EXHIBIT I

ARCHES Technical Submission to DOE - April 2023

The following document "Technical Volume" was initially submitted as part of our application to the U.S. Department of Energy (DOE) in April 2023 to become one of the Regional Clean Hydrogen Hubs.

This document now, August 2024 is being released publicly as ARCHES has reached agreement with Office of Clean Energy Demonstrations (OCED) the award and has entered into Phase 1 of the H2Hub. This document demonstrates a true hub approach, bringing together a diverse set of partners to help kickstart the hydrogen economy in California and the nation.

A few important notes:

- This document has been redacted to protect the business confidential information of ARCHES' partners.
- This document is a static document dated from April 2023. Our understanding of exact metrics, partners, timelines, and other variables are subject to change, and, indeed, have changed, since this initial submission. This document will not be updated to reflect current H2Hub plans.

If you have any questions about this document, please let us know!

- General inquiries: info@arches.org
- Press inquiries: media@arches.org
- Governmental (local, state, federal): government.affairs@arches.org

Project Title: **ARCHES-Hub**	
Exchange Control Number: **2779-1538**	Geographic Region: **California**
Prime Applicant: **Alliance for Renewable Clean Hydrogen Energy Systems**	
Sub-Recipients/ Project Partners: Air Products and Chemicals, Inc.; AES & Air Products Joint Venture, Amazon.com, Inc.; Chevron U.S.A.; Clearway Renewables LLC; Dash Clean Energy; Element Resources, Inc.; FirstElement Fuel Inc.; HC (Contra Costa), LLC; Intersect Power, LLC; Los Angeles Department of Water and Power; Linde, Inc.; Mote, Inc.; Nikola Corporation; Northern California Power Agency; Pilot Transit Centers LLC; Plug Power Mendota; Port of Long Beach; Port of Los Angeles; Port of Oakland; Rincon Band of Luiseno Indians; San Luis Hydrogen Partners, LLC; Scripps Institution of Oceanography; San Diego Gas and Electric Company; Southern California Gas Company; Universal Hydrogen Co. Transit Agencies (13); Center for Transportation and the Environment, Inc.; University of California (Berkeley, Davis, Irvine); California State University, Los Angeles; Renewables 100; LBNL, NREL, LLNL	
Do the proposed prime recipient and all subrecipients qualify as domestic entities? Yes x No If not, which entities will require a foreign entity waiver: Clearway Energy Group, Linde	
H2Hub Program/Project Manager: Ms. Angelina Galiteva	Email: Angelina.Galiteva@archesh2.org Phone: [redacted]
Business Contact: Dr. Scott Brandt	Email: Scott.Brandt@archesh2.org Phone: [redacted]
Confidentiality Statement: All pages with greyed-out materials of this document contain trade secrets, confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for evaluation purposes or in accordance with a financial assistance or loan agreement between the submitter and the Government. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.	
H2 Production Capacity: ~515 *(metric tons H_2/day)*	Total Period of Performance: 8 *(years)*
Total H2Hub DOE Funding Request: $ 1.25B	Total H2Hub Non-Federal Cost Share: $ 11.3B

For each category, please select all that apply:

Energy Feedstock:
- ☒ **Renewables:**
- ☐ Nuclear
- ☒ Fossil fuels
- ☒ Other: **Biomass, biogas**

End uses:
- ☒ **Electric power generation**
- ☐ Industrial *(e.g., ammonia, steel, synthetic fuel production)*
- ☐ Residential or commercial heating
- ☒ **Transportation**
- ☒ Other: **Ports**

Production Technologies:
- ☒ **Electrolysis**
- ☒ **Thermal conversion** *(e.g., reforming, gasification, pyrolysis)*
- ☐ Other:

Connective Infrastructure:
- ☒ **H2 pipelines**
- ☒ **H2 carriers**
- ☐ Underground H2 storage
- ☒ **Above ground H2 storage**
- ☒ **H2 fueling stations**
- ☐ Other

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1. ARCHES H2 LLC

1.1 The Alliance for Renewable Clean Hydrogen Energy Systems

California, as the fourth-largest global economy, has taken a leadership position in climate change by committing to a carbon-free economy with 100% clean electric grid (Senate Bill SB 1020), 85% greenhouse gas (GHG) reduction (baseline 1990; Assembly Bill AB 1279), and emissions reduction mandates for ports, trucks, and transit buses by 2035−2045, including the recently approved Advanced Clean Trucks Rule. The features of hydrogen are critically required to achieve these ambitious climate goals. Recognizing this, California has enacted many laws that support hydrogen for zero emissions, renewably fueled transportation, energy storage, and decarbonization (SB1014, SB1020, AB1279, SB905, executive orders N-79-20, B-48-18). With broad industry support, the state has authorized billions of dollars to support its future zero emissions economy and is one of the only commercial hydrogen fuel-cell vehicle markets in the world. However, California's hydrogen investments have been small in comparison to its investments in battery electric vehicle and grid-scale battery energy storage, so its nascent hydrogen market has not reached critical mass. Federal hub funding will catalyze, unlock, and build upon and scale California's success and demonstrate that clean hydrogen is essential for zero emissions. The **A**lliance for **R**enewable **C**lean **H**ydrogen **E**nergy **S**ystems (**ARCHES**) has been formed to actualize California's vision to produce and deploy renewable, clean H_2 at scale across multiple sectors to realize a self-sustainable marketplace and ecosystem while reducing local air pollution in the most challenging heavy-duty sectors in the most disadvantaged communities and providing strong community benefits for all.

ARCHES H2 LLC is a public-private nonprofit corporation founded by the CA Governor's Office of Business and Economic Development, the University of California system, The State Building and Construction Trades Council of California, and the Renewables 100 Policy Institute, working in partnership with utilities (e.g., LADWP, SoCalGas, NCPA), and private large and small businesses (e.g., Air Products, Chevron, FirstElement, Universal Hydrogen). ARCHES combines California's legacy of environmental leadership and community engagement; the University system's deep hydrogen expertise (including two of its affiliate DOE National Laboratories); and leadership in community engagement and diversity equity, inclusion, and accessibility (DEIA); the State Building and Construction Trades (with its 157 affiliated unions) leadership in organized labor, workforce development, and construction practices; and Renewables 100's leadership in renewable energy enactment and analysis. ARCHES' core principles are statewide, renewable, connected, multi-dimensional, objective unbiased governance, stakeholder and community engaged, solution-oriented, and equity- and justice-centered.

Starting from an initial core of interconnected Tier 1 projects seeded by DOE funding, ARCHES will unleash dramatic growth in hydrogen production and consumption by 2045. Building upon a core of three key sectors—(1) power, (2) transportation (including transit), and (3) ports—we expect significant hydrogen demand growth in these and adjacent hard-to-decarbonize sectors—industry, maritime, aviation, agriculture (ammonia), and others. Dispatchable, distributed, and seasonal storage for power is estimated to result in demand for 4 million metric tons per year (MMTPY). Hydrogen use in the transportation sector is expected to expand rapidly, with aviation and long-haul trucking demand predicted to reach 10 MMTPY. Port equipment and decarbonization is expected to result in 0.7 MMTPY. Hydrogen is also poised to play a key role in decarbonizing the maritime sector both directly and via hydrogen derivative fuels such as ammonia and methanol, with a predicted demand of about 1.4 MMTPY. Ammonia production from renewable clean hydrogen can also initiate a California fertilizer industry. Future opportunities beyond 2030 include decarbonizing highly polluting industries such as cement and steel manufacturing and other industrial processes, predicted to result in a demand of 1 MMTPY. In total, we expect the California region to result in a total hydrogen capacity of at least **17 MMTPY**, or 47,000 metric tons per day (MTPD), by 2045 with substantial reductions in GHG and pollutant emissions. **Figure 1.1** illustrates ARCHES' vision of the growth of the hydrogen economy in California towards 2045, including interconnections to neighboring states and international corridors. We should note that another key opportunity in California for hydrogen use are the various military installations, discussions of which are ongoing and will be catalyzed by hydrogen hub funding.

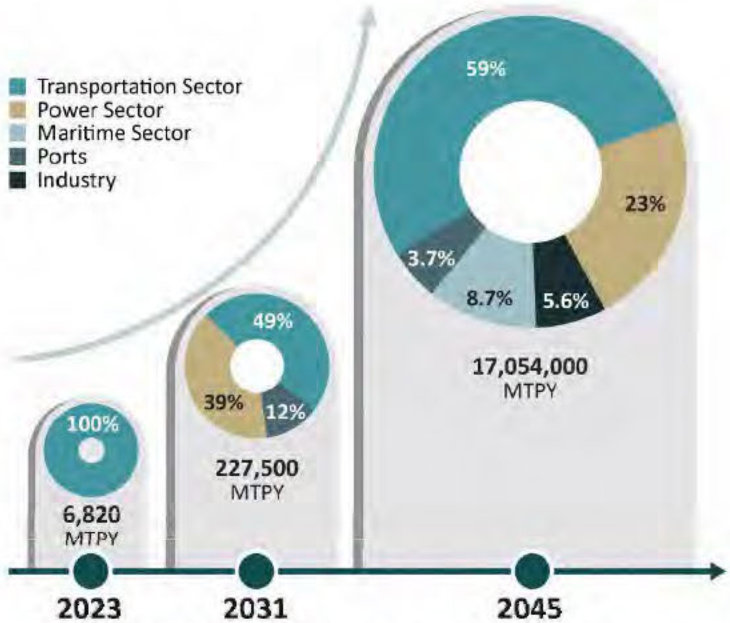

Figure 1.1: Growth projection of hydrogen in California

1.2. ARCHES LLC Organization To realize the vision of ARCHES requires a multidisciplinary team and organization across multiple fronts. ARCHES' organizational structure and governance model (**Figure 1.2**) is designed to ensure a strong community voice. Its small Board includes a balanced mix of public sector, industry, organized labor, and community representatives, ensuring the ability to move forward and make good decisions that will enable California's hydrogen ecosystem to grow in a way that will most benefit California and its communities. With the project execution experience, various industrial companies' financial strength, depth of team experience, and an already substantial hydrogen investment, infrastructure, and supported applications in California, the partners are ideally suited to develop, build, and operate ARCHES as an organization that will rapidly advance the production, distribution, storage, and conversion of hydrogen in the California region. ARCHES leverages the extensive experience of the University of California (UC) system in managing very large DOE facilities and contracts as well as those of the key industrial and organized labor partners who have combined experience of greater than 100 years of hydrogen deployment experience and related policy analysis and implementation and regulatory framework experience with the State of California. Many of the various partners also have long-standing hydrogen-related relationships and projects with each other.

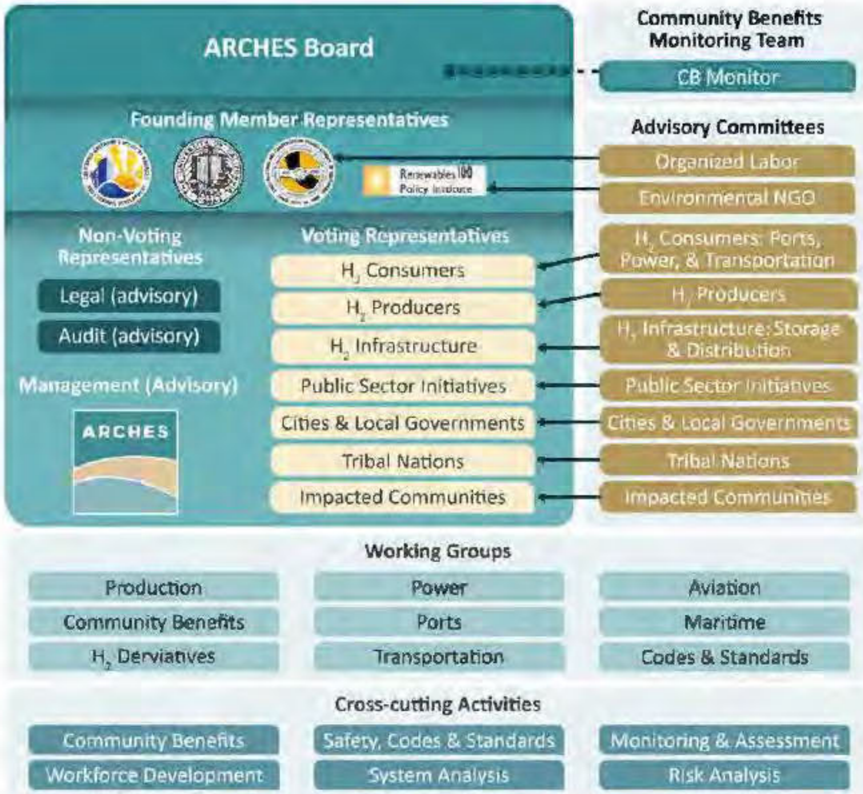

Figure 1.2: ARCHES LLC Governance Structure

The ARCHES organization will interface with the state on (1) hydrogen infrastructure planning, (2) hydrogen codes, standards, and safety, and (3) hydrogen policy. ARCHES will coordinate and manage cost-share and support transparent project vetting, technical, and financial analysis; enable crosscutting sectoral and hub activities, including detailed and comprehensive system integration and analysis work, risk assessment, and development and implementation of safety, codes, and standards; deploy adequate workforce development and community outreach and inreach resources at all levels; and respond to industry needs by managing the large network of public and private partners to work together on developing and enacting a holistic hydrogen ecosystem vision.

If selected, ARCHES will reach out to all other awarded H2 Hubs within the first three months of Phase I to initiate discussions on the formation of a dedicated working group for the establishment of the national clean hydrogen network and to share lessons learned. We hope that while California and the ARCHES ecosystem are nascent, we may still be able to share valuable policy and technological information and insights that are valuable to other regions. Thus, the tough lessons learned from ARCHES and early California investments and policy actions can readily benefit other hubs. We anticipate that ARCHES, especially with respect to the geographic and economic diversity and economic size of California, can help facilitate the greater hydrogen ecosystem and serve as an exemplar for the national clean hydrogen network, since most regions around the nation and around the world will inevitably rely on primary renewable sun and wind power in a sustainable energy future.

1.3 ARCHES Ecosystem

Over the last 18 months, ARCHES has coalesced the hydrogen ecosystem and participants in the California region to an unprecedented single coalition comprising producers, end users, infrastructure companies, engineering companies, utilities, communities, universities, NGOs, etc. Currently, the ARCHES network is comprised of 280+ signatories to memoranda of commitment to ARCHES. ARCHES has conducted many in-person convenings and initiated nine working groups to discuss sectoral challenges and ways to overcome them. This coordinated and comprehensive ecosystem is a direct result of the Hydrogen Hub FOA, which will only be emboldened and enhanced upon U.S. DOE selection of this proposal to move forward, together. These discussions and interactions led to a portfolio of selected projects, discussed in sections 2 and 3, to form the initial integrated project slate that comprises the U.S. DOE-funded portion of ARCHES. As shown in **Figure 1.3**, the ARCHES ecosystem comprises the slate of projects included explicitly for U.S. DOE cost-shared funding in this proposal (Tier 1), a portfolio of projects that align with ARCHES' principles and could be considered for funding depending upon additional resources or during Phase 1 alteration (Tier 2), and a set of nascent projects that can contribute to the ecosystem and expand its sectors at a later date or with state or local funding support, which includes partner organizations that are engaged but not specifically related to one or more funded projects. Overall, ARCHES seeks to serve as a matchmaker across all projects (e.g., matching supply with demand and infrastructure needs) to ensure a robust, resilient, and sustainable hydrogen marketplace.

Figure 1.3: The ARCHES ecosystem is comprised of Tier 1 (ARCHES-Hub) and Tier 2 projects and more than 280 current participating signatories.

2. ARCHES-HUB PROJECT SUMMARY

To realize its goals, ARCHES H2 LLC will initiate the ARCHES-Hub to unlock California's hydrogen market and ecosystem through 2031. ARCHES-Hub will deploy critical anchor projects and build the interconnected network through the federal funding in several key sectors—power, transportation (heavy-duty truck and transit), and marine port operations, as shown in **Figure 2.1**. The necessary catalyst to start the 17 million MTPY (47,000 MTPD) California region hydrogen ecosystem will be the $1.25B in federal funding to reduce the cost of producing and distributing hydrogen, spur demand and its use in multiple applications, and trigger private investments that will dramatically accelerate decarbonization and depollution of the regional economy and provide quantitative

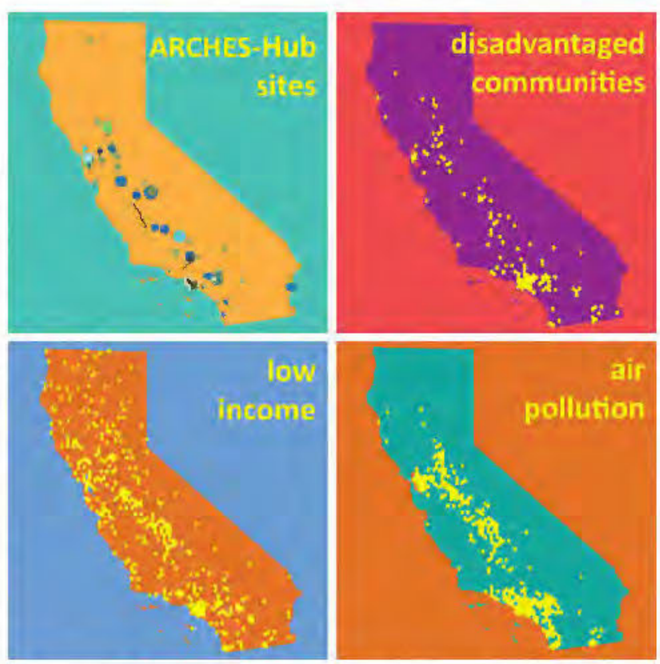

Figure 2.1: ARCHES-Hub sites, demographics, and air pollution

air quality and health benefits for all. For the ARCHES-Hub, we have identified an integrated hydrogen hub network of projects that will result in about 190,000 MTPY (515 MTPD) on average of new hydrogen production, distribution, and use by 2030 with a total cost of about $12.9B, providing a 10-times return on the federal investment by state, public, and private cost share, all enabled by the federal investment. The size, complexity, diversity, and community benefits of this proposal justify the federal ask of $1.25B (instead of $1B) and the ability of the ARCHES-Hub to serve as an exemplar for an interconnected national hydrogen-hub network and provide lessons learned at a scale and maturity that no other regional hub can realize today.

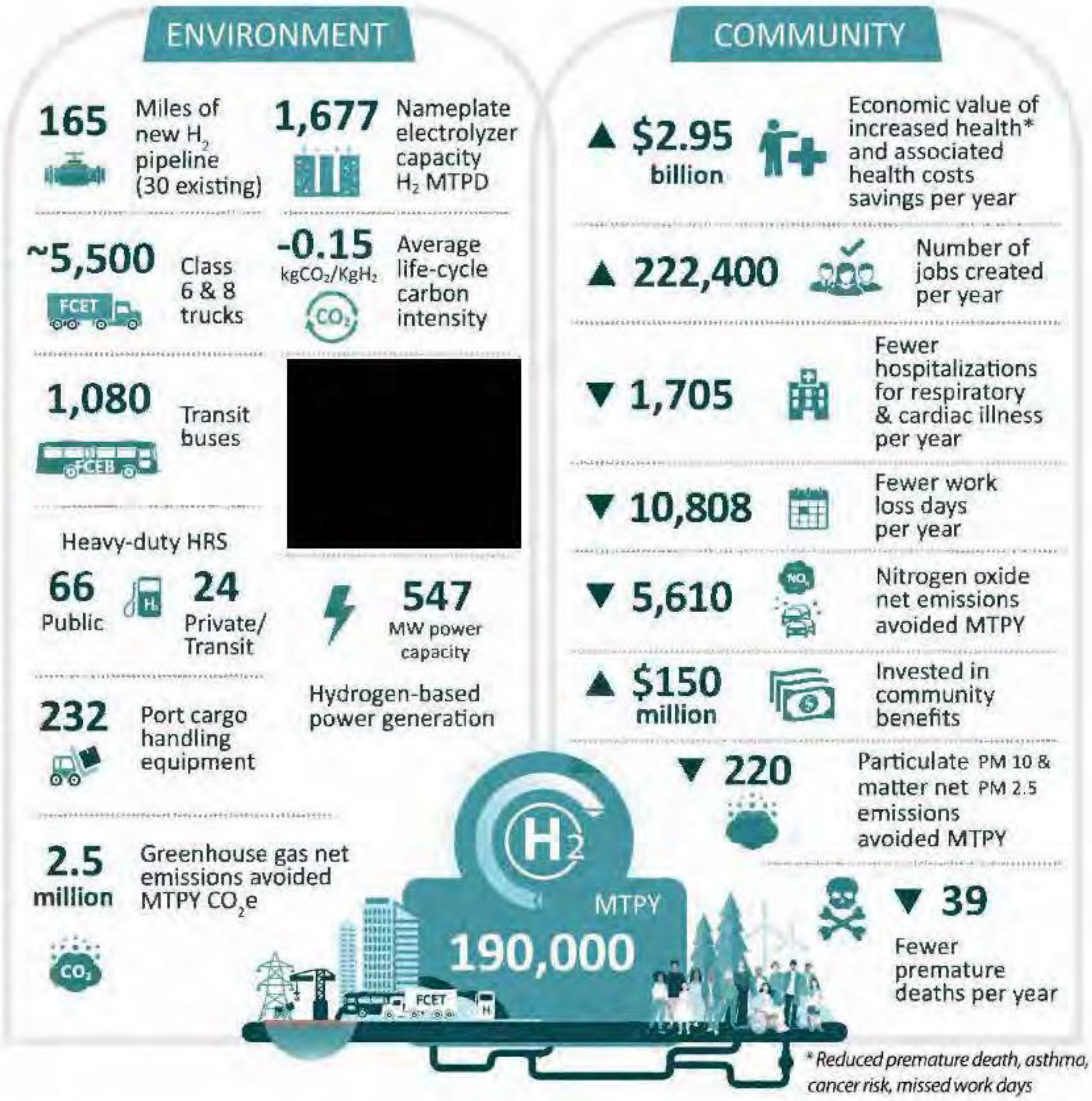

Figure 2.2: ARCHES-Hub metrics at full implementation in 2031 (conservative estimates)

Figure 2.2 highlights the contributions of ARCHES-Hub to unlock and initiate a sustained hydrogen markeplace in California region as well as the impact that ARCHES-Hub will have on the people. Of great importance is the fact that the proposed ARCHES-Hub is set to impact and directly improve traditionally disadvantaged communities as shown in **Figure 2.1**. While the details are discussed in the accompanying community benefit plan, it is worthwhile to acknowledge here the importance that ARCHES-Hub will have in communities across California.

2.1 ARCHES Project Proposal Process

Since the submission of the concept paper, ARCHES organized and conducted an internal call for proposals with clear guidelines and metrics (aligned with the FOA and ARCHES goals) for future hub hydrogen projects. ARCHES received over 96 viable proposals, with a combined U.S. DOE ask of $23B in federal share and more than $29B in cost share. Independent and critical reviews by recognized experts and community members concerning whether each proposal "Enables a Sustainable H2 Economy" and the ARCHES Ecosystem "Realizes Co-Funding and Market Viability," "Provides Realizable and Ready Actualization," and "Provides Strong Community Benefits" narrowed down the slate of initial projects to those that are most impactful and essential for initiating and activating the hydrogen ecosystem in the region (Tier 1 projects). The criteria used to evaluate projects also depended upon initial system analyses efforts regarding whether each project enables a greater ecosystem both within and outside of the DOE hub funding and timeframe. Projects not selected for initial funding are either located far away, have entirely balanced production and distribution at a single site, are relatively small scale, or did not have significant community benefits or interactions. Some of these projects are denoted as Tier 2 in section 3 and will be considered to replace selected Hub projects should ARCHES, working with U.S. DOE, determine that it is necessary to replace certain projects with others or add projects to the ARCHES-Hub as additional funding becomes available.

Projects focused on ammonia were deemed too nascent for the initial tranche of funding and large-scale deployment of aviation and maritime are likewise considered early for significant hub funding. While all of these are critical future industries that renewable clean hydrogen can enable and while the ARCHES-Hub infrastructure can facilitate both during and following the U.S. DOE hub effort and timeframe, they are not the focus of the ARCHES-Hub. Similarly, rail transport, which is expected to comprise a mixture of fuel cell, electric, and battery technologies in the zero emissions future, is not included significantly in this proposal; however, ARCHES is in close communication with Caltrans and their zero emission rail plans. We also note that many of the production locations and some of the use cases have been chosen based upon proximities to rail lines and anticipated future deployment of hydrogen along these rail corridors, which can also serve as mobile generators to add to overall energy system resilience in California. Similarly, although a large statewide interconnected pipeline network is not included within the hub timeframe and funding request due to the magnitude of funding and timeframe required to realize such an enterprise (although 165 miles of new regional pipelines are included as an initial investment in the network), the initial projects are chosen to be able to realize and use such a common carrier system as it is introduced in parallel efforts of both utility and private companies in the future.

A balance was also chosen between different pathways (i.e., projects, feedstocks, and technologies in proximity) to ensure closely matched production and offtake requiring only buffering storage. Similarly, a balance amongst different operation paradigms was also chosen to be seeded from the hub funding so that they can flourish together and complement one another. Such diversity enables the desired resilience due to some redundancy as well as an ability to bring together various technologies and enable both their specific as well as their overall system cost reduction. This diverse set of pathways and operating paradigms inherently reduces risk across the set of projects, reducing the likelihood that a single technological problem or failure will cause them all to fail together, making the entire ecosystem more robust, reliable, and resilient. The demand side is driven by power, ports, and transportation. The supply side is driven by electrolysis via solar and grid as well as biogenic production. None of the demand or supply pathways or paradigms works in isolation; for example, power is intricately related to the grid that sources production as well, and some production assets will operate to provide grid-firming to the increasingly renewable and clean utility grid network.

