in this mandate. As a result, this limits California's ability to support further methane and SLCP reductions from this scalable alternative fuel.	Through legislative direction, require the CPUC to open a new proceeding, or a new phase of an existing proceeding, to consider establishing procurement goals for GH_2 and require each gas investor-owned utility to annually procure a proportionate share of GH_2 to meet those goals.
Develop A Contracts For Difference (Cfd) Program To Accelerate GH_2 In New End Uses Outside Of The Transportation Sector	GH_2 is currently more expensive than incumbent fossil fuels for end users, particularly since the shared 100% GH_2 pipeline transport and geologic salt cavern storage infrastructure has not yet been built. Even after applying the Production Tax Credit in the federal IRA, some applications – such as process heat applications in the industrial sector – still cannot bridge the cost difference that end users may face between GH_2 and incumbent fossil fuel use, particularly in early GH_2 market development stages.	Direct the creation of a state agency-led CfD program that is aimed at reducing the cost gap between GH_2 and incumbent fossil fuels for specific end use applications where needed (e.g., certain industrial process heat applications). The program should aim to provide GH_2 buyers with price certainty for a set period of time, or until GH_2 delivered $/kg market price is equal to or less than the incumbent fossil fuel market price for the same quantity of energy.
Support GH_2 Refueling Infrastructure for Medium- and Heavy-Duty Vehicles, Ocean-Going Vessels, Harbor Crafts, and Off-Road Equipment	California's H_2 refueling infrastructure system is currently limited to light-duty on-road passenger vehicles. This approach restricts California's ability to fully support decarbonization of other fossil-fueled mobility applications, where low-cost GH_2 can accelerate the transition away from diesel and gasoline. The GHC supports battery electrification where possible; GH_2 will be particularly important for applications with long range or high daily utilization that are difficult to electrify.	Expand the state's H_2 refueling infrastructure credit through the Low Carbon Fuel Standard (LCFS) for medium- and heavy-duty vehicles,[32] ocean-going vessels, harbor crafts, and off-road equipment.

29. Arun Raju, et al., "Hydrogen Blending Impacts Study," University of California, Riverside, June 18, 2022.
30. See SB1440.
31. CPUC, "Decision Implementing Senate Bill 1440 Biomethane Procurement Program," January 25, 2022.
32. See GHC's Joint Letter on Updates to the Low Carbon Fuel Standard (LCFS) Regarding Heavy-Duty (HD) Hydrogen Refueling Infrastructure (HRI).

Develop a Vision for GH_2 Long-Duration Energy Storage (LDES) To Meet Reliability Needs	The state's Integrated Resource Planning (IRP) does not properly plan for the inclusion of GH_2 LDES for electric sector balancing and reliability. As a result, the state may unnecessarily rely on the continued use of fossil-fueled generation to achieve system balancing and reliability, while valuable renewable electricity curtailment increases. Electrolytic GH_2 is a commercially viable resource to achieve multi-day, weekly, and ultimately seasonal storage of low-cost renewable energy.	Consistent with Senate Bill 1369 (2017—2018), direct state agencies to plan and coordinate the procurement of electrolytic GH_2 as LDES through the state's IRP process. This planning process should also consider how to repurpose existing infrastructure to accommodate GH_2 to ensure a clean, reliable fossil-free electric system portfolio that is also affordable for all ratepayers.
Develop Electrolytic GH_2 Tariffs That Recognize the System Benefits of Electrolysis Equipment as a Demand Response Resource	California's grid needs greater flexibility and reliability, as exemplified by recent flex alerts and power outages. It is possible to electrolytically produce and store large amounts of energy for a significant period of time (e.g., days, weeks, or seasons) with GH_2. As a backup energy source for grid resilience, GH_2 energy storage systems can be used in combination with fuel cells, combustion turbines, or linear generators to convert the GH_2 back into electricity. This solution can be used as a demand response resource since it can provide system load when needed, and can also be curtailed during times of grid congestion. Today, no such pricing mechanisms are in place to support this opportunity.	Develop an electrolyzer tariff or demand response program that allows California's load-serving entities to create a "system-beneficial electrolytic GH_2 load." Require these load-serving entities to facilitate the delivery of green electricity to electrolytic GH_2 producers, while also enabling GH_2 producers to access and monetize the system benefits provided by demand-responsive electrolysis production.
Create A Framework to Prioritize Community Impacts in GH_2 Policy Making	Historically, the planning and siting of fossil fuel infrastructure has not sufficiently included the needs and concerns of frontline communities. These communities have been disproportionately harmed by the effects of fossil fuel production and use. The final vision and roadmap for a clean energy transition enabled by GH_2 must equitably include the needs, concerns, and interests of frontline communities through an equitable, transparent, and co-creative process.	As a first step toward a co-creative process, the State, in partnership with communities and environmental justice groups, should develop a community impacts framework that outlines a vision and tangible goals to be incorporated into GH_2 policy development. This framework should include guidance to policymakers and other stakeholders on best practices – such as guiding principles for improving equity, environmental, and energy justice – and a baseline for mitigating, tracking, monitoring, and remedying impacts.

2. WHY LOS ANGELES?

As the first regional initiative in the GHC's HyBuild North America platform, HyBuild LA is intended to be a model for rapid acceleration of additional GH_2 ecosystems throughout the nation. Los Angeles was selected as the first regional focus due to its abundance of potential scaled offtakers, forward-thinking leadership, decarbonization policies,[33,34] and strong renewable resource potential.[35] Once a mature GH_2 industry is developed, California – with its coastal position and many deepwater ports – also has the potential to serve as a net exporter of GH_2 and its derivatives to regions with limited renewable resource capacity. Large scale global procurement opportunities have already begun; for example, in 2022, Japan's largest power generation company issued a global request for proposals (RFP) to procure clean NH_3.[36]

2.1 | THE POLLUTION-REDUCTION POTENTIAL OF GREEN HYDROGEN IN LA'S MOBILITY SECTOR

The Los Angeles Basin currently suffers from some of the poorest air quality in the U.S., ranking highest in the country for ozone pollution.[37] In fact, 75% of the city's NOx emissions, a pollutant which leads to the formation of ozone, comes from diesel and gasoline combustion in mobility applications.[38]

Low-cost, mass-scale GH_2 can rapidly displace diesel and fossil fuels in difficult-to-electrify mobility applications, significantly improving air quality and public health. As home to the largest port in North America, multiple airports, and hundreds of thousands of heavy-duty, fossil fuel-powered trucks,[39] Los Angeles has abundant opportunities to lead the nation and demonstrate the potential benefits of GH_2 at scale.

> **"Access to predictable, large volumes of green hydrogen at less that $3/kg is a gamechanger. If this were the case, we would more rapidly accelerate transition from diesel to green hydrogen fuel cell-based equipment."**
>
> **Scott Schoenfeld**
> Former General Manager,
> Fenix Marine Services

With strong political and industry leadership, LA is already driving momentum for GH_2 in mobility applications. In the maritime shipping sector, the Los Angeles City Council and Long Beach City Council adopted a *Ship it Zero* resolution to support the transition to 100% zero-emission shipping in the San Pedro Bay by 2030.[40] The resolution calls on major global shippers to transition their fleets to zero-carbon fuels. In the aviation sector, World Energy has announced plans to expand their sustainable aviation fuel (SAF) production facility in Paramount by 700% and to transition to GH_2 feedstocks, making it one of the world's biggest SAF producers when work is completed in 2025.[41,42] In the on-road transportation sector, Los Angeles County currently has more H_2 fueling stations than any other county in the nation.[43] Given existing progress at the city and county levels, Los Angeles is well-positioned to lead the nation in GH_2-fueled mobility.

33. Office of Mayor Eric Garcetti, "L.A.'s Green New Deal," 2019.
34. California Senate Bill 100, 2018.
35. U.S. Energy Information Administration (EIA), "Where Solar is Found," Accessed February 8, 2023.
36. JERA Co. Inc., "JERA to Conduct International Competitive Bidding for the Procurement of Fuel Ammonia," February 18, 2022.
37. American Lung Association, "Most Polluted Cities," Accessed February 8, 2023.
38. California Air Resources Board, "Emissions Projections by Summary Category."
39. Quantity of trucks is extrapolated from data on truck registrations in CA and population distributions across the state (). HyBuild LA estimated that 50% of those were heavy-duty and might rely on GH_2 to decarbonize. See: U.S. department of Transportation Federal Highway Administraition, "Truck and Truck-Tractor Registraitions – 2019," November, 2020.
40. Ship it Zero Coalition, "L.A. City Council adopts Councilmember Raman's resolution calling for transportation to 100% zero-emission shipping at port of Los Angeles by 2023," November 9, 2021.
41. Curt Epstein "World Energy To Upgrade Sustainable Fuel Refinery," Aviation International News, April 25, 2022.
42. World Energy "World Energy Secures Permits; Will Completely Convert Its Southern Calif. Refinery to Create North America's Largest, World's Most Advanced Sustainable Aviation Fuel Hub," April 22, 2022.
43. Hydrogen Fuel Cell Partnership, "Station Map," Accessed February 8, 2023.

2.2 | LA'S COMMITTED ANCHOR OFFTAKER

Launching a mass-scale GH_2 hub requires a bankable offtaker to attract investment capital. The Los Angeles Department of Water and Power (LADWP), the nation's largest publicly owned utility,[44] is already demonstrating leadership as a first mover GH_2 offtaker. LADWP will be the largest offtaker of power from the Intermountain Power Project (IPP),[45] North America's largest GH_2 project under development today and the world's first combined cycle gas turbine intentionally designed and built to operate on 100% carbon-free GH_2.[46]

LADWP has also emphasized the role of GH_2 to help them achieve their commitment of 100% carbon-free energy by 2035.[47] This was a key finding in the National Renewable Energy Laboratory's (NREL) 2021 "Los Angeles 100% Renewable Energy Study" (LA100 Study), which is the most robust 100% renewable energy study undertaken to-date.[48] After millions of simulations, the landmark LA100 Study concluded that all paths to 100% renewable energy in the power sector will require thousands of megawatts of firm and dispatchable in-basin capacity to ensure system reliability.[49] The study identifies GH_2 as a leading scalable option to affordably provide electric system reliability and seasonal renewable energy storage.[50]

> **"There is no way to get to 100% renewable energy that I can see right now without hydrogen in the mix. It doesn't exist."**
>
> **Martin Adams**
> Chief Engineer and General Manager,
> Los Angeles Department of Water and Power (LADWP)

44. Jacquelin Cochran, et al., "The Los Angeles 100% Renewable Energy Study," National Renewable Energy Laboratory, NREL/TP-6A20-79444, March 2021.
45. Intermountain Power Agency, "IPP Renewed," Accessed February 8, 2023.
46. Jared Anderson, "Industry consortium pushing to commercialize green hydrogen in California by 2030," S&P Global Commodity Insights, May 17, 2021.
47. Emma Penrod, "As momentum for hydrogen builds, electric utilities chart multiple paths forward," Utility Dive, August 18, 2021.
48. Jacquelin Cochran, et al., "The Los Angeles 100% Renewable Energy Study," National Renewable Energy Laboratory, NREL/TP-6A20-79444, March 2021.
49. Ibid.
50. Ibid.

3. HYBUILD LA VALUES AND PRINCIPLES

HyBuild LA is a collaborative platform that brings together a diverse array of stakeholders that will be impacted by the GH_2 economy. The GHC developed and adheres to a set of values and principles for this initiative, which are intended to provide a framework to facilitate an inclusive and just clean energy transition:

- **Fight climate change and advance energy justice.**
  HyBuild LA's aim is to advance a clean and just energy transition. The vision for GH_2 in LA must prioritize restoration to those who have suffered the most from fossil fuel pollution and emissions, and ensure that these communities have first access to the benefits of clean energy. In identifying pathways forward, it is critical to listen to and respect the historical context of issues elevated by stakeholders.

  In recognition of the urgency of the climate crisis and the adverse health impacts faced by communities across the LA Basin today due to fossil fuel use, HyBuild LA should seek to create near-term, actionable roadmaps that can yield measurable progress to reduce emissions and mitigate climate change.

- **Build community and trust.**
  Creating a resilient and inclusive vision requires engagement from a diverse group of stakeholders and a safe space to express differences of opinion. To create this space, participants must be prepared to listen deeply and with empathy.

- **Employ a transparent and inclusive process that fosters co-creation and shares power and recognition.**
  HyBuild LA is committed to working inclusively with community stakeholders to jointly study and explore questions, areas of interest, or concerns related to GH_2, developing science-based guidance to identify pathways forward. To increase transparency, efforts should have measurable and trackable impact.

- **Foster competition to encourage innovation and reduce cost.**
  The GH_2 economy will require investment throughout the value chain and across sectors. Fostering competitive, technology-agnostic outcomes and a range of business models will help ensure that innovation and investment continue long-term, lowering the burden of the clean energy transition on ratepayers.

- **Cultivate and support champions for change.**
  Positive impacts can be exponentially multiplied by the success of individual champions. A key function of the GHC is to help identify, support, and empower these champions so they can inspire others to advance a clean and just energy transition.

- **Establish a sustainable underlying business and community value proposition.**
  A sustainable business and community value proposition is critical to establishing a cost-effective and self-sustaining infrastructure vision. Any proposed investments must achieve sustainable financial returns that can support private business investors and developers, while creating community benefits that sustain healthy, safe, vibrant local communities.

4. SCOPE AND APPROACH

In Phase 2, HyBuild LA provided a detailed view into GH_2 adoption and infrastructure scenarios in mobility sectors (e.g., aviation, shipping, heavy-duty trucking, and offroad equipment) in collaboration with Corporate Value Associates (CVA) and the American Bureau of Shipping (ABS). Once a 2030 baseline of 1.4 million metric tons of GH_2 demand per year across sectors (both qualified and unqualified) was established, HyBuild LA completed a first-of-its-kind water analysis with Pacific Northwest National Labs (PNNL), evaluating prospective recycled or repurposed water sources and related infrastructure to serve the demand for electrolytic GH_2 in the LA Basin.

Further, HyBuild LA worked with the UCI to analyze some of the quantifiable community impacts of the envisioned GH_2 ecosystem. Specifically, these studies demonstrated significant improvements in air quality and their subsequent public health impacts, as well as the tens of thousands of jobs that will be created to support the development of a GH_2 ecosystem. HyBuild LA hosted four listening sessions with community stakeholders, including environmental justice groups, labor organizations, and tribal nations, to gather input on these analyses and further assess their areas of interest in the GH_2 economy. Taking the learnings from the aforementioned efforts, LA provided policy and regulatory recommendations to enable the vision established in this initiative and provide innovative pathways for benefits. Finally, HyBuild LA worked with Sheppard Mullin to develop a “readiness assessment” of state and local (i.e., California and Los Angeles) regulation and oversight applicable to GH_2 systems.

This work was organized into three core workstreams (Figure 13): (1) Offtake and Infrastructure, (2) Community Impacts, and (3) Policy and Regulatory. The workstreams were managed and coordinated by Strategen, with analytical support from additional expert consultants.

Figure 13 | HyBuild LA Phase 2 scope of effort organized across three core workstreams.

Offtake and Infrastructure

Goal: Understand the demand for GH_2 in the LA region and identify a low-cost scenario for needed infrastructure required to meet demand.

Activities:

- Update regional GH_2 offtake potential, system infrastructure needs
- Explore water needs, potential sources, and infrastructure
- Update cost scenarios to include mobility infrastructure, updated water costs, IRA tax credit opportunities

Community Impacts

Goal: Co-create the vision and roadmap forward with key community stakeholders (including labor, environmental justice, and tribal stakeholders); work together to understand the community value proposition of GH_2.

Activities:

- Engage with key stakeholders to solicit input on areas of interest, opportunity, and concern
- Assess the air quality and public health impacts
- Assess economic development and job creation impacts

Policy and Regulatory

Goal: Identify and prioritize key policy and regulatory recommendations to realize a GH_2 economy at scale.

Activities:

- Identify policy and regulatory barriers and funding opportunities
- Develop innovative policies and programs to value and compensate GH_2
- As relevant, engage with local, state, and regional governments (incl. coordination with the Green Hydrogen Coalition's Western Green Hydrogen Initiative)

Expert Consultants

- Offtake and Infrastructure: ABS; CVA Corporate Value Associates; Strategen; Pacific Northwest National Laboratory
- Community Impacts: Advanced Power & Energy Program, University of California • Irvine; Strategen
- Policy and Regulatory: Strategen; SheppardMullin

The following sections provide a detailed overview of each workstream, including their respective key findings and methodologies, to provide greater depth to each topic area synthesized in the Executive Summary.

5. OFFTAKE AND INFRASTRUCTURE WORKSTREAM

The HyBuild LA Phase 2 Offtake and Infrastructure Workstream included three tasks: (1) an assessment of GH_2 adoption by sector, with a focus on heavy-duty mobility and materials handling applications, (2) an analysis of potential sources of water, including recycled or repurposed water resources, to meet the water needs for electrolytic GH_2 production, and (3) an analysis of the levelized cost of GH_2 and capital expenses associated with the HyBuild LA vision.

The following sections delve into these areas in greater detail. Each section will provide an overview of the methodology for the related analyses. HyBuild LA also undertook dozens of interviews over the past two years that underpin all analytical efforts. These expert interviews (detailed in the Appendix) helped to identify the potential for GH_2 adoption in each end use, review and validate assumptions, and provide feedback on the system design.

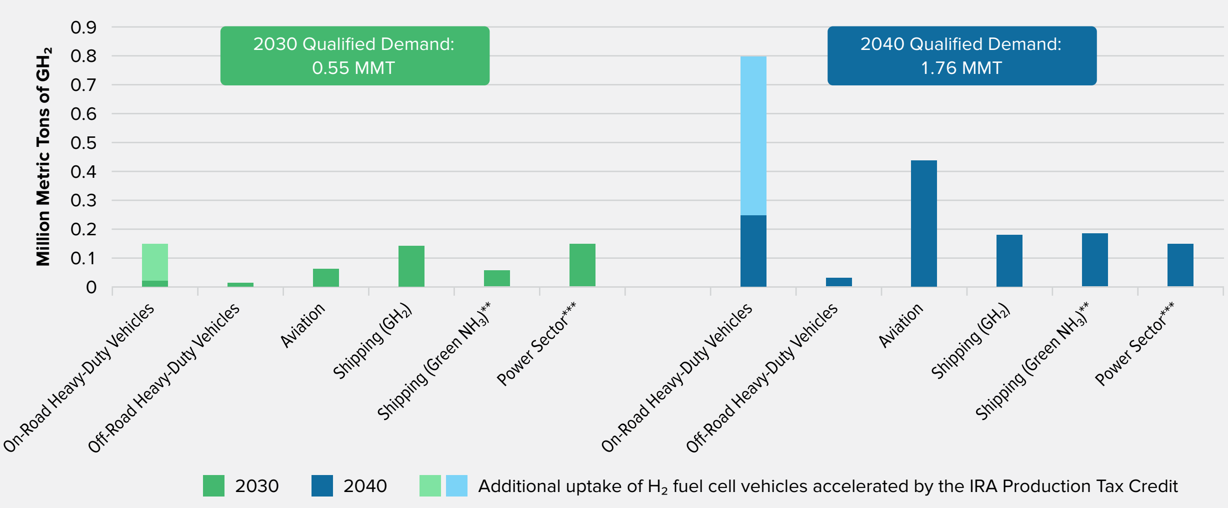
5.1 | GREEN HYDROGEN OFFTAKE ASSESSMENT

The Phase 2 offtake assessment builds upon the estimates of regional GH_2 offtake developed in HyBuild LA Phase 1, which identified a total qualified demand of 0.13 million metric tons (MMT) in 2030 in the power sector.[51] "Qualified demand" refers to potential demand that was validated through industry interviews or public announcements confirming a future interest or intention to purchase GH_2 if it becomes cost-competitive with existing fuels.

Phase 2 qualified an additional demand of approximately 0.43 MMT in 2030 from mobility sectors, including maritime shipping, aviation, and heavy-duty trucking. This estimate includes potential demand for GH_2 to produce derivative fuels, such as sustainable aviation fuels and green NH_3. The demand analysis was led by CVA with support from ABS, who led the maritime shipping demand analysis.

The figure below details the sources of qualified demand identified in HyBuild LA.

Figure 14 | Qualified GH_2 demand in the LA Basin for 2030 and 2040, by sector.*

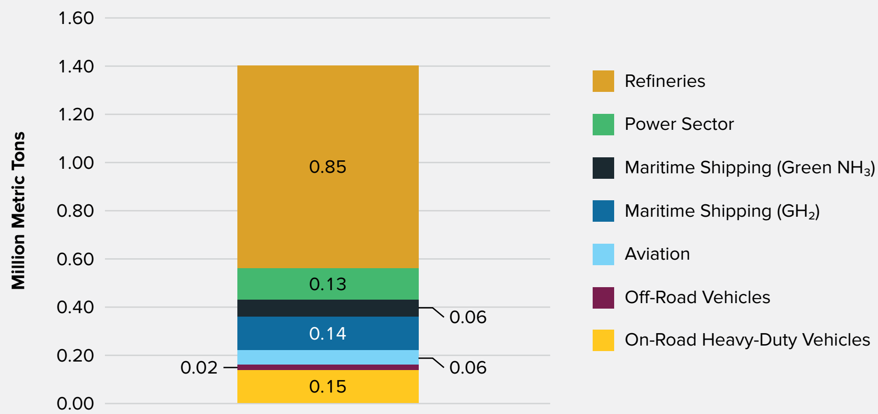


*Potential refinery demand has not been qualified, but may represent up to 0.85 million metric tons of demand annually.
**Due to safety concerns, green NH_3 is unlikely to be produced in the LA Basin from local GH_2 feedstocks.
***2040 Power sector demand was not formally analyzed. However, it is not expected to grow at the same rate as mobility applications.
Source: Corporate Value Associates and American Bureau of Shipping Analysis for HyBuild LA, 2022

51. Qualified demand is defined as demand confirmed through interviews with potential off-takers in the LA Basin. Non-qualified demand is an estimate based on energy and fuel use which could be replaced by green hydrogen or its derivatives, but could not be confirmed during interviews.

Importantly, several of the analyses within the HyBuild LA initiative (water analysis, jobs study, and the system plan) are based upon a GH_2 demand estimate of 1.4 million metric tons of GH_2 per year in 2030. This includes a potential unqualified demand of 0.85 million metric tons of GH_2 per year in refineries, which was assessed in HyBuild Phase 1 and assumes that a portion of fossil fuel-derived H_2 utilized in refineries today would be replaced with GH_2 as it scales and becomes available at a competitive cost. The total potential demand of all major offtake sources in the LA Basin is provided in the figure below.

Figure 15 | Total GH_2 demand in 2030 by sector.



As indicated previously, Phase 2 focused on developing a detailed characterization of mobility demand. The next sections provide a deeper dive into the methodology and findings for the following Phase 2 analyses: (1) land-based mobility, (2) aviation, (3) maritime shipping, and (4) stationary applications.

5.1.1 | Land-Based Mobility

Key Findings

The analysis shows that by 2040, heavy-duty trucks will represent the largest source of GH_2 demand. The associated GH_2 demands for land-based mobility in 2030 and 2040 by sector are identified in Table 1. The analysis only considers end uses that were more cost-effective to decarbonize with GH_2 rather than electrification, which was determined by calculating and comparing the relative costs of GH_2 use vs. electrification for different end uses on a total cost of ownership (TCO) basis (see Figure 16).

Figure 16 | Projected timing for GH_2 cost competitiveness in land-based mobility applications based on total cost of ownership.

Heavy-Duty Trucks

Fuel cell trucks with an operating range up to 400 miles from LA are competitive by **2026**.

Fuel cell drayage trucks operating near the ports are also competitive by **2026**.

Buses & Coaches

Fuel cell coaches for intrastate, long distance trips (ex: Greyhounds from LA to SF) are competitive by **2031**.

Forklifts

~45% of the fuel cell forklifts operating in the LA Basin will be competitive by **2024** (others are expected to be electrified).

Port Material Handling

Rubber-tired gantry cranes, yard tractors, and top-handlers in the Ports of LA and Long Beach will be mostly fuel cell-powered by **2035**, due to zero-emission targets and end user technical requirements.

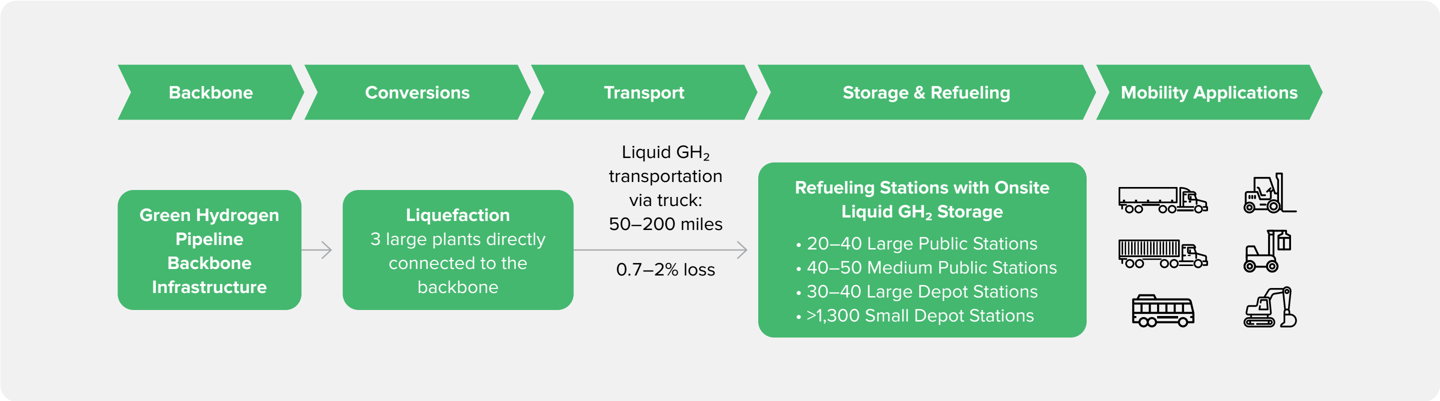
Table 1 | HyBuild LA estimated GH_2 demand from land-based mobility in 2030 and 2040.

Sector	2030 (kt)	2040 (kt)
Heavy-duty trucks	135	705
Drayage trucks	10	77
Forklifts	8	9
Coaches	3	10
Port material handling	7	24
Total	**163**	**825**

HyBuild LA also assumes that GH_2 will be transported in liquid form to supply fueling infrastructure for heavy-duty trucks, long-range buses and coaches, forklifts, and port material handling equipment that are not located close to the GH_2 pipeline backbone. Even though liquid GH_2 requires additional infrastructure compared to gaseous GH_2 (e.g., liquefaction, cryogenic pumps, evaporators, compressors, and buffer storage),[52] its energy density leads to significantly higher carrying capacity for trucks transporting it from the pipeline backbone, resulting in higher delivery capacities and lower overall delivered cost.

The selected delivery scenario assumes a few large liquefaction plants are situated along the pipeline backbone and are located as close as possible to trucking routes, the ports, and the city center. Within the LA Basin, refueling stations (both public and privately-owned) could be supplied with liquified GH_2 via truck delivery within a 50–200-mile radius from the liquefaction plants. Truck delivery of liquid GH_2 may be feasible for dispersed refueling infrastructure that is located beyond 200 miles from the GH_2 pipeline backbone, particularly if located along major transit corridors. However, if sufficient demand can be aggregated to justify implementation of a distribution pipeline, distribution pipeline delivery will be more cost-effective than truck delivery of liquid GH_2. Figure 17 walks through the GH_2 delivery flow for land-based mobility end uses.

Figure 17 | HyBuild LA 2030 high-level flow for GH_2 serving land-based mobility end users.



Methodology

HyBuild LA first developed an overview of potential GH_2-fueled mobility end uses and then identified an estimated total demand based on a realistic technology adoption scenario. To estimate demand, CVA and Strategen conducted over a dozen interviews with potential offtakers within the LA Basin, including fleet operators, fuel station owners, and OEMs to (1) qualify their energy transition strategies and willingness to shift towards low-carbon powertrains, (2) verify their fleet size and use profiles to assess their potential GH_2 demand, and (3) determine the economics that would make GH_2 competitive with alternative low-carbon technologies. Insights from these interviews, coupled with supplementary research, were used to develop a GH_2 demand estimate for land-based mobility end uses for 2030 and 2040.

52. Mario Conte, et al., "Hydrogen as Future Energy Carrier: The ENEA Point of View on Technology and Application Prospects," Energies, March 24, 2009.

In order to identify the most impactful mobility end uses that warranted further analysis, these end uses were prioritized based on (1) potential emissions reduction from GH_2 use, (2) the maturity of required technology, and (3) competitiveness of GH_2 with other decarbonization options. To ensure that HyBuild LA was only considering end uses that were least likely to be electrified, CVA calculated the relative costs of GH_2 use versus electrification on a TCO basis. Any end uses where electrification was a more cost-effective option were excluded from the demand analysis. As a result, estimates for HyBuild LA's demand estimates only include demand from end uses where GH_2 emerged as the more cost-effective decarbonization pathway.

The methodology for assessing this is the same across land-based use cases, with four main components:

1. **Development of route profiles to determine where and how far vehicles travel, as well as what share of fleet vehicles engaged in different types of trips.** These route profiles were created based on public sources and CVA case experience. Interviews were conducted to validate mileage, profiles, and locations.
2. **Analysis of refueling or recharging setup.** The refueling system was assessed using hypothetical scenarios based on benchmark data and trip modeling. The feasibility of the approach was validated through interviews. If no significant GH_2 application was evident after these first two steps, the third and fourth steps were not completed.
3. **Total cost of ownership analysis.** This was carried out to determine whether GH_2 is cheaper to operate than the alternatives (battery electrification), as well as the year in which GH_2 would become cost competitive. The TCO was modeled through a discounted cash-flow approach at each potential year, solving for a net present value of zero with a weighted average cost of capital of 6%. The model also incorporated future changes in vehicle prices and fuel costs (e.g., GH_2, electricity, diesel).
4. **Fleet penetration model.** This model determined the quantity of GH_2 vehicles in use in LA at different times and helped to identify drivers of demand. Cost- and regulation-driven demand for GH_2 vehicles was used to model fleet penetration of these vehicles, based on expected fleet growth and replacement rates. This fleet penetration assessment was then used to calculate total GH_2 demand.

CVA utilized the outputs from steps 1 – 4 as data points to estimate quantities of GH_2-powered vehicles, the annual GH_2 demand, the type and number of refueling stations required, the vehicle's TCO, and the constraints and conditions driving penetration of GH_2-fueled mobility. Applications that were projected to be unlikely candidates for GH_2 adoption include diesel trains, city buses, local and last-mile delivery trucks, light-duty vehicles, and construction equipment.

The analysis considered several potential GH_2 transport methods to determine the infrastructure needs to fuel land-based mobility applications. Ultimately, the analysis modeled two primary potential pathways to transport GH_2 from the GH_2 pipeline backbone to a fueling station:[53]

A. Gaseous GH_2: GH_2 can be compressed and then loaded onto a truck for delivery to compressed GH_2 storage. Trucks carrying gaseous GH_2 were assumed to have a capacity of approximately 160 to 300 kg.

B. Liquid GH_2: Once converted into a liquid via liquefaction, GH_2 can be delivered via truck, with a capacity between 2,000 and 6,000 kg per truck, to liquid GH_2 storage. From there, the GH_2 travels through a cryogenic pump, an evaporator, a compressor, and then into buffer storage.[54]

Ultimately, local GH_2 transport via truck as liquid GH_2 was determined to be the only commercially viable technology that could transport the required volumes of GH_2 from a pipeline to distributed fueling stations, so it was selected over gaseous GH_2 delivery for the purposes of the analysis.

53. Other pathways considered, such as transport via liquid organic hydrogen carriers (LOHCs), were excluded due to their pre-commercial status.
54. Mario Conte, et al., "Hydrogen as Future Energy Carrier: The ENEA Point of View on Technology and Application Prospects," Energies, March 24, 2009.

5.1.2 | Aviation

Key Findings

HyBuild LA estimates that starting in 2030, GH_2 will be utilized to produce SAF for domestic and international flights departing from Los Angeles International Airport (LAX). SAF is a drop-in fuel for low-carbon aviation that can be blended into fossil jet fuel (JET). Expected demand for SAF is identified for 2030 and 2040 in Table 2. By 2040, aviation is expected to represent the second largest source of GH_2 demand in the LA Basin.