2.2 ARCHES-Hub

Identified Tier 1 project end-uses occur within four main sectors: heavy-duty transportation, transit, power, and three marine ports. The production of clean hydrogen will be based on renewables and biomass inputs with careful consideration of water stress for the region and neighboring regions (e.g., along the Colorado River). The required distribution infrastructure will initially include pipelines and trucking and storage of gaseous and liquid hydrogen to the deployment locations as appropriate. For the hub, we have classified the various deployments into four main regions as shown in the map in **Figure 2.3**: Southern California (SoCal), Southern Central Valley (SCV), Northern Central Valley (NCV), Northern California (NorCal).

Figure 2.3: Map of four ARCHES-Hub deployment regions

Figure 2.4 shows the overall hydrogen flow from the 13 production projects through to the four regions and then to offtake in the three ports, transportation (including 13 transit agencies, aviation, maritime, and heavy-duty fuel-cell electric trucks (FCETs)), and six power projects. As seen, significant production is expected in the CA Central Valley due to its abundant solar resources (**Figure 2.3)**, along with some grid-connected electrolytic production in industrial areas, including evaluation of smaller-size distributed generation. Grid connection and dispatch is important to support increasing grid adoption of sun and wind power and to manage curtailment and grid congestion, especially since California is bound by law to produce an electric grid with zero emissions by 2045. In addition to electrolysis, there will also be clean hydrogen production via non-thermal gasification of woody biomass that will also enable fire mitigation, and also production via municipal waste gasification. These two latter bio-derived hydrogen production projects are driven by the need for larger, steady capacities in the project and will result in life-cycle emission carbon intensity scores of less than zero. It should be noted that in general a key issue for ARCHES-Hub and especially production in the Central Valley is that of water usage and type. Thus, technologies in ARCHES-Hub strive to be water efficient and approach thermodynamic limits of water use for production as much as practical, and, more importantly, have water agreements in place that mainly use wastewater and produced water from the regions that otherwise would have been discarded; in fact, additional water treatment plants and their optimization is considered in many ARCHES-Hub deployments. In all instances, care is taken to ensure that all ARCHES-Hub facilities do not impact already fragile water agreements and in many instances (e.g., offtake) result in less water usage and stress than incumbent technologies. While some of the produced hydrogen will be used close to the site of generation, especially in co-located hydrogen refueling stations (HRS), most will be trucked or transported in gaseous or liquid form to the various end uses. The distribution modality includes both gaseous transport in pipeline segments as well as various liquefaction plants and movement in liquid-carrier FCETs. Most of the offtake will be to the SoCal region, [redacted] The power sector will be a key enabler for the ARCHES-Hub due to its sizable and predictable demand in single locations in SoCal and NorCal. Once distributed, hydrogen will be used in several main interconnected transportation applications, including within ports (Long Beach, Los Angeles, and Oakland) for port equipment and drayage, for fuel-cell electric buses (FCEBs) within 13 transit agencies, and for transportation of goods *outside* of ports, mainly into the Central Valley. As port equipment and FCETs begin to be manufactured, they will immediately be put into service and there will be a transition past 2030 when the transportation demand becomes the greatest of all hydrogen demands in the California region (**Figure 2.4**).

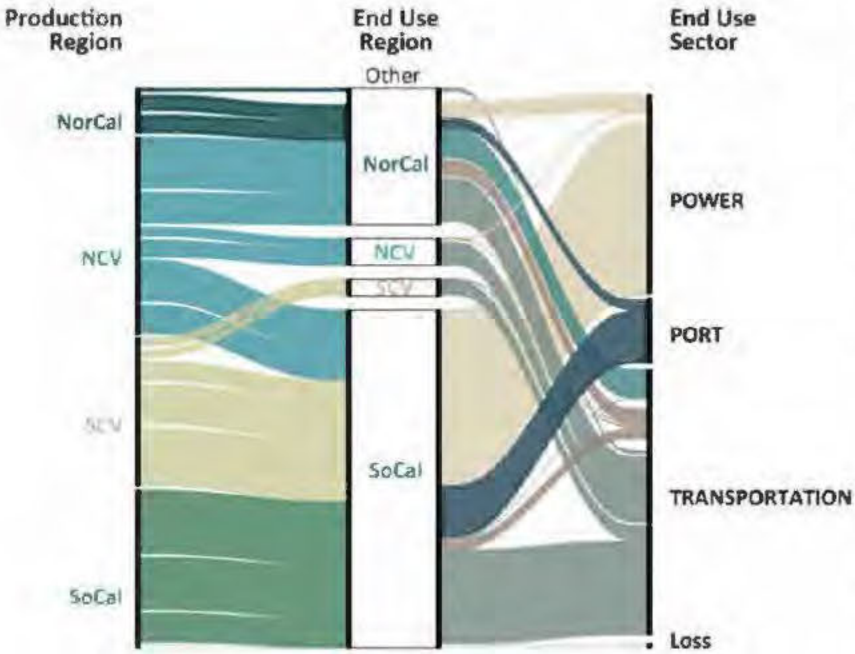

Figure 2.4: Sankey diagram showing hydrogen flow from production to end use by region (Figure contains business confidential information.)

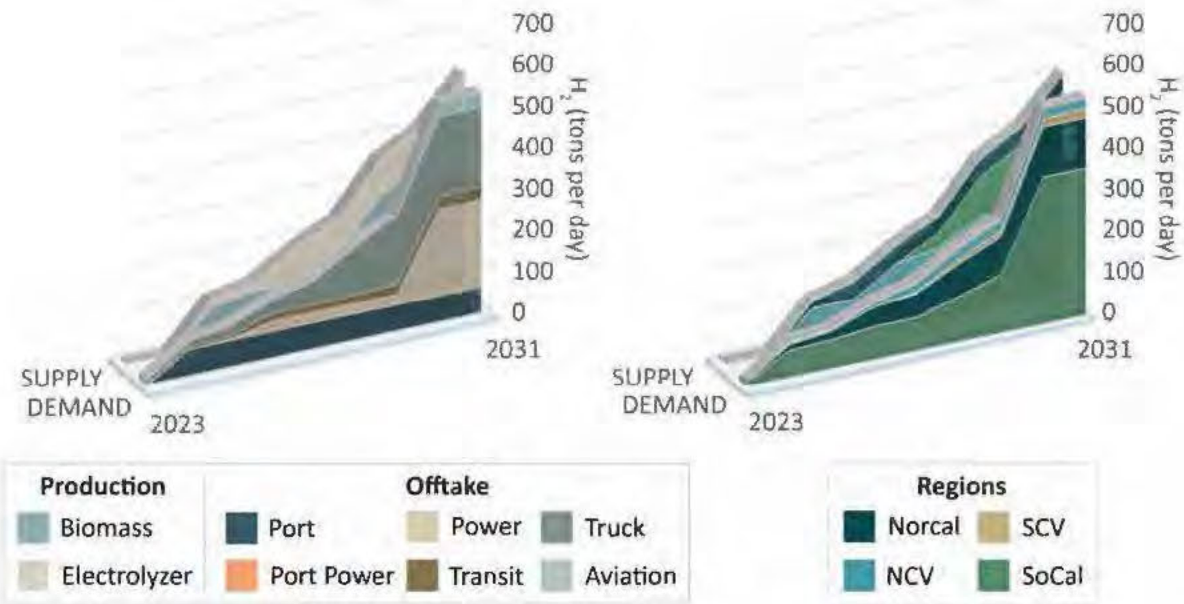

Figure 2.5: Hydrogen supply and demand by time and region (a) or sector (b) in ARCHES

ARCHES-Hub also has a few deployments that will open up new sectors and provide routes for future investments and scaling. These projects include a fuel-cell powered research ship, initial deployment of an hydrogen-powered fuel-cell commuter airplane network and concomitant refueling capability, evaluation of stationary fuel cells for both grid power firming as well as microgrids and back-up power for ports, and stationary fuel-cell gensets for resiliency on remote tribal lands.

Overall, as **Figure 2.5** shows, clean, renewable hydrogen use and production is expected to grow from about 6,820 MTPY (19 MTPD) today, used exclusively for production of transportation fuels, to an aggregate of over 187,000 MTPY (515 MTPD) within the hub by 2030. Mostly through private investment, the ARCHES hydrogen ecosystem will then scale rapidly to 17 MMTPY (47,000 MTPD) by 2045 by leveraging the infrastructure investments of the DOE-funded effort. Within the Hub's 2031 timeframe, production and consumption will be well matched geographically and temporally, requiring only small amounts of above-ground mainly liquid storage to be used as buffering capacity and accomplished with various liquid storage vessels (e.g., 250 m.tonnes H_2, 3500 m^3 tanks) and distributed gaseous storage for a total of around 1,700 m.tonnes; larger seasonal storage is left to be enacted beyond the federal funding timeline.

2.3 ARCHES' Responsibilities

ARCHES will be responsible for organizing, coordinating, and managing all aspects of the hub, consisting of an initial set of 39 project recipients (13 in production, six in the power sector, three port projects, 13 transit agencies, various FCET OEMs, one marine, and one aviation transportation projects, and eight infrastructure projects). ARCHES will be the connective tissue between projects throughout all phases and will drive further growth and expansion of the hub beyond the DOE funding period of eight years and beyond the initial projects and sectors identified for DOE Hub funding. As such, ARCHES will utilize a systems perspective and work with the deployments to ensure good fit and timing to optimize the balance between production and offtake from the early stages, through construction, and into full project operation. Thus, ARCHES will maximize project growth to achieve or exceed DOE goals.

ARCHES will manage all administrative tasks such as personnel, finances, hub communications, legal agreements, etc. ARCHES will have an outreach operation to inform policymakers about areas for future investments, policy and regulation requirements, and will work to inform and educate all relevant stakeholders, including the general public, about hydrogen opportunities and overall project progress. ARCHES will structure and coordinate a robust industry and community stakeholder process around each and every project development, including a conflict resolution process, should the need arise. As part of a comprehensive stakeholder engagement process, ARCHES will also support, oversee, and manage the enclosed Community Benefits Plan, which will again comprise an integral part of each and every project and activity of ARCHES.

ARCHES will retain institutional memory by recording and storing all hub projects' information, findings, conclusions, and lessons learned and will act as a feedback loop for continuous process and hub improvement. Other responsibilities include cross-cutting activities that would be relevant to multiple projects such as periodic techno-economic analyses (TEA) and life-cycle assessments (LCA), data collection and monitoring, risk management, safety, security, and codes and standards development and adherence, workforce development and education, all while assessing new hydrogen technology advancements prior to their deployment in the hub. Such cross-cutting activities will leverage the capabilities at UC campuses, LLNL, LBNL, NREL, and other national labs as needed as well as organized labor and State of California resources. Finally, ARCHES will closely work with the DOE to advance the growth of a hydrogen ecosystem, not only in California but at the national level towards a self-sustaining national hydrogen network.

3. BUSINESS DEVELOPMENT AND MANAGEMENT

***Objective:** The ARCHES-Hub, if funded by the DOE, will catalyze California's hydrogen economy by demonstrating the commercial feasibility of hydrogen production, distribution, and off-take in several critical sectors, including power, transportation (transit and trucking), and marine port operations at a scale (~ 515MTPD) that will drive down the cost of hydrogen* [redacted] *by 2031. This hub will further catalyze the transition to clean hydrogen of other hard-to-decarbonize sectors, such as heavy industry, aviation, and the maritime/shipping sector, leading to an estimated hydrogen use of over 47,000 MTPD or 17 MMTPY in 2045 in California.*

3.1 Proposed Hub Deployment Projects

As shown in **Figure 3.1,** the ARCHES-Hub consists of production sources, the interconnecting infrastructure, and offtake that all entail of a portfolio of Tier 1 projects, which are discussed in detail in the following sections. Also noted throughout are Tier 2 projects that are viable and compelling projects, which collectively result in an additional ~450 MTPD of hydrogen production and over ~600 MTPD of hydrogen end use. These projects, although not discussed further, are emblematic of the early ARCHES ecosystem that the hub funding will catalyze in the California region alone and that can be seen as replacements or additional projects that can be added to those in Tier 1 upon further discussion and negotiation in Phase 1 of the DOE effort and for state and local support throughout. The specific Tier 1 project deployments discussed in detail throughout the proposal are summarized in **Table 3.1**.

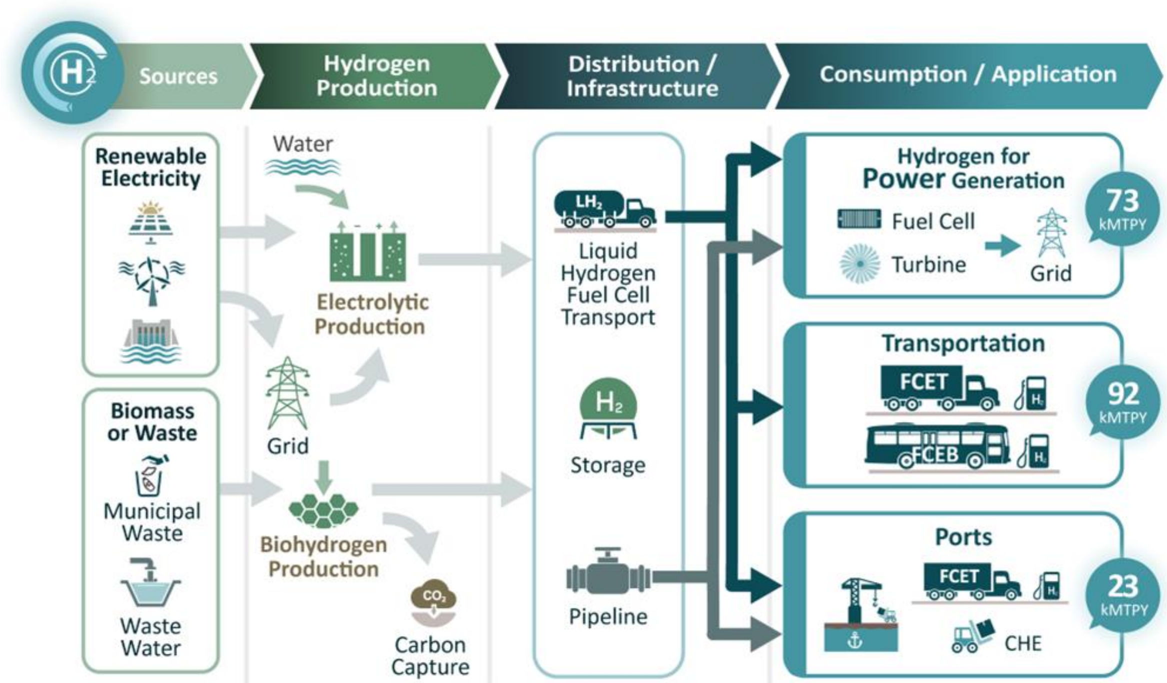

Figure 3.1: Diagram of the proposed ARCHES-Hub with capacity projections for 2030 in 1000's of MTPY (kMTPY)

3.1.1 Renewable, Clean Hydrogen Production

Critical to ARCHES is the production of renewable, clean hydrogen within the ARCHES region. This production and their deployments build confidence among potential producers that they would be able to reliably deliver renewable clean hydrogen to end users at a fair and transparent price via transportation infrastructure constructed as discussed in sections 3.1.3 and 3.1.5. Production will also build confidence among potential end users that they will be able to reliably source sufficient renewable clean hydrogen at a fair and transparent price for their respective transportation, industrial, power generation, and other end-use applications. Currently, there is an estimated 17 MTPD of clean hydrogen produced in the ARCHES region, mainly dispensed to light-duty fuel-cell electric vehicles. Renewable, clean hydrogen is predicted to grow by about 10 MTPD by the start of the hub, based on plants under construction.

As shown in **Figure 3.1**, renewable, clean hydrogen in the ARCHES-Hub will be primarily produced by direct connection of mainly solar power systems to electrolyzers in the CA Central Valley that contain high-quality solar resources (140 GW annual solar potential by 2035). Most electrolyzers will also be connected to the California grid, which contains a very high amount of renewable primary energy today (well over the 30% annual average as required by the current law) and whose renewable fraction will continue to increase over time to reach completely zero carbon emissions by 2045 as mandated by law (SB100). In fact, hydrogen can also help in terms of curtailment issues (more than 2.44 million MWh in 2022) and thus help with the further decarbonization of the grid. In many cases, battery storage will be used to complement renewable power sources to increase the capacity factor of electrolysis systems to further reduce hydrogen costs. In addition to grid and solar electrolysis, there are two different biomass projects within the hub that provide hydrogen in key regions and with constant production rates.

Table 3.1 List of all Tier 1 projects

Partner	Region	H_2 (MTPD)	Description
PRODUCTION			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
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[redacted]	[redacted]	[redacted]	[redacted]
[redacted]			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]			
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

**Note that some of these projects overlap with the power and transportation ones*

Within this proposed hub, 13 hydrogen producers will operate electrolysis systems for hydrogen production and two companies will operate biomass-based hydrogen production sites as shown

[redacted]

Figure 3.2: Production projects by size and location in 2030. Letters refer to project details in Table 3.3.

in **Figure 3.2**. From **Figures 3.1 and 3.2**, the majority of the production is in the Central Valley regions with its use mainly in the NorCal and SoCal regions. Note that this production in rural areas and delivery to high-demand urban and suburban areas is representative of most inhabited communities around the world, which could make the ARCHES-Hub the prototypical and extensible solution for decarbonization and depollution throughout the U.S. and the world. Collectively, the ARCHES-Hub combined installed hydrogen capacity will reach about 515 MTPD on average by 2030. As shown in **Figure 2.4**, this new capacity will start at 2 MTPD and then quickly escalate to 170 MTPD in 2027 and ramp to ~515 MTPD in 2031. Also as shown in **Figure 2.3**, the proposed production portfolio balances well in time with that required for end use, thereby requiring minimal storage capacity. Also, production is roughly equally split between gaseous and liquid hydrogen, the latter being critical for transportation to stations and longer distances without a pipeline, thereby requiring minimal storage. As discussed in section 3.1.5, [redacted] the specific details on this will be completed during Phase 1 of the hub. Prior to pipeline completion, gaseous and liquid FCET carriers will be used to distribute the hydrogen to the various end use locations. It should be noted that as listed in **Table 3.2**, there are a variety of Tier 2 production projects that are feasible throughout the state, including both biomass and electrolysis production projects. The Tier 1 projects were selected based on objective criteria, including site control, development stage and engineering design, strength of proposed organization, location close to (< 200 miles away from) end use or proposed pipeline, scalability, possible community benefits, initial TEA/LCA, etc. The federal funding towards production projects is around [redacted] due to their higher capacity factor and slightly lower TRL.

Table 3.2: List of Tier 2 production sector projects

Region	Name	Lead Organization	Concept	MTPD
SCV	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

While **Figure 3.2** shows the production center locations, **Table 3.3** (below) gives the summary data of the Tier 1 projects with more detailed data.

[redacted]

[redacted]

Table 3.3: Tier 1 production overview

Map Label	Project	MTPD	Capacity Factor (%)	Attributes	Water Consumption gal/kgH₂	Initial TEA* (to gate) $/kgH₂	Initial CI based on production LCA kgCO₂/kgH₂	Initial production
Electrolyzer-based production								
A	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]								
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]			[redacted]	[redacted]	[redacted]	

*Not including incentives; **Average weighted by respective MTPD [redacted].

Within the ARCHES-Hub, biomass production of hydrogen will reach higher production levels sooner than most of the solar-connected electrolyzers, as well as provide a constant rate of hydrogen production throughout the year. The two projects proposed are biogas conversion from municipal solid waste and non-thermal gasification of woody waste, the latter of which is also critical to wild-fire prevention. [redacted]

[redacted]. It should be noted that these costs are expected to drop as electrolyzer and balance of plant costs come down due to economies of scale and thus these are conservative estimates. Subsequent deployments after the ARCHES-Hub have actualized production of renewable, clean hydrogen at a sufficient scale are expected to become much less expensive and approach the Hydrogen Energy EarthShot Goal as the ecosystem matures, as risk is minimized (i.e., lessons learned), as electricity costs decrease, and especially as advanced technologies come to the marketplace.

The ARCHES hydrogen producers are all located within manageable distances of hydrogen offtakers or pipeline infrastructure across California, including hydrogen refueling stations for FCEBs and FCETs, and stationary and backup power applications, including at logistics and warehouse centers, and port cargo handling equipment (CHE). More details about offtake are provided in sections 3.1.2 through 3.1.5. As noted previously, some initial buffering capacity in the amount of 25 to 200% of daily production will be realized at each site and/or at each end use (e.g., ports) and intermediate liquefaction centers.

3.1.2 Power Sector Projects

As the California grid becomes more decarbonized and reliant on renewable generation assets, there is need for carbon-free 24-hour baseload, flexible ramping resources, and long-duration storage. Currently, the California region utilizes about 30 GW of natural gas power generation (both in-state and imports) during peak operations. Fossil-based generation is greatest at the end of the day and during peak summer operating conditions. In addition, there are existing mandates to phase out older, more polluting gas power plants, requiring more in-basin clean carbon-free local generation capacity. The entire power system of the fourth-largest economy cannot be decarbonized completely via conservation, solar, wind, and battery technologies alone. Renewable clean hydrogen is needed in addition to these technologies to operate the 100% carbon-free reliable, resilient, stable, and flexible grid of the future while complying with stringent state, regional, and federal reliability standards. Hydrogen is a fuel source that can replace natural gas to help optimize grid operations, improve reliability, and significantly reduce pollution and reliance on locally generated and imported fossil energy. In addition to the stationary large-scale grid-connected gas plants, there are GWs of customer-owned diesel-powered generators that can be readily replaced with non-polluting stationary fuel cells. Over time, as stationary fuel cells become less expensive and as stationary gas turbine plants retire, all urban power generation will be converted to zero carbon and criteria pollutant emissions fuel-cell systems.

Many of the existing gas turbine power plants are required for grid reliability and resilience (e.g., spinning reserves) and have not reached the reasonable end of their service life. As a result, many power turbines require a transition to zero emissions technologies and operations for both baseload and backup power. Converting existing gas turbine power assets requires substantial amounts of hydrogen that, for practical reasons, must be delivered via pipeline. For ARCHES, the most practical way to meet this challenge is to partially fund two main projects in this sector: [redacted]. These projects will also serve to demonstrate the concept of decarbonized power production without an increase in any criteria pollutants (which affect air quality) and to become first-in-the-nation at scale deployments. The ability to blend with natural gas initially as 100% hydrogen transitions to become technically and economically viable is essential in helping to buffer production and offtake in the earlier years of ARCHES. Critical to achieving this goal, and to scale and create and consume large amounts of intermittent and dynamic hydrogen demand, is a connective hydrogen pipeline network. [redacted] This network will be fed from various sources of hydrogen under rigorous safety considerations including from possible sources outside of ARCHES as described in section 3.1.5. [redacted]. Thus, the hydrogen will be generated during the day and used in the late afternoon when the turbine is dispatched to overcome the decrease in renewables and concomitant increase in demand (the so-called duck curve). At full pipeline buildout in the central valley, this plant as well as others that may come on-line [redacted] can be fed directly from that or shorter pipelines directly connected to storage and hydrogen production sites that utilize various renewable inputs.

While CA has the vision and policies to form a complete 100% renewable grid (and thus also to provide for clean hydrogen via grid electrolysis), there remains the requirement for power generation to bridge the inherently intermittent renewable sources. Thus, most of the electrolysis production projects have interconnections to the grid to ensure good business models and higher electrolyzer capacity factors while also supporting utility grid network increasing adoption of solar and wind power. While it is recognized that in-basin spinning reserves will always be required, peaker plants connected to the grid may be enabled by fuel cells, which are inherently higher efficiency and zero criteria pollutant emissions alternatives. Such fuel-cell peaker plants are more likely to be distributed to more efficiently and locally support dense urban and suburban resilient power demands with lower land area requirements compared to solar plus batteries. To realize this vision and provide offtake for the production in the [redacted] area, ARCHES will fund [redacted] to deploy a scalable fuel-cell-tethered power and production center that is grid-tied and provides grid services and firming. Once designed and deployed, this topology can readily be scaled throughout the state, including along the high voltage lines into the LA basin.

Similar to the [redacted] project, stationary fuel cells can be used as well to provide power and to help curtail related emissions at various end points. In ARCHES-Hub, we will work with [redacted] to install various stationary fuel cells [redacted]. We will also work with the [redacted] stationary fuel cell for backup power and will evaluate in Phase 1 the possibility of using [redacted]. Such possibilities will enable not only resilience of port operations, especially during times that they need to be curtailed during hot summer days or require running polluting diesel gensets, but also overcome existing electrical infrastructure constraints at these sites. Furthermore, the concept of fuel-cell gensets that can replace highly polluting diesel gensets for backup and emergency power will continue to be evaluated and promoted across the region. One example of a demonstrated need for this is in remote locations, where critical equipment such as water wells need to be able to be pumped regardless of grid availability. Thus, ARCHES will fund a deployment on the [redacted] to ensure that they have adequate emergency power for their critical vehicles and infrastructure, especially as they often have blackouts. These fuel cells will be supplied with hydrogen from smaller buffer tanks and grid-connected electrolysis tied as discussed in section 3.1.1. While such a deployment is not a heavy usage of hydrogen, its community impact and reach go far beyond many other projects. It is also seen as an exemplar deployment that can quickly scale and be translated across tribal nations and other more remote locations. A summary of power sector projects is shown in **Table 3.5**.

Table 3.5 Power sector project summary

	H2 (MTPD)	Power (MW)	Phase 4	Comments
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

3.1.3 Transportation

Table 3.6: List of Tier 2 transportation sector projects

Region	Name	Lead Organization	Concept	H2 MTPD
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

The decarbonization and depollution of the transportation sector is a critical element of ARCHES. Within the ARCHES-Hub, the transportation focus is on transit buses and heavy-duty trucking, two applications that can have immediate and significant health quality and environmental benefits for their communities. A smaller maritime shipping deployment as well as initiation of a first aviation deployment have also been included to initiate deployments and promote expansion in the future (beyond the hub timeframe) to the maritime shipping and aviation sectors, respectively. It is also expected that these efforts will help promote more fuel-cell vehicle uptake and hydrogen demand in the light-duty vehicle sector, although that is also separate from the ARCHES-Hub. Also, as mentioned, rail will be initially explored in conjunction with Caltrans and other activities, including possibly some Tier 2 projects (see **Table 3.6**) as well as from [redacted]

3.1.3.1 Transit Buses

California has approximately 200 transit agencies with a combined fleet of 13,000 buses. The composition of California's fleet includes 8,970 standard, low-floor transit buses, between 35 and 42 feet in length (69% of the statewide fleet) and 910 60-foot low-floor articulated buses (7% of the statewide fleet). The propulsion systems and fueling systems for these buses vary, with 28% (3,640) using diesel or diesel hybrid engines, 53% (6,890) fueled with compressed natural gas, 4% (520) either battery-electric buses or fuel cell-electric zero-emission buses, and the remaining 15% (1,950) are fueled with gasoline or other fuels. The California Air Resources Board (CARB) adopted the Innovative Clean Transit Regulation (ICT) in December 2018, requiring all public transit agencies to gradually transition to a 100% zero-emission bus (ZEB) fleet. The ICT regulation mandates an increasing annual ZEB purchase percentage beginning in 2023, with a 25% ZEB purchase of new bus purchases for large transit agencies, phasing in small transit agencies in 2026, and increasing to a 100% ZEB purchase requirement beginning in 2029.[1,2] Based on the latest reported data by transit agencies, as of December 31, 2021, there were a total of 934 ZEBs in the state, of which 510 were in service, including 56 fuel cell electric buses (FCEBs), and another 424 ZEBs were on order, including 62 FCEBs. The total of 118 FCEBs were deployed or ordered by five transit agencies.[3] In California, many transit agencies are selecting battery electric buses (BEBs) for small, initial ZEB deployments. However, two of California's larger transit agencies paving the path for zero emissions fleets—AC Transit and Foothill Transit—are committing to

Figure 3.3: Transit agency locations and status

[1] A transit agency that either (a) operates more than 65 buses in annual maximum service in either the South Coast Air Basin or the San Joaquin Valley Air Basin, or (b) operates in an urbanized area with a population of at least 200,000 and at least 100 buses in annual maximum service.

[2] All other transit agencies.

[3] California Air Resources Board, "Reporting Tool & Data". Available at https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/reporting-tool-data.

converting a large portion of their fleets to FCEBs after experiencing issues with range and infrastructure expansion with BEB deployments. Other agencies have also experienced challenges with deploying BEBs on long routes and achieving a one-to-one replacement for conventional diesel and CNG buses. This has led to a growing number of agencies seriously considering the use of FCEBs either in lieu of BEBs or as a complement to a fleet of BEBs.

ARCHES-Hub enables a much higher portion of FCEB deployments due to the interconnecting sectors, especially production, in lowering the Total Cost of Ownership (TCO) targets to be close to parity with diesel. Within the hub, 13 transit agencies have committed to expand or initiate FCEB deployments (**Figure 3.3**). [redacted] As FCEBs and HRS are TRL 8 technologies, ARCHES will work to provide [redacted] to lower the capex of the buses and also help build out the necessary HRS at the bus depots.

Public transit agencies provide critically important transportation services to many Disadvantaged Communities (DACs) and transit-dependent riders in inner cities who have no other modal choices. Most transit routes directly serve the top 25% of DACs identified by CalEnviroscreen 4.0.[4] Reduction in criteria emissions from FCEBs has a significant beneficial health impact on communities residing adjacent to bus routes by eliminating criteria emissions where these buses operate. Transit agencies also serve as major employers for drivers, mechanics, and administrative staff. The introduction of advanced technology within these agencies creates opportunities for workforce training, highly skilled jobs, and transition to a clean operating and working environment.

[redacted]

[4] CalEnviroScreen 4.0, California Office of Environmental Health Hazard Assessment, https://oehha.ca.gov/calenviroscreen

During the ARCHES-Hub eight years, as many as 1080 FCEBs and 22 transit fueling stations with 16 maintenance facility upgrades are planned to be put into service among 13 agencies, consuming up to 29 MTPD of hydrogen by 2030 and avoiding 106,500 MTPY of CO_2 and 1.6 MTPY of $PM_{2.5}$ emissions by 2030. Conservatively, by 2035, the number of FCEBs in service is expected to grow to nearly 1,900 buses, consuming as much as 45 MTPD. Funding will be used for FCEB purchases, infrastructure, and workforce training. An overview of the number of planned FCEBs and hydrogen fueling stations per agency is provided in **Figure 3.4**.

3.1.3.2 Fuel-Cell Electric Trucks (FCETs)

The heavy-duty transportation market in California is targeted to reach zero combustion engines of 100% of drayage stocks by 2035 and 100% of MD/HD stocks by 2045, per EO-N-79-19. The larger diesel vehicles typically produce about 600 mg of small particulates and 2.7 kg GHG per mile driven and are concentrated along specified transit corridors mainly from the ports to the inland valleys and along the main I-5 and SR-99 highways, thereby exacerbating the health and quality of life of nearby communities. From the ports, about half of the trucks travel 75+ miles on a single trip and often several hundred miles per day. Recognizing advantages that FCETs have over BETs,[5] such as faster refueling, longer distance travel, and ability to carry a higher amount of cargo weight, California stakeholders are developing rollout plans for zero-emission trucks to meet current mandates (of which ARCHES will initiate 5,500 FCETs to catalyze deployment and confidence in the technology). Reducing costs via economies of production scale in both vehicles and clean hydrogen and thus TCO is critical for market viability.

Similar to transit, a key for trucks is buying down both the CAPEX to close the gap with diesel trucks and the OPEX in terms of hydrogen fuel cost to provide a low TCO. Furthermore, when examining drayage trucks and some other heavy-duty trucking, there is a change in paradigm in that we are now asking smaller fleets to buy newer technology and trucks instead of the various second- and third-generation ones they are used to purchasing. Thus, ARCHES will work with various stakeholders (fleets, OEMs, etc.) in Phase 1 to determine novel ways to approach this problem, including different [redacted]) or other modalities.

In general, ARCHES will work with various clean-truck programs and fleets to leverage the just-passed California Advanced Clean Fleets rulemaking to generate a strong FCET demand that will entice OEMs to manufacture the needed vehicles and achieve economies of scale. Aligning demand with production and gaining commitments at given truck purchase price will be central to ARCHES' market growth mission during the next five years. Reaching truck price parity along with hydrogen price parity (through cost reductions and incentives) will both be critical (i.e., TCO) to spur adoption of the FCETs by various fleets.

[redacted],

[5] Zero Emission Bus Transition Plan, AC Transit 5x5.

[redacted] Doing larger deployments in this fashion will also provide for concomitant servicing, maintenance, and training to be established to ensure high utilization and capitalization of the trucks. Truck rollout informs the HRS rollout and vice versa as described in section 3.1.5.

In terms of fleets, ARCHES will work with partners, including the ports, fleets serving ports, and nearby station operators, with existing relationships. During the first couple of years of the program, a strong uptake of FCETs and demand for hydrogen will come from [redacted] and then utilized by smaller fleets in the ports, especially in the POLA/POLB region. [redacted] ARCHES is in discussions with major OEMs such as General Motors, Daimler, Nikola, Hyundai, Toyota, Hyzon, Cummins, Symbio, and Rocke to agree on the incentive for truck purchases as well as working toward commitments on truck roll-out plans. The ARCHES planned truck deployment is shown in **Table 3.7**.

Table 3.7: Planned ARCHES-Hub FCETs

Location	# of trucks	H2 use (MTPD)	CO2 Avoided (MTPD)	Criteria pollutants avoided (kg/day)			
				NO_x	PM	SO_x	CO
[redacted]							
Totals	5500	220	3045	3234	83	160	27698

3.1.3.3 Scripps Vessel

In addition to FCEBs and CHE in and around the ports (see section 3.1.4), there is value in decarbonizing the smaller maritime ships, as they contribute the most air pollution in the ports. However, for the most part, smaller watercraft have not adopted fuel cells yet. To deploy such a craft in a visible manner and entice the industry, [redacted] This vessel will enter service as a good southern California analogue to the hydrogen ferry that will soon enter service in the SF Bay Area.

3.1.3.4 [redacted]

A key polluting sector that is very hard to decarbonize through direct electrification is that of aviation. To this end, ARCHES-Hub will fund [redacted] resulting in supporting a robust hydrogen aviation economy that will allow California and the US to begin decarbonizing aviation in this decade.

3.1.4 Port Operations Projects

California has 12 marine ports, including three of the top 10 marine cargo ports in the nation, with 36% of all goods passing through the three largest (Los Angeles, Long Beach, and Oakland). The Ports of Los Angeles (POLA) and Long Beach (POLB), collectively referred to as the San Pedro Bay Ports (SPBP), together are among the top 20 bunkering ports in the world, and the total of California shipping fuel sales amounted to 3,552,545 m.tonnes as of 2020, associated with 11,012,890 m.tonnes of annual CO_2-emissions.[6] Drayage trucks and cargo-handling equipment (CHE) such as yard tractors, top and side loaders (picks), and rubber-tire gantry cranes (RTGs) currently operate on diesel fuel and are major contributors to pollution in the ports and in the surrounding communities, almost all of which are designated DACs. For example, in 2021, CHE at the POLA contributed 17 m.tonnes of PM, 414 m.tonnes of NO_x, and 184,837 m.tonnes of CO_2, amongst other emissions. Heavy-duty vehicles with concentrated use in ports and transportation corridors contributed 18 m.tonnes of PM, 1042 m.tonnes of NO_x and 444,814 m.tonnes of CO_2.[7] At POLB, the emission profile was similar to that of POLA;[8] the Port of Oakland is about 30% of the size of POLA, and its equipment and emissions profiles roughly scale with size. Other major emission contributors are oceangoing vessels, harbor craft, and locomotives that are not included in the federal funding of ARCHES-Hub due to their lower TRL. Currently, the three ports have 4,200 CHE and 20,000 trucks, which are expected to grow to 5,500 CHE and 26,000 trucks by 2035.

Most ports essentially operate as landlords with tenant relationships with their various freight operators. Contracting operations can be for various time periods, but this creates complexities around the prospects for adopting cleaner fuels for equipment operations. For example, ports may have direction to increase the sustainability of their operations, but since they do not directly control the operation of the underlying equipment, this may create tensions with their tenants who also may feel these pressures but also are under economic pressures given the relatively tight profit margins of goods movement enterprises. Marine ports are currently experimenting with and piloting hydrogen and fuel cell technologies for port operations. These include fuel-cell-powered heavy-duty drayage trucks that collect port containers and take them to inland destinations, fuel-cell powered port yard trucks that move goods around the port, fuel-cell powered top and side loaders (picks) for transferring cargo from ships to shore, and fuel-cell

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[6] HFO has a CO_2 emissions factor of 3.1 kg CO2/kg of fuel, https://www.egcsa.com/wp-content/uploads/CO2-and-sulphur-emissions-from-the-shipping-industry.pdf

[7] Port of Los Angeles Inventory of Air Emissions Technical Report, Starcrest Consulting Group, LLC, September 2022

[8] Port of Long Beach Inventory of Air Emissions Inventory, Starcrest Consulting Group, LLC, August 2022

powered rubber-tire gantry cranes that can move cargo containers for short distances around the port. Due to the existing relationships and structure, DOE funding is critical to bolster the credibility of hydrogen technologies among potential end users at the ports and reduce the risks associated with adopting a new, relatively unproven technology within the CHE sector. With DOE funding, multiple end users with varied operational formats are more likely to adopt fuel-cell CHE rather than waiting for other end users to demonstrate its viability, durability, and reliability.

ARCHES-Hub will focus on SPBP and the Port of Oakland, where GHG and particulate emissions are very high, and plans to target CHE and drayage trucks because of their high contribution to pollution and early adoption potentials driven in part by CA mandates and fleet behavior, including station proximity. The drayage trucks are part of the transportation deployment in hub as discussed in section 3.1.3.2. Additional concepts for ports include stationary fuel cell systems for power resiliency, and provision of shore power for ships (also known as cold ironing), and support for hydrogen fueling and fuel bunkering for large oceangoing vessels, passenger ferries, tugboats, and patrol vehicles. These will be evaluated in Phase 1 of the hub and are also mentioned in sections 3.1.2 and 3.1.5.

Table 3.8: Overview of hydrogen CHE in POLA, POLB, and the Port of Oakland

	CHE	H_2 Offtake (MTPD)	Reduction in MTPD		
			CO_2	NO_x	PM
[redacted]			3,431	6.93	0.11
			5,475	36.13	0.36
			8,906	43.07	0.47

ARCHES-Hub will work with the ports and the specific terminal operators to test and covert hydrogen fuel cell CHE (**Table 3.8**) and related infrastructure in two stages. [redacted] Memorandums of understanding and/or sub-grantee agreements will be executed between the ports and individual terminals to formalize the financial commitments and implementation obligations as described in the proposed scope and in the support letters.

It should be noted that although hydrogen fuel-cell technology is not the only path to zero-emission CHE compliance, it does provide a viable alternative that does not require significant and time-consuming on-terminal electrical infrastructure upgrades and will not further load the already overburdened electrical grid. Without DOE funding, the pace of hydrogen technology adoption will undoubtedly be slowed, potentially resulting in later adoption of these critical technologies into the port terminal working fleets and, as a result, the continued release of harmful NO_x and PM emissions into the air that could otherwise have been avoided. Similarly, successful deployments in this sector can readily translate over to those in other maritime (e.g., San Diego, Stockton, San Francisco, Sacramento) and even aviation ports (e.g., SFO, LAWA, Oakland, San Jose).

3.1.5 Infrastructure

A connective infrastructure that is open to all is critical for the efficient movement of hydrogen within the ecosystem from production to end use. Furthermore, such infrastructure can be a great enabler by providing low-cost, high-volume transport of hydrogen throughout the region as the hydrogen economy scales and takes off. This is important for ARCHES, since, as seen in **Figure 3.2**, most of the hydrogen production is not directly co-located with its end use. While the initial hydrogen production and end use are chosen to be in close proximity to be served by liquid hydrogen trucks, this is not expected for all future deployments beyond the initial ones in ARCHES-Hub. Furthermore, as volumes increase by combining production facilities or at specific large end uses, such as in the power sector, transport of gaseous hydrogen in 100% H_2-dedicated pipelines becomes the most cost-effective means of distribution the molecules, especially over longer distances. Such a pipeline network is not expected to reach all HRS (hence we still need substantial investment in transport via liquid in trucks) but will reach the largest offtakes and could provide trunk lines throughout the region.

Within ARCHES-Hub, Tier 1 infrastructure involves HRS (described in detail below) and the initiation of an expanded pipeline infrastructure as shown in **Figure 3.5.** In particular, [redacted] ensures that hydrogen supply will be available throughout the [redacted] region to support the adoption of zero-emission hydrogen technologies by downstream hydrogen end-users. It should be noted that while ARCHES-Hub will provide funding and support for the buildout of the hydrogen pipeline infrastructure, in some cases, connections to the hydrogen pipeline network by hydrogen end-users will occur beyond the timeline envisioned for the ARCHES-Hub and may require hydrogen being brought into the pipeline through various means outside the scope of ARCHES-Hub. The siting can also provide hydrogen to other industries as needed in the future. The pipeline will provide [redacted] and additional capacity in the future is expected to be added outside the hub timeframe by existing [redacted] and new players [redacted]

[redacted]

In addition to the [redacted], the initial stages of the [redacted] will be realized through two different common-carrier 100% H_2 pipelines [redacted]. This pipeline will connect various producers in the [redacted] While this initial line will come into service in 2029 and not be connected to other lines throughout the region initially, it will serve as a key example and critical future infrastructure. At the end of the line, [redacted] The second pipeline to be constructed simultaneously will be one that runs from [redacted], again utilizing existing [redacted] rights-of-way, thereby providing ready transport of hydrogen from [redacted] and future producers [redacted] that makes trucking more complicated. In Phase 1 of ARCHES-Hub, this line will be analyzed for any possible concerns around leakage or seismic and the appropriate safeguards and monitoring established. While the full pipeline buildout of the [redacted] is expected to be outside the timeframe of the hub, these initial branches will promote confidence from the communities and marketplace, and ARCHES analysis will continue to inform its planning based on the initial ARCHES deployments.

As shown in **Table 3.9**, there are a few Tier 2 infrastructure projects, where two are outside the immediate scope of ARCHES-Hub but could provide future benefits. The third one is an interesting Tier 2 pipeline possibility by [redacted], which is looking to work with CalTrans to [redacted]. This possibility and design will be further investigated in Phase 1 and incorporated into the ARCHES system analysis to inform future roll out.

Table 3.9: List of Tier 2 infrastructure sector projects				
Region	Name	Lead Organization	Concept	MTPD
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

In addition to pipeline infrastructure, there is a need to realize other necessary infrastructure. As noted, ARCHES will evaluate the use of more central 30–60 MTPD liquefaction plants (which numerous partners have expertise to establish) that aggregate different production sites (like using [redacted] to determine the most efficient and least expensive method of getting hydrogen to HRS and other end uses, especially early in the life of the hub.

For pipelines and distribution of the hydrogen, [redacted] Thus, we will enable the greater hydrogen market by democratizing hydrogen supply including the use of MOUs. ARCHES cross-cutting efforts will also play critical roles in analyzing the system, providing key codes and standards subject matter expertise, and promoting and realizing community engagement to establish regulations.

Finally, ARCHES-Hub will support the [redacted] infrastructure at the [redacted] This infrastructure will make hydrogen and possible hydrogen derivatives in the future and outside of ARCHES-Hub available that will be critical to ensuring the creation of the green shipping corridors and associated supply chains envisioned for the Port Complex. [redacted] and would include fueling capability for small and large harbor craft, although construction of this terminal is currently not part of the ARCHES-Hub proposal. ARCHES will provide analysis and support for various such terminals throughout the CA region and its many ports so that they can be readily implemented subsequent to the ARCHES-Hub funding.

3.1.5.1 HRS

The final critical infrastructure component is that of hydrogen refueling stations (HRS) for the proposed hydrogen truck deployments. Currently there are 54 open retail HRS for the light-duty vehicle (LDV) market with over 50 more in various stages of planning and construction. This is the sole HRS network in the nation and provides key lessons learned that ARCHES will leverage through discussion with the various operators and hydrogen councils, including the Hydrogen Fuel Cell Partnership and CTE, which is a partner and advisor in ARCHES. It is already clear that some spatial redundancy and regional ownership and upkeep are needed. Some of the reliability concerns with the HRS network for LDVs are expected to be ameliorated for heavy duty trucks

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and fleets due to the larger size, use and storage of liquid hydrogen, and more important criticality to the business model, which all correlate to dedicated maintenance as well as stronger ownership model that will result in high up-time. Such improvements can be witnessed in the reliability of the four existing FCEB stations, whose network is set to grow to 22 in the ARCHES-Hub (see section 3.1.3.1). Also, a key aspect of ARCHES-Hub will be an open ability for hydrogen contracts to be optimized and flow throughout the region through ARCHES-led MOUs and cross-party agreements along with transparent pricing.

For hydrogen truck fleets, ARCHES will build on the existing three heavy-duty stations by adding 66 stations [redacted] end of the hub Phase 3 timeframe (2030) with a total capacity (at 100% utilization) of 370 MTPD, thus providing growth opportunities and utilization of additional fuel-cell vehicles not envisioned within ARCHES-Hub. These stations will range in size but on average will be on the order [redacted]. Starting stations smaller with room to grow is envisioned in many cases, which can then be aligned with growing truck hydrogen demand. This approach helps maximize capacity factors and reduce overall station costs at any given point in time. Furthermore, this planned rollout will enable the best use of resources and adaptability as technologies for dispensing, storage, compression, or even on vehicles (e.g., liquid storage on trucks) continue to evolve.

The initial station rollout plan is well coordinated both spatially and temporally, with the expected FCET routes and deployments as shown in **Figure 3.6** with a summary provided in **Table 3.10.** The stations will be developed with

[redacted]

Figure 3.6: (**a**) Geographic distribution of final station map in 2031 with known (fixed) and unknown (variable) sites. (**b**) Station rollout plan by region over time.

 Contains Trade Secrets, Confidential, Proprietary, or Privilege Information Exempt from Public Disclosure

the early uses being to support a fleet for [redacted] goods transported to/from and within the ports, and, as time progresses and interconnectivity through the state and other hubs is realized, additional stations further from the initial deployment centers and moving out toward state borders. Roughly, the stations will be located around the three marine ports, Oakland airport, Ontario airport, Fresno airport, Sacramento, and along major trucking corridors (e.g., CA-99 and I-5) as seen in **Figure 3.6a**. The rollout will consist of stations initially being built in the NorCal region with linear increases in the other regions and eventually a higher station number in the SoCal region when the POLA and POLB FCETs and associated stations increase greatly. We also are planning to have stations collocated with production sites when they are transit corridors [redacted] which would not require any transport of the produced hydrogen other than possibly small dedicated pipelines. Specific station locations currently undefined will be determined during Phase I in cooperation with station developers and inputs from fleets and OEMs.

Table 3.10: Number of stations by provider and region

Provider	Region					Total
	SoCal	SCV	NCV	NorCal	Other	
[redacted]	[redacted]					[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]					[redacted]
[redacted]		[redacted]	[redacted]			[redacted]
[redacted]			[redacted]	[redacted]		[redacted]
[redacted]	[redacted]		[redacted]	[redacted]		[redacted]
[redacted]	[redacted]					[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

The Tier 1 station developers in ARCHES-Hub include [redacted] with an additional station upgrade [redacted]. Other developers in California [redacted] are expected to continue build out of their station networks mainly for light-duty, perhaps with some heavy-duty pumps, but are not considered within this proposal explicitly. As seen in **Table 3.10**, for maintenance most companies concentrate in regions although for redundancy there is some overlap. Furthermore, as seen in **Figure 3.6a**, some of these companies have already designated specific sites while others are still in the planning phase. As noted above, another feature is to use preferred station providers and integrators to ensure regional and ready maintenance, maximize station up-times, and realize economies of scale. While it is expected that the stations themselves will leverage different vendors, ARCHES will help to firm up and leverage plans and supply chains across the network as possible.

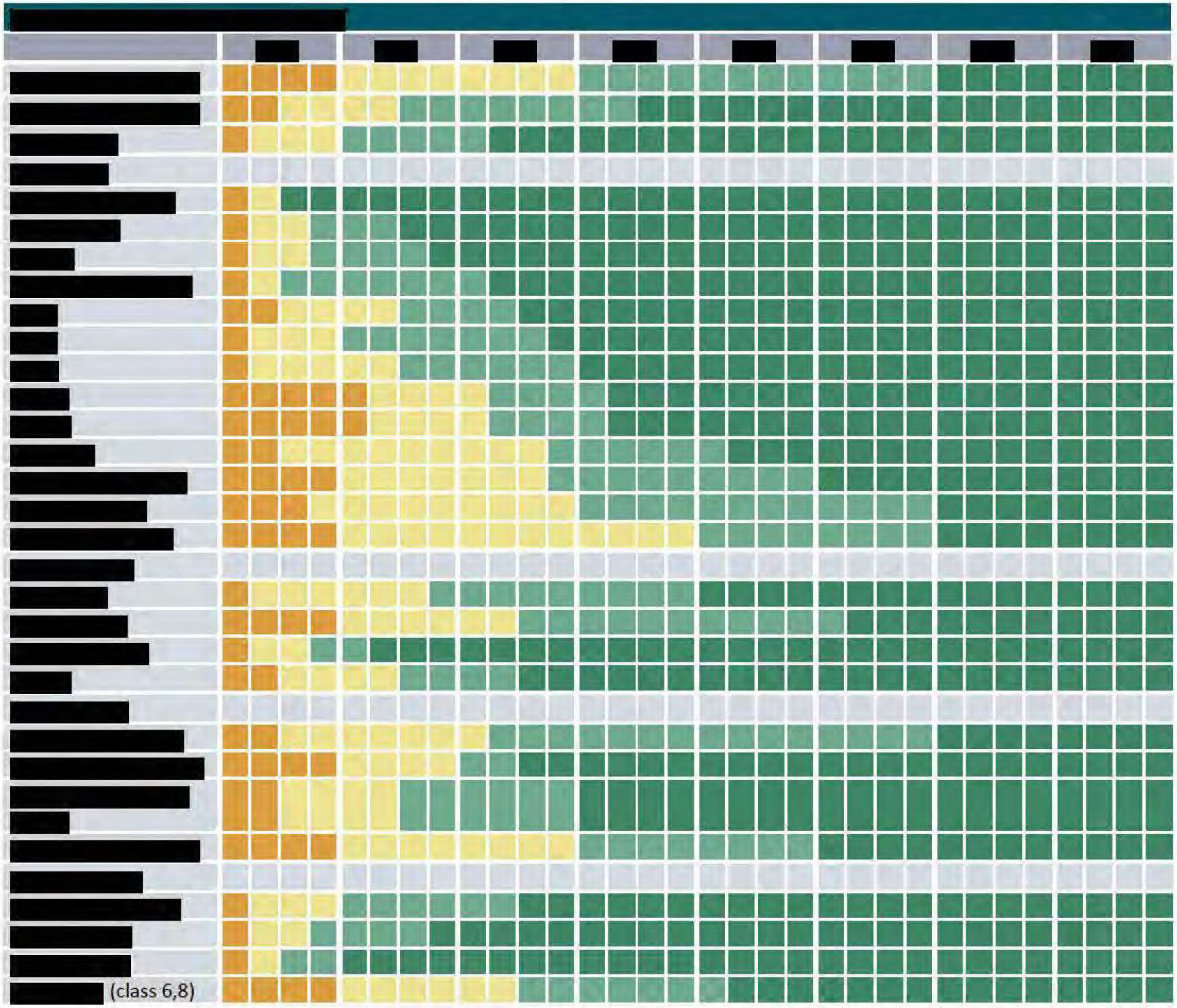
3.1.6 Process Flow Diagram

The overall ARCHES-Hub process flow diagram is shown in **Figure 3.7**. Although there will be a dedicated effort to match hydrogen production and offtake volume as the hubs develops, it is expected that there will be a general hydrogen market with supply and demand from outside the hub that will also help balance the system.