Table 2 | HyBuild LA estimated GH_2 demand from the aviation sector in 2030 and 2040.

GH_2 Demand for Aviation (input to SAF production)	
2030	62 kt
2040	440kt

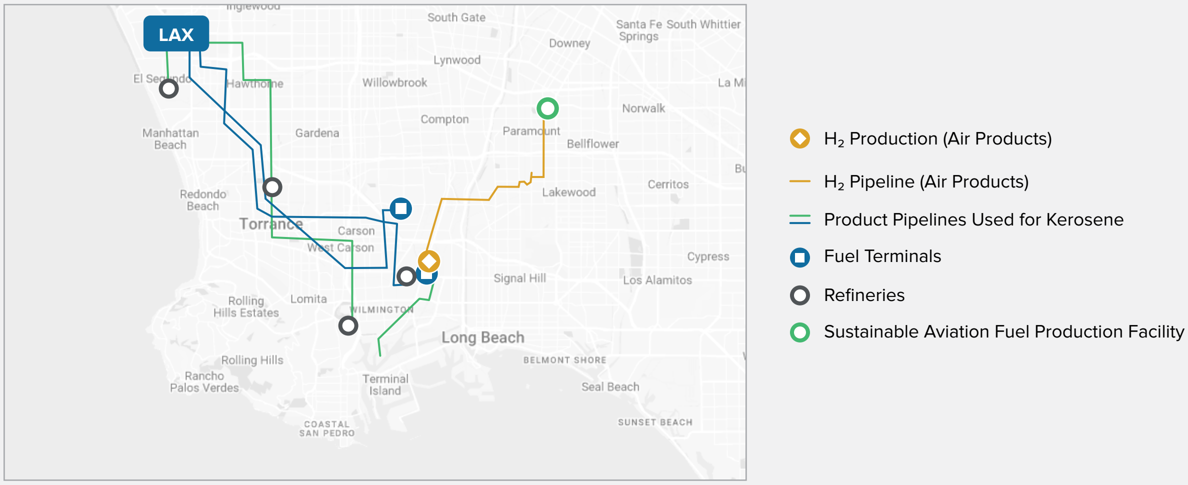
The estimate considers factors such as public corporate commitments that are likely to drive the demand for SAF, binding requirements for SAF and E-Kerosene adoption in Europe, subsidies, and more. The demand estimate also incorporates current regulatory limits on the blending of SAF into fossil JET. While the cost of SAF will not be competitive with fossil-derived JET in the evaluated timelines, cost competitiveness is not a primary driver of adoption; rather, local regulations, blending commitments and mandates, and limited availability of other low-carbon feedstocks contribute to increasing demand. Prices are anticipated to decrease with the technological maturity of GH_2 and carbon captured fossil fuels, both of which are feedstocks of the SAF process.

Figure 18 walks through the GH_2 delivery flow scenario for aviation in the LA Basin.

Figure 18 | HyBuild LA 2030 high-level flow for GH_2 serving the aviation sector, including sustainable aviation fuel production.

In the HyBuild LA adoption scenario, SAF would be supplied to LAX via a dedicated pipeline from Paramount, CA, which is home to a renewable fuels production facility operated by World Energy. Currently, existing JET pipelines run from nearby refineries to LAX; this infrastructure is shown in Figure 19. The HyBuild LA scenario envisions new pipeline capacity to connect additional production at the World Energy facility with this system.

Figure 19 | Current fuel terminal and product (kerosene) pipelines serving LAX.



Source: Corporate Value Associates for HyBuild LA, 2022

Methodology

Several aviation decarbonization solutions were evaluated for maturity via interviews and a review of relevant literature, with the results summarized in Table 3 below.[55] The maturity assessment concluded that SAF is the most mature and potentially competitive pathway for decarbonizing aviation compared to other alternatives. While green ammonia and GH_2 propulsion show exciting promise, they are unlikely to influence significant GH_2 demand before 2040.

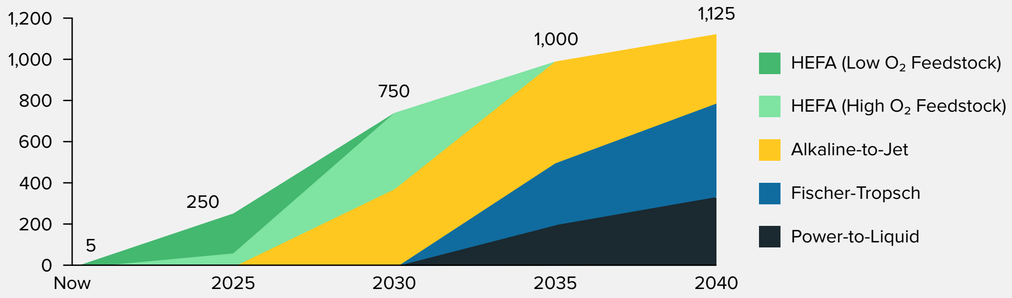
Table 3 | Sustainable aviation fuel maturity assessment summary.

Fuel Vector	Propulsion Technology	Fuel Storage	Maturity Phase	Commercial use in US
Drop-in SAF from organic feedstock	Jet engine (existing technology)	Existing JET storage (blended)	Mature Pilot Phase: Already blended across US; LAX and SFO have pilots	Current
Drop-in E-Kerosene SAF (Power-to-Liquid)	Jet engine (existing technology)	Existing JET storage (blended)	Pilot Phase: Small scale pilots currently underway	2025 (uncertain)
Direct GH_2 Use in Internal Combustion Engine or Fuel Cell	GH_2 turbo-jet, GH_2 or electric turbo-fan	Cryogenic GH_2 with special airframe design	Pilot Phase: Initial pilot flights planned, commencing 2025 with greater adoption after 2035	Pilots starting by 2025 with greater adoption >2040

55. Kristi Moriarty, "U.S. Airport Infrastructure and Sustainable Aviation Fuel," National Renewable Energy Laboratory, NREL/TP-5400-78368, 2021.

The HyBuild LA SAF demand analysis anticipates a shift of SAF production from hydrotreated esters and fatty acids (HEFA) feedstocks into more advanced and GH_2-intensive production pathways, based on technology maturity and feedstock availability, as indicated in Figure 20. The SAF production in 2025 is projected to utilize HEFA feedstocks, but by 2040, HEFA use is projected to be replaced by an even distribution between Alkaline-to-Jet, Fischer-Tropsch, and Power-to-Liquid production methods. All of these pathways require GH_2 as an input, increasing demand.

Figure 20 | Estimated SAF production quantities in the LA Basin by production pathway.



Source: Corporate Value Associates Analysis for HyBuild LA, 2023

Table 4 | GH_2 requirements of sustainable aviation fuel production pathways.[56]

SAF Production Route	Product	GH_2 demand (kg GH_2 / gallon SAF)	Other Feedstock
HEFA	Synthetic Paraffinic Kerosene	~0.13-0.37	Vegetable or animal oils
Alcohol-to-Jet	Synthetic Paraffinic Kerosene	~0.04	Iso-Butanol or Ethanol e.g., from ligno-celluloses[57]
Fischer-Tropsch	Synthetic Paraffinic Kerosene	~0.5-1.0	Ligno-celluloses
Upgrading Pyrolysis Oil	Synthetic Paraffinic Kerosene	No Data	Ligno-celluloses
Power-to-Liquid	E-Kerosene	~1.6	CO_2 from direct air capture

Source: Corporate Value Associates Analysis for HyBuild LA, 2023

56. Ausilo Bauen, et al., "Sustainable Aviation Fuels: Status, challenges and prospects of drop-in liquid fuels, hydrogen and electrification in aviation," John Maatthey Technology Review, 2022.
57. Ligno-celluloses may include agricultural or forestry waste.

5.1.3 | Maritime Shipping

Key Findings

HyBuild LA projects that GH_2 will be utilized to power transoceanic and port vessels directly and as a feedstock for green NH_3 and e-methanol, reaching a cumulative GH_2 demand of 260 kt by 2040 (see Table 5).

Table 5 | HyBuild LA estimated GH_2 demand from the maritime shipping sector in 2030 and 2040.

GH_2 Demand for Transoceanic and Port Vessels[58] (Includes GH_2 for direct use and as a feedstock for green NH_3)	
2030	196 kt
2040	360 kt

Green NH_3 can be produced by combining GH_2 with nitrogen via the Haber-Bosch process. This fuel is discussed as an option for shipping decarbonization as it does not emit any CO_2, has high energy density, and (unlike liquid GH_2) does not require cryogenic storage.[59] The largest use of NH_3 today is to create fertilizer, a process which currently utilizes H_2 made from fossil fuels. If GH_2 is used in this process instead, the produced ammonia is considered zero-carbon or "green."

E-methanol is typically produced by combining GH_2 and CO_2. If the CO_2 utilized is captured directly from a neutral source (e.g. direct air capture), e-methanol is considered a net-carbon-neutral fuel when combusted. It is viewed by the international shipping community as an accessible step towards zero-carbon shipping, as fossil-fuel based methanol is already available and utilized as a shipping fuel today.[60] Demand for e-methanol as a decarbonized shipping fuel was not included in the GH_2 demand assessment as the required quantities of GH_2 in e-methanol production are not as significant as for green NH_3, and the impact on the demand estimate would have been minimal.

The analysis estimates the end user cost for GH_2 supplied to ships in the Ports of LA and Long Beach will be \$5.35 – \$5.85/kg in 2030, assuming that a "base" delivery price of \$2.05/kg delivered to the pipeline backbone in the LA Basin is achieved.[61] The incremental cost (\$3.30 – \$3.80 in addition to the cost at the pipeline backbone) accounts for the cost of liquefaction, local storage, and dispensing equipment. Liquefaction makes up the majority of these costs and is assumed to occur at a system located close to the ports, operating at a capacity of 400 tons of GH_2 per day with 90% utilization. For reference, GH_2 used in fuel cell-powered cargo ships would likely need to be priced around \$5.40 to be cost-competitive against bunker fuel.[62] Additional details on end-user costs in the Ports of LA and Long Beach are provided in Appendix A.

Based on stakeholder feedback, the HyBuild LA scenario assumes that green NH_3 is unlikely to be produced or dispensed in the densely populated areas near the Port of Los Angeles and Long Beach. As such, it should be noted that the demand for GH_2 to produce green NH_3 may occur outside of the LA Basin. An alternative scenario detailing the potential of green NH_3 production in Northern California can be found in Section 6.

Methodology

The demand forecast is derived from the ABS' "Zero Carbon Outlook" report, which identified expected demand for low-carbon fuels across the global shipping industry out to 2050.[63] The viability of identified zero-carbon fuels (e.g., clean H_2, NH_3, methanol) are also supported by a report from the Ocean Conservancy.[64] The forecasts from the ABS report were adjusted for the HyBuild LA scenario, accounting for the ambitious emission reduction commitments that the Cities of LA and Long Beach have made for their ports, which indicate that they would be adopting zero-carbon fuel alternatives more rapidly than the global average. Specifically, the demand estimate assumed that the "Green Shipping Corridor" between LA and China would be decarbonized by 2030, primarily through the use of GH_2-powered ships.[65,66]

58. Regional best case with 10% of energy delivered from GH_2 and 3.5% from green ammonia.
59. Charles Haskell, "Decarbonizing shipping – could ammonia be the fuel of the future," Lloyds Register, May 6, 2021.
60. Dolf Gielen, et al., "Methanol as a scalable zero emission fuel," Global Maritime Forum," March 21, 2022.
61. Factoring in the Clean H_2 Production Tax Credit from the IRA would further decrease costs.
62. Assumptions based on American Bureau of Shipping analysis and professional opinion. Hydrogen fuel cell efficiencies based on: Elise Georgeff, et al., "Liquid hydrogen refueling infrastructure to support a zero-emission U.S.-China container shipping corridor," International Council on Clean Transportation, Working Paper 2020-24, October 2020.
63. American Bureau of Shipping (ABS), "Setting the Course to Low Carbon Shipping: Zero Carbon Outlook," 2022.
64. University College London, "Green hydrogen is the best option to transition the shipping industry away from fossil fuels," April 19, 2022.
65. ABS was an active participant in the O&I workstream and led this analysis.
66. Elise Georgeff, et al., "Liquid hydrogen refueling infrastructure to support a zero-emission U.S.-China container shipping corridor," International Council on Clean Transportation, Working Paper 2020-24, October 2020.

The adjusted forecast was applied to the expected demand for bunkering fuel in the Ports of LA and Long Beach. Expected demand was calculated by applying a 2.5% annual scaling factor to existing demand, which was based on ABS's forecasted growth in the maritime shipping industry. This yielded estimates for direct use of both GH_2 and green NH_3 in ships in both ports. The estimated demand and adoption rates were refined and validated according to the maritime shipping industry's asset investment forecasts and current demonstration projects.

These inputs and assumptions were used to create a "regional best case" estimate for shipping fuel demand, which was the basis for the overall regional demand used to develop a GH_2 infrastructure system plan (see Table 6).

This best-case scenario estimates that 10% of energy to fuel transoceanic and port vessels in the Ports of LA and Long Beach will be delivered from GH_2 and 3.5% from green NH_3 in 2030, based on expected use of each fuel. The results from this assessment indicate a demand of 315 kt/year of GH_2 as a feedstock for green NH_3 and 140 kt/year of GH_2 for direct use in 2030. By 2040, GH_2 as a feedstock for green NH_3 and direct GH_2 demand is expected to increase to 800 kt annually and 210 kt annually, respectively.[67] A conservative global forecast was also developed as a comparison point, based exclusively on the fuel allocations forecasted in the "Zero Carbon Outlook" report (see Appendix A).[68]

Table 6 | Regional best-case estimate for maritime shipping fuels.[69]

Regional Best-Case Estimate (Million Metric Tons)	2019	2030	2040	2050
Heavy Fuel Oil (HFO)	2.84 (86%)	2.47 (57%)	2.66 (48%)	1.85 (26%)
Liquid Natural Gas (LNG)/Bio-LNG	0.38 (14%)	0.88 (27%)	1.13 (25%)	0.87 (15%)
E-Methanol	0 (0%)	0.50 (6%)	0.86 (8%)	2.20 (16%)
Green NH_3	0 (0%)	0.31 (3.5%)	0.80 (7%)	2.65 (18%)
GH_2	0 (0%)	0.14 (10%)	0.21 (12%)	0.58 (25%)

67. Ibid.
68. American Bureau of Shipping (ABS), "Setting the Course to Low Carbon Shipping: Zero Carbon Outlook," 2022.
69. Elise Georgeff, et al., "Liquid hydrogen refueling infrastructure to support a zero-emission U.S.-China container shipping corridor," International Council on Clean Transportation, Working Paper 2020-24, October 2020.

5.1.4 | Stationary Applications: Power Sector and Refinery Operations

Key Findings

HyBuild LA estimates that power generation and refinery operations may represent significant sources of near-term aggregated demand by 2030, reaching 130 kt of demand per year in the power sector and an estimated 850 kt (unqualified) of demand per year in refinery operations.

Table 7 | HyBuild LA estimated GH_2 demand from stationary applications in 2030 and 2040.

	Demand in Stationary Applications	
	Power Sector	**Refinery Operations** (Not Qualified)
2030	130 kt	850 kt
2040[70]	Unknown	Unknown

While 2040 demand for GH_2 from these stationary applications is not shown in this report, demand for GH_2 from the power sector and refinery operations is not expected to grow at the same rate as other end uses (e.g., mobility). In the power sector, the analysis assumes that GH_2 will serve the need for clean, firm power to support electric sector resiliency and accommodate peak demands. Given this role, power plants are expected to have much lower utilization in the future. In refinery operations, GH_2 demand is expected to decrease by 2040, assuming that the global transition to renewable energy and California's bans on internal combustion engine vehicle sales will decrease demand for fossil fuels and refinery operations.

The power sector is considered a near-term offtaker for GH_2 because most gas turbines, both combined cycle and simple cycle, can already operate on a blend of GH_2 and natural gas and could transition to the utilization of 100% GH_2 with turbine upgrades.[71] Concentrated, predictable demand for GH_2 in the power sector can support investment in GH_2 transport and storage infrastructure, driving economies of scale and fostering accelerated GH_2 adoption in other, highly-polluting sectors in the region, such as heavy-duty trucking, materials handling equipment, maritime shipping, and aviation.

Today, oil and gas refinery operations represent the largest use of H_2 in the region.[72] This sector has the potential to be a near-term offtaker because GH_2 can be utilized as a direct replacement for the fossil fuel-derived H_2 used in refining, without additional end user equipment investments. However, it is important to note this demand is not considered "qualified" since multiple interviews with refineries during Phase 1 of HyBuild LA did not indicate plans to incorporate GH_2 or transition to low-carbon options.

Assumptions and Methodology

GH_2 demand in the power sector is based upon data from current and expected natural gas demand in LA Basin gas turbine power plants. Interviews were conducted with specific power plant owners and operators to validate assumptions and estimates around future GH_2 consumption in power plants in the LA Basin.

The demand assessment also incorporates information from the National Renewable Energy Laboratory's (NREL) LA100 study, which found that at least 2,400 MW of firm, dispatchable capacity within the LA Basin will be required under all potential scenarios to achieve 100% renewables in the power sector by 2035 and maintain local electric sector reliability. The LA100 study further identified GH_2 as a potential resource to meet this need.[73]

Table 7 above provides an estimated demand for GH_2 use at power plants in 2030. The demand estimates align with the City of LA's objective of achieving 100% zero-carbon electricity for LA by 2035.[74] Notably, the HyBuild LA demand estimates factored in expected reductions in run times for gas turbines in a high-renewable future where power plants would be utilized only for reliability.[75]

70. Demand for GH_2 in stationary applications was estimated in Phase 1 of HyBuild LA. The assessment did not quantify 2040 demand.
71. Mitsubishi Heavy Industries, "Decarbonizing Power Generation with a Minimum of Modifications," Accessed February 8, 2023.
72. Jose M Bermudez, et al., "Hydrogen," International Energy Agency, 2022.
73. The LA100 Study from NREL identified green hydrogen as the key pathway to reliably meeting LA's 100% renewable energy target. See: Jaquelin Cochran, et al., "The Los Angeles 100% Renewable Energy Study," National Renewable Energy Laboratory, NREL/TP-6A20-79444, March 2021.
74. City of Los Angeles, LA's Green New Deal Annual Report 2021 - 2022.
75. Jaquelin Cochran, et al., "The Los Angeles 100% Renewable Energy Study," National Renewable Energy Laboratory, NREL/TP-6A20-79444, March 2021

The HyBuild LA demand assessment for refining operations assumes that GH_2 will replace approximately half of the grey H_2 currently used in refining operations in the LA Basin. These quantities were estimated based on the capacity of refineries located in the LA Basin (i.e., barrels of crude processed per year)[76] and H_2's role in general refinery processes (primarily hydrotreating and hydrocracking).[77]

5.2 | WATER DEMAND AND SOURCES ANALYSIS

Electrolytic GH_2 production has a very low carbon intensity and is therefore the preferred GH_2 production pathway for many local advocates, environmental organizations, and policymakers in the LA Basin. This process requires high-quality water as a feedstock and, in recognition of water scarcity concerns in Southern California, HyBuild LA worked with the Pacific Northwest National Laboratory (PNNL) to explore potential resources to responsibly meet the water needs of the envisioned scaled GH_2 system plan.

The findings also explore the incremental water needs to produce green NH_3, due to stakeholder feedback expressing a desire to understand the separate process requirements of a potential green NH_3 industry.

Based on stakeholder feedback, the study evaluated sources of wastewater that can be recycled from other sectors to avoid drawing on the region's already stressed freshwater resources. In addition, the analysis also considered the opportunity to repurpose water that is currently used in the local oil and gas sectors, assuming that operations may ramp down in accordance with a statewide clean energy transition.

The table below shows the considered water sources. While not a recycled or repurposed water source, desalination was also discussed as an alternative option. However, it was ultimately not included in the proposed system vision due to stakeholder concerns about the feasibility of permitting and developing desalination projects.

Table 8 | Water sources evaluated in PNNL's water analysis for HyBuild LA.

Water Source	Definition
CA South Coast Wastewater	Wastewater currently sent to water treatment plants in the CA South Coast region (e.g., raw sewage)
SoCal Fracking Demand Offset	Water currently used in oil and gas fracking operations that can be diverted to other uses if fracking operations are reduced
SoCal Fracking Wastewater	Wastewater "produced" from fracking processes (e.g., flowback from fracking wells)
SoCal Refinery Water Demand Offset	Water currently used in oil and gas refining that can be diverted to other uses if refinery operations are reduced
SoCal Refinery Wastewater	Wastewater from refinery processes
Desalinated Water	Seawater that has been treated for commercial use

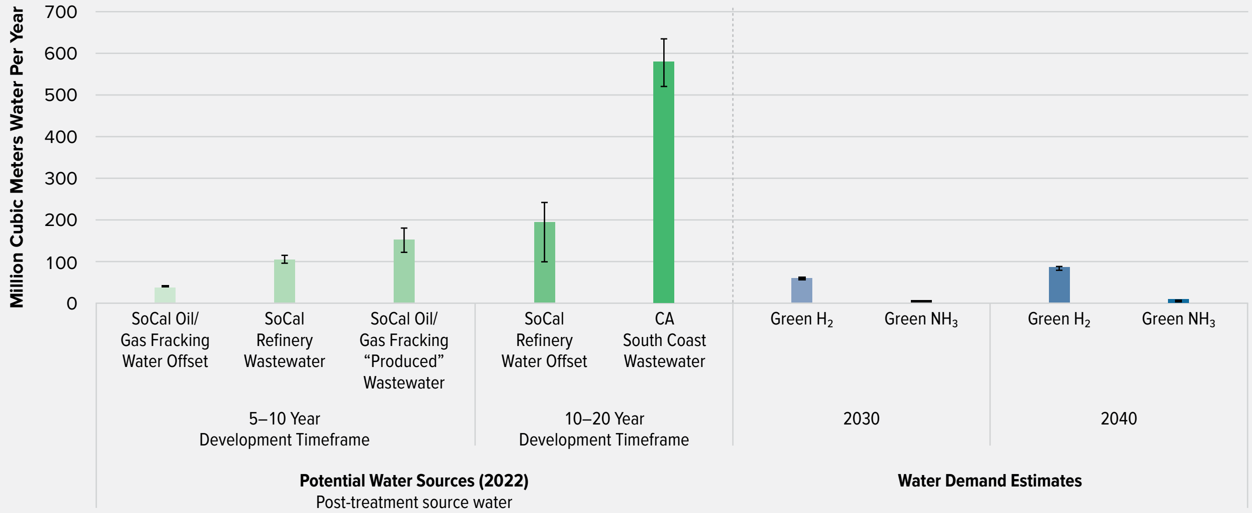
Key Findings

HyBuild LA found that the water needs for GH_2 and green NH_3 production can be fully met from ample recycled or repurposed water sources. The graph below shows the total water demand alongside the total volumes of water that may be available from each of the identified sources, accounting for any losses from water treatment processes. The study assumes that the treatment of recycled wastewater has a 50% yield (meaning 2 units of wastewater are required to produce 1 unit of recycled water that can be used for electrolysis), which is a relatively conservative estimate – stakeholders' feedback indicates that the industry often targets yields up to 85%.[78]

The green NH_3 water demands shown in Figure 21 represent the additional water that would be required to turn GH_2 into NH_3 after the GH_2 feedstock has been produced.

76. California Energy Commission, "California Oil Refinery History," January 2023.
77. Luigi Bressan, et al. , "Hydrogen generation in modern refineries," Digital Refining, January 2009.
78. Interview with David Schneider, Veolia.

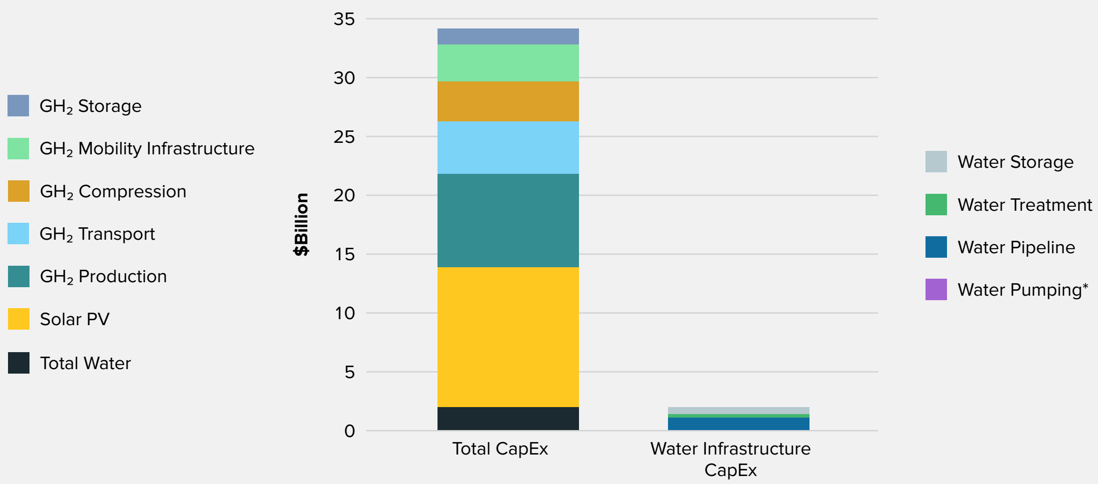
Figure 21 | Available quantities of potential water sources and estimated HyBuild LA water demands.



Note: Error bars represent ranges in model inputs from data sources.
Source: Pacific Northwest National Laboratory for HyBuild LA, 2022

Capital costs for the infrastructure to treat, transport, and store recycled or repurposed water for GH_2 and green NH_3 in 2040 amount to $3.3 billion in a high-cost scenario. This capital expenditure accounts for a relatively small portion of the total investments needed for the HyBuild LA vision (see Figure 22 below). The analysis found that the cost of recycled or repurposed water and the related infrastructure contributes $0.07 – $0.13/kg to the levelized cost of GH_2, depending on the infrastructure scenario. For reference, HyBuild LA estimates that the cost of utilizing municipal freshwater (rather than recycled or repurposed water) would cost approximately $0.03/kg of GH_2, if available.[79]

Figure 22 | Water infrastructure CapEx relative to total HyBuild LA CapEx.

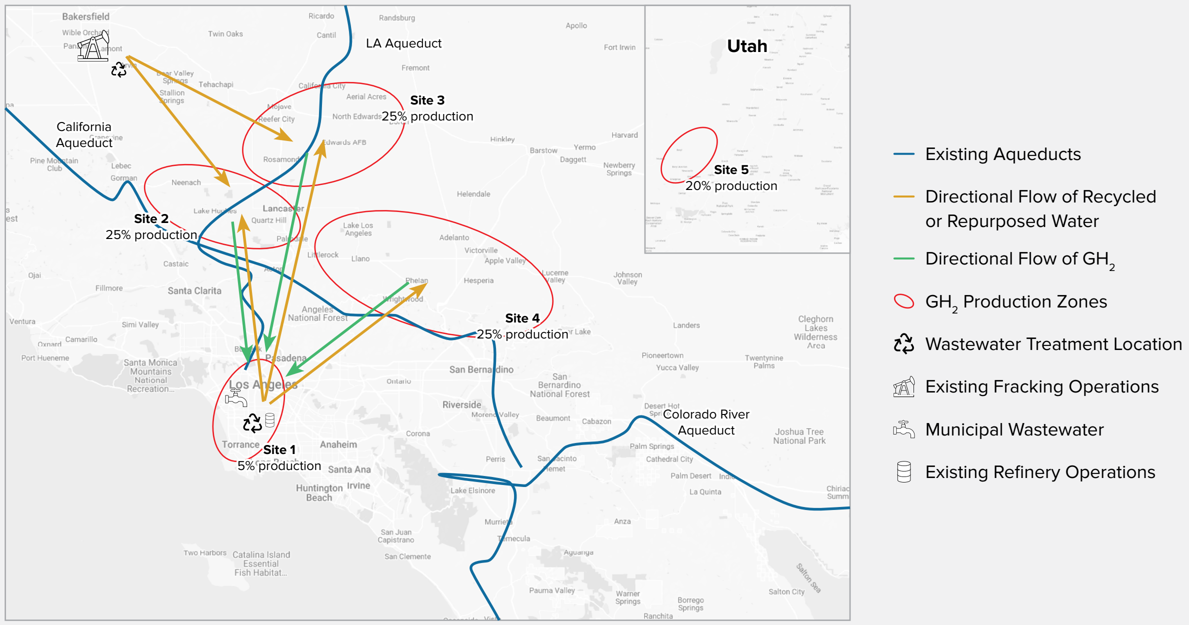


*Water pumping accounts for only 0.25% of total water capital costs, and is not visible on the chart.
Source: Pacific Northwest National Laboratory for HyBuild LA, 2022

79. Municipal water costs were estimated based on an average of residential rates in California during HyBuild LA Phase 1, which was calculated to be around 3.70 USD / cubic meter (~$10.00 per 100 cubic feet). See: UNC School of Government, "California Small Water Systems Rates Dashboard," July 1, 2020.

The majority of wastewater and repurposed water sources considered are located within the LA Basin, whereas GH_2 production is anticipated to occur closer to GH_2 production zones with high solar yield outside of the LA Basin. The highest-cost scenario includes water pipeline infrastructure to connect wastewater treatment sites to GH_2 production zones. This system plan is reflected below in Figure 23, resulting in all-in water costs of $0.13/kg of GH_2. This higher-cost scenario is reflected in the HyBuild LA LCOH of $2.05/kg GH_2.

Figure 23 | HyBuild LA scenario for supplying sources of recycled or repurposed water to electrolytic GH_2 production zones.



Note: HyBuild LA system plan assumes dedicated GH_2 pipeline connection with Central Utah.
Note: This map is illustrative and is not representative of planned infrastructure.
Source: Pacific Northwest National Laboratory for HyBuild LA, 2022

A lower-cost scenario eliminates the need for water pipeline transportation, resulting in an all-in water cost of $0.07/kg GH_2.[80] In this scenario, GH_2 producers could “swap” water rights with other entities, providing their treated wastewater resources to municipal water users in LA in exchange for access to water in the regional aqueducts that run close to the GH_2 production zones. It should be noted that this lower-cost scenario is conceptual and would require innovative policy and permitting solutions to be feasible. However, if enabled, this scenario could reduce water evaporation, system costs, and infrastructure requirements.

80. The LCOH referenced throughout the report reflects the higher-cost scenario of $0.13/kg GH_2.

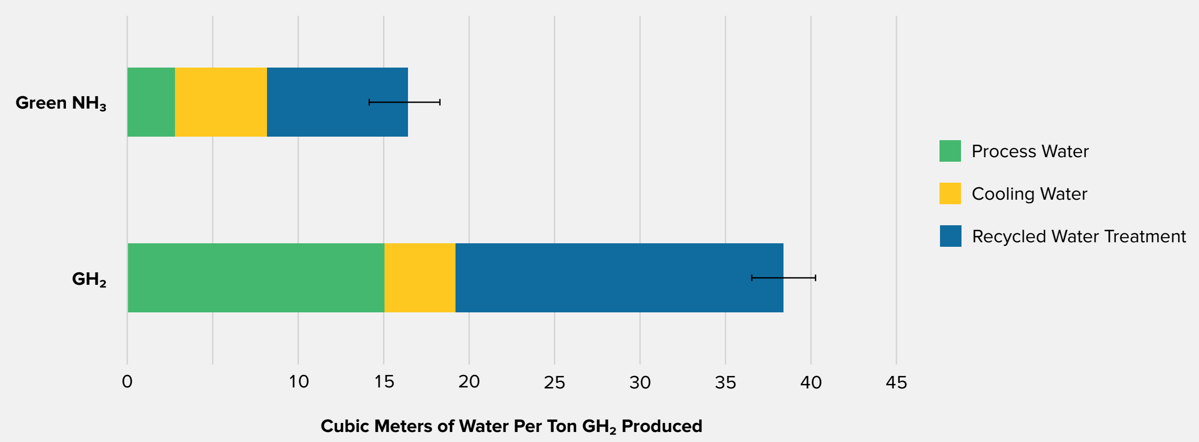
Assumptions and Methodology

PNNL utilized the total GH_2 and green NH_3 demand assessment (conducted by CVA) to evaluate water demand and associated infrastructure. Cost estimates from the water analysis were then incorporated into the levelized cost of GH_2 and total capital expense estimates for HyBuild LA overall.

Water demands for GH_2 and green NH_3 production include stoichiometric and process water demand, cooling water requirements, losses from the water treatment process, and potential water loss from leakage. PNNL collected data from literature and manufacturer specifications and conducted subject matter expert interviews to determine water demand for both GH_2 and green NH_3.[81] Manufacturer specifications for electrolysis process water range from 10.0 to 22.4 kg of H_2O required per 1 kg of H_2 produced.[82] Incorporating losses from evaporation and leaks, and cleaning needs, the total process input water was estimated at 15 kg H_2O/kg GH_2.[83] Cooling water adds about 4.2 kg of H_2O per 1 kg of H_2 produced.[84,85,86]

To meet water quality requirements for electrolysis, reverse osmosis (RO) and deionization (DI) treatment are required. Using a conservative assumption of 50% water loss associated with treating highly contaminated water, the total estimated water demand is 38.4 kg H_2O/kg H_2 produced. Water use per kg of green NH_3 is estimated to be less than half that of GH_2, due largely to reduced process water and water treatment requirements (see Appendix B for more details).

Table 9 | Breakdown of water use for GH_2 and green NH_3 production.



81. As alkaline electrolysis is the most widespread of the current hydrogen electrolysis technologies it was used as the baseline for water demand estimates for hydrogen production. However, water demands for proton exchange membrane (PEM) hydrogen electrolysis are similar.
82. Sofia Simoes, et al., "Water availability and water usage solutions for electrolysis in hydrogen production," Journal of Cleaner Production, 315, 128124, September 15, 2021.
83. Brophy, Brenor. Interview. Conducted by T. M. Harris. 2022.
84. Lampert, David et al., "Development of a life cycle inventory of water consumption associated with the production of transportation fuels," Argonne National Lab (ANL), ANL/ESD-15/27 121551, October 1, 2015.
85. Brian Boyd, et al., "Water Savings Potential and Energy Impact of Implementing Alternative Cooling Technologies in Commonwealth Edison's Service Territory," Alliance for Water Efficiency, August 2021.
86. Brian Boyd, er al., "Taking Inventory: A Guide for Identifying Cooling Towers and Estimating Water Use," Alliance for Water Efficiency, 2022.

Table 10 | Water requirements of the HyBuild LA system plan.

Resource	Unit	2030 Demand	2040 Demand
GH_2	MT GH_2/ year	1.43	2.17
Water for GH_2 Production	Mm^3 H_2O/ year	54.4	82.9
Green NH_3	MT Green NH_3/ year	0.38	1.03
Water for NH_3 Production	Mm^3 H_2O/ year	11.7	13.3

Three primary water source types were considered: surface water, groundwater, and alternative water.[87] Due to drought and water supply challenges in the Southwest, PNNL restricted its analysis to alternative water sources. These included recycled wastewater (e.g., sewage and stormwater runoff), recycled process water (e.g., fracking-produced water and refinery wastewater), and desalinated sea or brine water.[88] The analysis also considered water that could be diverted from the oil and gas sector, assuming those operations will be reduced.

The primary costs associated with water delivery are transportation, storage, and treatment. This assessment considered conservative estimates for each cost area based on known technology, resource requirements, and business conditions. The study considered two elements of water transportation cost: infrastructure (pipelines and pump stations) and electricity demand for pumping water from sources to GH_2 production sites. Capital costs for pipelines account for the largest capital expense, totaling $1.40 billion by 2040.[89] Annual maintenance costs are estimated at 4% of these initial capital costs.

Because the HyBuild LA system plan assumes GH_2 will be produced via solar PV, GH_2 production will fluctuate with solar availability. As a result, water demands for electrolysis will also fluctuate depending on the GH_2 production profile, requiring water to be stored so that it is available during periods of high demand (such as the peak solar summer season). PNNL modeled hourly demand for source water based on the hourly GH_2 production profile over a year to determine water storage sizing requirements. The analysis indicates 39.7 days of water storage would be required at a cost of $513.9 million and $629.3 million for capital expenses and $1.5 million/year and $2.5 million/year for operational expenses for 2030 and 2040, respectively.

This analysis assumes that RO, one of the most common technologies to treat water to the high purity levels needed for electrolysis, is utilized. Costs for RO are well-established. PNNL assumed a linear cost relationship based on a 36.5 Mm^3/year RO system at an average capital cost of $165.4 million and an average operating cost of $10.1 million/year, assuming an average energy demand of 3.0 kWh/m^3 treated. These assumptions lead to capital costs for RO water treatment of $276.1 million and $454.1 million and annual operating costs of $28.9 million/year and $47.5 million/year. This water system would require annual energy demands of 182.8 and 300.6 GWh/year in 2030 and 2040, respectively.[90]

It should be noted that the HyBuild LA study used a conservative assumption for water yield of 50%. As such, the cost estimates for RO will also be conservatively high. Higher water yield rates would decrease water treatment equipment needs, reducing overall cost.

Additional details on the methodology are available in the Appendix.

87. Alternative water refers to sustainable sources of water that can help to reduce reliance on fresh surface and groundwater resources. See "Best Management Practice #14: Alternative Water Sources," Office of Energy Efficiency & Renewable Energy, accessed January 20, 2023.
88. As recent efforts to establish large seawater desalination facilities in Southern California have failed due to social and political resistance, desalination was not considered as a primary potential source.
89. U.S. Bureau of Reclamation (USBR), "Southern California Comprehensive Water Reclamation and Reuse Study Phase II Final Report," July 2002.
90. Linares, R. V., et al., "Life cycle cost of a hybrid forward osmosis–low pressure reverse osmosis system for seawater desalination and wastewater recovery," Water Research, 88, 225-234, January 1, 2016.

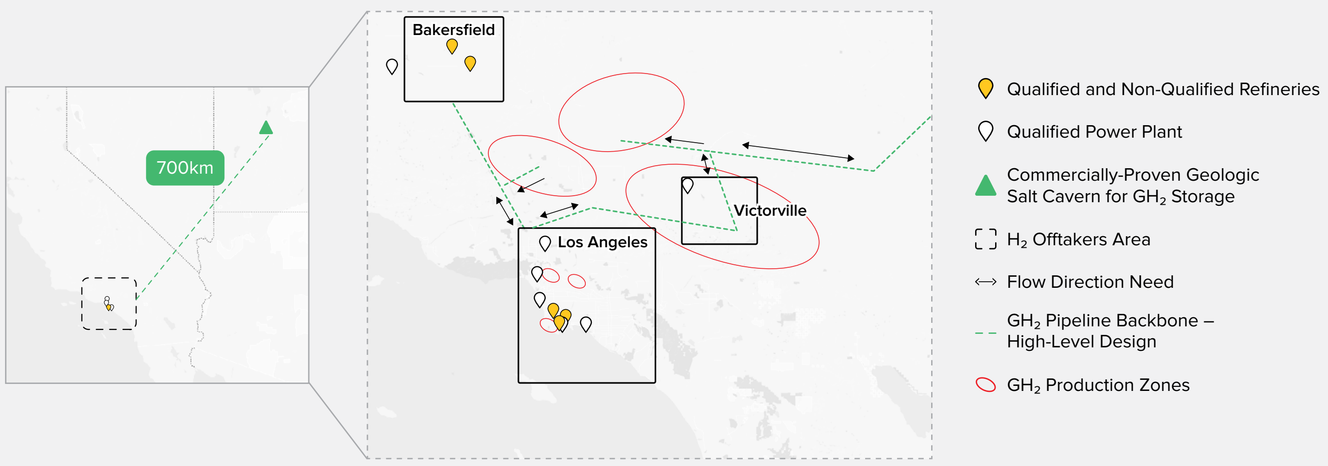
5.3 | SYSTEM PLAN

The HyBuild LA system plan, which was established in Phase 1, provides a lowest-cost scenario to serve the anticipated mass-scale demand in the LA Basin. This end-to-end system plan includes upstream production sources, midstream transportation and storage scenarios, and downstream infrastructure for select end uses.[91]

This analysis identified that the lowest-cost scenario would produce GH_2 via renewable electricity from dedicated photovoltaic solar systems in resource-rich regions, identified as "Production Regions", located outside of the LA Basin. These renewable energy resources would be co-located with electrolysis infrastructure and would deliver GH_2 to offtakers in the LA Basin via dedicated pipelines. To accommodate and balance seasonal variability in both production and demand, the GH_2 would be stored in an out-of-state geologic salt cavern site, which would be connected to the system via dedicated GH_2 pipeline. The aforementioned pipeline infrastructure is referred to as the "pipeline backbone" throughout the report. Other pathways for production, transportation, and storage explored in HyBuild LA (including rooftop solar and electric transmission) can be found in the High-Level Methodology section below.

The system plan developed in Phase 1 is represented in Figure 24 below.

Figure 24 | HyBuild Los Angeles System Plan.



Note: Electrolytic green hydrogen can be produced in Southern California and along the pipeline route.
Note: This map is illustrative and does not include all potential offtakers. Refineries, power plants, and cement plants are shown as sample potential offtakers.
Source: Corporate Value Associates Analysis for HyBuild LA, 2021

High-Level Methodology

Prior to undertaking this system plan analysis, a demand assessment was completed to understand the profile of offtake in the LA Basin. The demand assessment from HyBuild LA Phase 1 determined potential demand for GH_2 was sufficiently large and stable enough to require the development of mass-scale transportation and storage infrastructure. Three different scenarios were assessed for production, storage, and transportation of GH_2 to aggregated offtakers within the LA Basin:

1. GH_2 is produced in close physical proximity to large-scale renewable energy feedstocks outside of LA and transported to offtakers via a GH_2 pipeline backbone;
2. Renewable energy is transported from outside of LA Basin via electric transmission lines and GH_2 is produced in closer proximity to offtakers; and
3. GH_2 is produced near offtakers, utilizing rooftop solar production.

91. HyBuild LA Phase 2 considered infrastructure to support some mobility sectors (i.e., liquefaction and heavy-duty fueling stations).

The assessment concluded that the first scenario would enable the lowest delivered cost of GH_2. The second scenario of transportation via electric transmission was found to be more expensive per kg GH_2. The third scenario uncovered that rooftop solar would be insufficient to meet the scale of demand for GH_2 from potential offtakers.

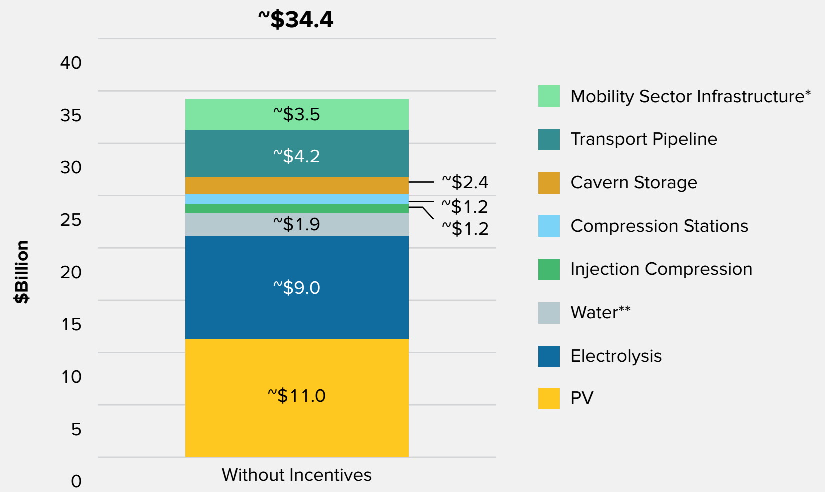
The analysis also identified the need to connect the system to geologic salt cavern storage to balance this mass-scale system, and determined that the closest commercially-proven geologic salt cavern site is located in Delta, Utah. These findings were carried forward as assumptions into the analyses of HyBuild LA Phase 2.

5.4 | HYBUILD LA CAPITAL EXPENDITURE AND LEVELIZED COST OF GREEN HYDROGEN

Findings

The HyBuild LA system plan,[92] which is designed to serve a total demand of 1.4 MMT GH_2, is estimated to require a total capital expenditure (CapEx) of $34 billion through 2030. The allocation of this cost by type of capital expenditure is shown in Figure 25.

Figure 25 | Capital expenditure estimate for the HyBuild LA 2030 system plan. Costs exclude development, land lease, and decommissioning costs.



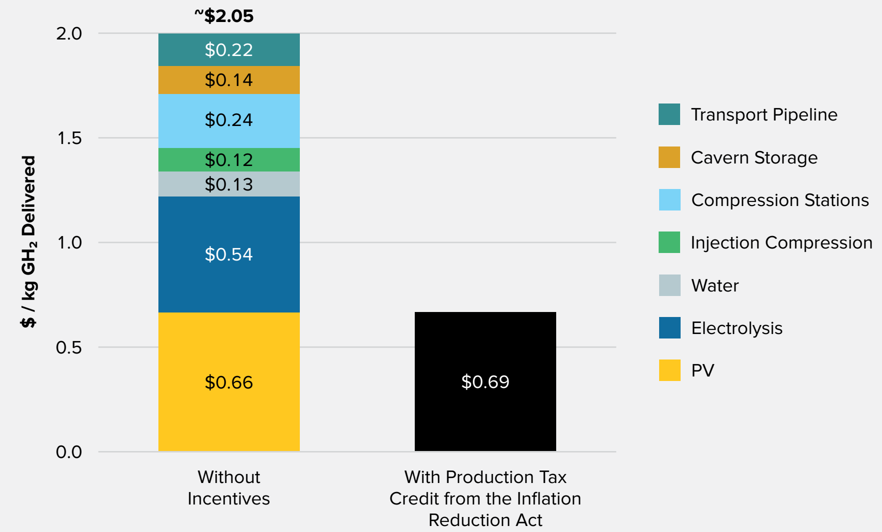
*Liquefaction, delivery, fueling
**Represents the higher-cost scenario for water
Source: Corporate Value Associates Analysis for HyBuild LA, 2022

This CapEx estimate was translated into a delivered LCOH of $2.05. The allocation of this cost by type of expenditure is shown in Figure 26.[93]

It should be noted that, while the total CapEx shown in Figure 25 includes additional downstream infrastructure for mobility applications (liquefaction, delivery of liquid GH_2 from the pipeline backbone via truck, heavy-duty fueling stations), these costs are not reflected in the LCOH of $2.05/kg GH_2.

92. Based on a total demand of 1.4 MMT of GH_2 per year.
93. Assumes that all producers generate $3/kg GH_2 produced over a period of 10 years and can sell all excess tax credits successfully on the market.

Figure 26 | Estimated levelized cost ($/kg) of delivered GH_2 in 2030, broken down by value chain element. Based on a total estimated demand of 1.4 MMT annually.



Source: Corporate Value Associates Analysis for HyBuild LA, 2022

Methodology

The HyBuild LA GH_2 system plan includes all components indicated in Figure 27 below.

Figure 27 | Key infrastructure parameters of the GH_2 system plan for the HyBuild LA vision.

Upstream	**Solar PV Installations**	**28 GWp** – Combined plant capacity **75 TWh** – PV electricity produced per year
Upstream	**Electrolyzers**	**22 GWe** – Combined electrolyzer size **37%** – Average load factor **1.4Mt H_2** – Annual production of GH_2
Upstream	**Compression at Injection**	**310 MW** – Cumulative compressor capacities **445t H_2/h** – Max flow
Midstream	**Compressor Stations**	**620 MW** – Cumulative capacities of all compressor stations
Midstream	**Underground Storage**	**130 kt H_2** – Effective maximal capacity **1,430M Nm^3** – Effective maximal volume
Downstream	**H_2 Transport Pipelines**	**1,300 miles** – GH_2 pipeline backbone
Downstream	**Distribution**	**10–15** – Number of major offtakers connected via distribution pipes **320 kt** – Cumulative annual production of liquid GH_2 for mobility **>1,000** – Number of public and private GH_2 refuelling stations

The system design developed for HyBuild LA utilized an LCOH tool created by CVA. The components for calculating LCOH include the cost per kg of GH_2 for electricity, electrolysis, GH_2 compression, storage, and transport to the LA Basin. The model assumes that all GH_2 is produced using solar energy from dedicated solar installations that are not connected to the electric grid, but rather produce GH_2 directly onsite to be transported to offtaker regions via a dedicated GH_2 pipeline.

The first model in the LCOH tool calculates the required capacity of GH_2 production and delivery equipment based on an annual GH_2 offtake target, which is used as an input to the cost model. Extensive solar and electrolysis plant data from both external sources and internal modeling are used to create 8,760 hours, or yearly, generation profiles to determine the quantity of energy available for GH_2 production via electrolysis at different times throughout the year. The model then estimates GH_2 storage and transportation infrastructure needs, considering the availability of storage options, GH_2 demand profiles for different offtakers, and the equipment required for storage (e.g., compressors, wells, and boosters). The analysis also determines the necessary GH_2 compression capacity and infrastructure size requirements for transport through pipelines to offtaker delivery sites, including the pipeline system connection to geologic salt storage in Delta, Utah. The required infrastructure components and their sizes are then passed to the cost model.

HyBuild LA defines "levelized cost of GH_2" as the lowest price point at which the system could deliver GH_2 considering all capital, operational, and maintenance costs for GH_2 production and delivery infrastructure.

The cost model conducts a discounted cash flow analysis of revenues, as well as capital and operating costs over the economic life of the project. Cost estimates for each component of the system are sourced from external references and internal expertise within CVA. The costs are projected over the lifespan of the project, which is assumed to be 35 years. The model calculates the GH_2 price that would provide sufficient revenue for the project to be economically viable (e.g., to have a net present value (NPV) of zero while realizing a return on capital of 6%).[94] This GH_2 cost is established as the "levelized cost of GH_2," defined as the lowest price point at which the project could deliver GH_2, considering all capital, operational, and maintenance costs for GH_2 production and delivery infrastructure.

94. Expected return on capital was based on discussions with stakeholders in other GH_2 hub projects, as well as in reference to developer bids for such projects in Europe and elsewhere.

6. COMMUNITY IMPACTS

The Community Impacts Workstream centered around two interrelated tasks: (1) engaging directly with community stakeholders and (2) conducting analyses to define the quantifiable impacts of the envisioned HyBuild LA end-to-end system plan on local communities, while focusing on communities that have historically been disproportionately burdened by negative environmental impacts and placement of energy infrastructure. For the second task, the GHC worked with UCI to conduct two studies assessing (a) the impacts of GH_2 adoption on air quality and public health, and (b) job creation that would be enabled by the proposed GH_2 system.

6.1 | STAKEHOLDER ENGAGEMENT

HyBuild LA engaged directly with key community stakeholders to build awareness of the emergent opportunities for GH_2 and to develop a co-creative space for identifying areas of interest and concern that could be carried forward into the GHC's market development activities. Additionally, this Workstream provided a forum for stakeholders to inform the technical analyses and system design of the HyBuild LA effort. These key stakeholders included environmental justice and environmental advocates, tribal communities, and union and labor representatives.

It should be noted that the efforts of HyBuild LA are not intended to replace the stakeholder engagement process used to develop projects; rather, these efforts are intended to elevate community questions and perspectives as the region pursues a GH_2 economy and associated infrastructure development.

Key Findings

HyBuild LA Phase 2 hosted four listening and educational sessions with the goal of creating a platform for stakeholder dialogue, covering the following four topics:

- Introduction to GH_2 – including information on the global GH_2 market, production pathways, and carbon intensity – and an overview of electrolyzer technology, GH_2 storage and transport mechanisms, and potential end-use applications.
- Federal, state, and local level GH_2 activities and opportunities, featuring speakers from the California Governor's Office of Business Development and the Port of Los Angeles.
- Impacts of GH_2 on air quality and public health, featuring speakers from the Advanced Power and Energy Program at UCI.
- Impacts of GH_2 on local job creation, featuring speakers from the Advanced Power and Energy Program at UCI.

These discussions created space for stakeholders to express questions, concerns, and areas of interest regarding a potential at-scale GH_2 ecosystem.

Through this process, the Community Impacts workstream identified that many community groups are experiencing lack of bandwidth to engage fully in GH_2-related processes, as GH_2 is often one topic among many important priorities. If not addressed, these capacity constraints may inadvertently prevent various community stakeholders from participating in the fast-moving GH_2 and energy infrastructure development processes and related market development processes. Investments into key stakeholders' bandwidth and capacity to engage on GH_2 is of critical importance, and must be considered prior to other ecosystem investments.

Table 11 provides a summary of the questions raised by stakeholders and initial actions taken or that need to be taken to address the questions.

Table 11 | Questions, areas of interest, and areas of concern raised by stakeholders in the Community Impacts Workstream of HyBuild LA Phase 2.

Area of Interest	Specific Questions	Initial Actions Taken
GH_2 infrastructure	• What would GH_2 infrastructure look like in LA, in the port, and in my own community? • What is the development process? How can stakeholders weigh in on projects? • Where will projects and infrastructure be sited? • What are the localized impacts of GH_2 infrastructure, including safety impacts, leaks, and health impacts?	The GHC offered all interested stakeholders access to a facilitated tour of GH_2 pilot equipment at the Port of LA's Fenix Marine Services Terminal. Further engagement with communities will be needed by developers and California's hub coalition, ARCHES, regarding individual projects as they are planned.
NOx and Air Quality Impacts	• What are the localized impacts of GH_2 combustion? • Would combustion operate on pure GH_2 or a GH_2 blend? What are the tradeoffs of each? • How will GH_2 displacement of diesel and natural gas impact NOx emissions and air quality? • How will GH_2 use impact NOx emissions and local air quality? • What is the impact of derivative fuels, such as ammonia, on air quality and NOx?	The Community Impacts Workstream provided stakeholders with a Q&A session with atmospheric scientists from UCI to discuss questions around emissions related to GH_2.
Fugitive GH_2 and Leakage	• What is fugitive GH_2, what is its impact on climate change, and how can it be managed? • What the impact of fugitive GH_2 on the safety of my neighborhood?	The GHC is collaborating on an ongoing basis with environmental stakeholders around further understanding fugitive GH_2 and ensuring strong climate integrity and safety standards of any resulting GH_2 projects.
Jobs and Safety	• What types of jobs, education, and skillsets would be needed in the GH_2 economy? • How will we ensure that workers maintain the family-sustaining wages they've worked hard to achieve in the oil and gas industries? • What will be the associated training and workforce development needs? • What safety standards and codes exist for GH_2? What still needs to be established to ensure GH_2 equipment is safe?	The Community Impacts Workstream collaborated with interested stakeholders on the jobs study to further understand GH_2 workforce opportunities. Further safety education and workforce transition work will be needed to ensure a just and inclusive energy transition.
Water Usage	• How can water be sourced sustainably?	Based on stakeholder feedback, the Pacific Northwest National Laboratory study for HyBuild LA considered only recycled or repurposed water (no freshwater sources).
Ammonia	• Where would infrastructure for green ammonia as a maritime shipping fuel be located? • How can we ensure it is safe? • Even if green ammonia is made, stored, and used elsewhere, how can Angelenos ensure community safety in other regions? • What are the health, safety, and environmental impacts of ammonia production, transport, storage, and combustion?	Based on stakeholder feedback, the HyBuild LA removed the assumption that any ammonia would be produced locally or bunkered in the Port of LA or Long Beach. Continued collaboration and knowledge sharing with international ports that are advancing green NH_3 as a shipping fuel is recommended.

While the HyBuild LA platform sought to address some of these questions (e.g., water usage), the GHC recommends that further work be done in each of these areas, in close collaboration with community stakeholders.

Methodology

The Community Impacts Workstream served as an avenue to increase transparency of HyBuild LA's efforts, and to create opportunity for local community stakeholders to access information regarding GH_2. The participants had full access to convenings and activities of all other workstreams, weekly update communications on platform activities, and access to a web-based portal containing materials from each analytical study.

Given HyBuild LA Phase 2's emphasis on end uses in and around the ports, outreach to prospective community participants started with stakeholder groups around the Ports of LA and Long Beach. The GHC first reached out to relevant contacts, including regional environmental justice groups focused on air quality, labor unions working with heavy-duty equipment in the ports, labor unions from local refineries, and more. The GHC then connected with additional stakeholders based on group recommendations.

This process was open to all representatives from the priority stakeholder groups (environmental advocates and environmental justice organizations; union and labor organizations; tribal nations) who wished to participate in this effort. Throughout the duration of this effort, the HyBuild LA webpage on the GHC website contained a form for stakeholders to indicate their interest to get involved in these activities.

To engage participants, the Community Impacts Workstream hosted four listening and educational sessions.[95] For transparency, sessions were recorded and the materials were distributed to the group. Each meeting allowed stakeholders time for questions and discussion with presenters.

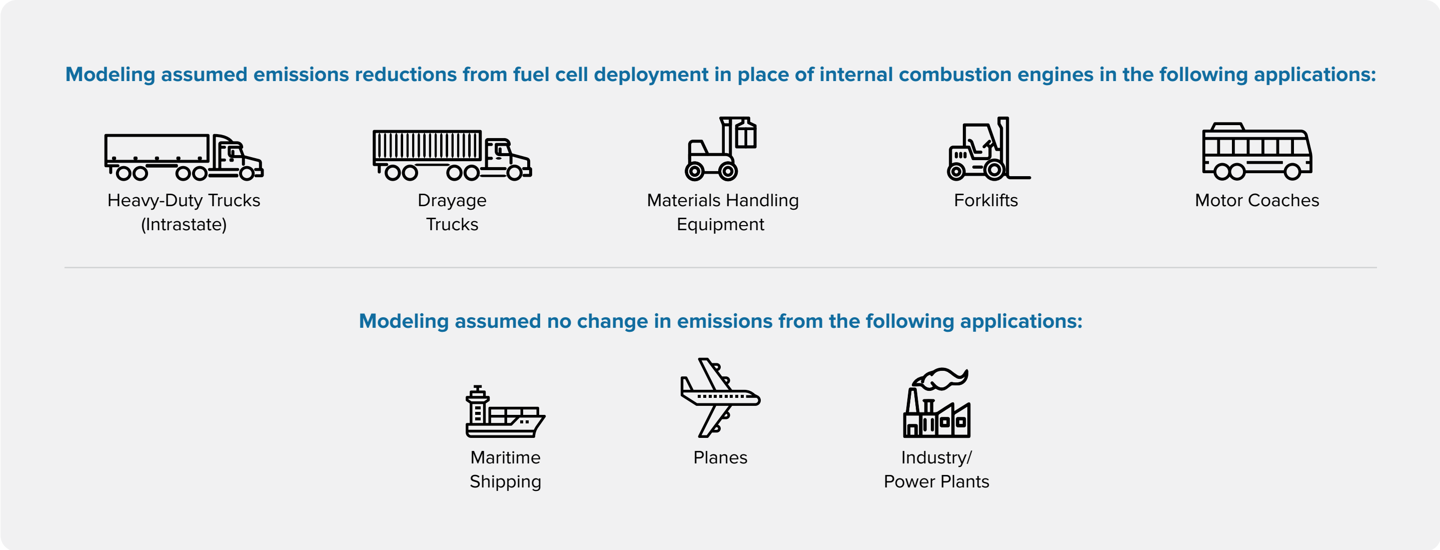
6.2 | AIR QUALITY ANALYSIS

HyBuild LA assessed the impacts of replacing fossil fuel combustion technology with GH_2 fuel cells in a variety of land-based mobility sectors, analyzing the impact this would have on pollutant emissions, air quality, and public health. This analysis also provided a specific view into the public health impacts from this scenario on disadvantaged communities (DACs) in the South Coast Air Basin.

The air pollution portion of the study specifically assessed three air pollutants: ozone, $PM_{2.5}$, and NOx. The study accounted for primary pollutants that are emitted directly from tailpipes, as well as secondary pollutants that are formed indirectly from chemical reactions in the atmosphere. These pollutant levels were used to develop the public health portion of the study, which specifically considered the human health impacts of $PM_{2.5}$ and ground-level ozone (caused by NOx). These pollutants are associated with negative health consequences in exposed populations and are commonly included in similar health impact assessments. This assessment studied the impacts of pollution reduction within the South Coast Air Basin – which includes Los Angeles County, Orange County, and the coastal (i.e., non-desert) portions of San Bernardino and Riverside Counties – and is not compliant with State and Federal health-based standards for ozone or $PM_{2.5}$.

The analysis considered the impacts of fuel cell deployment in place of fossil fuel combustion technology in the following applications:

Figure 28 | End uses considered in the HyBuild LA air quality assessment.



95. As listed previously, the sessions were: (1) Introduction to GH_2, (2) federal, state, and local level GH_2 activities, (3) Impacts of GH_2 on air quality and public health, and (4) Impacts of GH_2 on local job creation.

The study evaluated one summer month (July) and one winter month (January) for both 2035 and 2045. The years of 2035 and 2045 were selected because it enabled the study to align with the Reference Scenario in the California Air Resources Board's Scoping Plan, a reputable process which maps to the State's climate objectives. Annual modeling was not possible for this study given time constraints and the intensive computational requirements to run the models, so January and July were selected for analysis to demonstrate seasonal variation in air pollution caused by differences in meteorology and other factors. Notably, the months of January and July often have high pollutant formation periods, potentially resulting in higher pollutant differences from the Reference Scenario. As such, the results of both the air quality and health benefit assessments should not be multiplied directly to determine annual changes.

Findings

Results of the HyBuild LA analysis show notable air quality and public health benefits from reduced fossil fuel combustion, enabled by the use of GH_2 in zero-emission fuel cell electric technology.

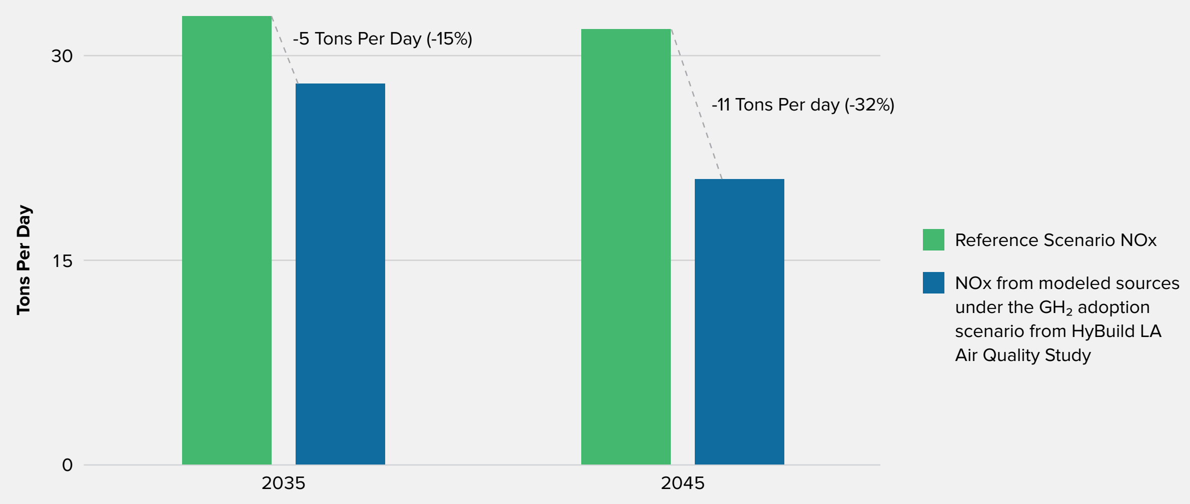
In reviewing the following public health benefits, it is important to note that the GHC recognizes that the value of human health and livelihood is much more complex than the dollar amounts shown in the findings below. This modeling exercise estimates public health benefits by determining the number of avoided incidence of harmful health endpoints (e.g., missed days of work, hospitalizations) in the study population due to air pollution improvements. From here, the model provides an economic valuation of those avoided health endpoints. The valuation includes both direct cost of illness for some endpoints, such as the average cost of a hospitalization, and willingness-to-pay for avoided incidence (e.g., premature mortality is measured through the value of statistical life). It should be noted that the value of statistical life represents a commonly-used statistical value that a group of people are willing to pay to avoid the risk of one death, and in no way attemts to represent an estimate of the value of a human life.

Finally, it should be noted that this analysis only evaluated two months out of each year (January and July 2025; January and July 2035), and that health benefits would be much higher on an annual basis. Further modeling, including annual air quality simulations, should be considered as a part of further community impact assessments.

NOx and Ozone

The use of GH_2 in the modeled end uses (e.g., intrastate heavy-duty vehicles, heavy-duty drayage vehicles, long-distance motor coaches, forklifts, and cargo handling equipment) reduces NOx emissions from the Reference Scenario by 15% in 2035 and by more than 30% in 2045 (see Figure 29).