[redacted]

3.1.7 Summary Preliminary Schedule

Figure 3.8 shows the preliminary schedule for the ARCHES-Hub and the phased timing of the proposed hub projects. As can be seen, some projects are expected to move rapidly through some of the early phases due to their maturity, while some more nascent ones will require additional design and analysis. In addition, within each project (e.g., ports, HRS) there may be an iterative process as some parts are being permitted while others may be already in construction or even operation. Overall, the various deployments will move through the phases at different rates and calendar times and ARCHES analysis is focused on keeping redundancy and a balance of supply and offtake overtime such that the hub network remains resilient and robust as it is being actualized through leveraging the initial DOE funds. Finally, the community benefits and cross-cutting efforts will occur throughout all years of the hub and a separate timeline is provided in the attached community benefits plan.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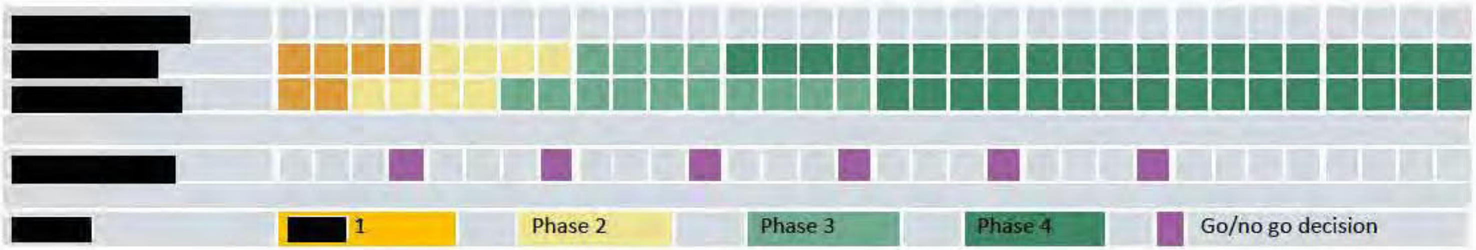
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Phase 2
Phase 3
Phase 4
Go/no go decision

3.1.8 ARCHES-HUB Project Team

The ARCHES-Hub project management team is described in detail in section 3.3.3.

3.1.9 Impact of DOE Funding and Other Funding Sources

DOE funding is the key that unlocks and charges the ARCHES ecosystem. DOE-funded deployment projects in ARCHES will become anchor projects to lead and guide the full decarbonization of fossil fuel-based sectors by 2045 in California. These projects provide risk reduction for all stakeholders of hydrogen industry-wide deployments by demonstrating technical, economical and societal benefits, and proof of feasibility, and thus legitimize and incentivize hydrogen use across multiple sectors. For programs of this nature focused on driving market transformation, government funding is critical, especially in early stages of technology development and deployment. The size, complexity, diversity, and community benefits of this proposal justify the federal ask of the maximum of $1.25B as does the ability of ARCHES-Hub to act as an exemplar for an interconnected national clean hydrogen-hub network and provide lessons learned at a scale and maturity that no other single hub can realize today. DOE funding is critical for the success of ARCHES and the existence of ARCHES-Hub. The funding will be used to mitigate effectively the technical, market, financial, and/or regulatory risks that project and technology developers face, realize economies of scale to buy-down the risk, and reduce the cost of new technologies. For about 20 years, California has been working to develop hydrogen fueling infrastructure. This has been significantly hampered by hydrogen suppliers being unwilling to take the market risk that enough hydrogen-fueled vehicles would be available to justify investing in hydrogen fueling infrastructure, and the OEM FCEV manufacturers are unwilling to scale hydrogen-fueled vehicle production aggressively due to an inadequate hydrogen fueling infrastructure. ARCHES intends to break this cycle by using the DOE funds to mitigate the risk of "pre-investing" in large-capacity hydrogen production and the associated infrastructure to catalyze the development of end use hydrogen consumer technologies, including evaluation of possible new markets such as ammonia. Evolution of these end-use technologies will lead to further investments and further emissions reductions, job creation, and other benefits to the local disadvantaged and frontline communities. Federal funding, through the accelerated deployment of hydrogen in many sectors—such as in power, transit, transportation, and ports—will significantly reduce GHG emissions and, more importantly, criteria pollutants at the local level, thereby providing an immediate much healthier work environment and tangible community benefits while substantially increasing the number of green energy jobs and careers in California. ARCHES will catalyze a much-needed increase in the quality of life for many DACs that are directly exposed to high-polluting emissions today. DOE-funded ARCHES deployment projects will accelerate the learning curve, identify and resolve unforeseen challenges, and lead to detailed, proven implementation of techno-economical roadmaps for future hydrogen projects in California and serve as best-in-class example for other regions around the country. DOE support of the ARCHES proposal will also be a critical signal to California that hydrogen is a viable path forward to decarbonize the hard-to-directly-electrify sectors. In fact, the substantial cost share from the state ($1.9B) and subsequently from private ($8.1B) and other public ($1.3B) is dependent upon the federal funds, providing an immediate 10x return on the federal investment.

ARCHES-Hub will make significant contributions to reaching DOE's Energy EarthShot production goal of \$1/kgH_2 by 2031 with less than 4 kgCO_2/kgH_2 on a life-cycle emission basis. Although it is not expected that the ARCHES-Hub on average will reach the target in its timeframe, with production (PTC) and low-carbon fuel standards (LCFS) tax credits, some producers will meet the DOE Energy EarthShot (**Table 3.3**) cost targets and without credits reach the interim \$2/kgH_2 target. In general, ARCHES-Hub will establish the marketplace and initial deployments will make great strides in reducing the cost of renewable, clean hydrogen by several times (the average ARCHES-Hub delivered hydrogen cost of [redacted], while realizing a carbon intensity of –0.15 kgCO_2/kgH_2. ARCHES will likewise approach various other DOE technology cost targets, thus helping enable the national goal of 10, 20, and 50 MMTPY of clean hydrogen by 2030, 2040, and 2050, respectively.

3.1.10 Growth Potential and Follow-on Funding from the Private Sector

ARCHES-Hub will build the most replicable and extensible clean hydrogen hub because it will focus on solar and other renewable power sources and leveraging the continually improving California grid. ARCHES will build upon and leverage many historical regulations, incentives, and investments of California in renewable power and clean fuels, which are expected to continue to evolve into the future to provide both "carrots and sticks" to give the regional hydrogen ecosystem long-term financial and operational viability. Solar and wind primary energy resources have been dramatically reduced in cost in recent years, and since scientific analysis predicts that costs will continue to drop as markets grow and new innovations are introduced, we expect the cost of hydrogen, mostly dependent on primary energy costs in the long-term, will continue to decline for decades. DOE, state of California, and private industry investments in hydrogen production, transport and storage, and consumption, together with innovations and scale-up enabled with DOE-sponsored regional hydrogen hubs and with the innovation supported by other DOE investments, will produce low-cost renewable, clean hydrogen in the California region and elsewhere.

In the early years of ARCHES-Hub [redacted] This will make hydrogen a popular choice for replacing diesel in long-haul trucks, port operations, ships, and other applications. After 2027, [redacted] Market lift-off is expected as a result of the federal "production tax credit (PTC)" and "investment tax credit (ITC)" programs for hydrogen combined with our state policy and regulatory framework that is unique to California with its large number of supportive, existing policies and regulations (e.g., Low Carbon Fuels Standard, Cap and Trade, Greenhouse Gas Reduction Fund, Advanced Clean Trucks Program). ARCHES, beyond its ARCHES-Hub, will continue for decades to support the regulatory policies that will lead to adoption of renewable and clean hydrogen technologies in the region and will work with private industry and policymakers to continuously reduce incentives to the point of hydrogen market self-sufficiency in all of the sectors that require hydrogen to achieve zero emissions. An example of California leadership is provided by the California Air Resources Board study entitled "Hydrogen Station Network Self-Sufficiency Analysis per Assembly Bill 8."

While the early years of the California regional hydrogen hub will include very significant funding from the private sector, these investments will often be predicated upon the support of federal funding, state funding, or federal and state incentives to help de-risk such investments. As shown, the private, public, and State investments result in a 10x return on investment from the $1.25B federal funding during the eight years of ARCHES-Hub performance period. Thereafter, we expect orders of magnitude greater private investments in renewable and clean hydrogen production, transmission and storage, and conversion in the region. These investments will be increasingly self-sufficient over time and will ultimately no longer require subsidies or incentives. Hydrogen economy investors will rely upon the ARCHES framework and actions and system analysis in the region to leverage the initial DOE investments made in the ARCHES-Hub to increasingly connect producers and consumers, and to interconnect the California region into the national clean hydrogen network. ARCHES has already reached out to potential interconnections along transportation corridors out of the state that can eventually become pipeline corridors. Finally, neighboring regions such as Oregon, Arizona, and Nevada have abundant renewable resources and thus can provide clean hydrogen to help feed the eventual large, 47,000 MTPD 2045 hydrogen demand in the state.

3.2 Business Plan

Major drivers for the rapid emergence of hydrogen as the fuel of choice for the decarbonization and depollution of hard-to-decarbonize sectors in California are its regulatory environment (see section 1), the increasing commercial availability of hydrogen technologies and equipment, significant funding (federal and state and private sources), and tax credits (both federal and state). Collectively, these drive down the cost of hydrogen by reducing both CAPEX and OPEX in all hub sectors and directly reduce the high cost of doing nothing about GHG and other pollutant emissions. ARCHES plans to apply a "ratchet" type process to match hydrogen production and necessary distribution infrastructure with hydrogen off take over the eight-year project timeline. ARCHES will also fund education and training programs throughout the region in coordination with organized labor, the California Workforce Development Board, private training, and public education resources to meet the growing demand for a competent hydrogen workforce.

The commercial feasibility of critical hydrogen technologies for the ARCHES-Hub is summarized below in terms of business, in section 4 in terms of technology development, and in section 7 in terms of preliminary TEA/LCA. Already, nearly all major hydrogen technologies are at TRL 6 or greater or are expected to be at TRL 8 or 9 by the time the affected hub project will become operational in Phase 4 (see **Table 4.1**).

3.2.1 Key Contracts, Permits, and Offtake Agreements

In line with the current development status of each hub deployment project, contracts, permits and offtake agreements are at different stages. Several production projects [redacted] have started the CEQA (California Environmental Quality Act) process, have engaged with authorities having jurisdiction (AHJ), and have had offtake discussions with companies such as [redacted], and others. All production projects that have not yet done so will begin contracting, permitting, and offtake agreement processes in Phase 1 and complete these by the end of Phase 2. [redacted] and is planning to apply for all other city, county, and state permits. In addition, many of the ARCHES partners are well experienced in permitting and such knowledge will be leveraged throughout the hub so that ARCHES can smooth the way for the projects. [redacted] When needed, ARCHES projects can complete the CEQA process through the California Energy Commission under a new California law (Assembly Bill 205) that provides a 270-day CEQA process for renewable energy projects. In addition, for projects without defined offtake agreements, ARCHES will act as a matchmaker, relying on the systems analysis and overall hub design to ensure that the hydrogen is being produced, distributed, and used in the most economical way for all parties. This matchmaking service will also be based on common carrier principles, resiliency and redundancy, shared maintenance and emergency supply agreements, and standardization and transparency in hydrogen price.

For HRS, individual projects are also at different permitting and offtake contracting stages. [redacted] plans to complete the permitting process for their HRS in Phase 2 and expects to execute several fuel purchase agreements with trucking fleets. [redacted] HRS are currently in process for CEQA/NEPA. [redacted] has several HRS in development for which it has achieved all permitting and is in discussion with the [redacted] for offtake agreements. [redacted] will use the same approach for the planned hub HRS. [redacted] has several Letters of Intent with various companies that have truck fleets, an H_2 purchase agreement with [redacted], and various contracts and lease agreements for future HRS sites. The State has an active program, led by founding member GO-Biz, to help HRS get permitted. In fact, GO-Biz wrote and implements the nation's leading Hydrogen Station Permitting Guidebook.[9] ARCHES plans to assemble a complete overview of the status of feedstocks, supplies, and related offtake agreements during Phase 1 of the hub.

3.2.2 Primary Site(s) Selection

Figure 3.9 shows the map of the ARCHES-Hub deployment sites across California and focused in four regions, although the HRS network will extend beyond them, assuming connectivity to other hydrogen markets outside of California. It should be noted that most of the sites for the deployments have been chosen with site control achieved (see enclosed Locations of Work document for specific addresses) except for some of the HRS that will be defined in Phase 1 pending discussions with OEMs and others.

[9] California Governor's Office of Business and Economic Development Hydrogen Station Permitting Guidebook, September 2020.

3.2.3 Market and Hub Financial Analysis

Due to the aforementioned drivers, the hydrogen market is developing rapidly. DOE and state funding reduce the risk for private sector investments as they lower CAPEX costs significantly and help lower the cost of hydrogen fuel as it moves from producer to consumer. ARCHES producer projects are fed by electricity behind the meter, significantly lowering the cost of hydrogen at the point of production (see production **Table 3.3**). Most electrolyzer-based projects are also designed to have a direct grid connection when needed to increase electrolyzer capacity factors during times when renewable energy production is not sufficient and are looking into the use of new renewable energy credits to ensure meeting PTC qualification.

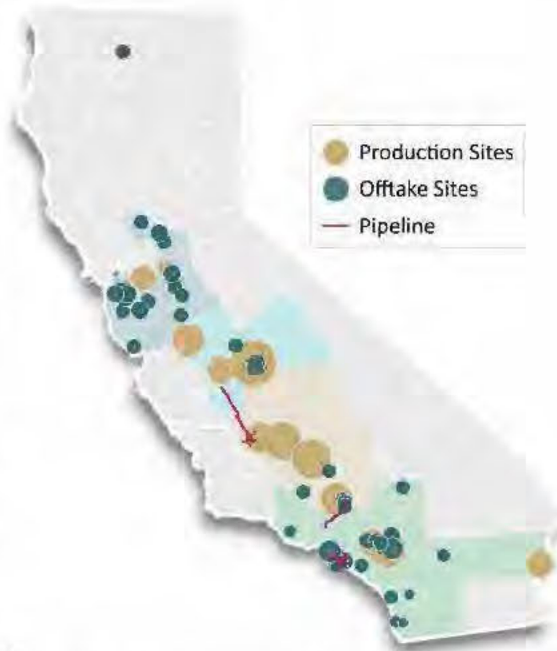

Figure 3.9: Primary project deployment site map

[redacted] Based on detailed analysis by various ARCHES partners and by examining cost parity with today's fuels, we arrive that market viability for different sectors in terms of price [redacted] Thus, based on the deployment mix within ARCHES-Hub, these markets will be enabled without factoring in future cost reductions due to scaling and new technologies. In addition, the spread in delivered prices for the different production avenues (see **Table 3.3** with additional costs added for delivery via pipeline or liquid carrier) [redacted] which demonstrate that even some of the harder cost requirement markets (e.g., aviation) can be met. Finally, using the average production price of hydrogen in [redacted].

[10] DoE National Clean Hydrogen Strategy and Roadmap, U.S. Department of Energy, Draft – September 2022.
[11] Pathways to Commercial Liftoff: Clean Hydrogen, Department of Energy, March 2023.

Market liftoff is heavily dependent on the guarantee of the cost of hydrogen (for end use), a market for hydrogen (for production), or the associated infrastructure to transport the hydrogen (e.g., for power). ARCHES effectively makes "an omelet from the chicken and egg dilemma" by utilizing a systems analysis approach coupled with coalescence of the major market players to build synergies by balancing supply and demand with critical infrastructure development to achieve system liftoff over time.

3.2.4 Feedstock, Supplies, and Offtake Agreements

In line with the current development status of each hub project, agreements for feedstock, supplies, and associated offtake agreements are in different phases. The larger and scalable all-electrolyzer-based production projects are located in close proximity of large solar farms or have rights to the land to build them, have or are negotiating water agreements with town or county municipalities (typically wastewater or produced water resources), and are strategically located near major power grid access points (and in varying stages of interconnect access with most having submitted applications or having rights) to switch over to grid electricity when renewable supply is not sufficient for those wanting to balance with grid power. For biomass conversion, [redacted] ARCHES will assemble a complete overview of the status of feedstocks, supplies, and related offtake agreements during Phase 1 of the hub.

3.2.5 Growth Plan

California has taken a leadership position in climate change by committing to a carbon-free economy with 100% clean electric grid (Senate Bill SB 1020) and 85% greenhouse gas (GHG, baseline 1990; Assembly Bill AB 1279) reduction by 2045. Given the limitations of direct electrification, hydrogen plays a critical role in achieving these ambitious climate goals. Recognizing this, California has enacted many laws that support hydrogen for zero emissions, renewably fueled transportation, energy storage, and decarbonization (SB1014, SB1020, AB1279, SB905, executive orders N-79-20, B-48-18). With broad industry support, the state has authorized billions of dollars in support of its future hydrogen economy, as seen in Governor Newsom's letter of commitment to provide cost share to ARCHES projects—if the DOE chooses to fund ARCHES. As noted above, the DOE federal hub funding will be the catalyst to enable and unlock the much greater portfolio of projects and interests in the hydrogen marketplace in California. With the DOE funding, this larger ecosystem including maritime, aviation, national and international transportation corridors, and a substantial expansion of production, fuel-cell powered backups, and fuel-cell powered medium and heavy-duty vehicles will become a reality, reaching our 47,000 MTPD forecast by 2045. With continued improvement in technology, ARCHES will play a role in translating that to the deployments so that economies of scale and cost reductions are realized, thereby opening up more markets (e.g., ammonia for agricultural use). Finally, almost all the projects described above are scalable in their locations and expected to grow as additional adjacent sites can be negotiated after successful closing of the hub funding or more end-use procurements as comfort and familiarity with the technology as well as the increased infrastructure occur. The various ARCHES-Hub deployments are backed by organizations with a commitment towards hydrogen and their clean energy goals.

3.3 Management Plan

ARCHES has assembled initially 51 partner recipients within 39 deployment projects and 5 crosscutting efforts to rationally deploy hydrogen technologies in production, transportation (FCEB, FCET, aviation, maritime), power, and three ports. As part of this process, ARCHES has already had numerous negotiations and formed a level of support amongst its partners that will enable rapid advancement through Phase 1 of the hub. ARCHES would kick-off a first hub meeting with its founders, stakeholders, and partner recipients, estimated to be in January 2024 or earlier, to organize the hub, provide ways of working together, communication plans, meeting schedules and hub short, medium, and long-term targets, and rollout requirements for the detailed hub planning phase, including community benefits plan actions. ARCHES will provide the stewardship needed to navigate a project of this size to a successful hydrogen hub ready to interconnect with other hubs and ready to lift-off towards commercial success.

3.3.1 Organization

The ARCHES-Hub executive team and management structure is designed to provide oversight and execute on the projects in a timely, agile, and robust manner (**Figure 3.10**). Although its umbrella organization, ARCHES H2 LLC, is a new organization, it is backed and supported by organizations (e.g., UC, State of California) with a long history in complex and large (multi-billion dollar) federal- and state-funded projects and is teamed with key industrial partners that have extensive hydrogen experience, and, as shown in **Figure 1.3**, in a network of over 280 public and private organizations. This structure provides experience and guidance for the ARCHES-Hub executive team.

The Chief Executive Officer of the hub will have oversight of the entire hub project and will be supported by an executive team in charge of community benefits, operations, finance, technology, and deployments (especially engineering, construction, and operations). Below those levels, key personnel such as analysis lead, safety officer, etc. will support the activities and project management. Oversight will be conducted by dedicated project liaisons assigned to each project and reporting to the executive team. Finally, appropriate staffing (contracting, finance, legal, administration, etc.) will ensure rapid and responsive organization. Overall, the ARCHES organization itself is relatively lean. The crosscutting activities such as workforce development; safety, codes, and standards; security and risk issues; systems analysis; market development; and community benefits and engagement will interact across projects and report through a respective executive officer as shown in **Figure 3.10**. Finally, the hub will engage knowledgeable expert advisors and organizations taken from the hydrogen ecosystem (cognizant of any conflicts of interests) to help inform and monitor overall sector deployments and markets.

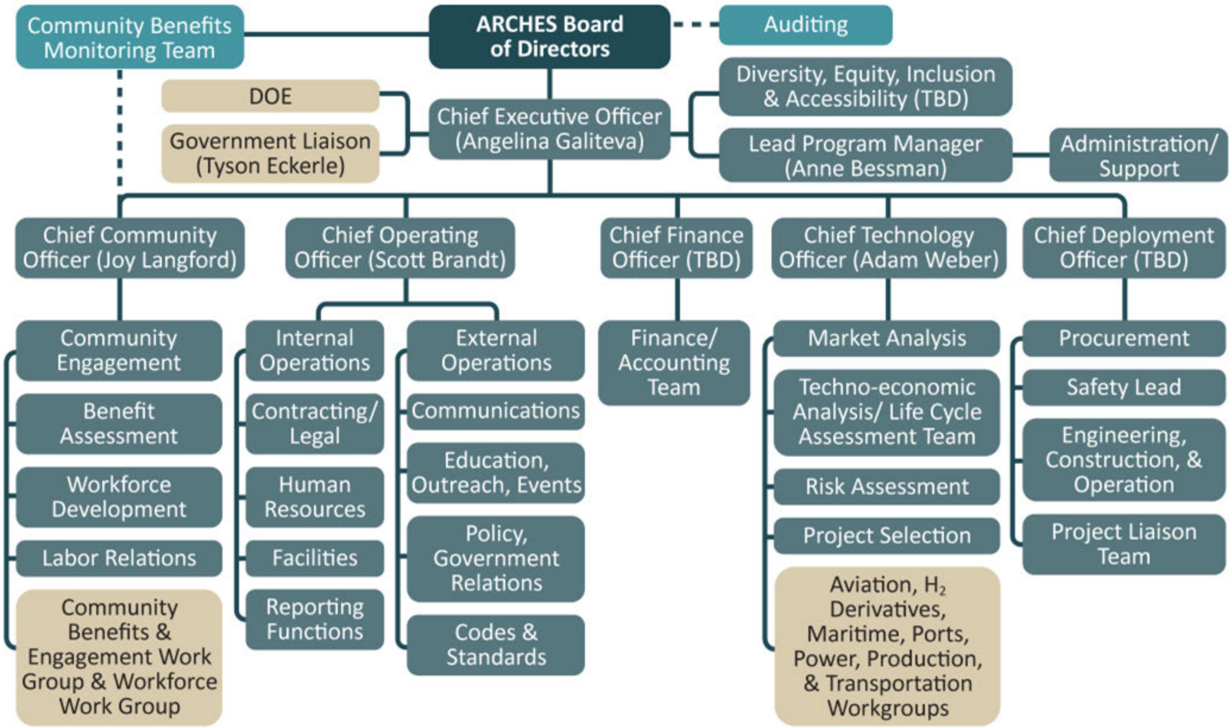

Figure 3.10: Organization chart for the Arches-Hub.

3.3.2 Management Team

Ms. Angelina Galiteva—CEO. Founder and Board Chair of Renewables 100 Policy Institute, dedicated to accelerating global transition to 100% renewable energy. Eleven years on the California Independent Systems Operator Board overseeing large-scale renewable integration. As Executive Director of Strategic Planning for LADWP, she oversaw the utility's renewable energy program. She has extensive executive leadership experience and is an attorney with JD and LLM degrees in International and Energy Law. **Dr. Scott Brandt**—Chief Operating Officer. Associate VP of Research & Innovation at UC Office of the President. Professor and former Vice Chancellor at UC Santa Cruz. He has held many leadership positions, including as PI of UC's NASA UARC with Ames Research Center, and has had extensive collaborations with UC's DOE National Labs. Fellow of the National Academy of Inventors. **Dr. Adam Weber**—Chief Technology Officer. He has over 20 years of experience in hydrogen and is a Senior Scientist at LBNL, where he is the Program Manager in charge of Fuel Cell and Hydrogen Technologies, Energy Conversion Group Lead, and co-Director of the DOE Million Mile Fuel Cell Truck Consortium. He is also a Fellow of the Electrochemical Society. Those outside activities result in his time (~35%) being less than full time. **Ms. Joy Langford**—Chief Community Officer. She is president of Joy Langford and Associates, a firm dedicated to increasing Public Private Partnerships to underserved communities in the State of California. Currently, she is also the Director of Water for Water Replenishment District, Division 1, serving over 4 million residents in South Los Angeles with clean, safe, and affordable water. Previously she was a senior environmental policy advisor for the California Legislature. She is a trained economist with a specialty in Race Studies and Urban

Planning from UC Santa Barbara. Her other commitments result in her time (40%) being less than full time.

The Chief Financial Officer and Chief Development Officer will be confirmed and hired in Phase 1 after an international search.