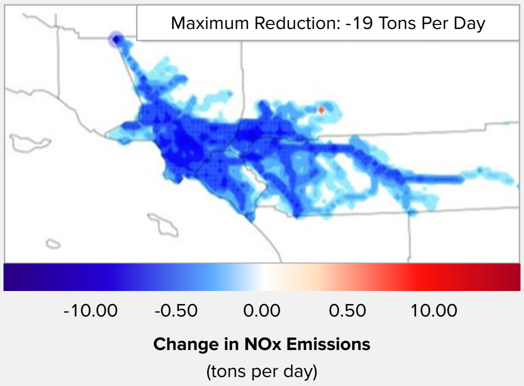
Figure 29 | Improvements in NOx for modeled sources in 2035 and 2045 due to the GH_2 deployment scenario, relative to the Reference Scenario.



Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

Direct NOx emissions reductions are most significant around the major transit pathways (see Figure 30 below), such as the I-710 and the I-10 corridors. However, ozone (which is formed from NOx in the atmosphere), distributes the benefits from reducing emissions across the region.

Figure 30 | Reductions in NOx emissions (tons per day) in 2045 due to the GH_2 deployment scenario.



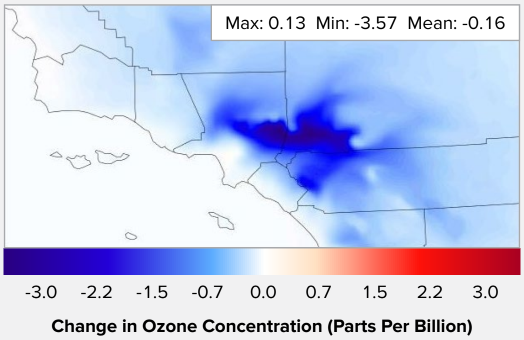
Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

The NOx reductions will result in improvements in ozone greater than 1 ppb, with the largest reductions occurring in eastern San Bernardino and Riverside Counties. In 2045, reductions in ground-level ozone in July (relative to the Reference Scenario) exceed 3.5 ppb.

For context, the regulatory standard for ozone is 70 ppb, and more than half of California's residents live in areas that exceed that health-based standard.[96] Of these nonattainment regions, the South Coast Air Basin and the San Joaquin Valley are the worst, as the only areas in the nation designated as "extreme" by the U.S. Environmental Protection Agency.[97] In the months modeled, peak ozone reductions occur in eastern San Bernardino and Riverside Counties, which are within the South Coast Air Basin and are home to a large population, including numerous DACs, according to CalEnviroScreen.

In a business-as-usual scenario without deployment of GH_2 in the modeled sectors, the Reference Case predicted a peak of 87 PPB in 2045 in the South Coast Air Basin. In the emissions reduction scenario, the improvements of 4 PPB by 2045 shown in Figure 31 can reduce 23% of non-compliance events, or events when the ozone reaches an unsafe level above 70 ppb.

Figure 31 | Improvements in maximum daily 8-hour average ozone (ppb) in July 2045 due to the GH_2 deployment scenario.



Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

96. Melanie Turner, "California adopts comprehensive strategy to meet federal ozone standard over next 15 years," California Air Resources Board, September 22, 2022
97. Environmental Protection Agency, "Current Nonattainment Counties for All Criteria Pollutants," January 31, 2023

In the winter month (January), ozone levels the Reference Scenario are lower than the health-based standard; thus, the modeling does not demonstrate avoided health benefits. However, the reduction in ozone results in significant public health benefits that are reflected during the summer month modeled (July). The avoided health incidence and the subsequent value associated with their avoidance during July 2035 and 2045 is shown in the table below. Overall, as a result of reduced ozone due to the GH_2 deployment scenario during the two modeled months (July 2035 and 2045), communities in the region are estimated to experience health benefits such as:

- 10 fewer premature deaths
- 73 fewer hospitalizations and emergency room visits

Table 12 | The avoided incidence of health issues and associated value caused by reductions of exposure to ozone as a result of the GH_2 deployment scenario in July 2035 and 2045.

		2035		2045	
Endpoint	**Pollutant**	**Incidents Avoided**	**Value of Avoided Health Incidents**	**Incidents Avoided**	**Value of Avoided Health Incidents**
Avoided Mortality, Respiratory	Ozone	2.36	$23,293,800.00	7.59	$79,750,741.20
Incidence, Asthma Onset	Ozone	34.19	$1,304,547.60	97.88	$3,987,905.50
Emergency Room Visits, Respiratory	Ozone	17.43	$32,304.70	49.97	$107,159.90
Asthma Symptoms	Ozone	15,131.73	$4,540,515.60	43,258.88	$13,824,045.70
Hospital Admissions, Respiratory	Ozone	1.32	$80,805.50	4.36	$299,086.70
Total			**$29,251,973.40**		**$97,968,939.00**

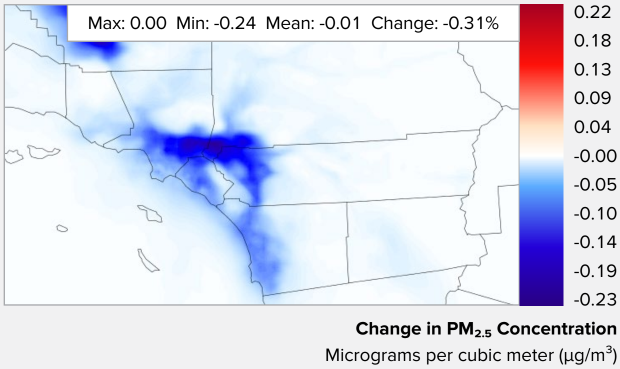
$PM_{2.5}$

Reductions in emissions of $PM_{2.5}$ will result in important public health benefits, given the well-established link between exposure to ambient $PM_{2.5}$ and various harmful health outcomes, including premature mortality, cancer, cardiovascular and neurological disease, enhanced susceptibility to infection including COVID, and many others.[98,99,100]

By 2035, the HyBuild LA winter scenario would result in improvements in $PM_{2.5}$ of greater than 0.24 micrograms per cubic meter ($\mu g/m^3$), with the largest improvements occurring in and around Los Angeles County and extending into western Riverside and San Bernardino Counties.

98. Ioannis Manisalidis, Elisavet Stavropoulou, Agathangelos Stavropoulos, and Eugenia Bezirtzoglou. "Environmental and health impacts of air pollution: a review." Frontiers in public health, 2020.
99. Kampa, Marilena, and Elias Castanas. "Human health effects of air pollution." Environmental pollution 151, no. 2, 2008.
100. Ali, Nurshad, and Farjana Islam. "The effects of air pollution on COVID-19 infection and mortality—A review on recent evidence." Frontiers in public health 8, 2020.

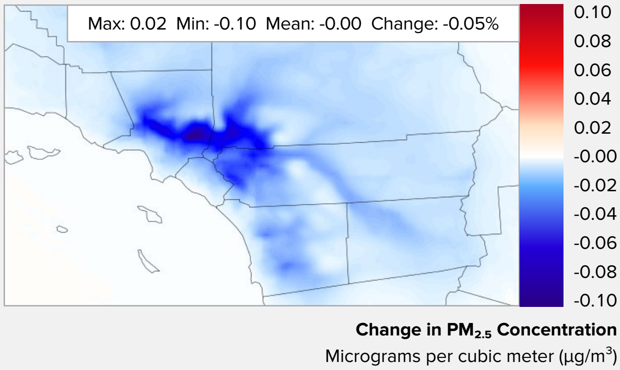
Figure 32 | Improvements in 24-hour average $PM_{2.5}$ (µg/m³) in January 2035 due to the GH_2 deployment scenario.



Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

Though it is less pronounced than in the winter month (due primarily to differences in seasonal meteorology), July 2035 still shows a measurable improvement in $PM_{2.5}$ of 0.10 µg/m³, with a similar spatial distribution to those observed for the winter scenario.

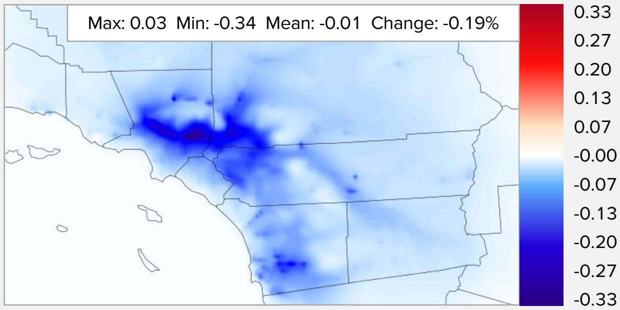
Figure 33 | Improvements in 24-hour average $PM_{2.5}$ (µg/m³) in July 2035 due to the GH_2 deployment scenario.



Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

In 2045, anticipated improvements in the winter month (January) exceed 0.72 µg/m³. Similar to 2035, the largest improvements occur in Los Angeles County and western Riverside and San Bernardino Counties. In July, improvements in $PM_{2.5}$ reach 0.34 µg/m³ with a similar spatial distribution to those observed for the winter scenario.

Figure 34 | Improvements in 24-hour average $PM_{2.5}$ ($\mu g/m^3$) in July 2045 due to the GH_2 deployment scenario.



$PM_{2.5}$ Concentration
Micrograms per cubic meter ($\mu g/m^3$)

Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

These reductions in $PM_{2.5}$ are expected to result in demonstrable public health benefits across the winter and summer months modeled. Overall, as a result of reduced $PM_{2.5}$ due to the GH_2 deployment scenario during the four modeled months (January and July 2035; January and July 2045), communities in the region are estimated to experience health benefits such as:

- 17 fewer premature deaths
- 890 fewer hospitalizations and emergency room visits
- 7,520 fewer work loss days

Table 13 | The avoided incidence of health issues and associated value caused by reductions of exposure to $PM_{2.5}$ as a result of the GH_2 deployment scenario in January 2035 and 2045.

		2035		2045	
Endpoint	**Pollutant**	**Incidents Avoided**	**Value of Avoided Health Incidents**	**Incidents Avoided**	**Value of Avoided Health Incidents**
Avoided Mortality, All Cause	$PM_{2.5}$	2.49	$24,964,396.40	10.43	$109,732,534.00
Hospital Admissions, Alzheimer's Disease	$PM_{2.5}$	118.22	$29,668,765.20	491.73	$136,681,480.00
Hospital Admissions, Parkinson's Disease	$PM_{2.5}$	9.46	$7,249,092.40	39.40	$33,452,558.60
Incidence, Lung Cancer	$PM_{2.5}$	15.42	$647,172.50	60.89	$2,830,426.80
Incidence, Asthma Onset	$PM_{2.5}$	452.58	$17,594,669.20	1,539.00	$62,688,065.20
Acute Myocardial Infarction, Nonfatal	$PM_{2.5}$	1.35	$758,322.20	5.51	$3,325,135.60
Asthma Symptoms	$PM_{2.5}$	3,850.52	$2,288.20	13,338.63	$8,779.20
Hospital Admissions, Cardiovascular	$PM_{2.5}$	2.09	$59,884.30	8.99	$283,761.80
Emergency Room Visits, Cardiovascular	$PM_{2.5}$	3.54	$7,064.00	14.34	$31,695.00
Hospital Admissions, Respiratory	$PM_{2.5}$	0.32	$5,328.10	1.39	$25,138.00
Emergency Room Visits, Respiratory	$PM_{2.5}$	5.90	$8,864.90	21.32	$35,493.10
Work Loss Days	$PM_{2.5}$	1281.47	$256,656.80	4520.69	$905,417.60
Total			**$81,222,504.30**		**$350,000,484.90**

Table 14 | The avoided incidence of health issues and associated value caused by reductions of exposure to $PM_{2.5}$ as a result of the GH_2 deployment scenario in July 2035 and 2045.

		2035		2045	
Endpoint	**Pollutant**	**Incidents Avoided**	**Value of Avoided Health Incidents**	**Incidents Avoided**	**Value of Avoided Health Incidents**
Avoided Mortality, All Cause	$PM_{2.5}$	0.66	$6,567,303.60	3.10	$32,573,499.80
Hospital Admissions, Alzheimers Disease	$PM_{2.5}$	25.56	$6,309,111.60	123.66	$34,373,219.40
Hospital Admissions, Parkinsons Disease	$PM_{2.5}$	2.17	$1,635,550.80	10.35	$8,789,364.30
Incidence, Lung Cancer	$PM_{2.5}$	3.54	$90,369.40	16.01	$459,779.00
Incidence, Asthma Onset	$PM_{2.5}$	105.15	$4,019,678.40	413.21	$16,834,523.80
Acute Myocardial Infarction, Nonfatal	$PM_{2.5}$	0.38	$209,113.20	1.69	$1,021,512.00
Asthma Symptoms	$PM_{2.5}$	1,032.05	$603.20	4,023.94	$2,648.50
Hospital Admissions, Cardiovascular	$PM_{2.5}$	0.58	$16,193.60	2.71	$85,605.60
Emergency Room Visits, Cardiovascular	$PM_{2.5}$	0.98	$1,917.80	4.35	$9,618.50
Hospital Admissions, Respiratory	$PM_{2.5}$	0.09	$1,444.90	0.42	$7,587.10
Emergency Room Visits, Respiratory	$PM_{2.5}$	0.58	$2,362.40	2.71	$10,765.30
Work Loss Days	$PM_{2.5}$	346.47	$68,253.60	1,370.90	$274,567.50
Total			**$18,921,902.50**		**$94,442,690.80**

Overall Public Health Impacts

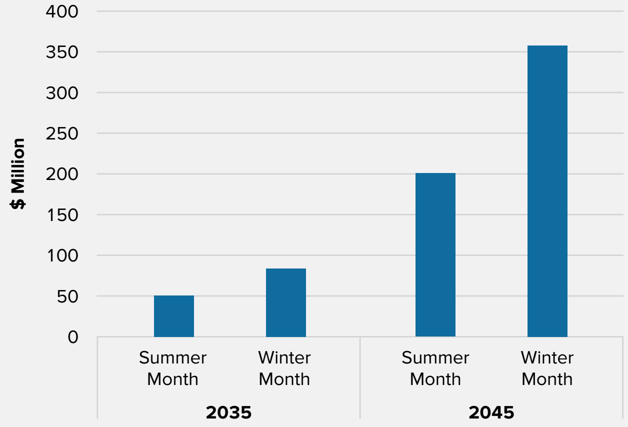
Reducing exposure from both ozone and $PM_{2.5}$ will result in meaningful public health benefits throughout the South Coast Air Basin, including avoided hospitalizations, fewer lost workdays, fewer incidences of disease resulting in reduced mortality, and more. As a result of improved air quality due to the GH_2 deployment scenario during the four modeled months (January and July 2035; January and July 2045), communities in the region are estimated to experience health benefits such as:

- 27 fewer premature deaths
- 964 fewer hospitalizations for respiratory, cardiovascular, and neurological illness
- 7,520 fewer work loss days

These avoided health impacts also have significant statistical value. The total health benefits of the four modeled months result in economic benefits ranges from approximately $50 million for July 2035 to over $350 million for January 2045. The avoided health incidences and health benefits are larger for the January months modeled, reflecting the larger improvements in winter due primarily to seasonal meteorology.

More detail reflecting the value of avoided health incidents by pollutant, relevant health incident, and modeled month are shown in Tables 12, 13, and 14 above.

Figure 35 | Value of total health benefits in the South Coast Air Basin caused by reductions of exposure to $PM_{2.5}$ and Ozone for the four months modeled.



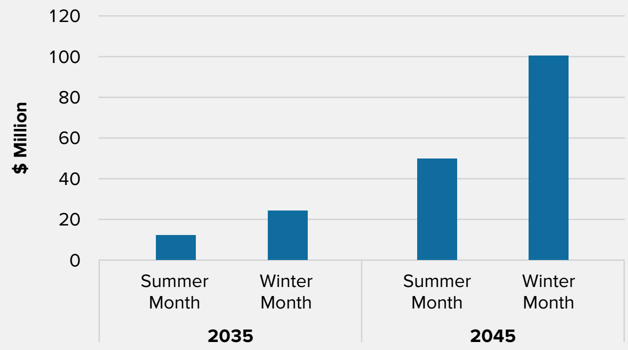
Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

Quantifying annual health benefits for the course of the year would demonstrate significantly greater benefits than those quantified for just two months. However, it should be noted that the results of this assessment represent two distinct conditions (July and January) and cannot be simply multiplied to determine annual impacts. A more comprehensive study, including an evaluation of what can be achieved from reducing annual or cumulative pollutant exposure reduction, should be completed to get an accurate assessment.

Impacts on Disadvantaged Communities

This analysis found that, in total, the benefits of improved air quality from the HyBuild LA scenario are significant within DACs identified by CalEnviroScreen (shown in the figure below). These benefits range from approximately $15 million per month in July 2035 (30% of total South Coast Air Basin health savings) to $100 million per month in January 2045 (28.5% of total South Coast Air Basin health savings). These results should be considered within the context that approximately 25% of the California census tracts are defined as disadvantaged within CalEnviroScreen – in other words, 30% of the benefits occur within 25% of the census tracts – which indicates that the benefits are moderately weighted towards DACs.

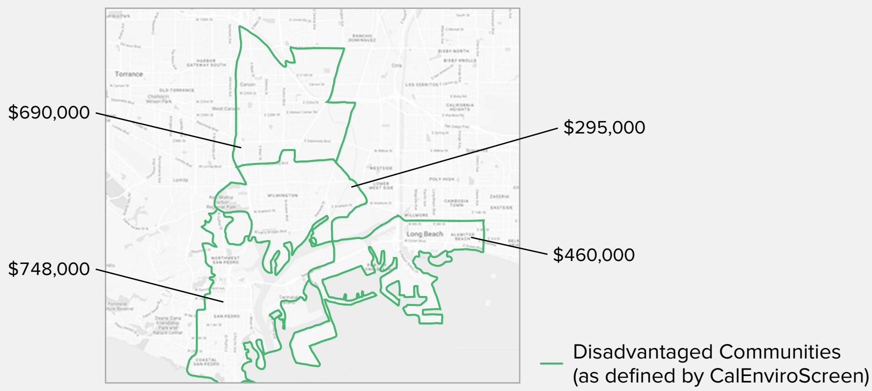
Figure 36 | Value of total health benefits that occur within disadvantaged communities in the South Coast Air Basin caused by reductions of exposure to $PM_{2.5}$ and Ozone for the four months modeled.



Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

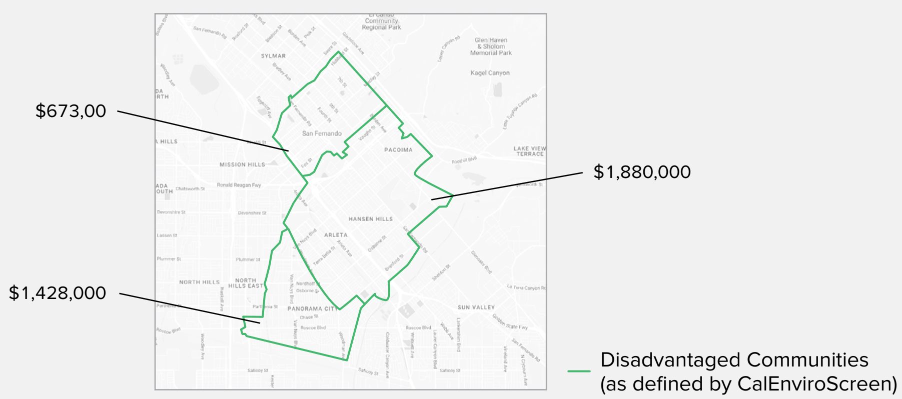
To further demonstrate the health benefits attained within DACs, seven representative communities[101] – which were located in areas particularly impacted by the technologies within the scenario, as defined at the census tract level from CalEnviroScreen – were evaluated to provide an estimate of the benefits that individual communities may experience. Based on stakeholder feedback, the analysis included DACs surrounding the Ports of LA and Long Beach and in the San Fernando Valley. In total for the four modeled months (January and July 2035; January and July 2045), the sampled neighborhoods attain benefits ranging from $295,000 to $1,880,000.

Figure 37 | Value of health benefits that occur within select disadvantaged communities surrounding the Ports of LA and Long Beach caused by reductions of exposure to $PM_{2.5}$ and Ozone for the four months modeled.



Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

Figure 38 | Value of health benefits that occur within select disadvantaged communities in the San Fernando Valley caused by reductions of exposure to $PM_{2.5}$ and Ozone for the four months modeled.



Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

101. Communities were sampled due to interest from stakeholders in Community Impacts Working Groups.

Methodology

This study built upon the findings from the Offtake and Infrastructure workstream, which determined the volumes and geographic location of GH_2 demand as a resource to displace fossil fuels in a variety of end uses. UCI's study considers how replacement of fossil fuel combustion with GH_2 in fuel cells in a variety of end uses may result in a reduction of local pollution.

UCI's Community Multiscale Air Quality (CMAQ) model was used to assess air quality impacts associated with emissions changes from the HyBuild LA system plan. The study considered both primary and secondary $PM_{2.5}$, ozone, and NOx. This model produced changes in air pollutant concentrations, which was compared to the air pollutant concentrations from a reference case.

The reference case was developed using a detailed inventory of total emissions across sector and source, and includes spatial and temporal information regarding source activity developed by the California Air Resources Board. The emissions were then grown and controlled to 2035 and 2045 using output from the E3 PATHWAYS model for technologies, fuels, and energy demand by AB 32 GHG Inventory sector. Additionally, data from various sources was utilized to account for changes in emission rates and control factors for on-road vehicles and other transportation sectors, and the CARB California Emissions Projection Analysis Model (CEPAM) 2019 v1.03 is used for stationary sources.

Because of the computational intensity of the pollution and atmospheric impact modeling, UCI specifically focused their episodic modeling on months that have the highest baseline concentrations of $PM_{2.5}$ and ozone – July and January – as they would provide insight into the maximum potential monthly impacts possible. The Environmental Protection Agency's BENMAP model (v1.5.8) was used to translate pollutant changes from CMAQ into health impacts.

The study utilized the following assumed penetrations of fuel cell electric technologies utilizing GH_2 for intrastate heavy-duty vehicles, drayage heavy-duty vehicles, materials handling equipment, forklifts, and motor coaches.

Table 15 | Fuel cell electric technology deployment assumptions for the HyBuild LA Air Quality Study.

	Deployment Level (% Utilizing Fuel Cell Electric)		
Application	**2035**	**2045**	**Additional Assumption**
Heavy-duty trucks	15%	31%	Deployment levels assumed for several heavy-duty trucks operating intrastate with max travel ranges of 400 miles
Drayage trucks	36%	75%	-
Materials handling equipment	26%	78%	-
Forklifts	44%	48%	Deployment assumed in all major categories in inventory
Motor coaches	None	55%	Reference case assumes high levels of battery electric bus deployment in 2045

Emissions from all other sources are held constant to the Reference Scenario, including some assumed to use GH_2, such as oceangoing vessels, planes, and natural gas power plants in the power sector.

The study conservatively assumes "no change" for power plant NOx emissions for the following reasons:

1. New or repowered turbines must meet local and state air quality standards for power generation facilities to be permitted.
2. GH_2 combustion for electric generation will utilize advanced dry low NOx combustion turbines, which are designed to reduce flame temperature and minimize NOx formation. The U.S. DOE estimates that with these advanced turbines, power plants will be able to achieve or improve upon current NOx emissions standards.[102]
3. Gas turbines in the field will be required to utilize selective catalytic reducers (SCRs), which have been in commercial operation since the 1970s. SCRs are used to reduce "at the stack" NOx emissions and ensure compliance with local air quality regulations.
4. Future power plant utilization will be significantly lower than today, as they will primarily be utilized to support reliability and resiliency, operating at much lower capacity will directly reduce all emissions.[103]

102. U.S. Department of Energy Hydrogen and Fuel Cell Technologies Office, "H2IQ Hour: Addressing NOx Emissions from Gas Turbines Fueled with Hydrogen," September 15, 2022
103. Jaquelin Cochran, et al., eds., "The Los Angeles 100% Renewable Energy Study," National Renewable Energy Laboratory, NREL/TP-6A20-79444, March 2021

For aviation, the primary application for GH_2 up to 2040 is expected to be as a feedstock to make SAF through a variety of processes. This cleaner fuel will technically combust identically to fossil-derived aviation fuels; however, it will be carbon-neutral as it utilizes carbon that is already in cycle (e.g., carbon capture).

Finally, the study assumes "no change" in emissions from the maritime shipping sector as the fuel, propulsion method, and potential fueling location for zero-carbon maritime shipping vessels has not yet been determined. Additionally, given California's requirement for ships to use shore power when at berth in the Ports of Long Beach and Los Angeles,[104] the Reference Scenario assumed that ships will utilize electricity close to shore. Ultimately, it is highly likely that sources such as maritime ships will achieve emissions reductions in the time period modeled. Thus, the scenario modeled is considered highly conservative and scaled GH_2 deployment would likely result in greater net air quality benefits.

6.3 | JOBS STUDY

The Community Impacts Workstream undertook a second analysis to assess the impacts that the GH_2 system envisioned in HyBuild LA would have on net job creation and skill mix.

The study assessed jobs needed throughout the GH_2 value chain (e.g., production, GH_2 transport, and end use) to serve the GH_2 demand of 1.76 MMT per year by 2040. The study also considered jobs associated with the production of GH_2 derivative fuels, such as SAF. While green NH_3 jobs were also measured, stakeholder feedback led to an assumption that green NH_3 would not be produced locally in the LA Basin. The following activities were included in the analysis:

- GH_2 pipeline and storage operations
- GH_2 fueling supply chain operations (i.e., liquefaction, refueling station operations)
- Solar power production operations
- Electrolytic GH_2 production operations
- SAF production operations
- Green NH_3 production operations

In this study, jobs are defined as the number of full-time-equivalent employees required in the industry in 2040. The methodology – which follows the process used in the Princeton Net Zero America study – uses activity factors, such as production quantities or operating capacity, and labor intensity for each activity, to estimate direct jobs required for the activity. The study also evaluated indirect jobs, defined as supporting labor associated with the activity, such as purchasing and accounting. This work is quantified through a multiplier applied to direct jobs.

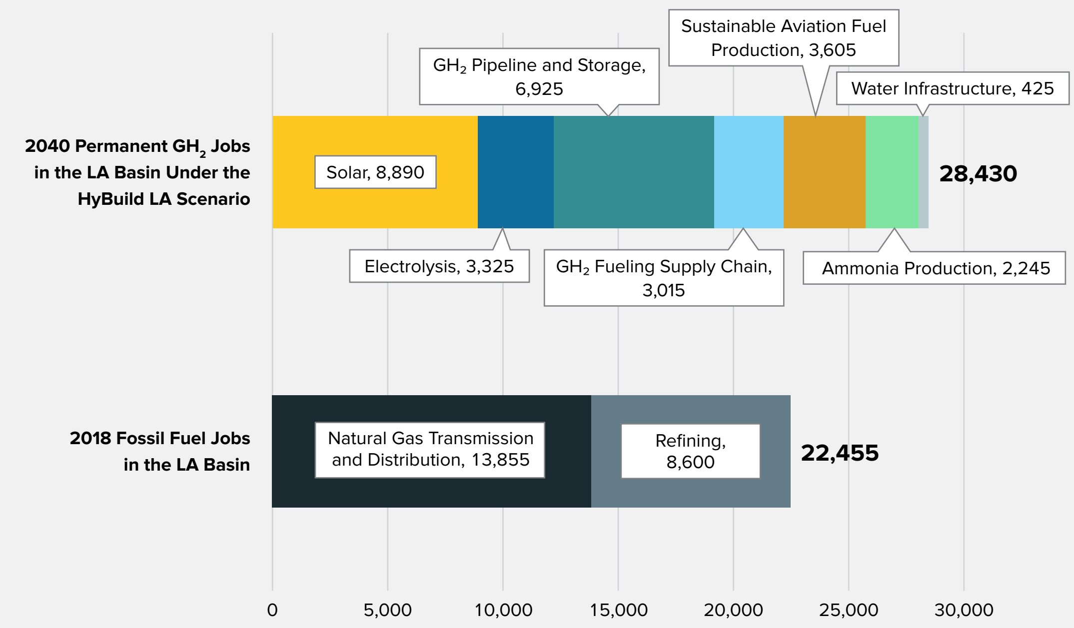
Findings

In total, GH_2 and its derivatives will create tens of thousands of jobs throughout Southern California by 2040. With this level of job creation, the GH_2 industry can offset potential job losses from local oil and gas industries, providing meaningful preservation and creation of high-quality jobs.

Many of the GH_2 jobs are similar to those from the incumbent fossil energy industry, such as jobs related to GH_2 pipelines and storage, fueling infrastructure, SAF production, and green NH_3 production. This creates a strong path for career transition as demand for fossil fuels decreases.

104. California Air Resources Board, "Ocean-Going Vessels At Berth Regulation," January 1, 2023

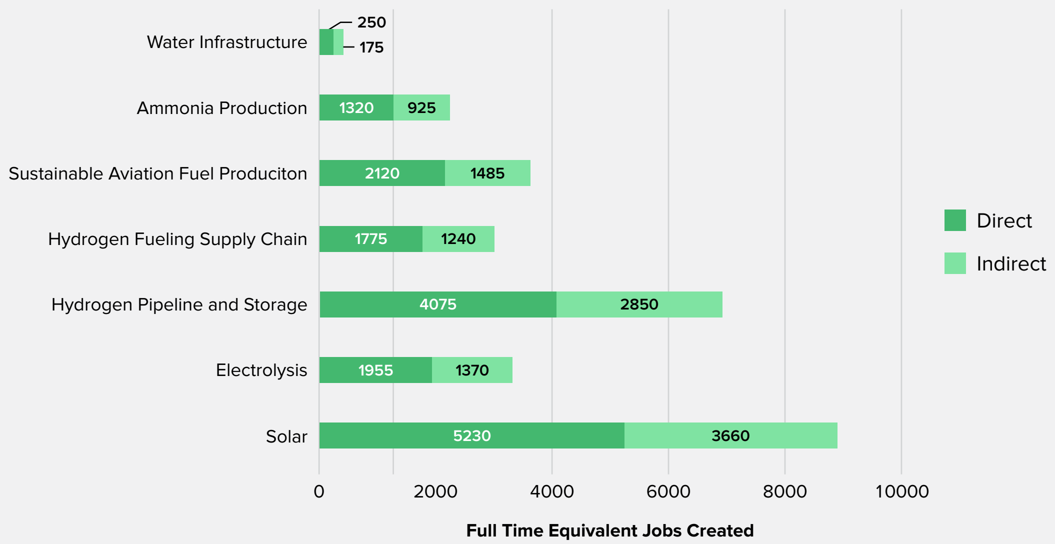
Figure 39 | 2040 GH_2 permanent jobs in SoCal compared to fossil fuel industry jobs.



Source: University of California, Irvine Advanced Power and Energy Program for HyBuild LA, 2022

Jobs created in the envisioned HyBuild LA ecosystem are projected to be made up of 16,725 direct jobs and 11,705 indirect (supporting) jobs. The division of direct and indirect jobs by each activity is detailed in Figure 40.

Figure 40 | 2040 Direct and indirect permanent jobs created as a result of the HyBuild LA scenario.



Source: University of California, Irvine Advanced Power and Energy Program

It should be noted that the job estimates from this assessment are conservative. For example, while HyBuild LA's estimates reflect a business-as-usual scenario, there are likely to be significant additional jobs from construction of GH_2-related facilities. Additionally, while the current analysis is based upon HyBuild LA's qualified GH_2 demand scenario, additional offtakers are likely to emerge as the industry matures, creating even broader industry growth.

Methodology

The study utilized the data sources from the employment analysis in Princeton's Net-Zero America (NZA) study, which assesses five different approaches to decarbonization and its subsequent societal impacts.[105] The NZA data was augmented by additional data gathered by UCI on labor and labor intensity related to GH_2 pathways not represented in the NZA cases. UCI's assessment adapted the scenarios to a regional view, with resource adoption scenarios consistent with the outcomes from the Offtake and Infrastructure Workstream.

The study utilized the following activity factors to estimate direct jobs:

Table 16 | Activity factors used to estimate direct job creation from GH_2 system development.