Key personnel and other advisers include:

Mr. Tyson Eckerle—CA State Liaison. Governor's Office of Business & Economic Development Senior Advisor for Clean Infrastructure and Mobility, Hydrogen Hub lead, and hydrogen market implementation and policy lead. Lead author of California's initial Hydrogen Station Permitting and Electric Vehicle Charging Station Permitting Guidebooks and ZEV Market Development Strategy. **Dr. Anne Bessman**—Lead Program Manager. Strategic Advisor in the Strategy and Program Management Office at the UC Office of the President with a dual appointment to the Research & Innovation Department. With over 10 years of program management experience and a background in research science (including at the NIH and Sandia National Laboratory), she brings extensive experience in organizational and process design. She will be 50% time on ARCHES and the rest conducting other opportunities and activities with UCOP. **Mr. John Harriel Jr**.—Senior Advisor on Community Benefits. "Big John" is Chair of the IBEW Local Union 11 Board and Superintendent and Diversity Manager for Morrow Meadows and mentor at South LA post-prison re-entry program 2nd Call. Founder of the nonprofit Big John Kares, which promotes educational equality and job access for inner-city kids. **Dr. Hanna Breunig—**Systems Analysis lead that oversees the hub TEA/LCA efforts, including air quality, water resources, hydrogen production, use, and distribution, etc. She is the co-director of the HyMARC consortium and has over a decade experience in hydrogen-related TEA/LCA. She will be working 20% time with the rest focused on her other projects at LBNL. **Mr. Jaimie Levin**—Senior Advisor on Transportation. Senior Program Manager and Director of West Coast Office for the Center for Transportation and the Environment. Former Director of Environmental Technology at AC Transit. He spent 23 years developing and managing FCEB and hydrogen infrastructure projects. He will be in charge of coordinating with transit and advising on FCET rollout including leveraging extensive experience in existing NorCal Zero project and lessons learned. He will be 40% time as he will continue to focus on other related activities at CTE. **Dr. Plamen Atanassov**—Senior Advisor for Business Development and production. He will focus on nurturing business interactions and market analysis. He is Chancellor's Professor at UCI and has led multiple projects and collaboratives, including those funded by the DOE. He has strong connections to the hydrogen industry and national laboratories. He is a Fellow of the National Academy of Inventors with 56 issued US patents, more than half of which are used by industry. He will be 40% time with the remaining being his academic responsibilities. **Dr. Jack Brouwer**—Senior Advisor for Technology Implementation including Ports and Power. He will advise on the implementation strategies and interactions, especially in the port and power sectors. He is Professor of Mechanical and Aerospace Engineering and Director of the National Fuel Cell Research Center (NFCRC) and Advanced Power and Energy Program (APEP) at UCI. He will be 40% time with the remaining being his academic responsibilities. **Dr. Jay Keller—**Senior co-Advisor for Safety, will help oversee the safety codes and standards in coordination with existing and future activities by the Building Trades. He is a former hydrogen lab program manager at Sandia National Laboratory and sits on various code bodies and consults with DOE on hydrogen safety. He will be 25% time with the rest being focused on his other activities. **Ms. Jennifer Hamilton**—Senior co-Advisor for Safety, will work with Dr. Keller in overseeing the safety, codes, and standards activities. She is currently the Deputy Director at the California Hydrogen Business Council and has 15 years of experience in safety, codes, and standards. She will be 10% time with the rest focused on her other activities.

Other key positions will be filled by highly qualified experts through an international external search in Phase 1.

The executive team will be responsive to the Board, where overall decisions concerning ARCHES will be made. As shown in **Figure 1.2**, the small Board of 11 members has diverse representation and will be initially chaired by **Dr. Theresa Maldonado–Board Chair**. Vice President for Research & Innovation, UC Office of the President. Former Dean and Professor of Engineering at UT El Paso. Former Associate Vice Chancellor for Research at the Texas A&M University System and founding Director of the Texas A&M Energy Institute. She was previously a division director in the Engineering Directorate at the National Science Foundation (NSF), where she was responsible for interdisciplinary research centers, research translation, and workforce development programs, among many other things. **Ms. Dee Dee Myers—Founding Board Vice Chair**. Senior Advisor to the Governor and GO-Biz Director. Former Exec. VP of Worldwide Communications and Public Affairs for Warner Bros, Managing Director of the Glover Park Group, and White House Press Secretary. **Mr. Chris Hannan—Founding Board Member**. Executive Secretary LA/OC Affiliate State Building Trades Council of California and statewide ARCHES representative of the State Building Trades Council of California.

ARCHES will leverage the University of California system's management acumen, including running three DOE National Labs, and subject matter experts who have actively researched hydrogen for decades, and can help guide, analyze, vet, and inform the projects. Of critical importance are the industrial project partners in this proposal who bring deep and extensive practical experience in hydrogen development and deployment (see **Table 3.11**).

Table 3.11: Overview of Project partners and their relevant experience

	Project Partner Contact	Experience
Production		
[redacted]		

[redacted]

3.3.4 Experience

ARCHES founding members and partners have extensive experience in hydrogen and/or large construction projects including those with federal grants. In addition, the more experienced partners in certain areas (permitting, installation, etc.) will support others who may not be as experienced, which is one of the many activities to be facilitated by ARCHES and what will contribute to making the hub to be greater than the sum of its parts.

For example, in terms of ARCHES founding members, the UC System, a ~$50B/year enterprise, has managed and run major construction projects that are on par with the hub activities. This includes running 10 campuses, three DOE national laboratories, and five major health centers, each with their own complex sustainability and infrastructure projects. UC is collectively one of the premier research institutions in the world, with vast experience, expertise, centers and institutes, and ongoing research in hydrogen energy, energy policy, labor economics, community engagement, environmental justice, DEIA, and many other related areas. ARCHES has drawn extensively upon the UC and UC National Labs' network of experts and will continue to do so as the ARCHES-Hub moves forward.

The UC system has led or partnered on numerous significant infrastructure projects. A few of them include:

- UC San Francisco Mission Bay Hospital Complex. Budget: ~$1.5B
- The UC Merced campus, the newest campus in the UC system and the nation's first major research institution of the 21st century. Since admitting its first undergraduates in 2005, UC Merced has demonstrated sustainability success in everything from green building and water conservation and efficiency to procurement. Further pushing the boundary, UC Merced has established the Triple Net Zero Goals: a set of goals for the campus to ultimately produce as much power as it uses, create zero landfill waste, and achieve climate neutrality. Initial budget: $1.3B.
- The UC System is a major partner in the TMT International Observatory. Estimated budget: $2.65B.
- UC Irvine, home to the National Fuel Cell Research Center and a hydrogen fueling station, is currently partnering with SoCalGas to demonstrate hydrogen use in its existing natural gas infrastructure on campus.

ARCHES' project partners have extensive experience in relevant projects including in major hydrogen infrastructure.
Some illustrative examples are:

Air Products [redacted]. This includes [redacted] of large-scale clean H2 projects worldwide. These large-scale clean H2 projects under construction include:

[redacted]

With the market knowledge, project execution experience, company financial strength, and an already substantial position in the hydrogen business in California, Air Products is the ideal partner to help develop a regional H2Hub that will rapidly advance the production and consumption of H_2 in California and throughout the US. Air Products has extensive experience developing and executing large capital projects in all phases of H_2 production, distribution, and utilization and brings a long history of working in collaboration with the DOE to successfully develop technology commercialization projects. The Air Products VSA CO_2 capture technology commercialization project in Port Arthur, Texas, that was conducted in 2012 is an example of

DOE funding being successfully deployed to enable technology advancement in the carbon capture space.

Intersect Power has developed, financed, and constructed some of the largest solar PV projects in California, with an average project size of ~550 MWp of solar PV and ~725 MWh of storage. Developing projects at this scale requires the permitting and acquisition of thousands of acres of land across multiple landowners and agencies, interconnection at the highest voltages that require engineering sophistication, structured offtake agreements across multiple buyers, and billions of dollars in capital from the project finance markets. In Intersect Power's brief six-year history, 675 MWp of solar PV and 448 MWh of co-located storage has been completed on-time and is now operating in California, and another [redacted] of co-located storage will be online in California by the end of next year. By the time this project, the [redacted], is expected to be in operation, Intersect Power will have more than two years of operations experience on managing a portfolio of more than [redacted] of battery storage that is either already online or expected to be online by the end of 2023. Intersect Power's southern California portfolio reflects our commitment to and collaboration with historically underserved communities. On recent projects i[redacted] CA, Intersect Power worked with construction contractors and local unions to hold job fairs on nearby tribal reservations to ensure our projects provide economic opportunities for these disadvantaged communities. The projects covered union training costs for interested tribal members and employed tribal members throughout the construction process. Each of these Riverside County projects also employed tribal monitors to ensure projects minimize impacts to historic and prehistoric cultural resources.

LADWP has built, maintained, and operated power plants for over 100 years. LADWP currently owns and operates four generating stations within the LA Basin in addition to Apex Generating Station in Nevada. LADWP has the technical expertise and project management experience that has resulted in the successful build-out of new power generating units as recently as 2015. What is more, LADWP is co-leading IPP Renewed1 (Utah facility), a first-of-its-kind project to replace the coal-fired power plant with hydrogen-capable combined cycle units collocated with utility-scale electrolyzers and salt-cavern hydrogen storage, all of which will be operational by 2025. The organization is deeply committed to achieving 100% carbon-free energy while ensuring reliable service, maintaining cost-effective rates, and improving environmental equity outcomes. It views green hydrogen as one of the key enablers to achieving these ambitious goals. In 2015, LADWP completed the Scattergood Unit 3 Repowering, a billion-dollar project in which a combined-cycle and two simple-cycle turbines were commissioned to improve system reliability and reduce emissions ocean-water once-through cooling. The Scattergood Unit 3 Repowering was procured and constructed under an EPC contract process. LADWP will build the future [redacted].

First Element Fuel (FEF) has the largest retail hydrogen refueling station network anywhere in the world, with 39 open retail stations representing over 70% of the market in California and delivering 1.7 million kg of hydrogen per year. This has been due largely to the public-private-partnership with the state of California (CEC and CARB) and FEF Investors and Partners. FEF is also completing the first-of-its-kind heavy-duty truck refueling station in Oakland as part of the NorCal Zero project. These experiences have provided the unique capabilities, expertise, and lessons learned that will allow FEF to execute on the HD HRS for the ARCHES-Hub.

POLA/POLB The Ports leadership and project team are highly reputable and trusted in the industry, with decades of demonstrated experience driving the establishment of long-standing relationships with public and private partners, seaports around the globe, and surrounding neighboring communities. The project team has successfully executed grant-funded projects valued at billions of dollars, ranging from major infrastructure to individual equipment demonstrations. The Ports and their project partners currently have diverse ZE battery electric and HFC demonstration projects of diverse scope currently underway and at different stages (e.g., California Joint Electric Truck Scaling Initiative, Toyota Tsusho America, Inc Zero-Emission Port Equipment & Hydrogen Supply Demonstration Project, SCAQMD – Daimler Zero Emission Trucks and EV Infrastructure Development and Demonstration Project, US DOE Zero Emission Cargo Transport Demonstration [ZECT II], Everport Advanced Cargo Handling Demonstration Project, etc.). Experiences and lessons learned from these demonstration projects are an invaluable contribution to the development and implementation of this proposal. The Ports are regularly engaged in international efforts advancing clean hydrogen development in goods movement operations as well. The European Hub, spearheaded by the Port of Hamburg, is called the Clean Port & Logistics Innovation Cluster (Hydrogen Cluster). The Hydrogen Cluster provides a test field at the Hamburg container terminal Tollerort, allowing real-life operation tests of hydrogen-powered terminal equipment. The Port of Los Angeles is a paying member of this cluster, meaning successes and lessons learned from this proposal have potential for international implementation.

3.3.5 Pending Investigations

ARCHES and its partners, to the best of their knowledge, and after surveying its partners as of March 2023, have no pending or threatened action, suit, proceeding or investigation, etc. by or before any governmental authority that relates to the hub personnel.

3.4. Financial Plan for the Hub

ARCHES requests $1.25B federal share for this proposed hub and plans to contribute $11.3B in cost share [redacted] over the eight-year project duration (2024–2031). The proposed cost share from the state of CA is subject to future appropriations (similar to any future funding commitments) and contingent on the federal funding and hub being approved. These combined funds will be used for project development, land and services, permitting and environmental tasks, procurement (of equipment, FCETs, CHE, FCEBs, etc.), construction services, construction, commissioning, and ramp-up to full operation.

Preliminary estimates show that the ARCHES-Hub will produce by 2030 over 515 MTPD of hydrogen, [redacted]

[redacted] 1080 transit buses and 22 HRS dedicated to transit, 5500 FCE trucks, [redacted] H_2 CHE within the ports, and the necessary distribution and buffering infrastructure [redacted] to connect this hydrogen supply and demand. The proposed hub funding has been summarized in **Table 3.12**.

[redacted]				
[redacted]	[redacted]			
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

3.4.1 Prime Applicant and Project Partners

ARCHES LLC is the prime applicant and is owned by the four founding members as shown in **Table 3.13**. The founding members are all established entities that oversee billions of dollars of investments (State, UC), hundreds of thousands of workers, and tens of billions in annual budget,

[redacted]		
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

including training, etc. (state building trades) and policy implementation (Renewable 100, which has been an NGO advocating for 100% clean power for over 15 years). ARCHES is currently funded via Go-Biz by the State of California and by UC Office of the President (UCOP). Increased funding for ARCHES as it ramps up the organization needed to manage the ARCHES-Hub has been included in the budget spreadsheet, [redacted]

[redacted]

Project partners range from publicly traded, profitable multi-billion-dollar companies (e.g., AES, AP, Linde, Chevron, etc.) to smaller privately held companies (Mote, H Cycle, etc.) who have substantial funding from corporate investors. All our Tier 1 partners are prepared to make significant cost-share contributions to the ARCHES-Hub as shown in **Table 3.14** and the overall by phase and sector breakdown in **Table 3.12.** See the detailed SF424 budgets for individual partner funding and cost share by phase, where the Phase 4 activities are nominally any working capital for operation and not necessarily the expected full operating expenses as those are not leveraging or relying on the federal hub funding.

In addition to the above partners, there are several organizations such as the Fuel Cell Partnership, FCET OEMs, Center for Transportation and the Environment, communities and community benefits organizations, etc. that will receive funding and a full accounting can be provided in Phase 1.

Table 3.14: ARCHES Tier 1 Deployment Project Contributors

Organization	Federal Funds ($M)	Cost Share ($M)
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
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[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

3.4.2. Financial Strengths

The **University of California,** chartered in 1868, is a public university system with 10 campuses, six medical schools, and five academic medical centers. UC is the largest US public university system in terms of revenue, with $46B of operating revenue in fiscal 2022. UC has a significant and highly regarded research component, with $6B of direct expenditures in fiscal 2022. Federal and private funding accounts for three-quarters of revenues supporting these research expenditures, inclusive of UC's operation of the Lawrence Berkeley National Laboratory as well as their joint operation of two other national labs. The system benefits from strong oversight and management, active collaboration across the medical centers, debt and capital planning, addressing of long-term post-employment benefit liabilities, and is an important regional catalyst for economic growth and innovation. UC has AA- (Fitch) and AA2 (Moody) bond ratings. **GO-Biz** serves as the State of California's leader for job growth, economic development and business assistance for the fourth-largest economy in the world. The State of California manages an annual budget of well over $200B. The **State Building and Trades** represents over 157 unions within the State of California, including a $250M annual training program. They have 66,000 apprentices and 500,000 union members with annual operating revenue of $6M, not including the training program. **Renewables 100 Policy Institute** is a 501c3 nonprofit, all-women lead organization that since its inception in 2007 has partnered with and administrated grants for numerous nonprofit organizations, as well as federal, state, and international government bodies, including the US Department of State, the US Department of Commerce, the Office of the Governor of California, the California Energy Commission, the German Federal Environment Agency, and several regional grid operators, with a focus on developing public-private partnerships and convening stakeholders from multiple disciplines to accelerate the transition to 100% renewable energy across sectors in ways that are most economical, ecological, and just. Renewables 100 Policy Institute has been in good standing since its establishment, with an annual budget in the hundreds of thousands of dollars plus matching in-kind partnerships valuing >$500,000, holds a current reserve in excess of $100,000, and is internationally recognized as one of the most effective and impactful leaders in the global transition to a carbon free future.

The financial strengths of our partners are described by way of several examples from our broad portfolio of partners:

Southern California Gas Company is the largest natural gas distribution utility in the country and is a subsidiary of Sempra Energy, a Fortune 500 energy services holding company that had [redacted]) in revenue in 2022. SoCalGas has an investment credit rating of A2 (Moody's) and A (Fitch) and has initial authority from the CPUC to explore the Angeles link using rate payer funds.

LADWP: The fiscal health or strength of an organization can be best indicated by financial metrics. LADWP utilizes three Power Financial Metrics: Capitalization Ratio, Operating Cash Target, and Full Obligation Ratio. These metrics are designed to ensure stability of LADWP finances and ability to pay debt service when due and are the primary basis for rating agencies to assign credit ratings for the Power System. The Department closely manages and monitors the Power System's key financials to avoid the deterioration of these metrics and are subject to ongoing reviews with the LADWP's financial advisors. Maintenance of strong credit is of the utmost importance for the Department, as it ensures continued access to capital markets and low-cost financing. The major credit rating agencies—S&P Global Ratings (S&P), Fitch Ratings (Fitch), Moody's Investors Service

(Moody's), and Kroll Bond Rating Agency (Kroll)—continually assess the credit of entities and ascribe ratings to their bonds. S&P, Fitch, Moody's, and Kroll currently rate the Power System at AA-, AA-, Aa2, and AA respectively. The expected debt funding for the LADWP's Power System is fixed-rate, long-term debt. LADWP has a history of healthy debt service coverage and reserve levels and operates on a capitalization ratio of 68% at the time of this writing.

AES & Air Products: Air Products had fiscal year 2022 sales of [redacted] from operations and has a current market capitalization of about $70B. Given the size of the company, its investment-grade credit rating (D&B 5A2 rating, S&P A rating, Moody's A2 rating) and strong cash flow, Air Products can self-finance the required matching funds needed to execute Phase 1, Phase 2, Phase 3, and Phase 4 of the proposed hydrogen production project if there is a binding commitment to receive the support funding upon successful start-up of the facilities.

The AES Corporation is a publicly traded, investment-grade rated Fortune 500 company. AES has access to both debt and equity capital markets for capital needs and raises. AES had a fiscal year 2022 revenue of [redacted] and has a current market capitalization of $[redacted]. AES can self-finance the matching funds needed to execute all phases of the proposed hydrogen production projects.

Linde: In 2021, Linde's cash flow from operations was [redacted] above 2020. Capital expenditures were [redacted] versus prior year. The company's net debt (ND) for 2021 was [redacted] and adjusted EBITDA was [redacted], ending the year with a ND/Adj. EBITDA of [redacted]. The company's credit rating from Moody's and S&P's is A2/A, respectively. The company maintains a [redacted] unsecured and undrawn revolving credit agreement with no associated financial covenants. No borrowings were outstanding under the credit agreement as of December 31, 2021. The company does not anticipate any limitations on its ability to access the debt capital markets and/or other external funding sources and remains committed to its strong ratings from Moody's and S&P.

Nikola: Nikola is looking at various options for individual station financing and will leverage capital from its balance sheet and from partners to meet the cost-share obligation. In November 2021, Nikola was awarded $1.66M from the Mobile Source Reduction Committee to install a publicly accessible MHD HRS at its site with TravelCenters of America in Ontario, CA. [redacted]. If policy implementation by CARB's Low Carbon Fuel Standard allows, Nikola will utilize hydrogen refueling infrastructure crediting to reduce operational expenses.

H Cycle: (1) Development capital (Phases 1 and 2 spend) [redacted] These funds are being used for project-specific detailed engineering, site control, interconnection process, permitting, community benefits, commercial negotiations, and consultants. [redacted]

[redacted] (2) [redacted] pre-purchase [redacted] This facility was provided by LLCCI in 2021 to accelerate deployment of H Cycle's first project in California. Funds are being used for detailed design and engineering, procurement, and manufacturing of the first unit by [redacted]

Intersect Power: Intersect is developing the [redacted] to access the project finance markets for non-recourse construction debt, term debt, and tax equity. Intersect Power raised [redacted] in non-recourse financing in 2021 and 2022 from market leading financial institutions to fund the construction of its 2.2 GW portfolio of PV and 1.4 GWh portfolio of storage projects currently under construction in California and Texas that will be online in 2023. Intersect Power plans to leverage our experience and relationships from these transactions to raise the capital required to construct the [redacted]. Intersect Power has sufficient development capital to advance the project to the start of construction, having raised [redacted] to fund development activities [redacted] Intersect Power also has extensive experience tapping the debt markets for development capital. Strategically, the H2Hub provides the [redacted] with grant funding to help secure further project financing, as well as strategic partnerships with other hub participants. The grant also significantly decreases the cost to produce hydrogen, a benefit that can be passed on to end users to spur greater demand for green hydrogen.

3.4.3 Other Federal Support

Most proposed projects have not applied for other federal support. Some of the projects are leveraging other federal funds for adjacent activities such as FCEB purchases from the transit agencies, but this will be tracked separately. Specifically, [redacted] has a pending DOE loan guarantee but will not use this as part of the proposed cost-share funding.

In terms of tax credits, there are the PTC and ITC from the IRA, which are being vetted with the IRS and under Treasury rules. We expect these to be available based on the extensive LCA that will be conducted, including the preliminary results in the attached spreadsheet and section 7. It is possible that during the timeline of the hub that additional federal money, including the DOE loan program, may be used. In this instance, the federal funding for a given project will always require 50% of non-federal cost share. However, when additional federal funds create an issue, the project will be placed outside of the ARCHES-Hub program and a Tier 2 project will substitute for the affected one.

3.4.4 Non-federal Support

As the levelized cost of hydrogen is one of the key drivers for hydrogen adoption that will be driven down by ARCHES-Hub (and by other hubs), there is a need to utilize incentives to further drive down the cost and thus promote adoption and economies of scale. Thus, projects will utilize LCFS, clean fleets, etc. (see section 7 for some preliminary analysis). [redacted] where the State contributions will come from existing and future programs. While there are no clawbacks of funds, the State funds are contingent on the federal hub award funds (i.e., ARCHES-Hub being funded) and may not be applied towards hydrogen technologies without such an award and signal.

4. ENGINEERING, PROCUREMENT, CONSTRUCTION AND OPERATIONS

4.1 Technology

The technology readiness levels of the ARCHES-Hub project deployments are relatively high, with the vast majority being at 8 or 9 today. All components are expected to be at a TRL of at least 8 by the end of 2031 (100% H2 capable turbine). Table 4.1 provides an overview of the TRL levels of key equipment.

Table 4.1: Technology readiness levels of major equipment by sector

	TRL		TRL		TRL
Production		**Transit**		**Ports**	
Electrolyzer	6-8	FCEB (40' and 60')	8	Stationary CHE	5-7
Gasification unit	7-9	HRS	9	Mobile Refueler	8
Waste conversion unit	8			Drayage trucks	8
Balance of plant (BOP)	9	**Transportation**		BOP	9
Liquefaction plant	9	HD truck Class 8	7		
Power Sector		HD truck Class 6	8	**Infrastructure**	
H2 capable turbine (30%)	8	Vessel	7	H2 pipeline	9
H2 capable turbine (100%)	6	Airplanes	5	HD HRS	7
Stationary fuel cells	7			Storage tanks, etc.	8-9
BOP	9				

4.1.1 Conceptual Engineering Design—Process Flow Diagrams by Sector

As the specific deployments have many variations and are extensive, here we present representative process diagrams of major ARCHES-Hub project motifs including electrolyzer-based production, biomass-based production, power-plant-based offtake, and hydrogen refueling stations. The overall ARCHES-Hub process flow diagram is shown in **Figure 3.7**, and the process diagrams presented here are expansions of the higher-level process elements. Other process flow diagrams are available upon request.

4.1.1.1 Production—Electrolyzer-based [redacted]

Renewable-based electrolysis of hydrogen is the majority production of clean, renewable hydrogen within ARCHES. This is being accomplished through either alkaline (TRL 8) or large-scale proton-exchange-membrane electrolyzers (TRL 6) using various vendors. Water treatment, hydrogen purification, and process cooling are at TRL 9 + (commercially proven). Hydrogen compression and storage also are at TRL 9 + (commercially proven).

System integration (based on the [redacted] production project, see **Figure 4.1**): A solar PV facility [redacted] is located on approximately [redacted] acres of land optioned for purchase from the [redacted] and will connect to the California Independent System Operator (CAISO) transmission system. [redacted]

[redacted]

Figure 4.1: Representative process flow diagram for all ARCHES-Hub electrolyzer-based production projects. *Note: Most will deliver to buffer/storage and not directly to a pipeline within the hub timeframe.*

4.1.1.2 Production—Municipal Solid Waste Based [redacted]

The Project consists of three distinct and proven industrial processes, which are all TRL 8 or 9: Waste Preparation Unit (TRL 9); Waste Conversion Unit (TRL 8); Hydrogen Production Unit (TRL 9). The waste preparation unit consists of material handling, processing, and storage equipment (including conveyors, shredders, magnetic and non-magnetic separators, plastic removal, etc.), which is found in common use across the waste management and recycling industries. These processes and components are at TRL 9. The waste conversion unit is supplied by [redacted] has been rated TRL 8 by two independent engineering firms[redacted]. More than 80 plants with similar types of municipal solid waste (MSW) conversion processes currently operate globally. The hydrogen production unit consists of processes and equipment, which are commonplace in refineries and petrochemical plants globally and in the US. These processes are all TRL 9. The MSW-to-hydrogen process diagram is shown in **Figure 4.2**.

This project requires four main utilities: (1) electricity, (2) heat, (3) process water supply, (4) wastewater treatment and disposal. [redacted] has already provided estimates for interconnection expense and water usage costs and can readily accommodate our needed water volumes. For wastewater treatment and disposal, the project plans to sign an agreement with the neighboring [redacted] wastewater treatment plant for disposal following pre-treatment on site.

[redacted]

4.1.1.3 Production—Woody Waste Based Biomass [redacted]

[redacted] process will use a biomass gasification facility [redacted] design leverages mature technologies, [redacted] team spun the core technology out of research at [redacted]. The least mature component of the system is the biomass gasification unit (TRL 7); however, a [redacted] using wood pellets and other relevant biomass feedstocks. [redacted]

[redacted] The TRL of the integrated system is 7 since the abovementioned projects are not yet complete. However, at the time of deployment, the TRL of the proposed project will be 8 or 9.

[redacted] performed the initial feasibility analysis and TEA of [redacted] systems. [redacted] project to complete [redacted] during the Phase 1 study period. [redacted] will leverage those [redacted]

4.1.1.4 Infrastructure—[redacted] Liquefaction Plant

The [redacted] project will include a new [redacted] total H_2 liquefaction plant using state-of-the-art and proprietary liquefaction technology and machinery to achieve a world-class power efficiency to further reduce the overall carbon footprint of the facility. The liquefaction plant will process H_2 gas generated via electrolysis. The liquefaction process begins with feed gas purification to remove water and oxygen using known catalytic and adsorption technology. [redacted]

[redacted]

The liquefied H_2 is delivered to the liquid H_2 storage sphere for distribution to customers.

4.1.1.5 Production/Offtake—[redacted]*)*

[redacted]

The fundamental design architecture for this project largely depends on existing, well-understood technologies as fossil-fueled gas-turbines and combined-cycle power plants that have been in operation for decades. The critical technology elements for this project are related to hydrogen and its impact on other systems. Since hydrogen burns hotter, changes in hot gas properties for hydrogen operation, especially at 100% H_2 feed, requires verification for compatibility as well as to ensure low NO_x generation, and cooling technologies for hot gas path components. Fuel flexibility between natural-gas and hydrogen is another important area for combustor technology to ensure the units can remain operational through a range of fuel blends, especially considering that the hydrogen supply may not be fully reliable as the infrastructure is being built out. These technology elements are considered TRL 6–8.

In the [redacted] **Figure 4.5**, the process flow comprises an existing [redacted] substation that interconnects with power electronics to feed a PEM electrolyzer system. (It should be noted that the [redacted] has indicated that they would be interested in procurement of excess oxygen produced via electrolysis.) [redacted] In addition, feed pipes will be verified for operation with 100% H_2, including working with ARCHES and other hubs in safety and codes and standards.

4.1.1.6 Hydrogen Refueling Stations for Transportation—[redacted]

Hydrogen refueling stations are a combination of several technologies, most notably on-site storage in the form of above-ground pressure vessels and/or cryogenic liquid hydrogen tanks, hydrogen compression systems, hydrogen cooling systems, fueling communication and control systems, and hydrogen fueling nozzles. Light-duty fueling applications and transit HRS are TRL 8, and there are several suppliers for the primary components. For HD stations, most of the components can be ported over from LD stations, apart from HD capable dispensers/nozzles, which are at TRL 6 and are in active development that ARCHES will leverage. The national hydrogen hub network and standards will ensure compatibility across OEMs and stations both within and outside of ARCHES.

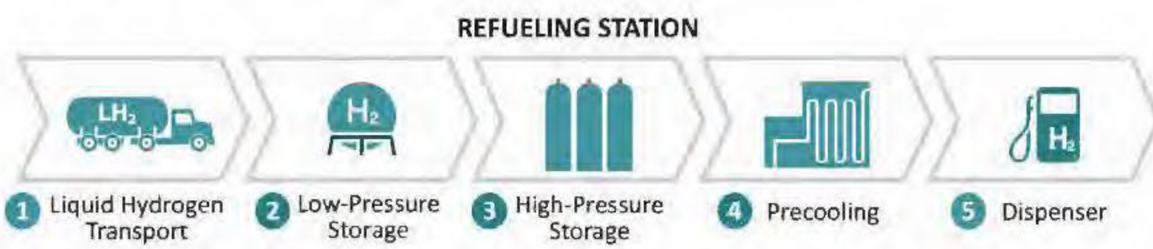

Figure 4.6: Typical hydrogen refueling station process flow diagram

System integration of hydrogen fueling stations into existing facilities is already a model that is being executed in the LD FCEV space in California. Here, existing retail fueling stations offer advantages in location and existing use case where the addition of hydrogen is highly complementary, and this model will be replicated in ARCHES using existing HD stations at key locations, although some new sites are also envisioned (see section 3.1.5.1). The addition of hydrogen requires additional space for equipment and associated electrical upgrades, which is often available at HD sites as they are often along travel corridors that are not densely populated urban centers such as in the LD space.

4.2 Performance Projections

4.2.1 Production

ARCHES as a whole [redacted] is projected to reach 515 MTPD average production with an installed (plate) capacity of 1677 MTPD. Several production sites already have plans for future increases in line with planned increases in nearby solar electricity production and by using modular electrolyzer systems for rapid expansion that leverage existing balance of plant (BOP) and water treatment. For electrolysis, the average capacity factor will be [redacted] with average water use of [redacted] gal/kgH_2 at an average carbon intensity in 2031 of −0.15 kgCO_2/KgH_2.

In terms of production from biomass, [redacted] from municipal solid waste feedstock in a non-combustion thermal conversion process. Annually, [redacted] deployment of the planned biomass gasification facility with integrated carbon capture and geological sequestration will produce [redacted]

4.2.2 Power

LADWP's proposed Scattergood Generating Station Units 1 and 2 will replace 346 MW capacity. Upon commissioning, the new units will be capable of using a minimum of [redacted] hydrogen by volume, which will increase to 100% when supply and combustor technology are available. At the [redacted] and 100% levels, LADWP estimates to use [redacted] and [redacted], respectively, avoiding life-cycle GHG of [redacted] respectively. Similarly, the frequently used, dispatchable power plant in [redacted] will utilize a [redacted] going to a 100% H2 turbine, with an annual consumption of hydrogen expected to be [redacted] respectively and CO_2 avoidance of [redacted] respectively. The [redacted] back-up system will provide key power for water wells during intermittent grid connectivity and will be [redacted] per unit. [redacted] to act as a dispatchable resource and help in grid firming, thereby establishing complementary alternatives to turbines.

4.2.3 Transportation

The 13 participating transit agencies currently have schedules for replacing CNG and diesel buses when they reach their end-of-service life. The primary performance metric will be the number of CNG or diesel buses replaced along with associated pollutant reductions. The goal for the 13 transit agencies is to collectively remove 552 diesel buses and 529 CNG buses. Combined, these 1,080 buses being replaced operate for approximately 191 million miles per year and consume ~500 MMSCF of CNG and ~6 million gallons of diesel fuel each year. Compared to modern fossil fuel buses (model year 2023), deploying zero-emission FCEBs will also reduce direct carbon emissions up to approximately 157,300 MTPY. In addition, compared to modern fossil fuel buses, FCEBs will reduce production of harmful emissions, including particulate matter under 2.5 micrometers ($PM_{2.5}$) by 92 MTPY and NO_x by 515 MTPY.

The primary performance metrics for FCE LD and HD trucks mirror those of transit buses. ARCHES aims to replace approximately 5000 Class 8 and 500 Class 6 HD trucks with FCET versions by 2030.

4.2.4 Ports

Performance parameters for the hydrogen-operated CHE will be similar to those of transit and transportation, reducing both CNG and diesel fuel-based pollution. Another performance parameter will be additional planned orders because of the demonstrated performance of hydrogen CHE within the hub, accelerating the transition to clean hydrogen and zero emissions of the remaining CHE in all three ports.

4.2.5 Infrastructure

All pipelines will use low-alloy carbon steel seamless pipe selected and installed in compliance with ASME B31.12 Standard on Hydrogen Piping and Pipelines. [redacted] is the world's leader in H_2 pipeline design, construction, and operation pipelines, with over 1,000 miles of H_2 pipelines deployed around the world (TRL 9) and possesses the technologies and know-how needed to build and safely operate the pipeline extensions proposed as part of this project. [redacted]

[redacted]

Hydrogen refueling stations for transit buses will have a nameplate capacity of 3 MTPD and HRS for HD FCETs will be in the 4–8 MTPD range (see **Table 4.2**), increasing over time. A specific example for performance targets for First Elements' HRS has been provided in **Table 4.2.** Note that while ARCHES is focused on HD applications, providing an LD dispenser allows that segment to grow outside of ARCHES-Hub and proliferate the H_2 market and ecosystem in the California region.

Table 4.2: Performance projections for FirstElement Fuel HRS	
HRS Technologies	**Performance Targets**
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

Storage—most production sites have somewhere between [redacted]. Nominally, there is some storage in the pipelines but that is not all available as it will decrease in pressure and become unusable as it is being consumed. At the various HRS, there will be roughly an aggregated total of 406 m.tonnes of storage. All told, the ARCHES-Hub will have around 1,700 m.tonnes of H_2 storage, mainly in liquid form and distributed throughout the state.

4.3 Engineering, Design and Procurement

The ARCHES-Hub has a high degree of complexity consisting of 39 deployment subrecipients of which 13 are in the production sector, 6 in the power sector, 13 transit agencies, FCET procurements, 3 ports, and 8 infrastructure projects. For this reason, only representative EPC samples for selected projects are described here. ARCHES has received detailed descriptions for each deployment that can be made available upon request.

In general, ARCHES recognizes the requirements and benefits of the "Build America Buy America" (BABA) provisions, and all deployments will leverage existing US manufacturing and supply chains as possible. All procurements and requests for EPC contracts or equipment will include this language to follow Buy America. However, some critical components necessary for project completion are not produced in the US, so select outside entities will be engaged as we wait and help establish a US manufacturing base. For such components, a waiver or similar process as determined by DOE will be followed that exempts such components from BABA requirements as long as the exemption is congruent with the American public's interest. Similarly, the scope and breadth of ARCHES and the other DOE hydrogen hubs also requires that some procurements occur outside of the US to minimize overall lead times, especially as ARCHES is planned as an eight-year hub, due to the relatively advanced stage of policy in the CA region for hydrogen deployments. Where possible, ARCHES will act as an aggregator to bring down procurement costs and times, including development of a preferred vendor database. This is the approach ARCHES will take in terms of OEMs for FCETs and FCEBs, for example, as mentioned in section 3.1.3.

Due to the complexity of the ARCHES-Hub, a high-level yet quantitatively detailed schematic of interconnection of major equipment including storage and connective infrastructure is not really readable and thus has not been provided, but can and will be provided upon request in Phase 1. However, we would note that the quantitative hydrogen flows from the production projects to the end use ones are captured in **Figure 2.4**. In addition, **Figure 3.1** shows overall interconnections as well with specific end uses noted and sizes, which is spatially resolved in **Figure 3.9** and discussed throughout Section 3 (e.g., production in **Figure 3.2** and **Table 3.3**, infrastructure in **Figure 3.6** and **Table 3.10** for HRS, pipeline in **Figure 3.5**, FCETs in **Table 3.7**, etc.). In addition, **Figure 3.7** shows the overall process flow diagram that is aggregated by sector and shows connectivity. The detailed interconnectivity can be seen as an amalgam of the above noted figures combined with more detailed EPC examples as in **Figures 4.1–4.6.**

4.3.1 EPC Production—[redacted]

Table 4.3 summarizes the equipment list for [redacted] hydrogen production project. The water source will be pretreated in a water treatment plant with an ultrafiltration system [redacted] Waste brine is sent to regional sewer or treatment plant. Demineralized water is fed to the PEM electrolyzer stack, where it is split into hydrogen and oxygen using an electric current.

Table 4.3: Key equipment list

Procurement Activities	Timeline [Months]
[redacted]	[redacted]
Heat [redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

Table 4.4: [redacted]

[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

The oxygen byproduct is saturated with water and is vented to atmosphere through a vent stack. The hydrogen also exits the stack saturated with water. Downstream, a deoxygenation and drying system purifies the hydrogen, removing any excess water vapor or oxygen. Hydrogen will come from the electrolysis plant at approximately [redacted] bar and be compressed to appropriate pressure per the delivery method (e.g., pipeline, liquefaction plant, FCET carrier). [redacted]

[redacted] will issue an RFP for the construction of the hydrogen production facility and has developed the procurement schedule shown in **Table 4.4**.

4.3.2 EPC—LADWP Scattergood Power Plant

LADWP proposes to construct and operate a dual-fuel, rapid-response combined-cycle generation system (CCGS) at Scattergood that replaces the once-through cooling turbines existing as [redacted]. The proposed CCGS would consist of a gas-turbine generator and a steam-turbine generator operating in tandem via heat recovery steam generation, which would substantially increase the fuel efficiency of electrical power production compared to the existing steam-boiler [redacted]. The CCGS would have the capability to operate on a mixture of natural gas and hydrogen fuel, accelerating the Department's transitions to a reliable, carbon-free electrical system. LADWP will issue a Request for Proposal (RFP) in Phase 2 of ARCHES that will result in an EPC contract for the project. The RFP will identify all the project parameters and performance metrics that must be met by the awarded contractor. While LADWP has a strong understanding of the activities that should be involved with the construction of a combined-cycle generating system at [redacted] those activities will be ultimately defined by the contractor so long as they satisfy the agreed-upon project parameters and performance metrics. Major equipment to be procured by the contractor include to but is not limited to a gas turbine; steam turbine; generators; heat recovery steam generator; selective catalyst reduction system; continuous emissions monitoring system; air cooled condenser; control module; distributed control system; balance of plant; and gas compressors. The awarded contractor will be responsible for procuring the necessary materials and equipment to construct a combined-cycle generating system that meets the project parameters and performance metrics outlined in the specification and the subsequent EPC contract including BABA.

4.3.3 EPC—Ports

The ports will employ a staged approach to evaluate the H_2 CHE technologies and see if new procurements or retrofits are possible. The EPC involves working with vendors and terminal operators to assess equipment and gain familiarity and confidence with their operability. [redacted]

4.3.4 EPC—[redacted] Hydrogen Fueling Station

[redacted] is currently building the world's largest heavy-duty and light-duty HRS in Oakland, CA as part of the NorCal Zero project.[12] Although all the equipment is commercial, the integration of the

[12] https://ww2.arb.ca.gov/lcti-norcal-zero-emission-regional-and-drayage-operations-fuel-cell-electric-trucks

station is still at TRL 7, system demonstration in an operational environment. As part of on-going innovation efforts to provide a conventional fueling experience, [redacted]. These efforts will conclude during Phase 2 (project development) and prior to the start of the Phase 3 (construction), so the HRS will be at TRL 8-9. The lessons learned will be promulgated throughout ARCHES and partners so that subsequent HRSs will come down the cost curve and can be readily replicated. The current equipment is procured from different companies and locales around the globe (as shown in **Table 4.5** below) today, and as additional US manufacturers come online they will be leveraged in due course. The HRS equipment has been used in our LD HRS at over 17 liquid delivery stations and has evolved as our experience increased.

[redacted]

[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

4.4 Cost Estimates

The ARCHES-Hub total project cost (TPC) is \$12.55B and covers the entirety of this envisioned eight-year H_2 Hub, including construction and two years of operation (see **Table 3.8**). The detailed budget has been provided in the attached Budget Justification Excel© spreadsheet. Due to the size and 9:1 ROI, ARCHES is requesting \$1.25B instead of \$1B. We believe this justified due to the size and scope of ARCHES, including diversity and breadth of deployments and the relatively advanced state of hydrogen in the CA region compared to most of the other expected DOE Hubs. This enables ARCHES to be further down the learning curves compared to the other hubs and thus able to provide lessons learned and pitfalls to avoid for the overall national hub network. Also, we believe this is justified due to the possibilities to scale the ecosystem quickly in CA including more advanced and other sectoral deployments (e.g., Tier 2 projects, aviation, ammonia, import/export terminals, rail, etc.).

[redacted]

		[redacted]	[redacted]	[redacted]
[redacted]				
	[redacted]	[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]

[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

4.5 Execution Schedules

The Integrated Project Schedule and some exemplar specific deployment project schedules can be found in section 8.6 as part of the Workplan section 8.

4.6. Intellectual Property Management Plan

ARCHES will work with its partners to create an Intellectual Property Management Plan (IPMP) during Phase 1. UC, LBNL, and most of the subrecipients have well established IPMP procedures, and best practices, especially when engaging in multiparty consortia. Although we do not envision extensive IP being developed as ARCHES-Hub is focused mainly on deployment, it is possible that such activities, especially around the codes and standards, etc., may result in IP. To the extent possible, ARCHES plans to make findings publicly available.

4.7 Operating and Disposition Plans

ARCHES will be responsible for organizing, coordinating and managing all aspects of the hub, consisting, amongst others, of an initial set of 39 hydrogen-based deployment project recipients (13 in production, six in the power sector, three port projects, 13 transit agencies, various FCET deployments, and eight infrastructure projects amongst others). ARCHES will be the connective tissue between projects throughout all phases and will drive further growth and expansion of the hub beyond the DOE funding period of eight years. ARCHES will also manage cross-cutting activities such as monitoring and reporting, certification, codes, standards, safety workforce development, education, systems and risk analysis, and community benefits plan activities amongst others. Over [redacted] of the budget will go to hydrogen-based deployment projects. ARCHES will carefully manage the flow of funds and work with the DOE to achieve approval for each proposed project on an annual basis or as needed.

The proposed hydrogen-based deployment projects, once completed, will be operated by the proposing companies or entities until the equipment reaches the end of its useful life that can be anywhere from seven to 40 years depending on the equipment. Depending on circumstances at that time the equipment will either be replaced with new technology or disposed of according to local, state and federal regulations.

For example, [redacted]

Similarly, equipment (CHE, FCETs, FCEBs) will be as much recycled as possible and in conjunction with standard processing at least as is done today and any more stringent recycling to be required in the future, with a focus on stack decommissioning and recycling to recover critical materials (platinum-group catalysis, fluorinated compounds, etc.).

In terms of HRS, there are 57 LDV stations in operation in CA and many more globally by ARCHES partners. [redacted] However, the equipment can be removed without significant cleanup. The steps to dispose of the equipment do not require special clean-up. The disposition will include purging the hydrogen, removing the equipment, and associated piping and deconstruction of the cement pads if need be. In fact, [redacted] has had to do site clean-up before installing equipment at existing gas stations, so the site is appreciably cleaner than had there been no HRS at all.

5. SAFETY, SECURITY, AND REGULATORY REQUIREMENTS

5.1 Safety

Safety is central to ARCHES' goal of being the safest hydrogen hub in the nation. It is also a moral obligation. ARCHES wants its and its partner employees to return home to their families safely. ARCHES will institute total safety values, which stress that nothing is more important than safety and that adherence to safety is a condition of employment. Our current leadership has built on this strong foundation. ARCHES believes:

- Nothing is more important than safety ... not production, not sales, not profits.
- Accidents and injuries are preventable ... not inevitable.
- Safety is a management responsibility ... and safety can be managed.
- Safety is an individual responsibility ... and a condition of employment.
- Safety is a way of life ... around the clock.
- Every task must be performed with a concern for safety ... for us, our fellow employees, our contractors, our visitors, our customers, and the communities in which we operate.

Process safety is critical to ARCHES and the safety of its and its partner employees, customers, and the communities in which ARCHES operates. While it is recognized that it is not possible to eliminate all process safety risks, we will strive to reduce risks to a tolerable level. To this end, ARCHES is committed to:

- Being an industry leader in process safety.
- Implementing a global process safety management system, applying best practices consistently across the hub.
- Striving to prevent process safety incidents by working closely with all projects by designing, building, operating, and maintaining facilities and equipment through sound engineering practices and operating discipline.
- Using a global risk management framework, applying hazard rate criteria consistently in addressing significant risks.

To meet these commitments, ARCHES will use a comprehensive Process Safety Management (PSM) system to support its partners to manage process hazards and reduce risk in all activities associated with handling chemicals and/or energy, including manufacturing, processing, storage, and transportation. This integrated program involves five core activities of define work scope, identify hazards, determine hazard controls, perform work, feedback, and analysis to determine how to improve safety. Such a program is routinely applied by ARCHES partners including founding members of UC, which deals with substantial amounts of hazardous materials on their campus and affiliated national laboratories, as well as the State Buildings and Trades, which takes safety to be a core precept in all that they do.

5.1.1 Development of a Comprehensive Safety Plan

ARCHES will organize dedicated safety sessions early in the ramping up of the hub and work with its partners to establish hub-wide safety procedures leveraging the vast experience amongst all projects, the national lab participants, and its own hydrogen experts. Including the partner organizations, ARCHES including the subrecipients have many decades of experience of working with hydrogen safely in various applications. ARCHES will organize periodic hydrogen safety workshops and training programs as part of education, workforce development, and outreach that will be updated annually and will require mandatory participation by all project safety officers who in turn will roll out safety plans and procedures to their own employees. ARCHES safety will be overseen by a dedicated safety officer, who will also interface with the other hubs and DOE including the safety panel lead by Pacific Northwest National Laboratory.

ARCHES' safety plan will be developed following the latest version of PNNL-25279-1, Safety Planning for Hydrogen and Fuel Cell Projects, and it will create an environmental health and safety (EHS) program that follows the ISO 45001 standard. All operations are to be performed in line with local state, federal, OSHA, National Fire Protection Agency (NFPA), ASME, and Department of Energy regulations and standards. The comprehensive safety plan will be developed and finalized in collaboration with its partners during front-end loading (FEL) and front-and engineering design (FEED) stages and periodically updated as new safety measures emerge.

5.1.2 Safety Program Leader

Many of ARCHES' larger partners ([redacted]) have dedicated safety officers in their organizations, whereas smaller companies use third-party organizations that specialize in hydrogen safety. ARCHES will recruit a dedicated safety officer who will work with all partner counterparts and other hub safety officers and third-party safety consultants to establish the highest standards of hydrogen safety within the hub, continuously monitor and record safety incidents, and create a rapid feedback loop for the implementation new safety measures throughout the hub. The safety officer will also integrate and work in detail with the codes and standards crosscutting effort within ARCHES and those external and internal consultants.

5.1.3 Hazard and Operational Analysis (HAZOP)

As part of required ARCHES minimum requirements for engineering design, a hazard and operability (HAZOP) review is to be performed for each hub process plant project when approximately 30% of engineering design has been completed. HAZOP reviews will be led by a trained and certified HAZOP Process Safety Engineer and supported by experienced technical project and operations personnel, including project liaisons, to identify potential hazards and impact to the process, environment, operations, and personnel. Action items are tracked electronically to completion. The HAZOP Process Safety Engineer will be a member of the hub Safety Program leader's team.

5.1.4 Working with Local First Responders

In an emergency requiring the immediate assistance of additional resources, trained first responders are contacted by, for example, an on-shift Control Room Operator. These first responders include local fire departments, ambulance/paramedics/EMS, and police departments. ARCHES, in collaboration with it partners, will proactively contact local fire departments to conduct walk-throughs of hydrogen facilities to make them acquainted with the facility layout for access and product awareness purposes (hydrogen). Also, ARCHES will coordinate and collaborate with all relevant fire departments to conduct on-site rescue training exercises that include confined space rescue and high angle rescue. This activity will be part of the safety program leader's responsibilities and will leverage the nationwide programs and training that have been developed by DOE over the last decades.

5.1.5 Hydrogen-specific Safety

The hazards associated with the use of hydrogen can be characterized as physiological (frostbite, respiratory ailment, and asphyxiation), physical (phase changes, component failures, and embrittlement), and chemical (ignition and burning). A combination of hazards occurs in most instances. The primary hazard associated with any form of hydrogen is inadvertently producing a flammable or detonable mixture, leading to a fire or detonation. Safety will be improved by designers and operational personnel through awareness of the specific hazards associated with the handling and use of hydrogen. A comprehensive safety and emergency response plan will be drafted in Phase 1 of the hub project.

5.2 Cybersecurity Threats and/or Vulnerabilities

ARCHES plans to have a comprehensive cybersecurity plan for the ARCHES-Hub in place by the end of Phase 1. At present, several of its large partners have cybersecurity protocols and standards as well as cybersecurity professional within their own IT department to address cybersecurity risks and vulnerabilities according to established procedures within their specific industry. This is especially true with the UC system. The regional hydrogen hub network represents a new ecosystem of interdependent entities that has no currently deployed peer. To guarantee resiliency, it is critical to understand and predict the system-level risks, vulnerabilities, and unknowns associated with the integration of hydrogen production, transportation, and end use. In the first phase of ARCHES-Hub, [redacted] will develop a scope for a Comprehensive Risk Assessment study, to be executed in later phases of the hub, which will look at strategic risks of introducing hydrogen and integrating it with existing infrastructure. The study will look across hazards to understand and as much as possible quantify risks. Priority areas include risks from cyber and physical attacks, supply chain risks, gray zone threats, natural hazards and technology integration risks. The outputs of the study would include strategic recommendations that can guide and inform the implementation of hydrogen production, transportation and utilization within the contest of production source and intended sector for consumption. The study also informs cybersecurity and risk management plans for the hub, as well as provide risk informed design guidelines that can be passed on to key entities and stakeholders. To execute the study, ARCHES will draw upon extensive capabilities and longstanding experience in quantitative risk assessment from both intelligent adversaries and natural hazards in conjunction with LBNL and UCB as noted in section 5.3 for critical infrastructure and in characterizing and quantifying impacts from cascading effects across infrastructure sectors. Particular attention will be paid towards understanding and developing the resilience of the entire hub network such that vulnerability for massive disruptions, as well as those at individual sites, are evaluated and mitigation methods developed. The Safety Program Leader will be responsible to establish hub-wide cybersecurity protocols, including the detection of vulnerabilities, monitoring, and upgrading cyber defenses.