System Element	Activity	Activity Factor (Direct)	Units	Source
GH_2 Pipelines	Transmission and Storage Operations	13.93	jobs/100,000 kg/d capacity	Assumed equal to natural gas system per unit energy based on[106,107]
GH_2 Pipelines	Distribution Operations	32.50	jobs/100,000 kg/d capacity	Assumed equal to natural gas system per unit energy based on[106,107]
GH_2 Fueling Infrastructure	GH_2 Supply Chain Operations – Liq.	18.00	jobs/100,000 kg/d capacity	U.S. DOE HDSAM model[108]
GH_2 Fueling Infrastructure	GH_2 Refueling Station Operations	218.00	jobs/100,000 kg/d capacity	U.S. DOE HDSAM model[108]
Solar Generation	Power Production Operations	264	jobs/GW utility-scale solar capacity	Net Zero America study[108]
Electrolysis	GH_2 Production Operations	80	jobs/GW capacity	Electrolytic H_2 production bids in CEC GFO-18-304
Sustainable Aviation Fuel	Production Operations	0.26	jobs/million kg/yr capacity	Assumed equal to petroleum refining from NZA[109] and LAEDC[106].
Green NH_3	Production Operations	0.34	jobs/million kg/yr capacity	Based on U.S. ammonia production and jobs from NAICS.com (code 325311).

To assess indirect jobs, the study utilized an indirect labor factor of 2.1 for jobs related to fuel or chemicals supply chains based on a jobs study from the Los Angeles County Economic Development Corporation (LAEDC)[110] and 1.7 for solar generation based on NZA.

Total jobs were then calculated using the following formula:
Jobs = [Activity Factor]*[Labor Intensity]*[Indirect Multiplier]

The analysis does not include manufacturing jobs or construction jobs. Assessment of manufacturing jobs would require further analysis of in-state manufacturing capacity serving the GH_2 market. Construction jobs were not reflected in the projections as these historical labor intensity factors reflect business-as-usual levels of construction activity. Based on the NZA report, that construction of this GH_2 ecosystem has the potential to add an additional 30% to the total job numbers. However, additional specific modeling would be required to assess facility construction scenarios.

105. Princeton University, "Net-Zero America: Potential Pathways, Infrastructure, and Impact," Net-Zero America, Accessed March 2023.
106. S. M. Sedgwick, T. Laferriere, E. Hayes, and Somjita Mitra, "Oil & Gas In California : The Industry, Its Economic Contribution and User Industries at Risk 2017," 2019.
107. D. Sadler and H. Anderson, "H21 North Of England Report," 2018. doi: 10.2307/j.ctt20q1vhk.6.
108. HDSAM model and documentation available at: https://www.hydrogen.energy.gov/h2a_delivery.html
109. E. Larson et al., "Net-Zero America: Potential Pathways, Infrastructure, and Impacts Report," Princet. Univ., pp. 1–345, 2020.
110. Shannon Sedgwick, et al., "Oil & Gas in California: The Industry, Its Economic Contribution and User Industries at Risk 2017," Los Angeles County Economic Development Corporation, July 2019.

7. POLICY AND REGULATORY

The Policy and Regulatory Workstream focused on two tasks: (1) working with regulatory attorneys from Sheppard Mullin to conduct a "readiness assessment" of California's state and local GH_2 regulation and oversight and (2) identifying and prioritizing key policy and regulatory recommendations to support findings from both the Offtake and Infrastructure and Community Impacts Workstreams. The Methodology component of this section further describes these activities.

The Policy and Regulatory Workstream's tasks and objectives include:

Task 1: GH_2 "Readiness Assessment"

Objective: Understand State & Local Regulation

- Conduct a readiness assessment of H_2 regulation and oversight in California
- Identify gaps in policy activities or jurisdictional authority of H_2 regulation
- Develop a plan to address the highest priority regulation that requires modification, clarity, or legislative action

Task 2: Identify Key Policy & Regulatory Recommendations

Objective: Develop Innovative Policy

- Identify and prioritize the top policy opportunities to lower the cost of GH_2 in recognition of its net benefits
- Evaluate a list of competing policies to identify those that may be the most effective in the short-term
- Establish a list of policy recommendations

7.1 | POLICY AND REGULATORY INNOVATION

Findings

Through the two key tasks outlined above, the Policy and Regulatory Workstream established recommendations that address barriers to (1) developing a scaled GH_2 hub, (2) promoting innovation, and (3) driving down the cost of GH_2 in recognition of its net societal benefits.

The following table details HyBuild LA Phase 2's policy and regulatory recommendations, the motivation for taking action, and the key next steps to be taken:

Policy and Regulatory Objective	Motivation	Key Actions
Adopt a Statewide Green or Renewable H_2 Definition	Today, each relevant California agency utilizes a different definition for green and/or renewable H_2. Without a common, established definition, it is challenging to establish GH_2 eligibility for compliance with existing state policy and programs. It is also challenging to make efficient, coordinated progress on the development of needed policies and programs to accelerate progress.	Direct state agencies to adopt a universal definition of "renewable H_2" so that eligibility for existing and future state programs, incentives, mandates, and procurement opportunities is clear. The GHC also recommends adopting an internationally recognized well-to-gate lifecycle carbon intensity (CI) framework for green and renewable H_2, which will enable consistency with federal CI requirements for tax incentive eligibility.[111]

111. Green Hydrogen Coalition, et al., "IIJA 'Clean Hydrogen' Carbon Intensity Framework," March 14, 2022.

Clarify GH_2 Infrastructure Permitting and Siting	The development of GH_2 infrastructure (e.g., production, storage, transport, and dispensing facilities) in California is challenging as a result of complex state and local permitting requirements, differing requirements across local jurisdictions, and insufficient opportunities for community engagement with respect to implementing new infrastructure. Limited understanding of existing standards for GH_2, along with complex permitting and siting requirements, will increase project costs and the timelines required for development.	Direct state agencies to jointly develop a permitting guidebook for the GH_2 supply chain (e.g., production, storage, transport, dispensing, facilities) to help stakeholders – including municipalities – responsibly navigate and safely implement GH_2 projects and infrastructure. As H_2 is already a globally traded commodity, this guidebook may also compile existing safety guidance and best practices from around the world. This guidebook should include optimal locations for permitting and siting GH_2 infrastructure based on: existing local, state, and federal regulation; and the lowest possible burden and risk to local communities.
Conduct a Water Regulation Assessment for GH_2 Production	There is not yet a sufficient understanding of water use regulations by local jurisdiction across the state, particularly for electrolytic GH_2 production. Lack of such knowledge could impact the ability to optimize GH_2 production facility siting.	Assess water use regulations and identify the pros, cons, and implications of using different water resources (e.g., municipal and industrial recycled waste water) for GH_2 production in different regions of the state, based on existing regulations. Publish and clarify findings for all stakeholders.
Certify Technology-Agnostic Renewable H_2 Eligibility in California's Renewable Portfolio Standard (RPS)	Currently, fuel cells are the only RPS-eligible technology that utilize renewable H_2. As a result, California's RPS Eligibility Guidebook does not allow other commercially available and environmentally responsible renewable H_2 technologies – such as combustion turbines and linear generators – to participate in the RPS program.[112] Such technologies can provide clean, firm dispatchable power for grid reliability and resiliency benefits.	Modify the RPS Eligibility Guidebook to ensure all environmentally responsible renewable H_2-capable technologies can participate in the RPS program.[113] Ensure that if the facility uses a combustion process to generate electricity, the combustion process must be appropriately controlled and regulated to meet all required emissions requirements.
Develop A Vision For A 100% GH_2 Pipeline Network in California, WhichWould Eventually Be Interconnected with Other Hubs Emerging Through DOE's Regional Clean H_2 Hubs Program	Coordinated planning is essential to accelerate the development of needed GH_2 infrastructure for California and the broader U.S. Without a plan for a statewide 100% GH_2 pipeline backbone and distribution network, GH_2 transportation will have to occur via truck or rail, which would dramatically increase the final delivered cost of GH_2 and limit scalability. Additionally, the lack of a statewide long-term gas planning strategy prevents important discussions – regarding, for example, the appropriate way to repurpose pipelines – which will impede GH_2 pipeline development.	Require state agencies to jointly develop a statewide vision for establishing a regionally-interconnected California GH_2 backbone. This vision would augment long-term gas system planning to include the evaluation and development of a transition plan to retrofit or replace existing natural gas pipelines with a 100% dedicated GH_2 pipeline backbone and distribution network, analogous to what is being done in Europe via the European H_2 Backbone Initiative.[114]
Clarify Jurisdictional Authority for Interstate Dedicated GH_2 Pipelines	Ambiguity exists regarding the entity that has interstate regulatory authority over 100% dedicated GH_2 pipelines. If left unresolved, uncertainty around jurisdictional authority will impede project development, regional pipeline infrastructure progress, access to out-of-state geologic salt caverns for GH_2 storage, and California's ability to achieve mass-scale GH_2 at low delivered cost.	Collaborate with neighboring states and other regional/ national institutions to develop the appropriate regulatory or legislative pathways. This is needed to clarify the appropriate regulatory authority to approve and regulate interstate 100% dedicated GH_2 pipelines.

112. Lin, Janice, "RPS Eligibility of Renewable Hydrogen Gas Turbines," The Green Hydrogen Coalition, October 5, 2021.
113. Ibid.
114. European Hydrogen Backbone, "The EHB initiative," Accessed February 8, 2023.

Establish a Safe GH_2 Blending Standard in the Natural Gas Network	Today, transporting GH_2 via truck and rail makes delivered GH_2 unnecessarily expensive. The most cost-effective way to transport GH_2 is via pipeline. While it is estimated to take several years to develop and deploy dedicated GH_2 pipelines, existing natural gas pipeline infrastructure may be able to catalyze progress by storing and transporting GH_2 at certain blending percentages. However, current policy does not allow for this opportunity, from the recent UC Riverside Study, which demonstrated that GH_2 can be safely blended into the existing natural gas grid at fractions at or below 5%.[115]	Establish an interim GH_2 blending standard at a volume fraction of 5% to begin moving GH_2 molecules through California's natural gas pipeline network to catalyze market development in the near-term. The standard should prioritize blending GH_2 into the natural gas system for hard-to-electrify sectors that require an alternative to electrification. While the GHC supports blending as a near-term solution to catalyze the GH_2 ecosystem, blending alone will not achieve the mass-scale vision established by HyBuild LA. Because of the scale, this vision requires dedicated 100% GH_2 pipeline infrastructure connected to out-of-state underground GH_2 storage in commercially-proven geologic salt caverns.
Expand California's Renewable Gas Mandate to Include GH_2	The CPUC, under the direction of Senate Bill 1440 (2017-2018),[116] approved biomethane procurement targets (72.8 billion cubic feet of biomethane by 2030) for gas utilities to meet the broader goal of reducing methane and other short-lived climate pollutants (SLCP) by 40% by the end of the decade.[117] However, GH_2 is not explicitly included in this mandate. As a result, this limits California's ability to support further methane and SLCP reductions from this scalable alternative fuel.	Through legislative direction, require the CPUC to open a new proceeding, or a new phase of an existing proceeding, to consider establishing procurement goals for GH_2 and require each gas investor-owned utility to annually procure a proportionate share of GH_2 to meet those goals.
Develop A Contracts For Difference (Cfd) Program To Accelerate GH_2 In New End Uses Outside Of The Transportation Sector	GH_2 is currently more expensive than incumbent fossil fuels for end users, particularly since the shared 100% GH_2 pipeline transport and geologic salt cavern storage infrastructure has not yet been built. Even after applying the Production Tax Credit in the federal IRA, some applications – such as process heat applications in the industrial sector – still cannot bridge the cost difference that end users may face between GH_2 and incumbent fossil fuel use, particularly in early GH_2 market development stages.	Direct the creation of a state agency-led CfD program that is aimed at reducing the cost gap between GH_2 and incumbent fossil fuels for specific end use applications where needed (e.g., certain industrial process heat applications). The program should aim to provide GH_2 buyers with price certainty for a set period of time, or until GH_2 delivered $/kg market price is equal to or less than the incumbent fossil fuel market price for the same quantity of energy.
Support GH_2 Refueling Infrastructure for Medium- and Heavy-Duty Vehicles, Ocean-Going Vessels, Harbor Crafts, and Off-Road Equipment	California's H_2 refueling infrastructure system is currently limited to light-duty on-road passenger vehicles. This approach restricts California's ability to fully support decarbonization of other fossil-fueled mobility applications, where low-cost GH_2 can accelerate the transition away from diesel and gasoline. The GHC supports battery electrification where possible; GH_2 will be particularly important for applications with long range or high daily utilization that are difficult to electrify.	Expand the state's H_2 refueling infrastructure credit through the Low Carbon Fuel Standard (LCFS) for medium- and heavy-duty vehicles,[118] ocean-going vessels, harbor crafts, and off-road equipment.
Develop a Vision for GH_2 Long-Duration Energy Storage (LDES) To Meet Reliability Needs	The state's Integrated Resource Planning (IRP) does not properly plan for the inclusion of GH_2 LDES for electric sector balancing and reliability. As a result, the state may unnecessarily rely on the continued use of fossil-fueled generation to achieve system balancing and reliability, while valuable renewable electricity curtailment increases. Electrolytic GH_2 is a commercially viable resource to achieve multi-day, weekly, and ultimately seasonal storage of low-cost renewable energy.	Consistent with Senate Bill 1369 (2017—2018), direct state agencies to plan and coordinate the procurement of electrolytic GH_2 as LDES through the state's IRP process. This planning process should also consider how to repurpose existing infrastructure to accommodate GH_2 to ensure a clean, reliable fossil-free electric system portfolio that is also affordable for all ratepayers.

115. Arun Raju, et al., "Hydrogen Blending Impacts Study," University of California, Riverside, June 18, 2022.
116. See SB1440.
117. CPUC, "Decision Implementing Senate Bill 1440 Biomethane Procurement Program," January 25, 2022.
118. See GHC's Joint Letter on Updates to the Low Carbon Fuel Standard (LCFS) Regarding Heavy-Duty (HD) Hydrogen Refueling Infrastructure (HRI).

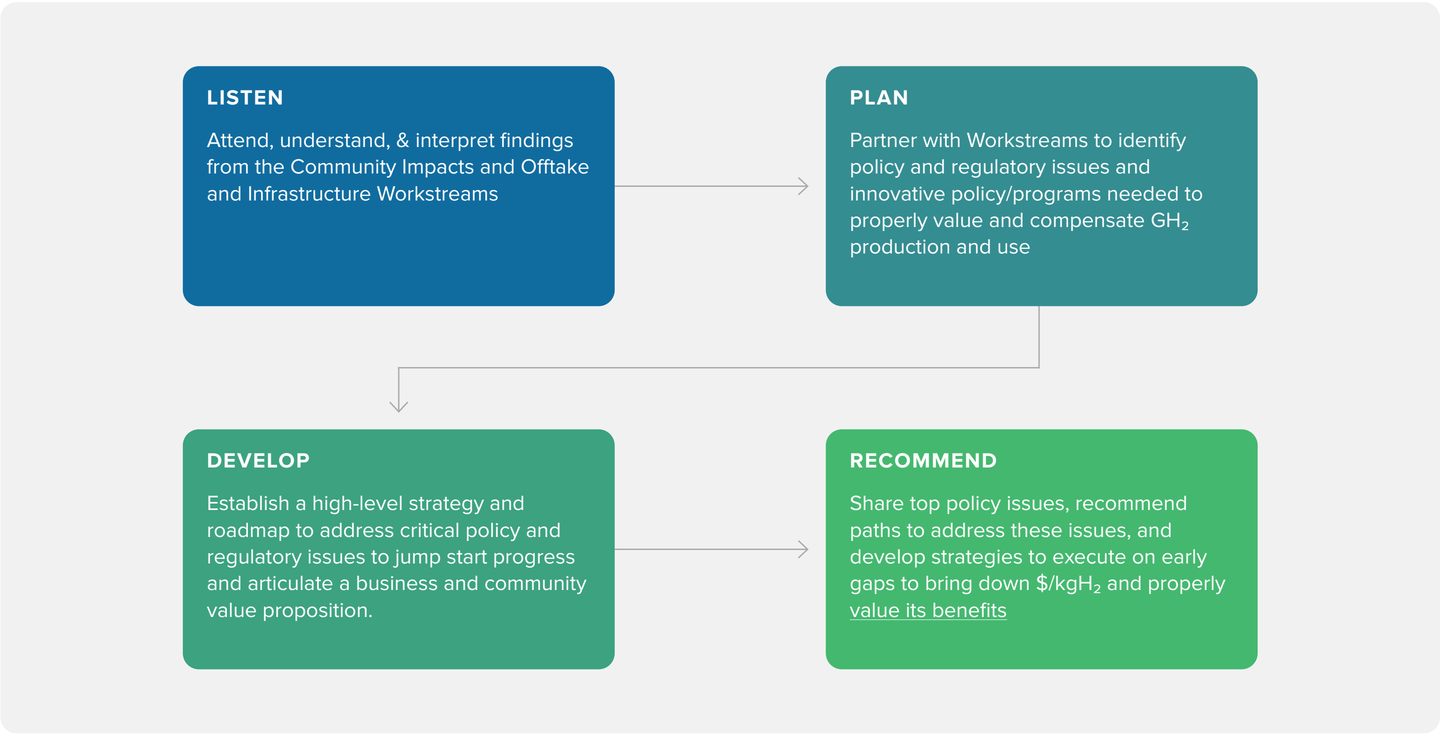
Develop Electrolytic GH_2 Tariffs That Recognize the System Benefits of Electrolysis Equipment as a Demand Response Resource	California's grid needs greater flexibility and reliability, as exemplified by recent flex alerts and power outages. It is possible to electrolytically produce and store large amounts of energy for a significant period of time (e.g., days, weeks, or seasons) with GH_2. As a backup energy source for grid resilience, GH_2 energy storage systems can be used in combination with fuel cells, combustion turbines, or linear generators to convert the GH_2 back into electricity. This solution can be used as a demand response resource since it can provide system load when needed, and can also be curtailed during times of grid congestion. Today, no such pricing mechanisms are in place to support this opportunity.	Develop an electrolyzer tariff or demand response program that allows California's load-serving entities to create a "system-beneficial electrolytic GH_2 load." Require these load-serving entities to facilitate the delivery of green electricity to electrolytic GH_2 producers, while also enabling GH_2 producers to access and monetize the system benefits provided by demand-responsive electrolysis production.
Create A Framework to Prioritize Community Impacts in GH_2 Policy Making	Historically, the planning and siting of fossil fuel infrastructure has not sufficiently included the needs and concerns of frontline communities. These communities have been disproportionately harmed by the effects of fossil fuel production and use. The final vision and roadmap for a clean energy transition enabled by GH_2 must equitably include the needs, concerns, and interests of frontline communities through an equitable, transparent, and co-creative process.	As a first step toward a co-creative process, the State, in partnership with communities and environmental justice groups, should develop a community impacts framework that outlines a vision and tangible goals to be incorporated into GH_2 policy development. This framework should include guidance to policymakers and other stakeholders on best practices – such as guiding principles for improving equity, environmental, and energy justice – and a baseline for mitigating, tracking, monitoring, and remedying impacts.

Methodology

The recommendations set forth by the Policy and Regulatory Workstream were developed using the guiding principles and policy priorities identified by HyBuild LA participants. The guiding principles are as follows:

- To create an equitable and sustainable GH_2 ecosystem, the business and community value proposition must be clearly articulated and prioritized.
- Progress must be measured with transparency and accountability.
- Engagement should be based on a transparent, inclusive, and co-creative platform.
- Recognize that we are learning by doing together with the aim of implementing projects at scale while prioritizing an equitable and just transition.

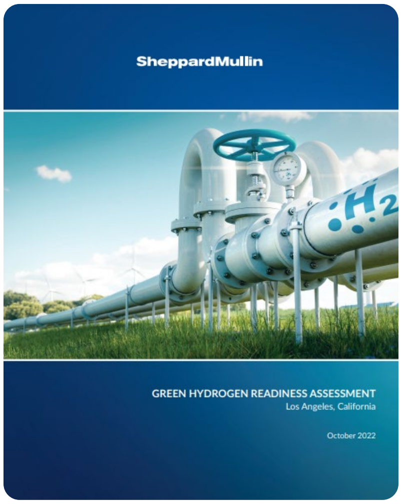
Within this workstream, a four-step process was implemented to advance key objectives:



First, the Policy and Regulatory Workstream identified any key policy and regulatory barriers to realize the vision established in the Community Impacts and the Offtake and Infrastructure Workstreams. Once this plan was in place, the Policy and Regulatory Workstream established a high-level strategy and roadmap to address critical policy and regulatory issues to jump start progress, while also brainstorming innovative policies that properly value and compensate for the environmental benefits of GH_2 production and use. Finally, this Workstream developed recommendations based on the highest priority areas identified by initiative stakeholders.

The activities of the Policy and Regulatory Workstream relied upon active stakeholder engagement and continuous collaboration with the other two HyBuild LA Workstreams to co-create strategic recommendations that not only bring down the cost of GH_2 but also properly value its benefits by addressing policy, regulatory, and programmatic gaps and barriers.

7.2 | GREEN HYDROGEN "READINESS ASSESSMENT" OF STATE AND LOCAL GH_2 REGULATION AND OVERSIGHT



HyBuild LA Phase 1 identified a need to better understand jurisdictional authority over GH_2 systems. Developing an informed roadmap for the GH_2 economy requires an understanding of the statutes, regulations, and regulatory bodies that have oversight over GH_2 infrastructure and across the value chain.

Working with Sheppard Mullin,[119] the Policy and Regulatory Working Group identified key hurdles in existing statutes and regulations that stand in the way of large-scale investment in GH_2 infrastructure. The final product was a *Green Hydrogen Readiness Assessment* of state and local (i.e., California and Los Angeles) regulation and oversight applicable to GH_2 systems.

Access the full document on Sheppard Mullin's website:
GH_2 Readiness Assessment of State and Local GH_2 Regulation and Oversight

119. Sheppard Mullin is a nationally renowned leader in renewable and clean energy with over 85 attorneys on its Energy, Infrastructure and Project Finance Team.

GH_2 "Readiness Assessment" Methodology

To complete this assessment, Sheppard Mullin evaluated 20 California agencies, one district agency, six county agencies (Los Angeles), and six city agencies (Los Angeles) by:

1. Reviewing regulations as currently written;
2. Identifying regulators and agencies with relevant jurisdictional authority; and
3. Identifying gaps in policy activities or jurisdictional authority.

The assessment provides a stoplight color-coding system for rating the extent to which a given regulation covers GH_2,[120] as well as an overview of regulation and oversight of GH_2 systems at various levels. This assessment informed the Policy and Regulatory Innovation findings.

120. Any attempt to create simple categories like those detailed in this table necessarily involves interpretations and a measure of subjectivity. Readers should read the underlying regulations and form their own conclusions, using the color-coding system only as a directional guide.

8. POTENTIAL BENEFITS OF A NORTHERN CALIFORNIA HUB CONNECTION

After nearly two years of studying the potential of a mass-scale GH_2 hub in Southern California, the GHC sought to understand the potential for the envisioned ecosystem to support decarbonization throughout California. Momentum for GH_2 continued to build throughout California in 2022; following the release of the U.S. DOE's $8 billion Clean H_2 Hubs Funding Opportunity Announcement, the State established the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES), a public-private consortium to create a sustainable, statewide clean H_2 hub.

To better understand the potential challenges and benefits of expanding the HyBuild LA vision to help serve mass-scale demand for GH_2 in Northern California, GHC undertook a preliminary assessment to determine: (1) the opportunity for GH_2 in Northern California, with a focus on the area around the Port of Stockton; (2) if the system demand could be satisfied through local infrastructure or if connection to the envisioned HyBuild LA system may be beneficial; and (3) if Northern California may provide additional opportunities to meet the State's growing demand for green NH_3.

Due to resource constraints, this portion of the report should be viewed as a preliminary assessment to identify key themes for further engagement. For example, the study does not include the entire northern part of the state, instead focusing on the area within a 100-mile radius of the Port of Stockton. Additionally, the demand assessment does not comprehensively evaluate all potential offtakers; thus, it likely represents a conservative estimate. Importantly, the GHC has not engaged community stakeholders in this region. Finally, the analysis only considers electrolytic pathways for GH_2 production, whereas Northern California has ample organic waste resources. The ultimate roadmap will require additional analysis and engagement.

8.1 | GREEN HYDROGEN DEMAND IN NORTHERN CALIFORNIA

In this preliminary assessment of major demand sectors in Northern California, HyBuild LA estimated 275 kt GH_2 demand by 2030. This assessment evaluated GH_2 demand in five sectors: maritime shipping, heavy-duty trucking, power generation, refining, and agriculture.

The maritime shipping estimate assumes that Northern California – more specifically, the Port of Stockton – will handle storage and delivery of green NH_3 for all shipping activity in California. The analysis considered the Ports of Oakland, Stockton, and Los Angeles and Long Beach. This assumption was based on the finding that the Port of Stockton is the only port in California that currently handles imports of NH_3, bringing in approximately 120 kt of ammonia imports each year to distribute to agricultural users throughout the state.[121,122] This scenario assumes that NH_3-powered ships coming to any port in California could be refueled at sea by bunkering ships carrying green NH_3 from the Port of Stockton.

Due to the significant potential demand for green NH_3 around the Port of Stockton, the demand assessment focused on other sources of GH_2 demand within a 100-mile radius.

Table 17 | Estimated GH_2 use cases and demand in Northern California for 2030.

End Use	Use Case	2030 Demand
Heavy-Duty Trucking	For use in fuel cell-based vehicles	95
Maritime Shipping – Serving Ports of Oakland and Stockton	To produce green NH_3	3.7
	For direct use in ships	1.3
Maritime Shipping – Serving Ports of LA/Long Beach	To produce green NH_3	55
Power Sector	For use in thermal power plants in place of natural gas	30
Refineries	For direct replacement of grey H_2 in refining processes	75
Agriculture	To produce green NH_3 as a feedstock to replace anhydrous ammonia currently imported.	20

121. Port of Stockton California, "Annual Comprehencive Financial Report," June 30, 2021.
122. CA Imports Source, State of CA Dept of Food and & Ag Report. Reference: categories 2 (anhydrous ammonia), 6 (aqua ammonia), 0 (non-farm use secondary/micronutrients).

8.2 | UNLOCKING SCALE AND LOW-COST RENEWABLES FOR NORTHERN CALIFORNIA'S GREEN HYDROGEN ECONOMY

Key Findings

This preliminary assessment found that the demand profile for GH_2 in Northern California is relatively inflexible. In this study, an "inflexible" demand profile for GH_2 implies that offtakers have limited ability to adjust the timing and quantity of their offtake, which creates additional system design challenges to ensure that offtakers can be consistently supplied with GH_2 (given the intermittent profile of renewable energy resources, which impacts the production profile of electrolytic GH_2). This creates additional system design challenges to ensure seasonal system balancing.

Table 18 | Demand profile for GH_2 in Northern California.

GH_2 End Use	Flexibility Potential
Green NH_3 Production	Low Flexibility: Decreasing the capacity factor of the Haber-Bosch process due to varying GH_2 supply degrades economics
Thermal Power Plants	No Flexibility: Co-firing must have consistent flow of GH_2 to meet demand
Refineries	Medium Flexibility: Refineries can utilize existing SMR infrastructure (grey H_2 / blue H_2 production) and blend it with GH_2
Mobility	Medium Flexibility: Some daily fluctuation from heavy-duty mobility (trucks), but must have reliable supply on a seasonal basis

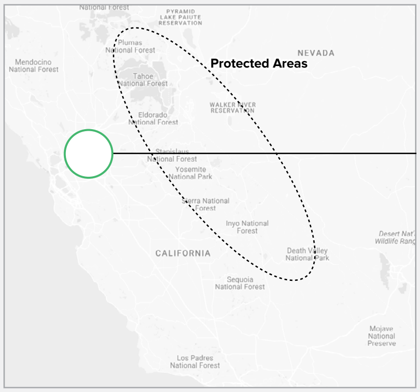
Because offtakers in Northern California are not flexible enough to follow seasonal solar and GH_2 production profiles, the assessment concluded that offtakers must have pipeline access to mass-scale GH_2 storage in geologic salt caverns. However, directly connecting to the closest geologic salt caverns in Delta, Utah would require a challenging route that crosses protected National Forest areas and the Sierra Nevada Mountains. Instead, this assessment found that storage capacity can be most cost-effectively accessed by connecting a mass-scale Northern California GH_2 hub system to the LA Basin system via GH_2 pipeline connection. The envisioned 300-mile pipeline between Northern and Southern California would follow existing rights-of-way and would enable Northern California to access geologic salt cavern storage in Utah by way of LA's GH_2 backbone pipeline.

Figure 41 | Scenarios for Northern California connection to geologic salt cavern storage.

Scenario 1

Direct connection from Northern California GH_2 ecosystem to geologic salt cavern storage

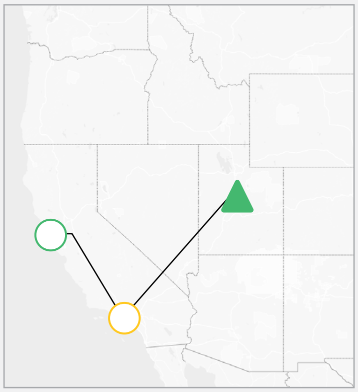
Not feasible: This pathway would lead through protected areas (National Forest and Sierra Nevada Mountains)



Scenario 2

Connection to geologic salt cavern storage via Southern California GH_2 ecosystem

Feasible: A dedicated pipeline connecting Northern and Southern California, following existing natural gas infrastructure routes, would enable shared access to geologic salt cavern storage



Dedicated GH_2 Pipeline Infrastructure (Conceptual)

Northern California GH_2 Ecosystem

Southern California GH_2 Ecosystem

Geologic Salt Cavern Storage Site

Because the solar yield in the Southern California desert is higher than solar yields in Northern California, this connection would also enable GH_2 to be produced utilizing the lower cost solar resource in Southern California and then transported north. This GH_2 is anticipated to cost approximately 15% less at the point of production in Southern California relative to GH_2 from Northern California.

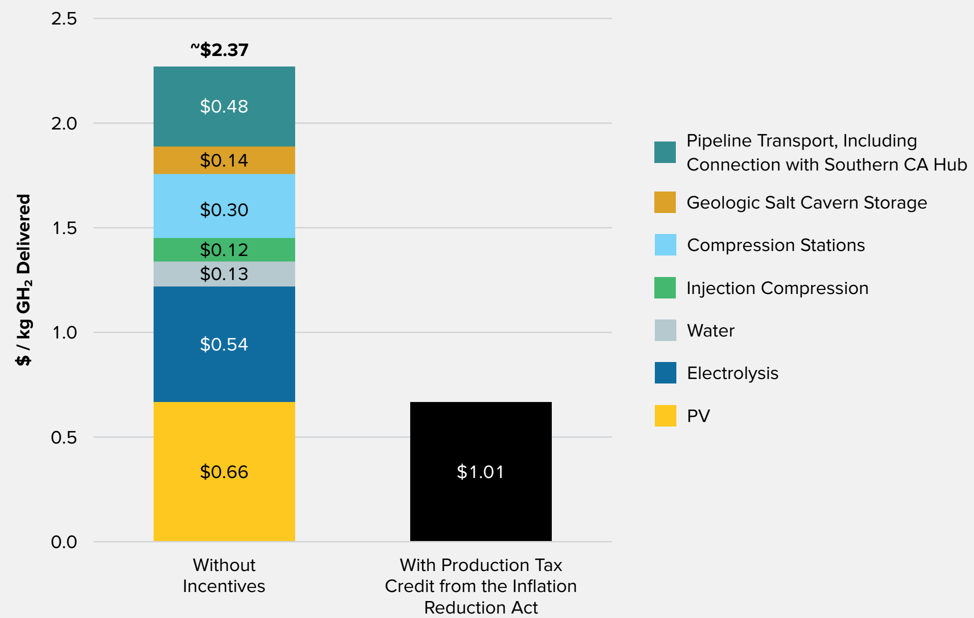
While this analysis only considered electrolytic pathways to produce GH_2, it should be noted that the Central Valley of California has abundant organic waste resources that may be utilized to produce GH_2 with a consistent production profile. These resources may be explored as a near-term solution to optimize GH_2 production and to help alleviate other environmental and societal problems caused by excess organic waste.

Northern California LCOH and CapEx

Based on this design, the delivered cost of GH_2 in Northern California would be around $2.37/kg in 2030, which would be reduced to $1.01/kg if utilizing the IRA Production Tax Credit.

It's estimated that a dedicated GH_2 pipeline connecting the HyBuild LA system with Northern California would require close to $750M in capital investment. This capital expenditure would result in an additional $0.32/kg in transport costs for offtakers in Northern California.

Figure 42 | Estimated levelized cost of GH_2 in Northern California in 2030.



Source: Corporate Value Associates for HyBuild LA, 2022

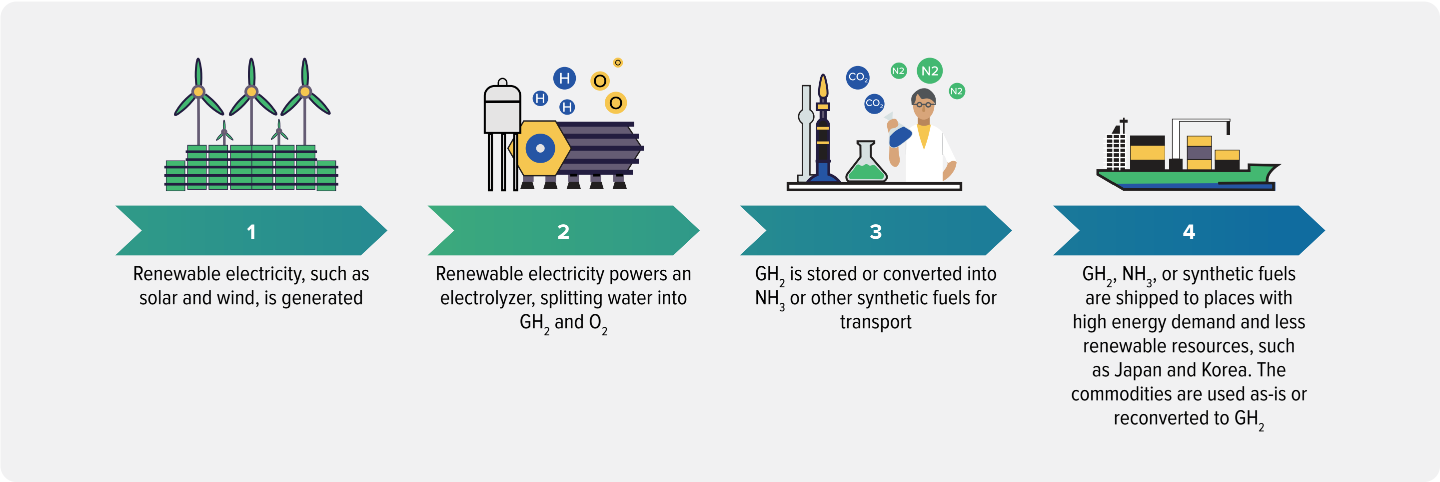
8.3 | ENABLING CALIFORNIA'S GREEN AMMONIA OPPORTUNITY

Since the 1970s, California has utilized imported ammonia (NH_3) to serve the local agricultural industry, taking advantage of low-cost fossil fuel resources in states like Texas as well as from abroad.[123,124] NH_3 is produced via the Haber-Bosch process by combining nitrogen with H_2, and today, this imported NH_3 and its fertilizer derivatives are all produced from fossil fuels.[125] With the war in Ukraine impacting global natural gas prices, in addition to California ceasing to import NH_3 directly from Russia, fertilizer prices skyrocketed to unprecedented levels.[126] In July 2022, the cost of anhydrous ammonia tripled from 2021 prices, negatively impacting California's farmers and consumers across the country.

Demand for green NH_3 in California is anticipated to increase, with shipping driving demand for approximately 316 kt of green NH_3. Rather than supply the agriculture and maritime shipping sectors with imports, California has the potential to bring NH_3 production in-state to increase jobs, create economic and export opportunities for the state, and hedge against fossil price volatility.

Stockton's long-standing experience with handling ammonia imports makes it the most viable prospective location to locate green NH_3 fuel for ships serving the state. It also has the potential to be a location for export of green NH_3, which could be a method of moving California-produced GH_2 around the world (see Figure 43).

Figure 43 | GH_2 export pathway.



Given this opportunity, HyBuild LA worked with CVA to evaluate (1) the total demand for green NH_3 in the state and (2) if California can produce its own cost competitive green NH_3.

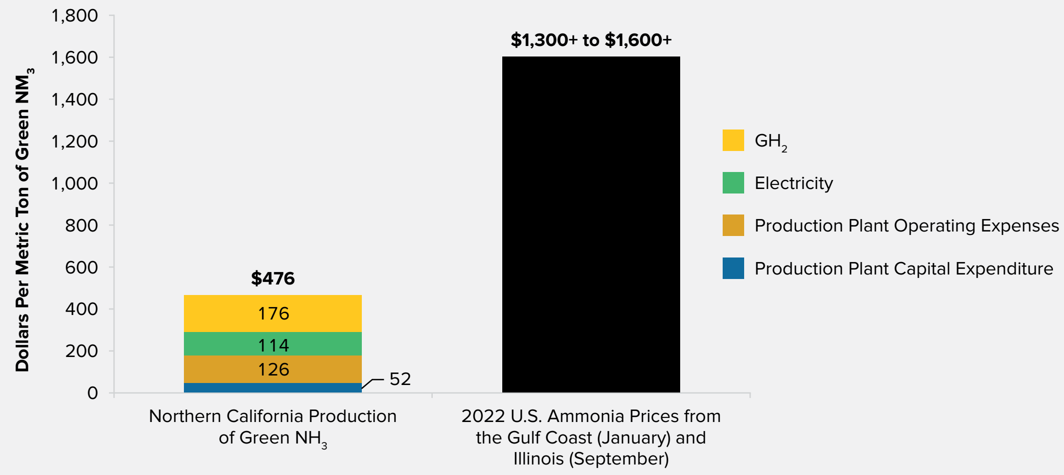
Key Findings

The analysis found that California's total combined annual demand for green NH_3 in the agricultural and maritime shipping industries would be around 444 kt of green NH_3 in 2030. This includes the demand from the Ports of Oakland, Los Angeles, and Long Beach, the primary ports driving demand for bunkering fuel across the state. This scenario assumes that NH_3-powered ships coming to any port in California could be refueled at sea by special bunkering ships carrying green NH_3 from the Port of Stockton.

The analysis estimated that Northern California can produce green NH_3 for $468/ton, a cost which is in line with price expectations for imported green ammonia in 2030.[127]

123. Brittany Johnson, "Fertilizer prices are skyrocketing for California Central Valley farmers. Here's why it matters," KCRA3, July 13, 2022.
124. U.S. EIA, "Natural Gas Weekly Update," April 1, 2021.
125. Ibid.
126. Brittany Johnson, "Fertilizer prices are skyrocketing for California Central Valley farmers. Here's why it matters," KCRA3, July 13, 2022.
127. Mahdi Fasihi, et al. "Global potential of green ammonia based on hybrid PV-wind power plants," Applied Energy, July 2021.

Figure 44 | Estimated cost of green NH_3 produced in Northern California from low-cost GH_2 feedstock compared to grey NH_3 pricing in 2022.



Source: BloombergNEF and Farm Doc Daily

Assumptions and Methodology

The scenario modelled has the capacity to produce 450 kt of green NH_3/year at a 90% capacity factor. This high capacity factor was critical to enabling a low levelized cost of green NH_3, allowing the plant's capital costs to be spread over a larger volume of production. As a result, the plant would require access to a consistent supply of low-cost GH_2 year-round. In this scenario, it is assumed this GH_2 is supplied via pipeline connection to the integrated Northern – Southern California system at $1.01/kg GH_2 (see above for more details on this LCOH).

The analysis assumes that a mixture of grid power and dedicated solar or power purchase agreements are utilized to meet the power needs of the Haber-Bosch process at a cost of $155/MWh. Other operating expenses reflected in the green NH_3 costs include water, labor, catalyst, and land (see Appendix for more details).

9. CONCLUSION

GH_2 is a key resource for deep decarbonization in Los Angeles. When deployed at scale in the LA Basin, GH_2 can dramatically reduce harmful local pollutants from mobility sectors, create diversely skilled job opportunities, and enable an affordable and reliable clean energy transition.

Rapid adoption of GH_2 technologies in hard-to-abate sectors can be unlocked by lowering the cost of delivered GH_2. HyBuild LA uncovered a pathway to achieve a levelized cost of delivered GH_2 of $2.05/kg by 2030 without incentives. However, this low delivered cost depends upon the use of large-scale, shared infrastructure, including a 100% GH_2 transmission pipeline that connects LA to mass-scale production regions and underground geologic salt cavern storage. If utilized, the IRA's Production Tax Credit can provide additional cost benefits for GH_2, lowering the levelized cost of delivered GH_2 in the HyBuild LA system plan to $0.69/kg. It is critical to get started on the near-term roadmap to tap into these 10-year tax credit opportunities and meet the urgency of the climate crisis.

The envisioned HyBuild LA hub – which includes electrolytic production of GH_2 from dedicated solar resources, water supply and treatment infrastructure, GH_2 compression, transportation via dedicated GH_2 pipeline backbone, interconnection with out-of-state salt cavern storage, local liquefaction, and truck delivery of GH_2 to fueling distributed fueling stations – is estimated to cost nearly $34 billion, delivering 1.4 MMT of GH_2 to the LA Basin.

While federal funding from the Infrastructure Investment and Jobs Act and the IRA will help to drive momentum, this hub will be primarily supported by private sector investment. Thus, it is critical to reduce regulatory uncertainty to secure investments into GH_2 infrastructure at scale. Some urgent actions for market enablement include: establishing a state definition for GH_2, streamlining permitting and siting of infrastructure, providing financial incentives, and developing a purpose-built and dedicated GH_2 pipeline network.

In addition to policy and regulatory innovation, catalyzing LA's GH_2 ecosystem will require a near-term, large-scale, committed offtaker to catalyze infrastructure investment. The power sector is a committed first-mover, motivated by the City of LA and LADWP's commitment to reach 100% renewable energy by 2035 and the need for significant quantities of firm, dispatchable, GHG-free power. It is important to note that all repowered power plants must either meet or outperform current regulatory emissions standards when converted to utilize GH_2. Demand at this scale will justify shared infrastructure and drive down end-user GH_2 costs, enabling adoption in highly polluting sectors, such as heavy-duty trucking, shipping, port operations, and aviation. While the power sector plays an important role in the establishment of a GH_2 market, it is unlikely to be a large consumer of GH_2 in the long-term, as in-basin power plants are likely to be utilized primarily for high-demand or emergency needs.[128]

The roadmap for the region must ensure a strong community value proposition and include local stakeholders in the planning processes from inception. A few areas for future collaboration identified in HyBuild LA's stakeholder engagement include: ensuring the safety of GH_2 infrastructure, providing input on infrastructure decisions, ensuring climate integrity of the system, maximizing public health benefits, creating jobs and career transition opportunities, and conducting analysis around appropriate uses for GH_2. Co-creating the region's GH_2 ecosystem will be a big undertaking for a diverse range of stakeholders. Community members should be supported as needed to create capacity and reduce barriers to engage in these processes.

"Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it's the only thing that ever has."

From our preliminary evaluation, the opportunity for local communities in the LA Basin to benefit from the GH_2 economy are immense; even conservative adoption estimates show significant air quality improvements, leading to public health benefits. By 2035, the public health benefits of the envisioned GH_2 economy can be valued at nearly $80 million for residents in January 2035 alone. The HyBuild LA adoption scenario is also estimated to create nearly 29,000 direct and indirect jobs, which have diverse skill demands that enable a just, clean energy transition. The GHC will continue to collaborate with key stakeholders to understand the interests and valid areas of stakeholder concerns.

Ultimately, HyBuild LA envisions the transition of the energy system we have relied upon for the last century to create a vibrant, inclusive, and clean energy economy. Creating a GH_2 hub at this scale has never been accomplished before. However, the work from HyBuild LA demonstrates that the vision for mass-scale, low-cost GH_2 to decarbonize multi-sectoral offtakers is commercially viable and technically achievable. Bringing the vision to life will require transformational leadership and collaboration across sectors, but in the words of the American anthropologist Margaret Mead: *"Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it's the only thing that ever has."*

128. Cochran, Jaquelin, and Paul Denholm, eds., "The Los Angeles 100% Renewable Energy Study," National Renewable Energy Laboratory, NREL/TP-6A20-79444, March 2021.

APPENDIX A

Offtake Assessment – Inputs, Assumptions, and Methodology

Authors: Corporate Value Associates (Mobility Infrastructure, Land-Based Mobility Use Cases, E-Kerosene for Aviation, Ammonia Production); American Bureau of Shipping (Maritime Shipping).

A.1 | MOBILITY INFRASTRUCTURE

A.1.1 | Fuel Delivery Infrastructure

HyBuild LA Phase 2 built upon the findings from the Phase 1 (2021) analysis, which found that a dedicated transmission pipeline carrying compressed GH_2 gas was the most cost-effective way to transport large volumes of GH_2 from production zones into the LA Basin. This infrastructure was referred to as the “pipeline backbone.”

For locations with large quantities of aggregated GH_2 demand, distribution pipelines are likely to be the lowest cost option. Where demand is dispersed or distribution pipelines are not feasible, truck transport of liquid hydrogen was selected as the lowest-cost option for delivery of GH_2 to refueling or local storage infrastructure within 50 – 200 miles from the GH_2 pipeline backbone. In the HyBuild LA scenario, liquefaction plants are placed at the most cost-effective locations along the GH_2 pipeline backbone to optimize for the costs and availability of land.

Truck delivery of liquid GH_2 may be feasible for dispersed refueling infrastructure that is located beyond 200 miles from the GH_2 pipeline backbone, particularly if located along major transit corridors. However, if sufficient demand can be aggregated to justify implementation of a distribution pipeline, distribution pipeline delivery will be more cost-effective than truck delivery of liquid GH_2.

A.1.2 | Other Fuel Scenarios Considered

In addition to transportation of liquid GH_2 via truck and transportation of compressed GH_2 via pipeline, HyBuild LA considered additional transport mediums: trucked transport of compressed gas, liquid organic hydrogen carriers (LOHC), and ammonia cracking (i.e., transporting as ammonia and then converting back into GH_2 at the destination). These storage and delivery methods were assessed based on infrastructure cost, technology maturity, and transport potential (including carrying capacity and the distances at which they could economically transport GH_2). This analysis of GH_2 transportation pathways concluded that truck delivery of compressed gas would not be feasible for GH_2 fueling stations for the applications considered in HyBuild LA, given the expected daily GH_2 demand at these facilities. LOCH and ammonia cracking were also excluded as they are not yet technologically mature and require higher-cost infrastructure.[129]

A.1.3 | Liquefaction Infrastructure Scenarios

Two different design options were analyzed for liquefication configurations: fewer, larger liquefaction stations that require greater GH_2 transportation distances via truck, and a greater number of smaller liquefaction stations, enabling shorter GH_2 transportation distances via truck. The first configuration includes two large liquefaction plants next to the GH_2 pipeline backbone, minimizing land use and maximizing economies of scale. Using this design option, the estimated cost of liquefaction and GH_2 transportation via truck in 2030 was determined to be $2.40/kg GH_2, with $2.10/kg attributed to the liquefaction process and the remaining $0.30/kg attributed to truck transport costs. The liquefaction costs can be further broken out into CAPEX (17%), liquefaction electricity (48%), and operations and maintenance and other OPEX (35%). This lower-cost option is reflected in the HyBuild LA scenario.

The second design configuration includes multiple smaller liquefaction plants next to the pipeline backbone, thus minimizing the average distance of GH_2 transport via truck. The estimated cost associated with the second design option is $3.10/kg GH_2, with $3.00/kg resulting from liquefaction costs, and the remaining $0.10/kg from truck transport. The liquefaction costs were divided between CAPEX (19%), liquefaction electricity (42%), and operations and maintenance and other OPEX (39%).

Table 1 identifies the inputs used in the liquefaction design calculation and Table 2 includes the associated sources.

129. Mario Conte, et al. ”Hydrogen as Future Energy Carrier: The ENEA Point of View on Technology and Application Prospects,” Energies, vol. 2, no. 1, pp. 150-179, 2009.

Table 1 | Liquefaction design calculation inputs.

Input	Design 1	Design 2	Unit
Technical Data			
Average transport distance	200	60	miles
# of plants	2	15	# plants
GH_2 loss from liquefaction process	0.7	1.4	%
Plant capacity	200,000	27,000	kg/day
CAPEX Data			
Infrastructure lifespan	30	30	years
Project start year	2025	2030	year
# of years for station construction	1	1	years
CAPEX	4,000	5,600	$/kg of liquefaction capacity
OPEX Data			
OPEX and O&M	6	6	% of CAPEX
Plant size	10,000	2,500	m^2
Land rent cost	4	1	$\$/m^2$
Electricity consumption	4	5	kWh/kg of GH_2 liquefied

Table 2 | Liquefaction design calculation sources.

Input	Source
Maximum supply capacity of one station	Connelly et al. 2019[130]
GH_2 loss	Derking et al. 2019[131]
Infrastructure lifespan	Connelly et al. 2019
CAPEX	Connelly et al. 2019
Land rent cost	USDA 2021[132]

130. Elizabeth Connelly et al., "Current Status of Hydrogen Liquefaction Costs," DOE, Hydrogen and Fuel Cells Program Record, #19001, August 6, 2019.
131. Henrie Derking, et al., "Liquid Hydrogen Storage: Status and Future Perspectives," Cryogenic Heat and Mass Transfer, Enschede, The Netherlands. Cryoworld Advanced Cryogenics, November 4, 2019.
132. USDA National Agricultural Statistics Service. "Pacific Region – State Cash Rent & Land Values," August 6, 2021.

A.2 | LAND-BASED MOBILITY USE CASES

Before developing an estimate for GH_2 demand in the mobility sector, CVA first filtered potential use cases based on whether GH_2 would provide a cost-competitive decarbonization solution compared to electrification. For this assessment, CVA developed sample use profiles for different mobility applications. These use profiles were utilized to compare the cost of fueling a particular mobility end use with GH_2, diesel, or electricity. The use cases are not based on specific facilities or vehicle routes; rather, they were developed with inputs from stakeholder interviews and other industry knowledge and are meant to be representative of general use patterns in Southern California.

The following sections identify use cases where GH_2 was determined to be a cost-effective option, provide details on the sample use profiles, and share any other relevant inputs that were utilized to study each use case. Mobility infrastructure use cases where GH_2 was not considered a cost-effective option, or where demand was too limited to warrant further analysis, are identified in Table 3.

Table 3 | Summary of use cases not included in offtake and infrastructure analysis.

Use Cases Not Included in Analysis		
Vehicle Types	**Use Case**	**Reason Why Not Included**
Trucks for last-mile delivery	Last-mile delivery in LA, using fleet of light trucks operating from single vehicle depot at logistic hub	Not competitive vs. electrification (can be charged overnight at stationary base sufficiently)
City buses	Los Angeles County Metropolitan Transit Authority (LACMTA) use of local/rapid/express buses	Not competitive vs. electrification (LACMTA already invested in charging infrastructure which can sustain use cases)
Diesel trains	Locomotives powering interstate cargo trains	Complete fueling need is out of scope for the HyBuild LA system (earliest refueling stop 800 miles from LA)
	Switcher locomotives powering intrastate cargo trains	Limited demand
	Amtrak Metrolink Commuter Trains	Not competitive vs. electrification
Heavy-duty construction equipment	A variety of equipment types operated by LA-based construction companies on construction sites around LA	Low maturity of technology, with very heterogenous and dispersed equipment fleet. Some construction site may utilize GH_2-powered mobile generators, but this application has limited scale of demand.

A.2.1 | Heavy-Duty Trucks

Based on Federal Highway Administration statistics on truck registrations in California[133] and population distributions across the state, it was estimated that around 450,000 heavy- and medium-duty trucks operate in the LA Basin. Assuming that 50% of this quantity are heavy-duty trucks (HDTs) and 22,000 are drayage trucks (which are assessed separately),[134] the addressable vehicle base was assumed to be around 205,000, growing to 240,000 in 2030 based on traffic flow predictions. The use case developed for the HyBuild LA analysis (described below) applies to 70% of this addressable vehicle base.

The HyBuild LA study assumed that public GH_2 stations would be available within 400 miles of LA, or that refueling would be available at route destinations for trips up to 400 miles outside of LA. In this scenario, 85% of GH_2 fuel would be provided by small depot-based, private refueling solutions with a capacity of 400 kg GH_2/day, and the remaining 15% would be provided at public heavy-duty GH_2 stations with 6 t GH_2/day. This extrapolation assumes there are 10 small depot base stations, each with a capacity of 0.4 t/day, at base and destination locations.

Assuming a 12-year vehicle replacement time, HyBuild LA anticipates that fleet penetration would reach nearly 30% of HDTs registered in the LA Basin by 2040, translating to a fleet of roughly 90,000 FCEV trucks by 2040. Estimated GH_2 demand from heavy-duty trucks and related fueling infrastructure projections are shown in Table 4. The projected annual demand at the pump is 135kt in 2030, increasing to 705kt in 2040.

133. Federal Highway Administration. "Truck and Truck-Tractor Registrations – 2019," U.S. Department of Transportation. November 2020.
134. Port of Long Beach. "Clean Trucks: Program Details." Accessed January 30, 2022.

Table 4 | Heavy-duty trucks and fueling infrastructure estimates in the HyBuild LA system plan.

Value	Unit	2030	2040
# of FCEV heavy-duty trucks in LA Basin	thousands of FCEVs	17	88
GH_2 demand/year (at the pump)	kt	135	705
# of small depot-based station at 400 kg/day capacity	#	1,051	5,505
# of public heavy-duty stations at 6,000 kg/day capacity	#	23	121

LA is both a destination and an origin for interstate trucking – 81% of the mileage traveled by trucks leaving, entering, or moving within CA is due to interstate transport.[135] While interstate travel dominates heavy-duty truck traffic in LA, many key destinations are within a 400-mile radius of LA. Traffic flow predictions include an increase in delivery volumes of 35% by 2040, with the same key destinations and routes as current delivery patterns.[136]

Table 5 | Key regions and destinations for heavy-duty trucking.

Key regions and roads for interstate heavy-duty truck traffic from/to LA
Bakersfield Region – Interstate 5 / CA99
Indio Region – Interstate 10
Barstow – Interstate 15 and 40
San Diego – Interstate 8
Interstate 8 / 10 Intersection
Flagstaff Region
Interstate 40 / U.S. 93
Key destinations for LA-origin heavy-duty truck traffic flows
San Francisco
Las Vegas
Phoenix
Sacramento
Saint George

Total Cost of Ownership Analysis

A total cost of ownership (TCO) analysis was undertaken to assess the point at which GH_2 fuel cell heavy-duty trucks may become cost-competitive with current internal combustion engine technology. This analysis was based on a sample trucking use case for heavy goods transport from a fleet operator that is based in the LA Basin, but operates interstate. The specific scenario evaluated in this use case assessment includes a dedicated fleet of 200 HDTs arriving and leaving from a warehouse in the LA Basin. It was assumed that 290 trips were started per day, some of which were interstate trips. Overall driving behavior for the HDT use case can be aggregated into three types of routes, depending on endpoint, mileage, and necessary refueling/recharging infrastructure.

135. Bureau of Transportation Statistics (BTS), "Freight Analysis Framework Version 5.3," December 22, 2022.
136. Ibid.

Table 6 | Generalized usage profiles for heavy-duty trucks.

Generalized HDT Routes (Assuming dedicated fleet of 200 HDTs)			
	Route type 1	**Route type 2**	**Route type 3**
Description of trip profile	Return trips and multi-pickup/ delivery within LA Basin	Direct to destination within daily driving distance	Multi-stop tours
Destination examples	• Ports of Long Beach/Los Angeles • SCALA Logistic Airport • LA last mile to customer	• San Diego • Las Vegas • Phoenix/Tucson • San Jose	Any other U.S. or Mexico location
Start – end (stops)	Depot – Depot (multiple stops)	Depot – 3rd party warehouse	Depot – 3rd party warehouse in another state
Idle time and locations of vehicles if no refueling	None (shift operation)	Can (at depot, overnight)	Must (driver rests at night)
Mileage/trip	50 (3 per day)	300-400 (1 per day)	1400 (5-day return)
Mileage/day	150	200-300	~300
Interstate trip	No	Some (NV, AZ)	Always
# of vehicles per trip type (% of total vehicles)	60 (30%)	100 (50%)	40 (20%)
Departures/day from depot (% of total departures)	180 (56%)	100 (31%)	10 (3%)
Total fleet mileage/day (% of total mileage)	9,000 (20%)	25,000 (54%)	12,000 (26%)
Refueling at own base depot (% of fuel required for trip)	Yes (100%)	Yes (40%)	Yes (20%)
Refueling at 3rd party depot (% of fuel required for trip)	No (0%)	Yes (40%)	No (0%)
Public refueling (% of fuel required for trip)	No (0%)	Yes (20%)	Yes (80%)

As demonstrated in Table 6, all HDT trips within the LA Basin (route type 1) can be refueled at small depot-based stations which can be supplied with liquefied GH_2 from the pipeline backbone. The longer, direct to destination routes (route type 2) would need to be fueled at small depot-based stations and at large public heavy-duty refilling stations. Finally, demand for GH_2 and related fueling infrastructure for route type 3 was considered out of scope for this analysis, as the HyBuild LA study found that it was uneconomic for an LA-focused hydrogen hub to supply liquid GH_2 via truck to fueling stations more than 400 miles from the LA Basin. However, given efforts to develop GH_2 hubs around the nation, it is highly likely that longer interstate routes with GH_2 fueling would eventually be enabled by hydrogen production in other regions.

An alternative charging scenario for battery electric vehicles (BEVs) was modeled for a TCO comparison. This scenario evaluates the same use case (i.e., the same trip types done as in Table 5), but instead includes all necessary charging infrastructure for electric trucks. The analysis assumed that BEV charging infrastructure for all trips within the LA Basin would be powered by Level 4 (350kW DC) charging points at a warehouse or depot. Outside of the LA Basin, the analysis assumed that 80% of the direct to destination routes would be powered by Level 4 warehouse or depot charging points, and the remaining 20% would be recharged at public fast-charging truck stations (Level 4 350kW DC). For long-haul trips, the analysis assumed that 20% of recharging would occur at the warehouse or depot and the remaining 80% would occur at public stations.

In 2030, FCEVs were determined to have the lowest TCO: $71 per 100 miles. BEVs were slightly higher at $72 per 100 miles, and diesel trucks significantly higher at $80 per 100 miles. The primary costs assessed were vehicle depreciation (based on starting capital costs), fuel costs, and operations and maintenance (O&M). Fuel costs at the pump account for the majority of costs for all technologies, contributing $58 per 100 miles for diesel vehicles, $47 per 100 miles for FCEVs, and $40 per 100 miles for BEVs. Vehicle depreciation is the second largest contributor to cost, at $25 per 100 miles for BEVs, $14 per 100 miles for FCEVs, and $12 per 100 miles for diesel. The smallest cost contribution is O&M, which accounts for $10 per 100 miles for diesel and FCEVs and $7 per 100 miles for BEVs.

The key drivers identified for GH_2 cost competitiveness in heavy-duty trucking applications are identified in Table 7. Due to decreases in capital costs for FCEVs, it is projected that FCEVs will become cost competitive by 2029. If the maximum Production Tax Credit from the Inflation Reduction Act is applied to GH_2 production to lower fuel costs, FCEVs could be cost competitive with diesel trucks as early as 2026.

Table 7 | Drivers and key dynamics for FCEV heavy-duty truck cost-competitiveness.[137]

Value	FCEV	BEV	Diesel	Key dynamic
Vehicle price (USD/unit) 2022/2030	$322k / $180k	$620k / $281k	$170k / $159k	FCEV strongly decreasing and BEV slightly decreasing, diesel stable
GH_2 costs ($/kg) 2022/2030	$12 / $2	N/A	N/A	Assuming $2/kg at the pipeline backbone after 2030
Diesel/electricity price increase (%/year)	N/A	1%	2%	Starting price of $1.40/L for diesel and $0.20/kWh for electricity
# of trucks required to meet transportation needs	160	167	160	Due to tonnage capacity and charging time difference

A.2.2 | Drayage Trucks

The analysis of drayage trucks considered the use case of picking up and delivering containers between the Port of Long Beach and a warehouse within the LA Basin. A sample trip profile was used to summarize drayage truck operation. The routes considered were primarily short distance, returning to the depot and crossing the port terminals multiple times a day. Expected destinations included a local warehouse within 20 miles of the port area, or a maximum transportation distance to the West Barstow railyard. Typical mileage per trip would range from 5 to 200 miles, with an average mileage per day for a vehicle of around 120 miles, assuming an average of 3 trips and an average of 60 miles per trip. This analysis also assumed drayage trucks would have an idle time of 8-10 hours overnight.

For drayage trucks, the analysis assumes that about 80% of trip mileage is refueled at small, depot-based stations, supplied with liquid GH_2 via truck from the pipeline backbone with a capacity of 400 kg GH_2/day. The remaining 20% of fueling needs are assumed to be provided by medium public stations that have a capacity of 1.4 t GH_2/day, also supplied by the pipeline backbone.[138]

An alternate scenario utilizing BEVs was assessed as a comparison. This scenario assumed that charging infrastructure for all trips within the LA Basin would be powered by Level 4 (350kW DC) charging points; 80% of the direct to destination routes would be powered by Level 4 warehouse or depot charging points, and the remaining 20% would be recharged at public heavy-duty fast charging stations (Level 4 350kW DC).

BEVs were determined to have the highest TCO at $114 per 100 miles. Diesel and FCEVs had slightly lower TCOs, at $112 and $109 per 100 miles, respectively. Fuel costs at the pump accounted for most of the cost for all technologies, contributing $80 per 100 miles for diesel vehicles, $73 per 100 miles for FCEVs, and $59 per 100 miles for BEVs. Vehicle depreciation contributed $48 per 100 miles for BEVs, $26 per 100 miles for FCEVs, and $22 per 100 miles for diesel. The smallest contribution came from operations and maintenance, with $10 and $11 per 100 miles for diesel and FCEVs, respectively, and $7 per 100 miles for BEVs.

FCEV drayage trucks were determined to be cost competitive by 2026 when compared with BEVs. This was primarily driven by decreasing FCEV CAPEX costs. Inputs for this analysis are illustrated in Table 8.

137. Inputs extrapolated from interviews and relevant literature. See: Chad Hunter, et al., "Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks," NREL/ TP-5400-71796, September 2021.
138. Sample trip profile developed with reference to: Andrew Papson, et al., "Key Performance Parameters for Drayage Trucks Operating at the Ports of Los Angeles and Long Beach," CALSTART, November 11, 2013.

Table 8 | Drivers and key dynamics for FCEV drayage truck cost-competitiveness.[139]

Value	FCEV	BEV	Diesel	Key dynamic
Vehicle price (USD/unit) 2022/2030	$322k / $180k	$620k / $281k	$170k / $159k	FCEV strongly decreasing and BEV slightly decreasing, diesel stable
GH_2 costs ($/kg) 2022/2030	$12 / $2	N/A	N/A	Assuming ~$2/kg at the pipeline backbone after 2030
Diesel/electricity price increase (%/year)	N/A	1%	2%	Starting price of $1.40/L for diesel and $0.20/kWh for electricity
# of trucks required to meet transportation needs	50	55	50	Due to tonnage capacity and charging time difference

The estimated addressable vehicle base for drayage trucks is 13,000 of the 22,000 registered in the Ports of Los Angeles and Long Beach.[140] Most drayage trucks do not travel interstate and can be fully sustained by fueling within the HyBuild LA system. Expected annual sales of new drayage trucks are projected to reach 1,256 in 2040. Assuming a 10-year vehicle replacement time, fleet penetration would reach approximately 70% of drayage trucks operating in LA ports by 2040, or nearly 10,000 FCEVs.

Table 9 | Drayage truck and fueling infrastructure estimates in the HyBuild LA system plan.

Value	Unit	2030	2040
Number of FCEV drayage trucks	Trucks	1,401	10,270
GH_2 mobility demand/year	kt	11	77
Number of small depot-based station at 400 kg/day capacity	Depot Stations	28	205
Number of public medium stations at 1,400 kg/day capacity	Public Stations	36	267

A.2.3 | Forklifts

The analysis of forklifts is based on a sample use case that assumes a single depot operates a fleet of 100 forklifts running 1 to 2 shifts per day. A typical forklift route would stay within the depot area and travel to diverse storage sites within the warehouse or outdoors. On average, each forklift has 8 hours per day of usage time, and forklifts are estimated to operate 300 days per year. All forklift refueling is assumed to occur at the depot.[141]

A GH_2 refueling setup for the forklift use case would consist of a small refueling station with a daily capacity of 400 kg GH_2 and multiple dispensers (between 8 and 12) to serve the fleet of 100 forklifts. Liquid GH_2 fuel would be delivered by truck from the pipeline backbone.