5.3 Seismic Threats and/or Vulnerabilities

Perhaps unique to the California region, seismic safety concerns are tantamount, especially when dealing with hazardous gases and liquids. In this respect, David McCallen from LBNL will be tasked with helping to develop and analyze seismic considerations for all ARCHES deployments. He will coordinate and work with the Pacific Earthquake Engineering Research Center (PEER) at UC Berkeley on advanced performance-based earthquake engineering design. To deal with the full set of challenges in implementing a hydrogen economy, this leading California expertise in earthquake science and earthquake engineering will provide the most economical and robust seismic design. The team will utilize existing energy system design standards and methodologies and experimental testing data (from gas and electric systems) that can be directly leveraged for application to hydrogen systems. This task will support the requirement to collect and communicate safety related data to the Hydrogen Safety Panel.

5.4 Permitting

Many of ARCHES larger partners have a well-defined permitting process in place that typically starts the process of seeking permits during the middle of the engineering design phase (Phase

2). Some have their own permitting experts and others use external consultants that establish a permit sequence of events. During Phase 1, ARCHES will require its partners to complete a Critical Issues Analysis and identify specific gaps in regulations, codes, and standards (RCS). Furthermore, this assessment will be deployed to identify relevant federal, state, and local regulations, applicable permitting requirements, and potential for site constraints, including sensitive biological resources, wetlands, and cultural resources. Based on this analysis and in coordination with qualified permit consultants, ARCHES then will work with its partners to complete a full suite of environmental surveys to delineate the boundaries of sensitive resources. This activity will be conducted in conjunction with the State of California, a founding partner of ARCHES, and leverage their expertise and knowledge. The survey results are used to inform preliminary site design as well as to define the discretionary permitting strategy for a project including land use permit, wetland permits and incidental take permits for protected species. Where impacts are anticipated, the project will be designed to avoid or to minimize impacts in consultation with communities and experts, and where impacts cannot be avoided, ARCHES will consult with appropriate agencies (USFWS, USACE, state wildlife, FAA, etc.) to determine the need for permit approval. As part of this process, ARCHES will also work with local municipalities and jurisdictions to ensure a smooth permitting process as well as engage with community organizations early and often (see the Community Benefits Plan) to address any concerns. A more comprehensive permitting workflow overview will be prepared during Phase 1 with our partners.

5.5 Codes and Standards

The Regulations Codes and Standards (RCS) activity will be a top-level resource available to all ARCHES programs. This resource will be staffed by [redacted]. The team will work with all ARCHES projects as a team member on RCS issues identified by the project. It will provide education relative to RCS. The team will work to resolve code issues raised by the project and will identify code gaps and bring them to the relevant code development organizations (CDO), and Standard Development Organizations (SDO). These organizations include ISO, NFPA, ICC, IMO, SAE International, CSA Group, CGA, etc. We will fill the gaps by identifying potential risks. And, when necessary, perform risk evaluations for the project. We will work with the project teams when securing project permits to execute the project.

5.6 NEPA (National Environmental Policy Act)

ARCHES plans to comply with all NEPA requirements and reporting schedules. A comprehensive set of Environmental Considerations Summaries has been included in this submission. In addition, ARCHES projects have to comply with California Environmental Quality Act (CEQA), and ARCHES will look to ensure alignment between the two. In addition, ARCHES is working with the State of California to apply fast-track application processing for local and state review and associated permits.

5.7 Other Considerations

As presented earlier (see section 2), the ARCHES-Hub consists of Tier 1 partners. ARCHES recognizes that in some instances project sites may not be realizable at some point during the detailed project planning. Therefore, ARCHES has assembled a Tier 2 set of partners and projects (see section 3.1) that are able to replace those that cannot be realized. To minimize this from occurring and as part of this Plan B process ARCHES will:

- engage in early and frequent communication with all applicable federal, tribal, state, and local authorities having jurisdiction (AHJs).
- undertake a thorough review of all relevant federal, state, and local statutory and regulatory authorities. Relevant federal statutes and authorities could include but are not limited to Clean Air Act, Clean Water Act, Endangered Species Act (ESA), and National Historical Preservation Act (NHPA).
- include in its proposals frequent and extensive consultation with local community stakeholders with a potential interest in the proposed site(s), aligned with activities in the Community Benefits Plan.
- leverage the opportunity to use data from ARCHES projects to capture environmental data of benefit to regulatory agencies, as part of Justice40 goals, and the industry as a whole. ARCHES will monitor all its sites and the environmental effects of its projects from site assessment through commissioning and throughout the entire life of the H2 Hub.
- continually evaluate the technical requirements, costs, safety, and other relevant concerns and issues as delineated throughout this proposal and in section 6.

6. RISK ANALYSIS AND MITIGATION

6.1 Risk Management Plan

The ARCHES CDO (TBD) will be responsible for overseeing all hub risk-related aspects and will work in conjunction with the CTO and the various project liaisons, the systems analysis lead and team members, and the deployment partners. This team will ensure that risks are actively identified, analyzed, and managed throughout the life of the project. Risk categories will include commercial, technical, construction, schedule, regulatory, permitting, safety, scale-up, infrastructure, financial, management, organizational, and market-related risks. Risks will be identified as early as possible in the project so as to minimize their impact. Integrated project team members and liaisons are responsible for identifying risks, their dependencies within the project, and the context and consequence of the risks. The team members will also be responsible for determining the impact, timing, and priority of the risks as well as formulating the risk statements. Risks will be assigned to risk owners who will determine which risk will require mitigation and contingency plans and perform a cost benefit analysis of the proposed mitigation strategies. The risk owner is responsible for monitoring, controlling and updating the status of the risks throughout the project lifecycle. The risk management approach will include a risk register. An initial risk register is described in the next section.

6.2 Risk Register

Table 6.1: Summary of most important risks by sector

Risk	Impact	Risk mitigation and response strategy
ARCHES		
Collaboration amongst competing companies and interests	Project deployment delays or project partners dropping out	ARCHES will be both an adjudicator and a mediator to make sure that interests can be met.
Getting sufficient community support for the deployment of projects	Delay of project deployments	ARCHES will be proactive in executing its community benefits plan and work with all community stakeholders early on.
Production		
Electrolyzer procurement and efficient operation (or similarly for key biomass equipment)	Schedule delay; higher cost of H2	Closely coordinate planning etc. with reputable electrolyzer manufacturers; work with BOP stakeholders to ensure high water quality; optional grid connectivity will increase electrolyzer utilization factor
Permits	Project delays and/or higher capital costs	Leverage experience with permitting process; engage all stakeholders at the earliest time possible and seek inputs; work with permitting entities, community representatives, and regulators early.
Regulatory risk	Insufficient incentives to drive demand for H2 adoption	Support continuity of enacted and legislated mandates across administrations and actively participate in the regulatory rule making process with both elected and regulatory officials.
Long-term off-take agreements	Project economics uncertainty	Develop partnerships between producers and off-takers early.
Power		
Permits	see Production	see Production
Public opposition	H2 is not well understood and misinformation can erode public support	Deploy public awareness programs to improve stakeholders' understanding of the benefits of a hydrogen economy.
Hydrogen leaks and safety	No hydrogen will be stored on site; no fugitive leaks with upgraded seals and connections at project facility	Implement the most advanced technologies available to detect and address potential leaks as soon as possible, and deploy leak detection and other safety factors

		throughout the design process while applying all applicable safety standards. Proposer is committed to ensuring safety of our communities and employees as we deploy hydrogen-capable units.
Transportation Transit (buses and dedicated HRS)		
Vehicle price, infrastructure costs and fuel price	Purchase fewer buses than planned with associated reduced pollution benefits	Since budgets will likely be not flexible the only available mitigation strategy currently is to purchase fewer buses and/or HRS, in line with budget limitations
Manufacturing readiness	Inability to produce approximately 1,000 buses in the planned timeframe	Restrict the number of OEMs to increase their volume and reduce their cost. Issue an RFP for about 1,000 buses over multiple years
Performance (bus travel range)	This could limit acceptance of H2 buses	Establish a competitive process to evaluate performance characteristics
Transportation Trucks (Class 6 and 8 FCE trucks)		
Buy America compliance	Stringent requirements can be difficult; noncompliance can result in not receiving critical funding	ARCHES will comply with Buy America provisions and work with terminal operators and OEM to ensure requirements are met
Ports		
Operational transition from diesel to hydrogen	Implementing new technology requires infrastructure upgrades and additional training for all employees operating hydrogen-fueled technologies	The Ports expect that the transition to hydrogen will be smoother than a transition to battery-electric applications, primarily due to fewer anticipated infrastructure upgrades, reduced training requirements, and refueling and operational performance comparable to diesel
Buy America Compliance	Stringent requirements can be difficult; noncompliance can result in not receiving critical funding	Ports will comply with Buy America provisions and will work with terminal operators and OEM to ensure requirements are met
Developing regulations/ protocols	As technology to support hydrogen fuel is new and rapidly changing, Regulations and protocols needed to standardize and guide the industry has not been finalized and is currently under development.	The Ports are positioning themselves to be an industry leader in this space by partnering with industry leading vendors that are working with regulatory officials on upcoming protocols
Infrastructure		
Permits	see Production	see Production
Market demand	Low HRS/buffer/pipeline/tank throughput	Partner across value chain to understand deployment timing and locations
Legend: yellow: low risk, orange: medium risk; red: high risk		

7. TECHNICAL DATA AND ANALYSIS

7.1 Preliminary techno-economic analysis (TEA)

A preliminary TEA was conducted to assess the technical and economic viability of all key proposed hub components and their interconnection at the scales proposed for the hub. Proposed processes, operation, equipment, and energy and material balances were derived for all key components of proposed projects and for all connective infrastructure identified by the systems analysis team led by LBNL and comprised of members from various UCs. Proprietary data necessary for conducting the TEA was requested and clarified in project proposals and follow-up discussions with project applicants. A nonbiased TEA evaluation was conducted by the systems analysis team to verify data provided, to ensure consistency with the overall hub design, and to fill in missing information. This process used the proprietary data, published data, and modeling approaches from DOE tools including HDSAM, GREET, and H2A, as well as a method used in the Los Angeles HyDeal analysis that applies EPA BenMAP for estimating the monetary value of net avoided human health impacts. All assumptions, rationale, and system design and boundaries are described in detail in this section, with representative process flow diagrams provided in section 4. Some details can also be found in the Excel© attachment; however, as our hub is complex, comprising numerous hydrogen producers and end users in different regions, we note that the Excel© attachment is an aggregation and not representative of individual components of the hub or the costs realized in specific locations (can be provided by request). As such, we include an additional tab "TEA Producers" summarizing additional details of our hydrogen production and transportation systems. Our approach for determining levelized cost of hydrogen (LCOH), the cost of regional storage hubs to smooth seasonality of production, and cost of transportation is described in detail in the sections below. We use H2FAST to estimate internal rates of return, internal sales price of hydrogen, and profitable levelized price of hydrogen. Due to the nature of H2FAST, we have submitted weighted values in the TEA LCA Excel file that will allow reviewers to apply H2FAST to our complex ARCHES-Hub.

7.1.1 Primary Product Value Stream

The primary product of the hub is *hydrogen*, used for FCET and FCEB refueling, port CHE refueling, and power. Results of the TEA are presented for either one kilogram (kg) of H_2 (e.g., the levelized cost of H_2 \$/kgH_2) or for MTPD H_2 delivered. The nameplate capacity (1677 MTPD by end of 2029) is derived from the size of the electrolyzers (MW x 24 hr divided by 50.4 m.tonnes H_2/MWh) and maximum production capacity of the biomass facilities. In practice, the facilities produce H_2 based on the availability of the renewable energy resource and energy-storage or related systems leveraged. As expected, the average production at the hub level (515 MTPD by 2030; 185,667 MTPY) is different from the hub-level nameplate capacity. We assume 1%–2% loss of product from transportation and a 2% loss of product from regional liquid storage facilities, reflecting that state-of-the-art technologies for liquefaction and compression storage and delivery are employed. [redacted] This storage in addition to the storage at producers and at end users allows the hub to supply an average of ~190,000 MTPY if needed.

The forecast price of the primary hub product provided in the Excel© table is the weighted average LCOH delivered across the entire hub by year; this is estimated based on the producers that come online each year at their respective nameplate capacities and capacity factors. All producers come online at full nameplate capacity by 2030, at which point the nominal production price of H_2 is [redacted] The average price increases to [redacted] If solar-based production can in fact achieve a $3 PTC with a CI of 0 (rather than the conservative approach we took), the LCOH decreases to [redacted] These values are used as internal prices within the H2FAST model, which is used to generate a project-wide breakeven cost [redacted]. As noted in the TEA Producers tab, price varies significantly based on the technologies used, price of electricity, transportation distance and mode, and capacity factor. As seen in the **Table 7.1** and **Table 3,3**, prices and CI of produced hydrogen vary regionally and among producers.

Table 7.1: Price and carbon intensities of produced hydrogen by region

[redacted]

7.1.2 Co-products and Waste Streams

Services of the end use of hydrogen include freight transport for trucks and port equipment, passenger transport for buses, aviation, and power generation. To run H2FAST, we model services as coproducts: H_2 to fuel, H_2 to jet fuel, H_2 to port, H_2 to power. We include captured CO_2 from [redacted]. Oxygen is vented.

In the process of treating and deionizing wastewater provided to the electrolyzer-based H_2 producers, wastewater is generated at a rate of 2.7 gallons per m.tonne hydrogen produced. This wastewater is delivered to local treatment facilities by sewer or truck at a nominal cost of $0.004/gal wastewater; no evaporation ponds will be used in the hub. Landfill solids will be generated over the course of the hub, primarily in the form of rejected materials from municipal solid waste (MSW) processed at [redacted] We assume this material is transported by diesel truck and account for emissions in the LCA, which would decrease if FCETs are used. Other landfill solids may include used components of electrolyzers, and spent tires from trucks and buses. While we include the cost of these components' replacement and maintenance, we do not explicitly calculate disposal costs.

We find this acceptable as we apply a decommissioning cost to H_2 producers of $0.01/kg$H_2$, and we assume landfill disposal fees for tires are captured in the cost of purchasing tires, as described in sections below.

7.1.3 Hydrogen Production

Proprietary data on capital costs were provided by some producers; however, in most cases, we apply current values derived from the DOE H2A model for PEM and alkaline electrolysis facilities. Up-front capital costs for electrolysis-based producers were estimated at the scale of hub deployment, based on the nameplate capacity of the electrolyzer and type of electrolyzer (PEM or alkaline). Up-front capital costs include the electrolyzer stack [redacted], the balance of plant (BoP) (which includes mechanical BoP, water treatment systems, and electric BoP), and the hydrogen conditioning system. The hydrogen conditioning system is largely comprised of either a compressor [redacted] or liquefaction system [redacted] and associated onsite storage which varies from half a day to 3 days of storage [redacted] depending on the facility. We assume hydrogen is produced at a pressure of 20-30 bar. This onsite storage is in addition to the regional liquid storage facilities, and the storage at end users.

A construction, installation, and contingency cost of 20% (in comparison to 12% in H2A) of total uninstalled capital was assumed when proprietary information on construction was unavailable. Construction is assumed to be 12 months. Non-depreciable assets only include land and are already owned by the producers. We assume a blanket decommissioning levelized price of $0.01/kg$H_2$.

Major refurbishments involve stack replacement every 67,500 hours of operation lifetime for alkaline and 60,000 hours for PEM, with time between determined based on the facility's capacity factor. The useful life of the electrolysis facility and equipment is 20 years, while liquefiers are 30 years, and compressors and storage tanks are 15 years, based on H2A and HDSAM; depreciation is derived from the same source. Fixed operating expenses include:

- The main non-energy variable annual expenses of the electrolyzer facility, compression and liquefaction systems and storage facilities are cooling water and liquid nitrogen replacements, as well as electrolyte (KOH) replacement, which are estimated based on the production of the facility. Water consumption (for H_2 production as well as for cooling) is derived from proprietary information from the producers, [redacted]
- Energy consumption for electrolysis facilities is broken down into energy for the: electrolyzer stack ([redacted]), BoP, compressor (2.2 kWh/kgH_2 similar to HDSAM), liquefier (11.3 kWh/kgH_2 for producers based on CA-GREET and 9 kWh/kgH_2 for regional liquefiers based on DOE HTFC record 9013) and miscellaneous including water treatment. Values were derived from H2A for stack, BoP, and miscellaneous. [redacted]

[redacted]

- Biomass facilities provided proprietary data, which allowed us to derive estimates of equipment costs, energy and water costs, and feedstock costs, as well as resulting LCOH [redacted] assume a woody biomass feedstock price of [redacted] from biomass supply curves informed by the DOE 1 Billion Ton Studies.[13] We estimate 5% of MSW is rejected, but do not assume a cost.

7.1.4 Hydrogen Connective Infrastructure

Hydrogen is transported by pipeline, gas trailers, and liquid trailers. We model the liquid and 500 bar compressed gas transport system using the DOE HDSAM model; additional details on our methodology for estimating and sizing fueling stations and truck trailer fleets based on distance and hydrogen delivery can be found in Aikaterina et al 2021.[14] Approximately [redacted] MTPD of H_2 are delivered daily by liquid fuel cell trailers [redacted], delivering 3 m.tonnes each, and 254.5 MTPD of H_2 are delivered daily by gaseous fuel-cell trailers [redacted], delivering 0.8 m.tonnes each. Distance for transportation is added to the cost of the delivered hydrogen, and is conservatively estimated by taking the highway distance between a producer and the end user farthest from it in its service region. [redacted]

[13] Kenneth Skog, Jamie Barbour, Marilyn Buford, Dennis Drykstra, Patti Lebow, Pat Miles, Bob Perlack, Bryce Stokes, Forest-Based Biomass Supply Curves for the United States, Journal of Sustainable Forestry, Volume 32 2013; pp. 14-27.

[14] Aikaterini Anastasopoulou, Hiroyasu Furukawa, Brandon R. Barnett, Henry Z. H. Jiang, Jeffrey R. Long and Hanna M. Breunig, Technoeconomic analysis of metal–organic frameworks for bulk hydrogen transportation, Energy and Environmental Science, The Royal Society of Chemistry 2021.

The main annual expenses for trailers that vary by distance traveled are: labor, replacement of tires, tolls, fuel (H_2 assuming 0.15 kg per mile), insurance, permits, and licenses.[14] Refurbishments (10% overnight CAPEX every five years), useful equipment lifetime and depreciation of components were taken from HDSAM, and from the US Technical targets for Hydrogen Delivery for liquefiers and storage tanks.[15] Pipelines were given a 40 year lifetime, with 15 years between refurbishment at 25% overnight CAPEX.

7.1.5 Hydrogen End Use: Trucks & Transit

FCETs and HRS at ~6 (4-8) MTPD nameplate capacities (see **Table 3.7**) and HD vehicles were modeled using data generated in an ongoing project by UC Davis and NREL.[16] We assume a capital cost of $[redacted] per station, with 66 stations in total. Heavy duty trucks were assumed to be Class 8 [redacted] or Class 6 [redacted], and have a capital cost of [redacted] per truck, with 5,500 trucks in total; details are provided in the Excel© file. Variable operating expenses were estimated assuming an average transportation distance of 322 km per truck. We assume trucks consume 0.15 kg/mile or 44 kg per truck per day, with stations dispensing ~2–5 MTPD depending on regional distribution of trucks. By 2030, trucks consume 184 MTPD.

Bus station costs were estimated from proprietary data [redacted] Operating expenses, refurbishments and economic assumptions were assumed to be the same as those used for the Connective Infrastructure derived from HDSAM, except non-energy variable costs for bus stations, which was approximated to be the same as the value used for HDV refueling stations. Maintenance facilities are estimated to cost [redacted]. We assume buses consume 28 kg/day of hydrogen, with daily in-service buses at approximately 85%. By the end of 2030, transit consumes 30.3 MTPD. [redacted] we use a value of [redacted] per dispenser, while trailers and module equipment is reflected in the cost numbers for the connective infrastructure. [redacted]

7.1.6 Hydrogen End Use: Port Equipment

[redacted]

Fixed and variable operating expenses are approximated at 2.5% overnight capital, with 10-year useful lifespans, refurbishments every five years at a cost of 25% overnight capital, and depreciation the same as heavy duty vehicles. By 2030, port equipment consumes 60.5 MTPD (not including the 3 MTPD for power). The [redacted] vessel has a total project cost of [redacted] and consumes 400 kgH_2 per day.

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[15] US Department of Energy, DOE Technical Targets for Hydrogen Delivery, https://www.energy.gov/eere/fuelcells/DoE-technical-targets-hydrogen-delivery

[16] California Hydrogen Analysis Project: The Future Role of Hydrogen in a Carbon-neutral California, UC Davis, Institute for Transportation Studies, Review Draft February 22, 2022.

7.1.7 Hydrogen End Use: Power

The large power end users are retrofits of natural gas power plants. One includes the purchase of a turbine for [redacted] Small power application will use fuel cells, such as in warehouses and ports, and are not considered major infrastructure. Power consumes 203.2 MTPD. The pipeline delivering hydrogen to the power end users is described in the Connective Infrastructure.

7.1.8 Financing Procurement and Structure

Values were compiled for the H2FAST analysis. As such the assumptions above are aggregated in the spreadsheet as weighted inputs. We assume a lifetime of 30-year, a discount rate of 8% and hydrogen sold at its levelized cost which changes during the course of the project based on the producers that come online. We assume a debt equity ratio of 2.33 with one-time capital incentive for simplicity. We assume 1.9% inflation, 6% interest rate, 30% income tax rate, twelve months of working capital, and no depreciable capital.

7.1.9 Other Incentive Availability

We assume a PTC credit for producers that are not using RECS, not capturing CO_2, and that fall below 4 $kgCO_2/gH_2$; we assume \$85/tCO_2 to captured CO_2 [redacted] we assume the PTC is taken over the ITC, but this must be carefully evaluated in Phase 1. Aside from PTC incentives, the California Low Carbon Fuel Standard (LCFS) can result in a dramatic decrease in the price of H_2, especially for the biomass facilities sequestering CO_2. While the price has fluctuated, we feel a value of \$100/m.tonne avoided CO_2 to be reasonable. Upon consulting with CARB, the LCFS applies to producers serving truck, transit, aviation and port applications; correspondence with CARB confirmed that aviation and port cargo handling equipment would be eligible for LCFS based on the producer CI and equipment type. Avoided CO_2 emissions are described in detail in the following section, and are estimates by point location, and aggregated by region and end use in the submitted Excel© file on tab "LCA Hub". When considering the total cost of ownership of the hub, factors such as the monetized value of health impacts may come into discussion. While there are no existing incentives to account for these savings, we quantify the value of avoided PM2.5 and NOx from mobile sources, to derive an estimated value of \$2,949M. This estimated was informed by emission offsets in the San Joaquin Valley using BenMap. However, a full evaluation of air quality impacts and value is necessary to understand the nuances of emission offsets and the benefits to specific communities. This work will be conducted during the proposed project.

7.2 Emissions and Resource Consumption Life-cycle Assessment (LCA)

A hybrid LCA approach was used, where processes described in detail in the preliminary TEA were explicitly modeled, while upstream greenhouse gas (GHG) emissions were taken from GREET, CA-GREET, utility data, and from literature. Emissions for electrolysis-based hydrogen facilities comprise energy production and delivery, water delivery and treatment, operation and maintenance including feedstock life cycles, H_2 compression, H_2 liquefaction, H_2 transport, and H_2 leakage. Energy, water and feedstock consumption is described in the preliminary TEA; electrical processes at the production facility are powered by the same source. While the GREET model represents PV based electrolysis production of H_2 as having 0 GHG emissions, we use a value of 20 gCO_{2eq}/kWh for PV sourced energy. No criteria air pollutants are associated with solar based hydrogen production. Criteria air pollutants from the grid are estimated using eGRID emission factors for CAMX where utility specific forecasts for 2030 could not be acquired. NOx emissions range from 0.03-0.23 g/kWh, while PM10 range from 0.005-0.01 g/kWh. The regional liquid storage facilities are assumed to be powered by the regional grid. Key emission factors used in the preliminary LCA for producers are summarized in **Table 7.2**.

GHG emissions and criteria air pollutants emissions for biomass facilities are proprietary data, and include diesel truck biomass transport, diesel truck waste transport, PPA-solar electricity, natural gas, chemical feedstock life cycles, CO_2 treatment compression and sequestration, hydrogen conditioning and direct emissions from the facility. CO_2 emissions from biogenic sources are not counted. CO_2 captured from biomass regrowth, that may be recalcitrant over 100 years in gasification solids, and emissions that might be avoided from forest fires are not counted. We assume 400 $kgCO_{2eq}$ are avoided per m.tonne MSW waste to landfill.

Net emissions from replacing natural gas in power plants assumes no change in efficiency, and a MJ displacement of natural gas. Net emissions from HDV trucks assumes hydrogen trucks are 40% more fuel efficient. Emission factors from the EPA are used to reflect the aging fleet of class 8 and class 6 trucks in California.[17] Net emissions from transit buses were estimated using GREET and we assume a 1:1 displacement of CNG and diesel buses due to their higher efficiencies, which may be conservative; net avoided CNG and diesel bus miles were provided by CTE for the 13 transit agencies. Emissions from natural gas and California's low sulfur diesel were estimated using CA GREET. It is important to note that the emissions provided in GREET are for new buses, which is not representative of the degrading buses expected to be taken out of circulation that have much higher emissions. Net emissions from port equipment assumes a 1:1 displacement of the same type of equipment; emissions profiles were provided by the ports. Emissions factors for ground transport and takeoff of planes were collected from literature for jet fuel similar to kerosene.[18,19,20] Electricity necessary for pipeline compressors, centralized liquefaction facilities, port, truck and bus refueling stations are assumed to use local grid electricity, requiring local grid emission factors be applied. Trailers transporting gas or liquid H_2 are assumed to have zero direct emissions. However, if these trailers are fueled by diesel, we note the average CI of our hub hydrogen would increase to 0.31 $kgCO_2eq/kgH_2$.

7.3 Data Collection and Reporting

To inform market adoption and evaluate progress towards the ARCHES-Hub goals, ARCHES will collect project, environmental, technical, financial, operational, and socio-economic data and report these to the DOE and communicate findings to all stakeholders. For example, during operation, mass and energy flows into, out of, and between major subsystems (e.g., electrolyzer,

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[17] https://nepis.epa.gov/Exe/tiff2png.cgi/P100EVY8.PNG?-r+75+-g+7+D%3A%5CZYFILES%5CINDEX%20DATA%5C06THRU10%5CTIFF%5C00001432%5CP100EVY8.TIF

[18] https://pubs.acs.org/doi/10.1021/es101325r

[19] https://pubs.acs.org/doi/10.1021/acs.est.7b05719

[20] https://iopscience.iop.org/article/10.1088/2515-7620/ac6938/pdf

storage, compressor, terminal) and operating performance (e.g., maintenance and reliability metrics) for all subsystems of the ARCHES-Hub will be reported. ARCHES will also report financial information (e.g., operating and financial cash flows). In addition to the required data collection and reporting during the period of DOE project funding, ARCHES will voluntarily provide operating performance data beyond the period of performance for the award. ARCHES will track and report on several outcomes and outputs related to the Community Benefits Plan, including those related to the Justice40 Initiative; community and labor engagement; diversity, equity, inclusion, and accessibility; and job quality. All data monitored and collected will be done in conjunction with the overall national hub network data plan to be described by DOE in Phase 1.

8. WORKPLAN

8.1. Project Objectives

The ARCHES-Hub, if funded by the DOE, will unlock California's hydrogen economy by demonstrating the commercial feasibility of hydrogen production, distribution, and off-take in the critical sectors of, power, transportation (transit and trucking) and marine port operations, at a scale (~515 MTPD) that will drive down the average breakeven cost of hydrogen to [redacted] by 2031 based on H2FAST. This hub will further catalyze the transition to clean hydrogen of other, hard-to-decarbonize sectors, such as heavy industry, aviation, and the maritime shipping sector leading to an estimated hydrogen use of over 47,000 MTPD or 17 MMTPY in California by 2045. Specific project objectives are:

- To establish an exemplary hydrogen hub in California that starts at a level of 30 MTPD of clean, renewable hydrogen production and associated offtake and reaches ~515 MTPD by 2031, with associated GHG and criteria pollutant reductions;
- To demonstrate commercial feasibility of hydrogen as a viable substitute fuel for hard-to-decarbonize sectors such as the power, transportation, and port sectors at a steadily declining cost of delivered hydrogen to the point where lift off can occur (2031);
- To develop a hydrogen hub that will be self-sustaining and ready to connect to other hydrogen hubs in the nation by the end of 2030;
- To create the core of a successful hydrogen ecosystem and marketplace in California that will enable rapid growth and expansion to adjacent sectors including heavy industry, aviation, maritime, agriculture, and others; and
- To execute on the proposed Community Benefits Plan (CBP) in areas such as easy access to better long-term career opportunities in partnership with labor, improved community health outcomes, and meaningful access to training and advancement opportunities. The workplan for the CBP is described in the attached CBP document.

8.2. Technical Scope Summary

The ARCHES-Hub will initially be comprised of over 39 distinct interconnected projects that will be established and guided by a range of critical activities provided by ARCHES to connect the individual projects into a well-organized enterprise over time that is ready to grow. Within the portfolio of exciting projects many are already in one or another phase while some have not yet started. ARCHES' functions will move through Phase 1 during Year 1, Phase 2 during the following two years, Phase 3 in the subsequent three years, begin ramp-up and operations in the following two years (Phase 4, end of federal funding) and then, in Phase 5, operate and grow the hub indefinitely.

Over the past several months, ARCHES has extensively negotiated the scope and associated funding of work with its many Tier 1 partners (and also Tier 2 partners) that required multiple iterations to align the scope of work with available funding for each partner. In many cases, projects proposed a larger scope of work than funding would permit. For this reason, detailed project schedules were not available from projects at the time of the writing of this proposal which prevented ARCHES from producing a fully integrated project schedule.

As an interim approach we provide a first-level schedule for the ARCHES-Hub organization tasks with the associated work breakdown structure (WBS) and, then representative project schedules from the sectors (production, power, transportation, ports, infrastructure) in section 8.6. Arches will organize and facilitate all four Phases of the hub supported by the DOE and continue to grow in Phase 5 on a self-sustaining basis.

Phase 1 - Project Organization and Planning
Phase 2 - Detailed Hub Design
Phase 3 - Engineering, Procurement and Construction
Phase 4 - Ramp-up and Operation
Phase 5 - Lift-off and Accelerated Growth (self-sustaining)

8.3. WBS and Task Summary Description

The WBS for the entire hub is multi-dimensional and has a high degree of complexity mainly due to the 39 Tier 1 projects, and the fact that projects are currently in different stages. It is more appropriate to create a WBS for each project on its own in the future, as will be fine-tuned in Phase 1. These plans could be linked using the conceptual WBS in **Figure 8.1**, as they are joined both by cross-cutting interactions as well as interdependencies as production and offtake are balanced.

The WBS and task summary description here describes the ARCHES tasks as presented in the Integrated Project Schedule (IPS) in section 8.6. ARCHES is planning annual go/no-go decision points synchronized with the end of each budget period, and each project will have their own phase go/no-go decision.

Budget Period 1: Q1 – Q4

<u>ARCHES Phase 1 (Q1-Q4)</u>

<u>Task 1:</u> Hub Coordination (Q1-Q4)

ARCHES will organize a kick-off meeting in Q1 to begin the integration of ARCHES and each hydrogen project into the hub, establish ground rules, ways of working and begin the process of detailed planning of the entire hub. ARCHES will establish a monthly hub meeting (virtual meeting due to the large geographic region of the hub) to further coordinate the hub, provide actionable agenda items, and keep records of next steps and tasks for tracking purposes.

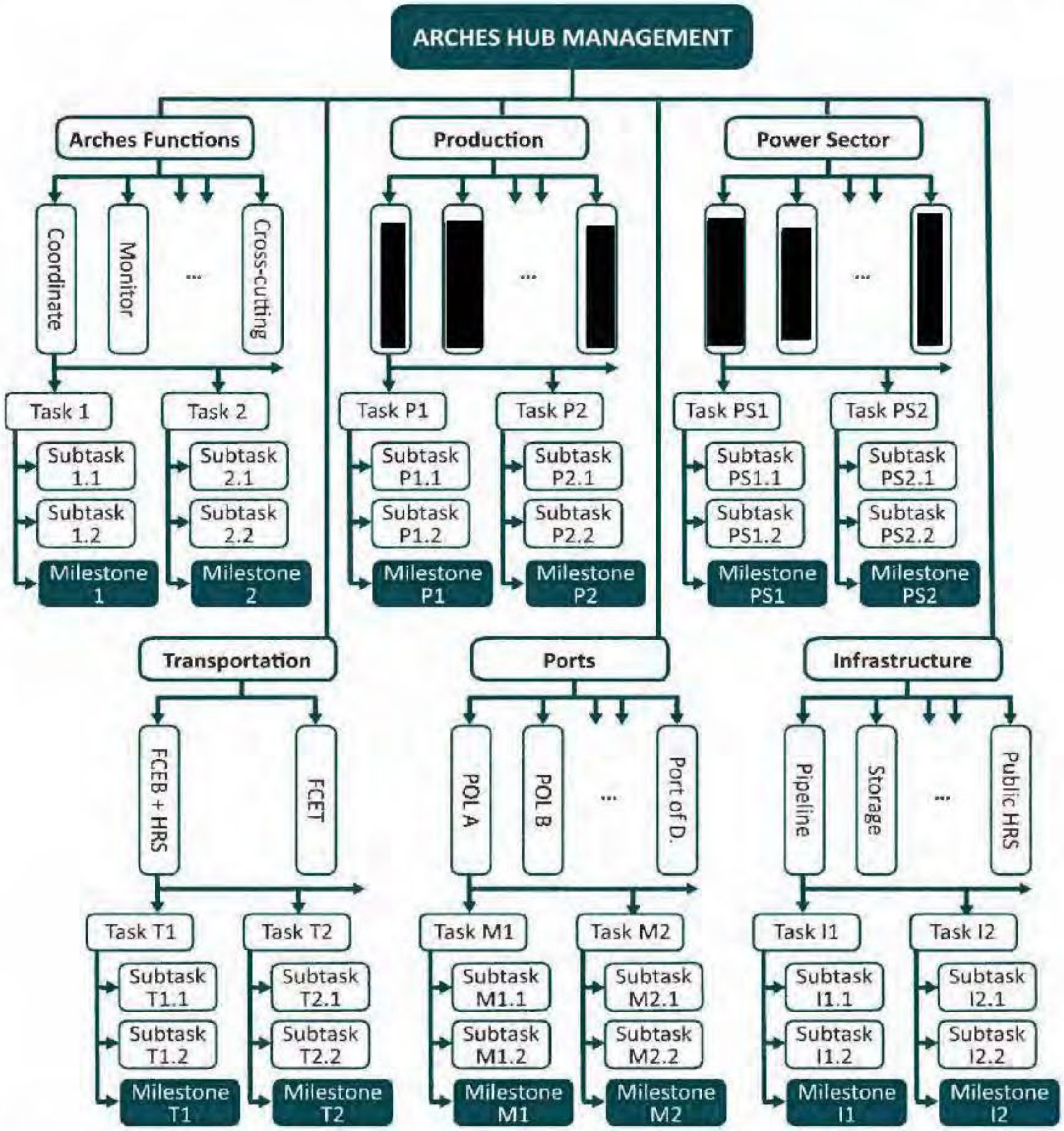


Figure 8.1: Conceptual WBS for the entire ARCHES-Hub.

ARCHES will also initiate a range of cross-cutting activities for which ARCHES will be directly responsible. ARCHES will complete the staffing of its organization by the end of Q4. ARCHES will also initiate environmental impact statements and scope for all deployments in Phase 1.

Task 2: Business, Management, Financial, Risk Management Plan Updates (Q2–Q4)

ARCHES will work with partners to update the business, management, IPMP, financial, and risk management plans (from the full proposal) based on inputs from detailed hub planning activities by each organization. These plans will be further updated by the end of each subsequent phase.

Task 3: TEA and LCA Updates (Q3-Q4)

The full proposal TEA and LCA analyses and assumptions will be refined, more detailed production and consumption data will be included in the models, and more accurate pollution and cost date will be integrated. This task will result in more refined performance projections for the ARCHES-Hub.

Task 4: Establish Safety Plan (Q3-Q4)
As part of fully staffing arches, a highly qualified (hydrogen) Safety Program Lead will be recruited during the first two quarters. The Safety Program Lead will organize a safety committee consisting of counterparts at the partner projects that will be tasked to establish a hub safety plan based on best practices and identify gaps and risks as they emerge during the design of the hub. The safety plan will be completed at the end of Q4 in Phase 1.

Task 5: Hub Concept Validated (Q4)
As partner projects provide their detailed hub plans throughout Phase 1, ARCHES will continue to monitor and model the hub evolution to provide a high level of confidence that the planned hub will be executable within the eight-year timeframe and on budget. At the end of task 5, the hub will be fully validated.

Milestone 1.1: BP, MP, FP, RMP, SP, TEA & LCA updates completed.
Milestone 1.2: Hub concept validated to enable start of Phase 2. (SMART milestone)
Go/no go decision budget period 1 (Q4)

Budget Periods 2: (Q5-Q8) and Budget Period 3: (Q9 - Q12)
ARCHES Phase 2: (Q5 – Q12)
Task 6: Agreements (Q3 – Q11)
ARCHES will arrange and support the formation of agreements for different aspects of the hub, production agreements, hydrogen offtake agreements, hydrogen transportation agreements as well as hydrogen storage agreements. ARCHES will facilitate these agreements, having the complete view of the hub, so that the production, distribution/storage and offtake are optimized, that is that produced hydrogen spends minimal time in storage and while transported.

Task 7: 90% Engineering Design (Q5 – Q12)
Although most of the engineering design of the hub will be managed by project partners, ARCHES will keep accounting of their status to make sure that it will reach at least 90% completion at the end of Phase 2 in preparation for the implementation phase. ARCHES will record and archive all engineering plans and drawings to be available long after the funded hub period.

Task 8: Class 1 Cost Estimate (Q9–Q12)
As part of the engineering design, specific equipment and contractors will be identified that will enable an accurate cost estimate (Class 1) for the entire hub. This cost estimate will include lead times and supply chain factors as well as near term inflation. The contingency budget will also be updated.

Task 9: Permits in Place (Q6–Q12)

The ARCHES-HUB will require numerous permits for land use, water use, air and soil impacts, and to meet all local, regional, state, and federal regulations. The hub will have a permit register and permitting plan that will support each project through the permitting process. ARCHES will use the permit register to start permitting processes based on their lead times so to reach a completed hub permitting process with all required permits approved and in place.

Task 10: Safety Plan Executable (Q10–Q12)
The safety plan established in Phase 1 (Task 4) will be further refined and laid out in such a way that it can respond to safety incidents in an actionable, effective manner to address issues and to learn from such incidents. There will be a built-in feedback-loop to update safety rules and measures to avoid repeating former incidents and practice ISM.

Task 11: Updated Risk Analysis (Q11–Q12)
The initial risk management plan and register established initially in the full proposal and then updated during Phase 1 will be further updated and analyzed with inputs from the engineering design to address any remaining risks in the order of priority. Risk mitigation strategies will be employed as outlined in the risk register.

Task 12: Mature TEA and LCA (Q12)
Detailed performance data from the engineering design will be included in the TEA and LCA analysis and lead to a mature TEA and LCA providing a more accurate overview of the anticipated performance of the hub.

Task 13: Technical Verification and Validation Plan (Q12)
Along with the TEA and LCA ARCHES will work with its partners to verify and validate all hub elements and their operational readiness. For this purpose, the ARCHES cross-cutting activities will establish tests and models to predict operational readiness of the hub before committing major resources for its full implementation in the next Phase.

Milestone 2.1: Class 1 cost estimate completed and submitted to the DOE
Milestone 2.2: Mature TEA and LCA and V&V plan in place (SMART milestone)
Go/no go decision 2 Budget period 2 (Q8)
Go/no go decision 3 Budget period 3 (Q12)

Budget Period 4: (Q13- Q16), Budget Period 5: (Q17–Q20) and Budget Period 6: (Q21–Q24)
ARCHES Phase 3: (Q13–Q24)
Task 14: Regular Status Reporting (Q2–Q32)
ARCHES will deliver quarterly high-level hub status reports to the DOE to inform the DOE about progress, potential changes and issues. This report will include an operational, technical, and financial (actual spending versus planned spending) summary.

Task 15: EPC Progress Reporting (Q13–Q24)
Engineering, procurement and construction reports will be provided on a quarterly basis during this period with special attention to supply chain bottlenecks and spending rate. This phase is

expected to experience the highest spending rate of all phases and thus needs to be closely monitored.

Task 16: Safety and Permit Reports (Q13–Q24)
As the construction and installation of hydrogen facilities progresses, the safety and permit teams will further assess safety and permit needs for each unique site. This will be an ongoing process during this period and ARCHES will continue to coordinate and record these activities.

Task 17: RMP, TEA & LCA Updates (Q21–Q 24)
As the construction of various hub elements and the installation of hydrogen related equipment progresses, the risk register will be further updated with many risks resolved and newly emerging risks and associated mitigation plans recorded. Towards the completion and initial testing of completed hub elements TEA and LCA models will be further refined by ARCHES and reported to the DOE.

Milestone 3.1: Hub construction, equipment installations and initial testing completed
Milestone 3.2: Updated risk register and updated TEA & LCA analysis reports
Milestone 3.3: Hub is ready to ramp-up and move towards operational phase (SMART milestone)
Go/no-go decision 4 Budget period 4 (Q16)
Go/no-go decision 5 Budget period 5 (Q20)
Go/no-go decision 6 Budget period 6 (Q24)

Budget Period 7: (Q25–Q28) and Budget Period 8: (Q29–Q32)
ARCHES Phase 4: (Q25–Q32)
Task 18: Financial Model Updates (Q25–Q32)
With the construction, installation and final testing activities largely concluded the hub is ready for ramp-up and operation for the initial two years. At this point a recap of the actual CAPEX compared to the planned CAPEX will be provided and the OPEX will be refined based on conditions in 2029 and 2030. Financial models will be refined and run to forecast OPEX spending.

Task 19: Revised growth Plan (Q31–Q 32)
Throughout the ARCHES-Hub development and as part of the BP and FP the hub growth plan will be further developed and refined. As the hub (along with other hubs) drives down the cost of hydrogen and demonstrates the financial and technical viability of hydrogen in hard-to-decarbonize sectors and, as it demonstrates benefits to the affected communities and gains their support, support the demand for it will increase. ARCHES will proactively communicate the many benefits of hydrogen and begin to draw in new investments especially from the private sector when green hydrogen becomes cost-competitive with fossil fuel-based energy resources. ARCHES will use scenario analysis to prepare various possible growth strategies and revise the growth plan on an annual basis. A final version will be delivered to the DOE and the investment communities in Q32 of the hub area.

Task 20: TEA and LCA update with real hub data (Q30–Q 32)

During this operational phase of the hub, myriad valuable data will become available to prove system models based on real-time data. This will allow ARCHES to improve the models so they can be used for the planning of its own growth and for future hydrogen enterprises in California and elsewhere. The TEA and LCA analysis will be provided based on actual, real data of the hub. Gaps between models and real data will be identified and necessary correction to the models will be made to further improve the accuracy of the models.

Task 21: Ongoing Data Collection and Monitoring (Q30–Q32 and beyond)
With the hub in full operation in this phase, periodic and routine data collection will be instituted to further improve and perfect the hub and to make it a showcase for new hydrogen investments. ARCHES will organize and collect all critical hub data and will analyze it, identify findings, and produce conclusion and recommendations.

Task 22: Community Benefits Plan Implementation (Q1–Q32)
Throughout the development of the hub, ARCHES will also implement the CBP that is included in a separate document in this proposal and has a more detailed schedule of activities. The CBP is an integral component of ARCHES that will steadily increase support for hydrogen further accelerating its growth.

Task 23: Final Report (Q32)
By the end of 2031 ARCHES will submit a final report about the hub outcomes, the hub experience, its tremendous efforts, and the impact of DOE funding on hub and California.

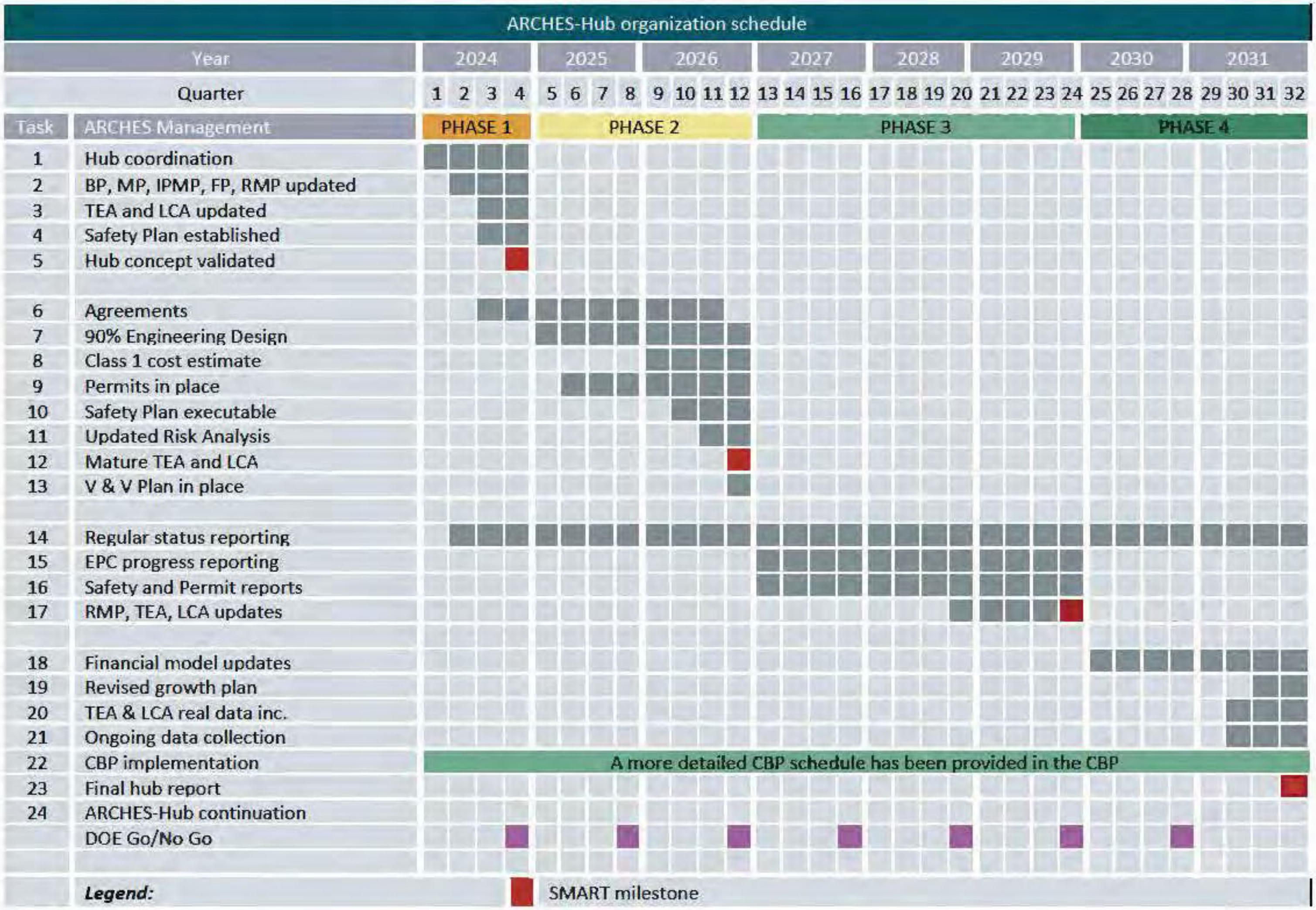
Milestone 4.1: Revised Growth Plan to grow California to 1.64MMTPD of H2 by 2045
Milestone 4.2: TEA and LCA for the hub based on real operating data
Milestone 4.4: Final ARCHES-Hub report (SMART milestone)
Final go/no-go decision point 7 Budget period 7 (Q28)

8.4. Go/No-Go Decision Points
There will be six go/no-go decision points starting with Q4, 2024, and then in each subsequent year. The last go/no-go decision will be in Q24 focused on full hub operation. The hub will have four budget periods starting with 2024 and ending in 2031 that cover the four hub phases.

8.5. End-of-Project Goal
The end-of-project goal for the ARCHES-Hub will be having achieved the planned production (~515 MTPD), distribution infrastructure (pipeline extension, H_2-carrier FCETs, tanks, temporary storage, etc.) and offtake of hydrogen (515 MTPD) with the initiation of a self-sustaining hydrogen economy in California ready to grow exponentially towards 47,000 MTPD in 2045, and ready to also physically connect with other hubs to begin building a nationwide hydrogen network. ARCHES will have achieved wide-ranging community benefits and support for hydrogen in all impacted communities.

8.6. Integrated Project Schedule

Architecting a hydrogen hub of the scale proposed is as challenging as it is exciting. Given the number and the diversity of projects with many disparate projects (in time, scope and cost), we provide a first-level project schedule for ARCHES activities in **Figure 8.1**.



Furthermore, the following selected project schedules illustrate the diversity of projects and their timing across the ARCHES-Hub. Here we show high-level production-related schedules from [redacted] It should be noted that some project plans differ in terms of initial timing and their definition of phases based on existing activities.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

8.6.8 Transportation Schedules

For all fleets that expect to refuel at their own stations (including transit agencies), they will be expected to install refueling infrastructure along with the purchase of the vehicles. New fueling station installation can take up to two years. Ordering buses and/or FCETs will be timed such that HRS installations will be completed and operational when buses and/or FCETs arrive. For fleets that will operate their vehicles "over the road" and will rely at least partly on public refueling, they will need to have good availability of HRS in the areas where they operate, or in some cases across the whole state, by 2030. Therefore, the procurement of FCETs for this case will be timed with the readiness of public HRSs.

The ARCHES rollout plan for public stations includes considering four main regions and placing stations in those regions as soon as possible, based on the proposals received from station providers. We have further specified locations where possible, taking into account the likely density of trucks in urban areas, around ports, and on major highways within the state. There will need to be both enough stations to help minimize "detours" in truck driving patterns to reach stations and the ability to dispense enough fuel so that all trucks can refuel as needed. While further specification of this on a spatial basis will be conducted during Phase I of the project, we currently envision a station rollout that allows a basic coverage in the most important areas by 2025 (14 stations) and ongoing rapid growth (e.g., 24 by 2026), in line with early truck deployments (see **Figure 3.6**). By 2030, the 66 stations envisioned should provide a full network around the state (on or next to highways), along with denser station coverage in key areas such as near ports. There will also be the possibility of some mobile refuelers that can be moved into different locations as needed.

However, throughout the early roll-out period, it will be critical to align planned truck sales with plans for station locations and create some early coverage areas that are well aligned. Port areas of northern and southern California and locations along the I-5 corridor from Sacramento to southern LA will be important for early location of stations, such as the [redacted] expected to be in service by 2025. Both transit projects and FCET will primarily be procurement projects. The procurement will be timed with the completion and operational readiness of the public and private HRS. A preliminary HRS rollout plan for FCETs is shown in **Figure 8.2**, which was informed via the initial plans for FCETs and availability of renewable, clean hydrogen production. It is expected that the HRS and hydrogen production may be the limiting factor for FCET rollout assuming that the OEMs can meet the demand, which will be further assessed in Phase 1 of the hub.

[redacted]