An alternative scenario was analyzed, which included BEV forklifts charged overnight at a forklift charging station with 50 charging spots. The nominal power for this station is assumed to be 1,000 kW, and the output per charger would have 20kW of AC charging power. Based on these assumptions, the TCO comparison showed that FCEV forklifts would be more cost competitive than BEVs by 2028.

139. Inputs extrapolated from interviews and relevant literature. See: Chad Hunter, et al., "Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks," NREL/ TP-5400-71796, September 2021.
140. Port of Long Beach. "Clean Trucks: Program Details," Accessed February 7, 2023.
141. Sample profile developed with reference to: John Sullivan, "How Long Will an Average Forklift Last?" Toyota Material Handling Northern California, December 13, 2016.

Table 10 | Drivers and key dynamics for FCEV forklift competitiveness.[142]

Value	FCEV	BEV	Propane	Key dynamic
Vehicle price (USD/unit) 2022/2030	$35k / $30k	$30k / $25k	$25k / $23k	FCEVs and BEVs strongly decreasing, diesel stable
GH_2 costs ($/kg) 2022/2030	$12 / $2	N/A	N/A	Assuming $2/kg at the pipeline backbone after 2030
Propane/electricity price increase (%/year)	N/A	1%	1%	Starting price of $0.7/L for propane and $0.20/kWh for electricity
# of forklifts required to meet operational needs	100	110	100	BEV additional quantity due to charging time difference
O&M cost ($/year)	224	500	1500	Strongly decreased O&M for FCEVs and BEVs

By 2030, TCO per day is projected to be $36 for diesel forklifts, and as low as $27 for BEV and $26 for FCEVs. The majority of costs for diesel forklifts are fuel costs, which are $18, compared to the fuel costs for BEVs and FCEVs, which are $8 and $7 respectively. For BEVs and FCEVs, the largest portion of cost is allocated to vehicle depreciation, at $19 for FCEVs and $17 for BEVs, and slightly lower at $14 for diesel. The remaining cost is due to operations and maintenance, which was calculated to be $4 for diesel and $1 for both BEVs and FCEVs.

The total addressable forklift vehicle base in the LA Basin was estimated to be approximately 40,000 forklifts.[143,144] Of the total addressable vehicle base, 55% was assumed to be electrified, as BEVs already have significant market penetration and some depots have already invested in charging infrastructure.[145] It was assumed that that FCEV forklifts will replace all remaining fossil fueled forklifts from 2025 onward and will be fully competitive with BEVs by 2028. Expected annual sales for FCEV forklifts are projected to be over 5,000 by 2040, making up nearly half of total forklift sales for that year. Fleet forklifts tend to have short operational life of approximately 4 years, so approximately 45% of forklifts could be FCEVs by 2030.[146]

Table 11 | Forklift and fueling infrastructure estimates in the HyBuild LA system plan.

Value	Unit	2030	2040
# of FCEV forklifts	k #	19	21
GH_2 mobility demand/year	kt	8	9
# of small depot-based station at 400 kg/day capacity	#	194	214

A.2.4 | Coaches

Coaches operating from a base in the LA Basin and traveling interstate for individual business and leisure charters were analyzed in the HyBuild LA study. There is a complete base of approximately 2,000 coaches registered in and operating out of the LA Basin, including a variety of operators and trip profiles.[147] Generally, coach depots are smaller than those used by heavy-duty trucks.

Four potential usage profiles were evaluated within the coach use case, which were developed consistent with data provided by HyBuild LA interview participants:

- Route 1 includes fast routes around LA (e.g., LAX shuttle). Coaches on these routes spend at least 4 hours per day at the depot for cleaning and refueling. The typical mileage per vehicle per day is 150, with around 300 vehicles dedicated to this type of route. The refueling profile is similar to that of city buses and is likely not favorable for GH_2 compared to BEVs.

142. Inputs extrapolated from interviews and relevant literature. See: Simon Walker, "Compare LPG Forklift to Hydrogen Forklift," Lean INC Material Handling, July 24, 2021.
143. Reese Wagner, "Forklift Accident Statistics in the United States," December 15, 2020.
144. Zippia, "Forklift Operator Demographics and Statistics in the US." September 9, 2022.
145. Industrial Truck Association, "North American Forklifts Have Record 2015 Sales; Nearly 2/3 Were Electric," Industrial Distribution, February 24, 2016.
146. John Sullivan, "How Long Will an Average Forklift Last?" Toyota Material Handling Northern California, December 13, 2016.
147. United Motorcoach Association. "Motorcoach industry by the numbers," November 2021.

- Route 2 includes charter coach travel within California. Destinations may include San Diego, Palomar, and Yosemite. These vehicles would have at least 10 hours per day of idle time, which could be taken anywhere in Southern California. Coaches on Route 2 may make 1 to 2 trips per day with mileage per trip varying between 120 and 400 miles. Approximately 1,500 vehicles have been allocated to this usage profile, and all of the refueling for these trips would be done at public refueling stations.
- Route 3 includes intrastate commute to and from LA via transit providers. Destinations in these cases may be locations such as Fresno and San Jose. These vehicles would spend a maximum of four hours per day in a coach yard and would only take one trip per day. These routes would cover approximately 600 miles and would generally be round-trip, so coaches would start and end their trip at the same depots based in the LA Basin. There are approximately 100 coaches allocated to this usage profile which would divide their refueling between the LA Basin depot (around 20% of mileage) and public refueling stations (80%).
- Route 4 includes interstate commutes to and from LA via transit providers. Destinations for this route profile include Las Vegas, NV, and Tulsa, OK. As these routes require refueling outside of California, they were not considered by the HyBuild LA system.

Table 12 | Generalized usage profiles for coaches.

<table>
<tr><th colspan="5">Generalized Coach Routes</th></tr>
<tr><th></th><th>Route type 1</th><th>Route type 2</th><th>Route type 3</th><th>Route type 4</th></tr>
<tr><td>Description of trip profile</td><td>Fast routes around LA (e.g., LAX Shuttle)</td><td>Charter coach travel in California</td><td>Intrastate commute from/to LA via transit providers</td><td>Interstate commute from/to LA via transit providers</td></tr>
<tr><td>Destination examples</td><td>• Santa Barbara Airbus Stop</td><td>• San Diego
• Palomar
• Yosemite</td><td>• Fresno, CA
• San Jose, CA</td><td>• Las Vegas, NV
• Tulsa, OK</td></tr>
<tr><td>Start – end (stops)</td><td>LAX to Santa Barbara Airbus Yard</td><td>From LA Basin to Santa Barbara and back</td><td>San Bernadino Greyhound Terminal to Fresno Terminal</td><td>San Bernadino Greyhound Terminal to Tulsa Terminal</td></tr>
<tr><td>Idle time and locations of vehicles</td><td>Min. 4h per day at depot (cleaning and refueling)</td><td>Min. 10h per day anywhere in Southern CA</td><td>Max. 4h per day in coach yard</td><td>Max. 4h per day in coach yard</td></tr>
<tr><td>Mileage/trip</td><td>100 (3 per day)</td><td>120 to 400 (1-2 per day)</td><td>600 (full day)</td><td>1,800 (3 days)</td></tr>
<tr><td>Mileage/day</td><td>160</td><td>200</td><td>600</td><td>600</td></tr>
<tr><td>Interstate trip</td><td>No</td><td>No</td><td>No</td><td>Yes</td></tr>
<tr><td># of vehicles per trip type</td><td>300</td><td>1500</td><td>100</td><td>100</td></tr>
<tr><td>Departures/day from depot
(% of total departures considered)</td><td rowspan="6">Similar profile as city buses, likely not competitive vs. BEV</td><td>2250 (96%)</td><td>100 (4%)</td><td rowspan="6">Requires refueling out of California, cannot be sustained by HyBuild.</td></tr>
<tr><td>Total fleet mileage/day
(% of total mileage)</td><td>450k (88%)</td><td>60k (12%)</td></tr>
<tr><td>Refueling at LA Basin depot
(% of fuel required for trip)</td><td>No (0%)</td><td>Yes (20%)</td></tr>
<tr><td>Refueling at 3rd party depot
(% of trip mileage)</td><td>No (0%)</td><td>No (0%)</td></tr>
<tr><td>Public refueling (% trip mileage)</td><td>Yes (100%)</td><td>Yes (80%)</td></tr>
</table>

The types of refueling infrastructure that could be used for coach applications include medium public refueling stations with 1.4t GH_2/day capacity and large public refueling stations with 6t GH_2/day capacity. Intrastate commuter coaches could also use overnight refueling if the operator has their own depot.

The alternative charging setup for BEVs would include public fast charging stations (Level 4 350kW DC chargers) with some depot charging (Level 4 350kW DC charging point) in the case of intrastate commuting coaches. For a company-owned fuel/charging station to be economic, a fleet size of more than 20 would be required, and less than 10% of all coach companies meet this condition.[148]

148. United Motorcoach Association, "MOTORCOACH Industry by the Numbers," 2021.

Based on this analysis, FCEV coaches were determined to be more competitive than BEVs for route types 2 and 3 by 2033. Full leverage of IRA Production Tax Credits could accelerate FCEV coach cost competitiveness by up to four years.

Table 13 | Drivers and key dynamics for FCEV coach competitiveness.[149]

Value	FCEV	BEV	Diesel	Key dynamic
Vehicle price (USD/unit) 2022/2030	$1,270k / $635k	$1,000k / $600k	$500k / $461k	FCEV and BEV strongly decreasing, diesel stable
GH_2 costs ($/kg) 2022/2030	$12 / $2	N/A	N/A	Assuming $2/kg at the pipe after 2030
Diesel/electricity price increase (%/year)	N/A	1%	2%	Starting price of $1.4/L for diesel and $0.20/kWh for electricity
# of coaches needed to meet transportation needs	1,600	1,680	1,600	Due to charging time difference

By 2030, the TCO per 100 miles would be $117 for FCEVs, compared to $108 for diesel and $128 for BEVs. For diesel and BEVs, the largest cost component is fuel costs, which are $59 and $70 respectively, compared to $46 for FCEVs. The other major cost driver is vehicle depreciation, which accounts for $38 in the case of diesel, $50 for BEVs, and $57 for FCEVs. Finally, all technologies have relatively small contributions from operations and maintenance, with $14 for FCEVs, $11 for diesel, and $8 for BEVs.

Based on the above analysis, FCEVs were determined to be the most cost-competitive option for decarbonized coach travel for approximately 80% of the 2,000 total coaches registered in the LA Basin (i.e., those traveling Routes 2 and 3). Because few operators would be able to sustain their own refueling solutions, only about 2% of fuel would be supplied via small depot-based refueling stations. The remaining fuel would be split evenly between public large GH_2 stations (6t GH_2 per day) and medium GH_2 stations (1.4t GH_2 per day).

Driven by regional decarbonization targets, annual sales for FCEV coaches are projected to reach 154 in 2035 and 194 in 2040. With an expected vehicle replacement time of 12 years, FCEV fleet penetration is assumed to reach around 60% of coaches registered in and operating from the LA Basin by 2040, with approximately 1,800 FCEV coaches deployed based on expected market growth.

Table 14 | Coach vehicle and fueling infrastructure estimates in the HyBuild LA system plan.

Value	Unit	2030	2040
# of FCEV coaches	k #	500	1800
GH_2 mobility demand/year	kt	2700	10300
# of small depot-based station at 400 kg GH_2/day capacity	#	1	2
# of public medium stations at 1,400 kg GH_2/day capacity	#	7	25
# of public large stations of 6,000 kg GH_2/day capacity	#	2	6

A.2.5 | Port Material Handling Equipment

Port material handling equipment evaluated in this portion of the analysis include rubber-tired gantry cranes (RTG), yard tractors, and top handlers in the Port of LA and Long Beach. The ports have set a goal to transition to zero-emission handling equipment by 2035 and have determined that electrification would not be feasible for significant portions of the fleet operating equipment due to the demands of their duty cycles, which require long periods of continuous operation.[150] Thus, it was assumed that at least 80% of the zero-emission port handling equipment in 2035 would be fuel cell based.

Assuming a 4-year operational use life for material handling equipment, and factoring in the 2035 zero-emission equipment goal, CVA estimated that the projected fleet of fuel cell handling equipment in 2035 would include 1,900 yard tractors, 370 top handlers, and 150 RTG cranes.[151] As port handling equipment does not leave the terminal, all refueling would need to occur on site through a combination of stationary and mobile refueling options.

149. Inputs extrapolated from interviews and industry sources.
150. Long Beach City College Workforce Development, "Zero-emission Port Equipment: Workforce Assessment," Port of Long Beach. Accessed February 7, 2023.
151. Estimates of existing port equipment based on interviews with Toyota Tsusho and Fenix Marine Services.

A.3 | AVIATION USE CASE

In addition to land-based mobility end uses, the HyBuild LA analysis also looked at potential use for GH_2 in aviation and maritime shipping, considering both direct use of GH_2 and use of GH_2 as a feedstock for the production of derivative fuels. CVA conducted the assessment for GH_2 use in aviation, while the American Bureau of Shipping (ABS) conducted the assessment for the maritime sector.

E-Kerosene for Aviation

Analysis of sustainable aviation fuel (SAF) production assumed a 2% annual increase in consumption of kerosene (also known as Jet-A, or JET).[152] Other key assumptions included a $2B investment by World Energy to expand production capacity at their Paramount facility to 340 million gallons of SAF production annually by 2025;[153] a 2030 goal of 3 billion gallons of SAF production in the U.S. (25% of which would be produced in the LA area); and further momentum to increase production beyond 2030.[154] This analysis also assumed a shift in production pathways of SAF would occur, from the use of hydrotreated esters and fatty acids (HEFA) feedstocks to more advanced and GH_2 intensive routes (as these methods mature and the necessary feedstocks are available). For example, the projected production method of SAF in 2025 was limited to high and low O2 feedstock HEFA, but by 2040, production was projected to be evenly distributed between Alkaline-to-Jet, Fischer-Tropsch using organic feedstocks, and Power-to-Liquid using GH_2 and CO2 as a feedstock.

Assuming that the H_2 used in SAF production would be gradually replaced with GH_2 from the HyBuild system, demand for GH_2 was estimated to be 62 kt in 2030 and 439 kt in 2040.

Table 15 | Projected uptake of SAF in 2030 and 2040.

Metric	Unit	2030	2040
SAF available in LA Basin	M gallon	750	1125
Share of total U.S. JET consumption	%	2.5%	3.4%
Share of LAX JET consumption	%	54%	73%
Average GH_2 intensity of SAF production process (kg GH_2 per gallon SAF)	kg/gallon	0.21	0.78
GH_2 demand from the HyBuild LA system	kt	62	439

A.4 | MARITIME SHIPPING SCENARIO

Conservative Zero Carbon Fuel Adoption Scenario

The HyBuild LA system plan utilized a Regional Best-Case Forecast scenario to estimate demand for GH_2 in the maritime shipping sector in 2030 and 2040. This scenario, which is detailed in the main body of the report, assumed that LA clean energy initiatives like the Ship It Zero resolution[155] would spur the accelerated decarbonization of shipping routes between LA and Shanghai. In addition to this scenario, ABS also developed a Conservative Forecast for maritime shipping fuel use that assumed the Ports of LA and Long Beach's zero-carbon fuel use would progress at the same rate as global trends, without accounting for any regional acceleration to meet local carbon reduction goals. While usage rates for each type of bunkering fuel would be the same in 2040 and 2050 in both scenarios, use of zero-carbon fuels would advance more slowly in the conservative case, leading to lower projected adoption levels in 2030. These estimates are based on the "Zero Carbon Outlook" report published by the ABS with no adjustments for LA's more stringent emission reduction targets.[156]

152. Kristi Moriarty. "U.S. Airport Infrastructure and Sustainable Aviation Fuel." National Renewable Energy Laboratory, NREL/TP-5400-78368. February 2021.
153. Air Products, "Air Products Teaming Up with World Energy to Build $2 Billion Conversion of Sustainable Aviation Fuel (SAF) Production Facility in Southern California," April 22, 2022.
154. The White House, "FACT SHEET: Biden Administration Advances the Future of Sustainable Fuels in American Aviation," The White House, September 9, 2021.
155. Kim Biggar, "Long Beach City Council passes Ship It Zero resolution," Splash 247.com.
156. American Bureau of Shipping (ABS), "Setting the Course to Low Carbon Shipping: Zero Carbon Outlook," 2022.

Table 16 | Conservative estimates of shipping fuel usage levels by fuel type.

Fuel Type (Million Metric Tons)	2019	2030	2040	2050
Heavy Fuel Oil (HFO)	2.84 (86%)	3.03 (70%)	2.66 (48%)	1.85 (26%)
Liquid Natural Gas (LNG)/Bio-LNG	0.38 (14%)	0.88 (27%)	1.13 (25%)	0.87 (15%)
E-Methanol	0 (0%)	0.08 (1%)	0.86 (8%)	2.20 (16%)
Green NH_3	0 (0%)	0.09 (1%)	0.80 (7%)	2.65 (18%)
GH_2	0 (0%)	0.01 (1%)	0.21 (12%)	0.58 (25%)

The cost estimate of \$5.30 – \$5.80/kg for GH_2 delivered to ships in the Ports of LA and Long Beach in 2030 includes liquefaction, storage, and dispensing costs. This analysis assumed that liquefaction would occur at a plant system operating at a capacity of 400 tons of GH_2 per day and a 90% utilization rate, located within close proximity to the ports. The cost of storage and dispensing was assumed to resemble cost profiles of a large refueling station (e.g., around \$1.20 – 1.50/kg GH_2). These additional costs are added to a "base" GH_2 cost of \$2.05/kg, delivered to the LA Basin via dedicated pipeline.

The point at which GH_2 and bunker fuel reach cost parity was calculated based on their relative energy contents and the relative efficiencies by which maritime propulsion equipment could translate that energy into mechanical force. The analysis assumed that ships in the Ports of LA and Long Beach primarily used very low sulfur fuel oil (VLSFO) with a lower heating value of 39.0 megajoules (MJ)/kg, and that ship combustion engines operated at efficiencies of 45%.[157] GH_2 was assumed to have a lower heating value of 120.2 MJ/kg, with ship fuel cells operating at efficiencies of 54%.[158] A reference price of \$1,033/ton was used for bunker fuel in the Ports of LA and Long Beach,[159] and the study assumed that ship operators would be willing to pay a 20% premium for fuels that would meet Southern California's stringent carbon emission restrictions.[160,161]

A.4.1 | Ammonia Production

HyBuild LA also undertook a preliminary assessment on the potential to produce cost competitive green NH_3 in Northern California that could serve the estimated demand from the martime shipping sector and agricultural sector throughout the state.

This analysis considered the economics of two scenarios to produce green NH_3 near the Port of Stockton in 2030: (1) this scenario assumed all GH_2 that would be needed as a feedstock to produce green NH_3 is produced in Northern California, utilizing local solar resources for electrolysis; and (2) this scenario assumed that green NH_3 production in Northern California would be connected to a consistent supply of GH_2 from the LA-area hub via a dedicated pipeline. Both scenarios assumed that grid electricity would be used to power the Haber-Bosch process to produce green NH_3. In the LA hub-connected scenario, roughly 25% of electricity for NH_3 production was assumed to be sourced from lower-cost solar power via PPAs, with the rest being supplied by connection to the electrical grid.

In Scenario 1, the system does not have access to mass-scale storage of GH_2. As a result, production of both GH_2 and green NH_3 follow solar availability. This would require significant oversizing of both the GH_2 and green NH_3 production to accommodate disparities in solar production across the year. The added capital costs to oversize production equipment made green NH_3 in this scenario uncompetitive with global prices.

The primary inputs for the green NH_3 production model are provided in Table 17. This analysis is built upon other analyses from the offtake and infrastructure workstream (e.g., GH_2 demand, LCOH). The related sources and methodology for these inputs are described in the earlier sections of this appendix.

157. Assumptions provided by ABS based on industry expertise.
158. Elise Georgeff, et al., "Liquid hydrogen refueling infrastructure to support a zero-emission U.S.-China container shipping corridor," International Council on Clean Transportation, Working Paper 2020-24, October 2020.
159. Based on VLSFO prices in May 2022. See: "LA / Long Beach Bunker Prices," Ship & Bunker.
160. Assumptions provided by ABS based on industry expertise.
161. Kim Biggar, "Long Beach City Council passes Ship It Zero resolution," Splash 247.com.

Table 17 | Inputs for green NH_3 production model.

Inputs	Units	Data	Source
GH_2 demand in Northern California (100 mi radius from Port of Stockton)	kt/y	275.0	CVA Northern California demand assessment
Levelized cost of delivered GH_2 (utilizing the production tax credit from the IRA)	$/kg	0.69	CVA LCOH analysis
Grid electricity price (June 2022)	$/MWh	178.0	U.S. estimate from EIA[162]
PV PPA electricity price (July 2022)	$/MWh	41.9	LevelTen Energy[163]
PV Factor Load	% year	26%	CVA Northern California Connection Analysis
WACC	%	6.00%	Industry estimate[164]
Usage of GH_2 to produce NH_3	t GH_2/t NH_3	0.177	FuelCell Works[165]
Energy requirements for Haber-Bosch	MWh/ton NH_3	0.738	Fasihi et al.[166]
% of Electricity from Grid vs. Solar PPA (North-South Scenario)	% of total use	75%	CVA Northern California Connection Analysis

The ammonia production model utilized over 20 points of reference data from existing ammonia production plants, which range in capacity from 3 to over 1,200 kt green NH_3 per year, to develop a regression formula that calculated CAPEX cost as a function of production capacity. Using this methodology, CVA estimated that an ammonia plant with 450 kt of annual ammonia production capacity would require roughly $262M in upfront CAPEX. This CAPEX was annualized over the lifetime of the plant, which is estimated at 20 years, and then divided by production volumes to determine the contribution to the levelized cost of green NH_3.

In addition, the model included OPEX per ton of green NH_3 based on projected electricity and GH_2 usage, chemical and catalyst costs,[167] labor and maintenance costs,[168] and process and cooling water needs.[169] The estimated CAPEX and OPEX values were then combined to provide a final levelized cost of NH_3.

162. U.S. Energy Information Agency, "Table 5.6.A. Average Price of Electricity to Ultimate Customers by EndUse Sector, by State, November 2022 and 2021 (cents per kilowatt-hour)," Accessed February 2023.
163. LevelTen News, "North American Renewable PPA Prices Rose 5.3% in Q2 and Nearly 30% Year-Over-Year, Spurred by Specter of Solar Tariffs and Inflation, According to LevelTen Energy," LevelTen Energy, July 13, 2022.
164. Based on discussions with stakeholders (e.g., offtakers, developers, financiers) in other green hydrogen hub projects, as well as in reference to developer bids for such projects in Europe and elsewhere.
165. FuelCellWorks, "Green Ammonia Now Cheaper than Fossil Fuels," April 25, 2022.
166. Mahdi Fasihi, et al., "Global potential of green ammonia based on hybrid PV-wind power plants," Applied Energy 294, 2021.
167. Gulf Petrochemicals and Chemicals Association, "The Roadmap to Carbon-Efficient Agriculture: How can the Agri-Nutrients Industry Support It?" GPCA Webinar Series, April 7, 2021.
168. Ibid.
169. Based on HyBuild LA water resource analysis conducted by PNNL.

APPENDIX B

Water Demand and Sources Analysis – Inputs, Assumptions, and Methodology

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B.1 | WATER DEMAND AND SOURCES

B.1.1 | Water Demands of Green Hydrogen Production via Electrolysis

In the GH_2 electrolysis process, renewable electricity breaks the bonds between hydrogen and oxygen in purified water to produce constituent gases. Manufacturer specifications for process water can range from between 10.0 to 22.4 kg of H_2O[170] required per 1 kg of GH_2 produced, depending on the type of electrolysis equipment used (Simoes, Catarino et al. 2021). In addition to the process water requirements, estimated losses from evaporation and leaks add roughly 10% to water demand, and cleaning needs add approximately 25% additional water demand per unit GH_2 produced. The HyBuild LA analysis estimates the total process input water demand for electrolysis is approximately 15 kg H_2O / kg GH_2, based on the water needs for alkaline electrolysis equipment (Brophy 2022).

Additional water demands for electrolysis result from process cooling requirements using evaporative cooling systems (i.e., cooling towers) and water losses occurring in the water treatment process. Because the HyBuild LA plan consists of large scale centralized hydrogen production facilities, cooling water demands account for approximately 4.6 kg of H_2O per 1 kg of GH_2 produced (Lampert, Cai et al. 2015). Water that is not evaporated in the cooling tower, can be recycled and reused in the cooling process to recover approximately 10% of the input or makeup cooling water (Boyd, Harris et al. 2022, Boyd 2022). Therefore, after recovery, roughly 4.2 kg of cooling water is required per kg of GH_2 produced, for a subtotal of 19.2 kg H_2O / kg GH_2 for input process and cooling water demands.

Electrolysis systems require high-quality water as a feedstock, and in recognition of water scarcity concerns in Southern California, the HyBuild LA scenario modeled the use of alternative water sources to avoid dependence on the region's limited freshwater resources.[171] At a minimum, two-phase reverse osmosis (RO) and deionization (DI) treatment is required for these resources to reach needed purity. Within these processes, water treatment losses can range from as low as 8% of the raw water when higher quality source water is used, and up to 50% when highly contaminated water is used (e.g., raw wastewater or "produced" water from crude oil extraction). As such, if using recycled wastewater, another 19.2 kg of raw water is required, bringing the total estimated water demand for GH_2 electrolysis to 38.4 kg H_2O / kg GH_2 produced.

B.1.2 | Water Demands of Green Ammonia Production via Haber-Bosch

Similar to GH_2 production, green NH_3 production from the Haber-Bosch process has process, cooling, and treatment water demands. The Haber-Bosch process uses high temperatures and pressures to convert atmospheric nitrogen (N_2) and hydrogen gas (H_2) to ammonia (NH_3) using a metal catalyst in an exothermic reaction. Due to the large amounts of waste heat produced in the Haber-Bosch process, cooling systems – typically evaporative systems – are required. As the Haber-Bosch process is a separate process from electrolysis, the water needs for this process are incremental to the 38.4 kg of water required to produce 1 kg of GH_2.

170. t: metric ton; m^3 H_2O / t NH_3 = liter H_2O / kg NH_3 = kg H_2O / kg NH_3.
171. See Table 2 for a list of considered resources.

B.1.3 | Total Water Demand Findings

The component and total water demands for GH_2 and green NH_3 are compiled and illustrated below in Table 1 and Figure 1.

Table 1 | GH_2 and green NH_3 production process water demands with mid, high, and low estimates.

	Water Demand				
Production Phase	Mid	High	Low	Unit[(a)]	Source
GH_2 Alkaline Electrolysis Process Input Water	11.1	11.7	10.6	m^3 H_2O / t GH_2	(Simoes, Catarino et al. 2021)
Process Water Losses[(b)]	10%	10%	10%	Percent of Input	(Simoes, Catarino et al. 2021)
Process Cleaning Water[(b)]	25%	25%	25%	Percent of Input	(Simoes, Catarino et al. 2021)
GH_2 Electrolysis Total Input Water	15.0	15.7	14.2	m^3 H_2O / t GH_2	(Simoes, Catarino et al. 2021)
GH_2 Processing Cooling Water[(c)]	4.2	4.4	3.9	m^3 H_2O / t GH_2	(Lampert, Cai et al. 2015)
GH_2 Water Treatment Loss	19.2	20.1	18.2	m^3 H_2O / t GH_2	(Shields 2022)
GH_2 Production Total Water Demand	38.3	40.2	36.4	m^3 H_2O / t GH_2	Calculation
NH_3 Haber-Bosch Process Input Water	2.1	2.6	1.5	m^3 H_2O / t NH_3	(Will and Lukas 2018)
NH_3 Haber-Bosch Total Input Water	2.8	3.5	2.0	m^3 H_2O / t NH_3	Calculation
NH_3 Processing Cooling Water[(c)]	5.4	5.7	5.1	m^3 H_2O / t NH_3	(Will and Lukas 2018)
NH_3 Water Treatment Loss	8.2	9.2	7.2	m^3 H_2O / t NH_3	(Shields 2022)
NH_3 Production Total Water Demand	16.5	18.4	14.3	m^3 H_2O / t NH_3	Calculation

(a) t: metric ton; m^3 H_2O / t NH_3 = liter H_2O / kg NH_3 = kg H_2O / kg NH_3
(b) Percentages for water losses and cleaning water used for both GH_2 and NH_3 production
(c) Assuming a 10% reduction of total cooling water demand from recovery

B.1.4 | Evaluated Water Sources

The water sources, definitions, estimates of availability, development timeframes, and data sources utilized for this analysis are included in Table 2. Due to concerns around stressed freshwater resources in Southern California, this analysis only considered recycled wastewater, water that could be diverted from local oil and gas operations, or desalinated seawater as sources for electrolytic hydrogen production demand.

Table 2 | Potential water sources and details for the HyBuild LA estimated demands.

		Existing Availability (Mm^3 / year)		Estimated Development Timeframe	
Potential Water Source	**Definition**	**Raw**	**Treated[a]**	**Years**	**Source**
South Coast California Wastewater	Wastewater sent to water treatment plants in the CA South Coast region (e.g. raw sewage)	1,153	577	10–20	(Rodman, Cervania et al. 2018)
Southern California Fracking Offset	Water used in oil and gas fracking operations that can be diverted to other uses, assuming fossil fuel production operations are reduced	42	39	5–10	(Pfister, Vionnet et al. 2016)
Southern California Fracking Produced Wastewater	Wastewater "produced" through fracking operations (i.e. flowback from fracking wells)	301	150	5–10	(Bohan 2021)
Southern California Oil Refinery Offset	Water currently used in oil and gas refining that can be diverted to other uses, assuming refinery operations are reduced	262	241	10–20	(Pfister, Vionnet et al. 2016)
Southern California Oil Refinery Wastewater	Wastewater from the crude oil refinery processes	207	104	5–10	(Pfister, Vionnet et al. 2016)
Desalinated Seawater	Seawater or brackish water that has been treated for commercial use	(b)	(b)	10–20	-

(a) Treated to quality required for hydrogen electrolysis via two-pass RO and DI
(b) Limited by infrastructure devoted to desalination, not seawater availability

B.2 | WATER INFRASTRUCTURE REQUIREMENTS

The infrastructure required to meet the water demands for GH_2 production includes water transportation from the recycled or repurposed source to the GH_2 production site, including water pipelines and pumping stations; water treatment plants to achieve the required quality for electrolysis and Haber-Bosch;[172] and water storage at the production site.

B.2.1 | Water Treatment

High quality water is required for GH_2 and green ammonia production to prevent interruptions in operations from impurities contaminating the processes. As such, all potential water sources, regardless of the raw water quality, would need to be treated through a two-phase RO process with a final DI treatment. The HyBuild LA scenario assumed that a dedicated RO/DI water treatment plant would be located at each production site

The amount of water loss (i.e., discharged as waste sludge and brine) in the treatment process depends on the source water quality. Table 3 identifies all stages of treatment and their associated water losses. For example, with raw sewage wastewater, approximately 38% of the influent water is removed in the primary and secondary treatment process, roughly 8% of the secondary wastewater effluent is rejected in the tertiary/recycled water treatment process (to Title 22 water quality standards), and about 14% of the recycled water is rejected when treated with RO/DI to the quality required for GH_2 production. The total water lost in the process of upgrading raw wastewater to electrolysis-quality water is 51%.

172. Due to safety concerns, it's possible green NH_3 production via the Haber-Bosch process will take place at specialized facilities and not located at GH_2 production sites in Southern California.

Table 3 | Water treatment process details.

Wastewater Treatment Process	Effluent Water Quality	Percent Effluent from Influent by Volume[(a)]	Source
Primary & Secondary	EPA Effluent Guidelines[(b)]	62%	(Shields 2022)
Tertiary/Wastewater Recycling	Title 22 Guidelines	92%	(Shields 2022)
Reverse Osmosis	5-60 Total Dissolved Solids [TDS]	86%	(Shields 2022)
Raw Wastewater to Electrolysis Quality	<5 microsiemens/cm	49%	(Will and Lukas 2018, Shields 2022)

(a) Effluent (treated water output) volume divided by influent (raw water input) volume
(b) epa.gov/eg

B.2.2 | Water Transportation

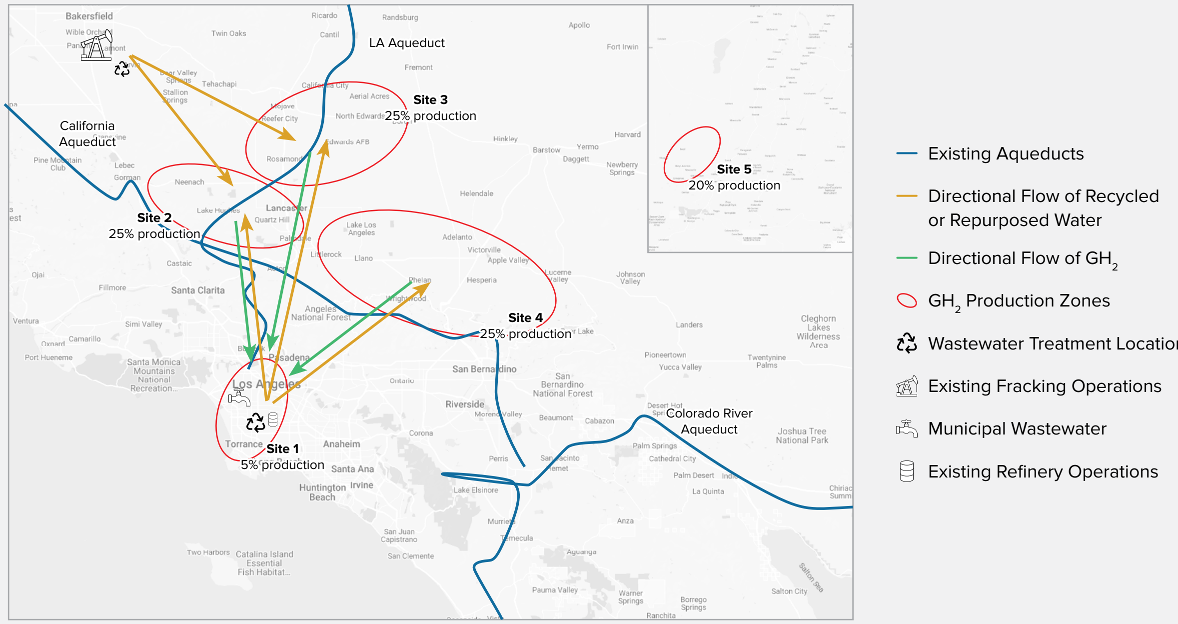
Water transportation has two primary considerations: infrastructure such as pipelines and pump stations, and electricity requirements for pumping the water from the alternative water sources to the production sites.

1. Water Pipeline Infrastructure

Water pipeline distances, sizing, and configuration depend on a variety of factors, including the number and locations of sources and production sites, the magnitude of demand at each site, and the location of water treatment facilities. Each proposed site detailed in Figure 2 is assumed to have source water delivered from several alternative water sources to meet the production demands. It's also assumed that the RO and DI treatments required to purify water past Title 22 guidelines will occur at the H2 production site. However, the configuration and locations of water treatment and transportation systems are only representative and would need to be optimized based on further analysis at each production site.

The HyBuild LA scenario assumes recycled or repurposed water is transported from LA to each GH_2 production site outside of the city, where final water stages of treatment (i.e. RO and DI) are completed. The details of this scenario are defined in Table 4. In the case of Site 5 in Utah, it was assumed wastewater would be sourced from local sources (not from LA). Additionally, pipeline infrastructure distances were assumed to be built along existing roadways and transportation right of ways.

Figure 1 | Map of Southern California showing high-level details of proposed production sites, water sources, and product flow directions.



Note: HyBuild LA system plan assumes dedicated GH_2 pipeline connection with Central Utah.
Note: This map is illustrative and is not representative of planned infrastructure.
Source: Pacific Northwest National Laboratory for HyBuild LA, 2022

Table 4 | Wastewater transportation needs from LA to potential HyBuild LA GH_2 production sites.

Production Site	Percent of Total HyBuild LA System GH_2 Production	Annual Recycled Water Demand 2030; 2040 (Mm^3/year)	Distance from LA Source[(a)] (km)	Elevation Change from LA Source[(b)] (m)
Site 1	5%	3.5; 5.8	32	-124
Site 2	25%	17.7; 29.1	129	675
Site 3	25%	17.7; 29.1	185	587
Site 4	25%	17.7; 29.1	129	873
Site 5	20%	14.1; 23.3	(c)	(c)

(a) Distances were determined using Google Maps along established roadways, and may be longer or shorter based on final planning and configuration (Mehta, Kanani et al. 2019).
(b) Elevation changes determined using Google Earth from the center of the proposed production site area. These quantities show net elevation changes, but do not include peaks or dips in elevation between the sites.
(c) Site 5, located in Utah near St. George, was assumed to obtain all recycled water from nearby sources with a transportation distance assumed to be 100 km and elevation change to be 200 m.

The diameter of the water transportation pipeline depends on the volumetric flow rate of the water being transported through the pipeline as detailed in Table 5 (USBR 2002). The greater the volume flow rate, the larger the required water pipeline diameter. Capital costs for pipeline construction also increase with pipeline diameter.

Table 5 | Details for determining required water pipeline diameters and associated base costs factors.[(a)]

Diameter (m)	Volumetric Flow Rate (m^3/s)	Volumetric Flow Rate (Mm^3/year)	Base Capital Cost[(b)] ($USD22/m of water pipeline)
0.15	0-0.02	0-0.6	$308.56
0.30	0.02-0.11	0.6-3.5	$487.20
0.46	0.11-0.25	3.5-7.9	$719.98
0.61	0.25-0.45	7.9-14.1	$952.76
0.76	0.45-0.69	14.1-21.8	$1,212.60
0.91	0.69-1.1	21.8-34.5	$1,494.09
1.22	1.1-2.15	34.5-67.8	$2,251.97
1.52	2.15-3.91	67.8-123	$3,166.83
1.83	3.91-6.4	123-202	$4,265.75
2.13	6.4-8.72	202-275	$5,478.35
2.44	8.72-11.38	275-359	$6,777.56
2.74	11.38-14.4	359-454	$8,190.45
3.05	14.4-17.8	454-561	$9,684.55
3.35	17.8-21.52	561-679	$11,238.19
3.66	21.52-25.62	679-808	$12,856.79

(a) Table values converted from table A-2 in the Southern California Comprehensive Water Reclamation and Reuse Study Phase II Final Report by the United States Bureau of Reclamation (USBR 2002)
(b) An inflation rate of $1.65 was used to adjust $USD02 to $USD22 (USBLS 2022)

Cost scaling factors were used to adjust final capital costs for pipeline construction to reflect potential increased costs due to barriers (e.g., crossing water bodies or mountainous areas). An estimate of the base cost for water pipelines on each land-use type was determined using Google Maps analysis and expert determinations to approximate an overall cost scaling factor for all pipeline construction modeled in this study (Table 6). This was used to calculate an average cost scaling factor weighted according to the percentage of pipeline length constructed across each land-use type. This weighted average was determined to be 1.68, so the total of base capital costs determined by pipeline length and diameter was multiplied by 1.68 to determine to total estimated pipeline construction costs (Table 7).

Table 6 | Estimated percent of water transport pipeline on different land-use types and associated scaling factors based on additional cost to build on specific terrain and land-use types.[(a)]

Land-Use Type	Cost Scaling Factor	Estimated Percent of Pipeline on Land-Use Type
Urban-Residential	1.2	2%
Urban-Commercial	1.53	2%
Urban-Industrial	1.53	2%
Urban-Transportation	1.53	2%
Urban-Airports	10	0%
Urban-Mixed	1.35	5%
Urban-Agricultural	1	10%
Urban-Forest & Range	1	10%
Water-Wetlands	7.5	1%
Water-Streams/Canals	5.33	0.5%
Water-Bays/Estuaries	7.5	0.5%
Water-Lakes/Reservoirs	10	1%
Water-Open Space	1	30%
Water-Unknown	1	1%
Barren-Salt Flats	1	0%

Land-Use Type	Cost Scaling Factor	Estimated Percent of Pipeline on Land-Use Type
Barren-Beaches	5.33	0%
Barren-Dunes	0.75	0%
Barren-Rock	7	5%
Barren-Mines	1.2	0%
Barren-Transitional	1.2	5%
Barren-Mixed	1.2	5%
Freeways-Cross	5.33	1%
Freeways-Follow	0.8	5%
Freeways-Cross Interchange	10	0%
Highways-Cross	5.33	0.5%
Highways-Follow	0.8	5%
Railroads-Cross	5.33	0.5%
Rivers-Cross	5.33	0.5%
Rivers-Follow	0.8	5%
Canals-Cross	5.33	0.5%

(a) Land-use types and cost scaling factors are sourced from table A-3 in the Southern California Comprehensive Water Reclamation and Reuse Study Phase II Final Report by the United States Bureau of Reclamation (USBR 2002)

Table 7 | Water pipeline infrastructure capital cost details.

Pipeline	Pipe Diameter (m)	Pipeline Distance (km)	Pipeline Cost (USD$22)
LA to Site 1	0.46	32	$38.7M
LA to Site 2	0.76	129	$262.8M
LA to Site 3	0.46	185	$223.8M
LA to Site 4	0.76	129	$262.8M
Bakersfield to Site 1	0.3	185	$151.4M
Bakersfield to Site 2	0.91	113	$276.9M
Bakersfield to Site 3	1.22	129	$488.1M
Bakersfield to Site 4	0.61	209	$334.6
Site 5	0.91	100	$251.0M
Total	**-**	**1,211**	**$2,290.1M**

2. Pumping Station Power Requirements

Electricity requirements in the HyBuild LA water scenario include: (1) the pumping power needed to transport water from the source to the GH_2 production sites; and (2) the power required to pump the water through the RO treatment process.

The total estimated electricity requirements for water transportation and treatment are provide in Table 8. For 2030 and 2040, the pumps' collective average energy demand would be equivalent to 15.6 and 29.1 MW, and the pumps' annual energy use would be equivalent to 490.1 and 917.6 TJ/year, respectively.

Table 8 | Details from power and energy calculations to transport recycled wastewater to each production site in 2030 and 2040.[a]

Source to Production Site	Recycled Wastewater Demand 2030; 2040 (Mm^3/year)	Volumetric Flow Rate 2030; 2040 (m^3/s)	Pipe Diameter 2040[b] (m)	Pump Power 2030; 2040 (MW)	Annual Pump Energy 2030; 2040 (TJ)
LA to Site 1	3.5; 5.8	0.11; 0.18	0.46	0.02; 0.8	0.6; 2.7
LA to Site 2	17.7; 29.1	0.56; 0.92	0.91	3.27; 47.5	103.1; 170.9
LA to Site 3	17.7; 29.1	0.56; 0.92	0.91	3.22; 47.0	101.7; 169.1
LA to Site 4	17.7; 29.1	0.56; 0.92	0.91	4.03; 58.5	127.1; 210.4
Local to Site 5	14.1; 23.3	0.45; 0.74	0.91	4.5; 7.5	142.5; 234.9
Total	**70.7; 116.3**	-	-	-	**475.1; 788.1**

(a) Pre-treatment water volume requirements are oversized to account for RO/DI treatment losses at the production site (~14% loss from recycled wastewater).
(b) It is assumed the pipe diameter required for the flow in 2040 is installed for 2030 demands to accommodate increase in production and demand.

Table 9 | Pumping station infrastructure capital and energy operating cost details for 2030 and 2040.

Pipeline	Water Input Volume (Pre-Treatment) (Mm^3/year)	Capital Costs of Pumps 2030; 2040 ($USD22)	Annual Energy Requirements 2030; 2040 (TJ)	Annual Cost of Energy that is Required for Pumping 2030; 2040 ($USD22/year)
LA to Site 1	2.7; 4.4	$0.2M; $0.3M	0; 0	$0; $0
LA to Site 2	8.8; 14.5	$0.6M; $1.0M	43.9; 79.6	$2.4M; $4.4M
LA to Site 3	4.4; 7.3	$0.3M; $0.5M	24.6; 58.1	$1.4M; $3.2M
LA to Site 4	13.3; 21.8	$0.9M; $1.5M	88.8; 170.3	$4.9M; $9.5M
Bakersfield to Site 1	1.5; 2.5	$0.1M; $0.2M	2.6; 10.8	$0.1M; $0.6M
Bakersfield to Site 2	15.5; 25.4	$1.1M; $1.8M	86.5; 156.7	$4.8M; $8.7M
Bakersfield to Site 3	23.2; 38.1	$1.6M; $2.7M	113.2; 196.5	$6.3M; $10.9M
Bakersfield to Site 4	7.7; 12.7	$0.5M; $0.9M	62.2; 122.8	$3.4M; $6.8M
Site 5	14.1; 23.3	$1.0M; $1.6M	69.1; 122.8	$3.8M; $6.8M
Total	**91.2; 150.0**	**$6.4M; $10.5M**	**490.9; 917.5**	**$27.3M; $50.9M**

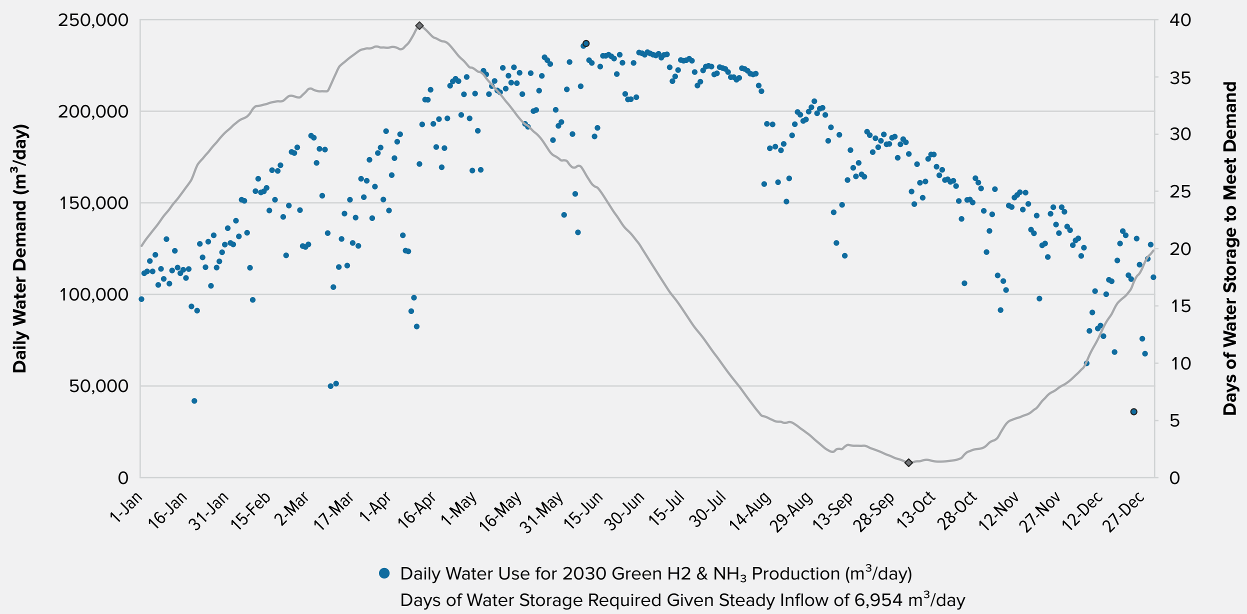
B.2.3 | Water Storage

Post-Water Treatment Storage

If GH_2 and green NH_3 were produced steadily over the course of the year at a single production site, the hourly water demands would be 6,954 m^3/hour for 2030 and 11,435 m^3/hour for 2040. This was calculated by dividing the total annual water demands by 8,760 hours per year. However, GH_2 production will fluctuate seasonally based on solar resource peaks, meaning that water demands will also fluctuate throughout the year. By contrast, recycled or repurposed water will likely be supplied steadily over the course of the year.

To balance the seasonal water demands from GH_2 and green NH_3 production, the analysis determined that a total of 39.7 days of water storage would be required in mid-April to meet increased summer production rates. Water would be pulled from these storage tanks throughout the summer and early fall, with water storage tanks being close to empty in early October. Water storage would then fill up during the decreased winter production rates to meet the following summer's demands.

Figure 2 | Total daily water demand and days of water storage required for 2030 HyBuild LA GH_2 and green NH_3 production estimates. This model assumes a steady inflow of treated source water and a variable solar profile driving the daily production rates and water demands in Southern California. Maximum and minimum values for both demand and storage are highlighted with grey diamonds.



Pre-Water Treatment Storage

Pre-treatment water storage requirements will depend on the quality of water being stored prior to water treatment. The lower the quality of water being treated at the production site, the larger the volume of pre-treatment storage required. The analysis assumed a scenario of constant onsite water treatment rate and two-days of onsite pre-treatment water storage to accommodate minor variations of raw water supply. Estimates for concrete water storage tank capital and maintenance costs were determined using a 2019 study for the City of Madera (Carollo 2019). A power function regression was made utilizing three data points (2.5, 3.25, and 5 million gallon tanks) from the City of Madera study, and Excel trendline features were utilized to determine capital costs, adjusting for economies of scale for the large tank sizes required at the production sites.[173] Total onsite construction costs, scaled by the power function derived from the City of Madera study, were used for the capital cost estimates. Finally, a fixed total 20-year recurring cost of $1,800/$m^3$ divided by 20 was used for the annual cost estimates. Results of this analysis are provided in Table 10 and Table 11.

173. Capital costs per m^3 of water storage was given by $CAPEX/$m^3$ = $2.27x105 * ($m^3$ storage required)-0.593

Table 10 | Post-treatment concrete water storage requirements and estimated costs at each production site for 2030 and 2040.

Production Site	Annual Treated Water Demand 2030; 2040 (Mm^3/year)	Water Storage Requirement 2030; 2040 (Mm^3)	Water Storage Capital Cost ($USD22)	Water Storage Annual Cost ($USD22)
Site 1	3.1; 5.0	0.33; 0.54	$46.5M; $56.9M	$0.07M; $0.12M
Site 2	15.2; 25.0	1.66; 2.72	$89.4M; $109.5M	$0.37M; $0.60M
Site 3	15.2; 25.0	1.66; 2.72	$89.4M; $109.5M	$0.37M; $1.8M
Site 4	15.2; 25.0	1.66; 2.72	$89.4M; $109.5M	$0.37M; $1.8M
Site 5	12.2; 20.0	1.33; 2.18	$81.7M; $100.0M	$0.29M; $0.48M
Total	**60.9; 100.2**	**6.6; 10.9**	**$396.4M; $485.4M**	**$1.46M; $2.40M**

Table 11 | Pre-treatment concrete water storage requirements and estimated costs at each production site for 2030 and 2040.

Production Site	Annual Recycled Wastewater Demand 2030; 2040 (Mm^3/year)	Pre-treatment Storage Requirement 2030; 2040 (km^3)	Pre-treatment Water Storage Capital Cost ($USD22)	Pre-treatment Water Storage Annual Cost ($USD22)
Site 1	3.5; 5.8	17, 27	$13.8M; $16.9M	$3.6K; $6.1K
Site 2	17.7; 29.1	83; 137	$26.5M; $32.5M	$18.4K; $30.3K
Site 3	17.7; 29.1	83; 137	$26.5M; $32.5M	$18.4K; $30.3K
Site 4	17.7; 29.1	83; 137	$26.5M; $32.5M	$18.4K; $30.3K
Site 5	14.1; 23.3	67; 109	$24.2M; $29.6M	$14.7K; $24.2K
Total	**70.7; 116.3**	**334; 549**	**$117.5M; $143.9M**	**$73.6K; $121.0K**

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APPENDIX C

Air Quality and Public Health Analysis

C.1 | APPROACH

An integrated modeling approach was utilized to characterize and quantify the air quality and associated public health impacts of the HyBuild LA GH_2 adoption scenario relative to a business-as-usual Reference Scenario to provide insight into the co-benefits that are achieved in 2035 and 2045.

Using outputs from E3's PATHWAYS model, spatially and temporally resolved characterizations of pollutant emissions were developed for all sectors and sources in California – including stationary, area, and mobile source emissions – to develop an analytical baseline. The HyBuild LA Phase 2 demand assessment developed by CVA was used to provide a scenario for fuel cell deployment in place of fossil fuel combustion technology in the following applications:

Modeling assumed emissions reductions from fuel cell deployment in place of internal combustion engines in the following applications:

- Heavy-Duty Trucks (Intrastate)
- Drayage Trucks
- Materials Handling Equipment
- Fuel Cell Forklifts
- Fuel Cell Buses (Motor Coach)

Modeling assumed no change in emissions from the following applications:

- Maritime Shipping
- Planes
- Industry/ Power Plants

Emissions were forecast to 2035 and 2045 utilizing a detailed base year California Air Resources Board (CARB) pollutant emissions inventory (2020 CARB v0018), and were spatially and temporally resolved using the Sparse Matrix Operator Kernels Emissions (SMOKE v4.7) model.

Emission changes were translated into impacts on atmospheric pollution levels, including ground-level ozone and fine particulate matter ($PM_{2.5}$), via an advanced photochemical air quality model called the Community Multiscale Air Quality (CMAQ v5.3.2). This model accounts for atmospheric chemistry and transport. Given the intensive computational requirements to run CMAQ, an episodic air quality modeling approach was used; January and July were selected for analysis relative to the Reference Scenario to demonstrate seasonal variation in air pollution.

Air quality changes were then used to conduct a health impact assessment using the Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP v1.5.8) which provides a quantitative estimate of the incidence and value of avoided harmful health outcomes associated with air pollution in each scenario. Finally, the health impact results were analyzed through an environmental justice screening tool called CalEnviroScreen 4.0, which enabled UCI to quantify the benefits that occur specifically within socially and economically disadvantaged communities (as identified in CalEnviroScreen 4.0).

C.2 | SCENARIO ASSUMPTIONS

The HyBuild LA air quality analysis utilized the assumed adoption levels of FCEVs from each mobility end use in the Offtake and Infrastructure Workstream. The study developed an emissions reduction scenario for the South Coast Air Basin which was then compared to a business-as-usual Reference Scenario to determine emissions, air quality, and health benefits. The assumed penetration of fuel cell electric technologies relative to the total addressable fleet in the LA Basin are shown in Table 1. Considered end uses include intrastate heavy-duty trucks (HDT), drayage trucks, materials handling equipment, forklifts, and motor coaches. Emissions from all other sources were held constant to the Reference Scenario due to a lack of data.

Table 1 | HyBuild Scenario Assumptions.

	Deployment Level	Additional Assumptions
Fuel cell heavy-duty trucks (intrastate)	**2035:** 15% FCEV **2045:** 31% FCEV	Deployment assumed for several HDV categories operating intra-state that are applicable
Fuel cell drayage trucks	**2035:** 36% FCEV **2045:** 75% FCEV	
Fuel cell materials handling equipment	**2035:** 26% FCEV **2045:** 78% FCEV	
Fuel cell forklifts	**2035:** 44% FCEV **2045:** 48% FCEV	Deployment assumed in all major categories in the invetory
Fuel cell buses (motor coach)	**2035:** No FCEV **2045:** 55% FCEV	Reference case already assumes high levels of zero emission buses in 2045 (minor impact)

C.3 | POLLUTANT EMISSIONS

Baseline pollutant emissions represent a highly detailed inventory developed by CARB (CARB 2020 v0018), which includes total emissions by sector and source as well as spatial and temporal information regarding source activity. The emissions are then forecasted out to 2035 and 2045 using output from the PATHWAYS[1] model for technologies, fuels, and energy demand in each sector identified in California's Global Warming Solutions Act (AB 32). Additionally, data from EMFAC 2021 v1.0.1[2] for on-road vehicles, OFFROAD2021[3] for other transportation sectors, and the CARB California Emissions Projection Analysis Model (CEPAM) 2019 v1.03 for stationary sources was used to account for changes in emission rates and control factors.[4]

The pollutant emissions inventory was then processed into air quality model-ready format using the Sparse Matrix Operator Kernel Emissions model (SMOKEv4.7) to resolve the location and timing of the emissions to correspond with the responsible sources (e.g., the location of refineries, the locations of residential and commercial buildings, the locations of major roadways and the traffic patterns for vehicles).[5] On-road vehicle emissions were spatially resolved to the locations of vehicle activity using the Emissions Spatial and Temporal Allocator (ESTA) model developed by CARB.[6]

C.4 | AIR QUALITY

Atmospheric chemistry and transport were simulated using the Community Multiscale Air Quality model (CMAQ, v5.3.2) to provide a comprehensive understanding of impacts on pollutant concentrations, accounting for both primary (emitted) and secondary (formed) species, including ground-level ozone and $PM_{2.5}$.[7] CMAQ was developed by U.S. EPA and is widely used for air quality assessments of emission inventories,[8] energy sectors integrating alternative technologies in energy systems,[9] regulatory compliance[10] and research associated with tropospheric ozone, PM, acid deposition, and visibility.[11,12] The use of CMAQ is particularly important to assess air quality because a significant portion of the pollution impacting California populations is secondary and forms in the atmosphere. Depending on season and region, secondary $PM_{2.5}$ can comprise 40-60% of the total atmospheric $PM_{2.5}$ burden in California.[13]

For this work, the SAPRC-07 chemical mechanism[14] was utilized to model gas-phase chemistry, and AERO6 module[15] was used to calculate aerosol dynamics. The simulation domain is the same as Reference[16] with a 4 km x 4 km horizontal resolution that covers California. The Advanced Weather Research and Forecasting Model (WRF-ARW, 3.9.1)[17] was used to downscale meteorological conditions from the NCEP North American Regional Reanalysis dataset.[18] Boundary conditions were generated using the Community Atmosphere Model with Chemistry v2.1 (CESM2.1/CAM-chem).[19] Biogenic emissions, including those from vegetation and soil, were generated using the Model of Emissions of Gases and Aerosols from Nature (MEGANv2.1).[20] Although simulations are conducted for the year 2045, the boundary and meteorological conditions were held constant with the 2020 base emission inventory year to ensure that resulting impacts were attributable only to changes in anthropogenic emissions associated with the changes in the HyBuild LA scenario.

The two pollutants considered to assess air quality and health were $PM_{2.5}$ and tropospheric ozone, as many regions of California experience ambient levels in excess of State and Federal health-based standards[21] and both are well known to be associated with health consequences in exposed populations and commonly included in similar health impact assessments.[22,23,24] For consistency with ambient air quality standards, ground-level concentrations have been reported as maximum daily 8-h average ozone (MD8H) and 24-h average $PM_{2.5}$.

Table 2 | Overview of the air quality modeling tools utilized and sources of data inputs.

	Model
Base Year Inventory	2020 CARB v0018
Emissions Processing	SMOKE v4.7 and ESTA
Air Quality Model	CMAQ v5.3.2
Chemical Mechanism	SAPRC-07 and AERO6
Biogenic Emissions	MEGAN v2.1
Meteorological Files	WRF-ARW v3.9.1
Boundary Conditions	CESM v2.1/CAM-chem

Two simulation periods were conducted to capture the effect of seasonal variation in meteorology and emissions concentrations including a summer month (July) and winter month (January). July was selected as it includes conditions conducive to high ozone and $PM_{2.5}$ concentrations, including high surface temperatures, an abundance of sunlight, lack of natural scavengers, and the presence of inversion layers.[25] Similarly, the month of January was included as it is associated with high levels of $PM_{2.5}$ in some regions of California, including the South Coast Air Basin (SoCAB) and the Central Valley. For both seasons, the first five days of the simulation period were considered model spin-up and excluded from the analysis. The CMAQ output has been validated for the 2020 base year using observational data from the U.S. EPA's Air Quality System[26] and found to be within the statistical parameters established by the scientific community for acceptable model performance.[27]

C.5 | HEALTH IMPACTS

Epidemiological studies have shown that reducing air pollution exposure results in reductions in the incidence of harmful health endpoints. Public health benefits from the HyBuild LA system were quantified and valued using The Benefits Mapping and Analysis Program — Community Edition version 1.5.8 (BenMAP) from the U.S. EPA.[28] BenMAP allows for the quantification of the avoided incidence and economic value of health endpoints that result from differences in air pollution concentrations.

The endpoints selected for the health analysis, as well as the corresponding reference for the concentration-response function used to quantify reductions in the incidence of certain health issues from reduced exposure to $PM_{2.5}$ and ozone, are shown in Table 3 and Table 4. The selection of inputs, including concentration-response functions, baseline incidence rates, and valuation functions, generally follow those recommended by the U.S. EPA in the BenMAPv1.5.8 user's manual.[29] Additionally, the quantification of avoided incidence of premature mortality due to reduced short-term exposure to $PM_{2.5}$ was estimated using Atkinson et al. 2014[30] following methods used by the South Coast Air Quality Management District.[31] A value of statistical life of $8.7 million was used to quantify mortality risk reduction benefits as recommended by the U.S. EPA. The health benefits were quantified in 2015 dollars, and then converted and reported in 2022 dollars. Health impacts were quantified for the entire month of July and January, except for the first five days of each month which were discarded as model spin-up.

Impacts were estimated for avoided short-term exposure to ozone and $PM_{2.5}$ in July. In January, only the impacts of avoided exposure to $PM_{2.5}$ was estimated given that ozone concentrations are generally below health-based standards in winter and share an inverse relationship with precursor emissions, which prevented useful conclusions from the results. Finally, the estimated health savings were quantified specifically within census tracts that have been identified as DAC using the CalEnviroScreen 4.0 tool.[32] Population projections to 2045 at the census tract level were obtained from GeoLytics.[29]

Table 3 | Health endpoints and their concentration-response function reference included in the BenMAP analysis for reduced exposure to ozone.

Ozone Health Endpoints	Reference
Avoided Mortality	Huang et al. 2005
Emergency Room Visits, Respiratory	Barry et al. 2018
Hospital Admissions, Respiratory	Katsouyanni et al. 2009
Asthma Symptoms	Lewis et al. 2013
Incidence, Asthma Onset	Tetreault et al. 2016

Table 4 | Health endpoints and their concentration-response function reference included in the BenMAP analysis for reduced exposure to $PM_{2.5}$.

$PM_{2.5}$ Health Endpoints	Reference
Avoided Premature Mortality	Atkinson et al. 2014
Hospital Admissions, Alzheimer's Disease	Kioumourtzoglou et al. 2016
Hospital Admissions, Parkinson's Disease	Kioumourtzoglou et al. 2016
Incidence, Lung Cancer	Gharibvand et al. 2016
Incidence, Asthma Onset	Tetreault et al. 2016
Acute Myocardial Infarction, Nonfatal	Zanobetti et al. 2009
Asthma Symptoms	Rabinovitch et al. 2006
Hospital Admissions, Cardiovascular	Bell et al. 2015
Emergency Room Visits, Cardiovascular	Ostro et al. 2016
Hospital Admissions, Respiratory	Bell et al. 2015
Emergency Room Visits, Respiratory	Krall et al. 2016

C.6 | AIR QUALITY AND HEALTH IMPACT ASSESSMENT CAVEATS

Assumptions and caveats should be considered when interpreting the results of this analysis.

Of note, episodic modeling provides insight into the maximum impacts of the GH_2 adoption scenario on air quality but does not provide a comprehensive understanding of the air quality impacts. Due to the selection of modeling periods coinciding with high pollutant formation periods, the pollutant differences and the corresponding health impacts are also maximized during those periods and may not be as significant in other months. The results of both the air quality and health benefit assessments represent two distinct months and cannot be used to estimate other periods.

Additionally, health benefits have been quantified and reported for reduced short-term exposure to $PM_{2.5}$ and ozone for two months in 2035 and 2045, so therefore, the results do not provide a comprehensive accounting of the health benefits that could be achieved annually or cumulatively. Further, although BenMAP can be used to estimate long-term health impacts such as those occurring from annual average $PM_{2.5}$ changes, impacts have been reported for short-term exposure to ozone and $PM_{2.5}$ as appropriate for the modeled episodes. It should be noted that the value of health benefits related to avoided short-term exposure is significantly lower than those estimated for long-term exposure, which are generally 8–12x higher.

C.7 | REFERENCES

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HyBuild™ North America is the GHC's platform to architect low-cost, mass-scale green hydrogen hubs throughout the continent. The first regional focus of the platform, HyBuild Los Angeles, was launched in 2020 and has identified a pathway to achieve $2.05/kg delivered green hydrogen costs in the Los Angeles Basin to serve multi-sectoral offtakers, reduce air pollution, and create diversely skilled local jobs.

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