Appendix A
Current green hydrogen pilots and projects in the U.S.

(As of April 2021)

1. Los Angeles Department of Water and Power's Intermountain Power Green Hydrogen Project (Delta, Utah)

Background:

- **Intermountain Power Agency** serves 23 Utah and six California municipalities. It is managed by the Los Angeles Department of Water and Power.
- Coal provides just **3 percent** of California's power generation, most of it from an 1,800-megawatt coal-fired power plant in Delta, Utah, that began operation in 1986 at a cost of $5.4 billion (**$12.7 billion** in today's dollars). Los Angeles takes nearly **50 percent** of the power.
- **LA's power generation** must be 55 percent renewable by 2025, 80 percent by 2036 and 100 percent by 2045. California **SB 100** established a mandate of 100 percent renewable and carbon-free power generation by 2045.
- The Intermountain Power green hydrogen project is considered the most **"ambitious"** project in the U.S.

The Intermountain Power Project, or IPP:

- Power generation ($1.9 billion, including upgrades to the transmission system):

Two natural gas units totaling 840 megawatts will replace the 1,800-megawatt coal plant that will close in 2025.

The turbines are **Mitsubishi-Hitachi Power Systems**, or MHPS, J-series, air-cooled gas turbines that will initially burn 30 percent green hydrogen with 70 percent natural gas.

With expected engineering upgrades, the turbines will run on 100 percent hydrogen by 2045.

- **Hydrogen production** – $585 to $648 million – with current alkaline electrolyzer capital cost estimates, not including installation costs[1]:

Hydrogen would be produced using electrolysis.

Water rights will be transferred from the coal-fired plant.

Water usage would be about 90.5 million gallons per year.[2]

Hydrogen production would occur during the spring and fall, when there is substantial excess generation of wind and solar power, that is, when power is cheapest.

The IPP hub, with more than 500 megawatts of alkaline electrolyzers initially to produce 30,000 tons of hydrogen per year, will be connected to substantial renewable resources:

- 370 megawatts of existing utility-scale wind power
- 2,300 megawatts of future utility-scale solar
- **1,500 megawatts** of wind from Wyoming to come online in 2025
- Geothermal generation
- Canadian hydro generation

- Hydrogen production is expected to expand to supply transportation fuel.

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1. *Current* **cost of alkaline electrolyzers**, *according to two sources: $1,083 to $1,200 per kilowatt = 1,083,000 per megawatt x 540 = $585 million/1,200,000 x 540 = $648 million.*
2. *The Intermountain Coal-Fired Power Plant consumes* **11.2 million** *gallons of water per day – 4 billion annually.*

- Energy storage of hydrogen and compressed air, a **$1 billion project**:

MHSP contracted with Magnum Development, which owns the salt dome caverns in Utah.
More than 100 caverns can be constructed.
One cavern can hold **5,500 tons of hydrogen**, enough to fill up 200,000 hydrogen buses.
1,200 megawatts of compressed air storage by 2025 – at 100 percent capacity factor – would provide power for 48 hours.

Jobs:

- The coal plant **employs 400 people**, with an average salary of $94,000.
- The natural gas plant is to **employ 125**.
- Other jobs data not provided.

2. NextEra hydrogen pilot projects

Background:

NextEra is the country's largest owner of wind and solar power:

More than **15,000 megawatts of wind** in 14 states
2,600 megawatts of utility-scale solar, mostly in the Southeast and California
More than **14,000 megawatts** of solar, wind and energy storage planned for deployment
Plans to add **30 million solar panels** (12,000 megawatts) in its Florida Power & Light service territory by 2030
Plans to add **$1 billion in battery storage** in 2021.

The Okeechobee Energy Center Green Hydrogen Project:

- The project is at the $750 million, **1,622-megawatt, combined-cycle natural gas plant** at the Okeechobee Energy Center, in Florida.
- NextEra plans to **use solar power** – otherwise curtailed due to overproduction, that is, essentially free electricity – to produce hydrogen with a **20-megawatt electrolyzer**.
- The pilot is expected to come online in 2023.
- A portion of the natural gas usage will be defrayed by green hydrogen at one of the facilities units.
- Estimated cost is **$65 million**
- NextEra has identified **50 hydrogen pilots** that include power production and transportation and heavy industry applications.
- The company expects to **add to its potential pilot projects** over the next six months.
- The pilots are considered relatively small investments for the purpose of gaining knowledge and waiting on anticipated electrolyzer cost reductions in coming years, prior to scaleup.

3. Orlando Utility Commission Integrated Solar, Battery and Hydrogen Project (Orlando, Fla.)

Background:

- Florida-based **Orlando Utility Commission**, or OUC, is a municipal utility serving 250,000 customers.
- OUC has **goals** of supplying municipal buildings with 100 percent renewables by 2030 and a citywide goal of 100 percent renewables by 2050.

OUC Hydrogen Project, initiated by Giner ELX, an electrolyzer manufacturer:

- Goals of the project:

Demonstrate an integrated system of hydrogen production, storage, electric supply and municipal fuel cell vehicle fleet fueling
Generate hydrogen and power to optimize the economics of solar energy
Project completion by May 2023

- Total project cost is $9 million

  $4 million from DOE for studies, materials and time

  Balance from OUC

- The studies:

  A techno-economic analysis of system design, integration and cost-optimization, conducted by the University of Florida's Solar Energy Center

  NREL modifying its modeling for the national electric system to determine whether electrolyzers can increase solar penetration

- Partners:

  Giner ELX
  Electrolyzer engineering and installation

  OUC
  Solar power investment/provide fuel cell vehicles

  GM
  Fuel cell for electric generation

  OneH2
  Hydrogen storage, compression, dispensing

  University of Florida
  Techno-economic analysis

  NREL
  National study to determine effectiveness of electrolyzers in increasing solar penetration

- Components of the project:

  Three electrolyzers with 510 kilowatts of output

  Three fuel cells with total output of 210 kilowatts

  A battery system that will provide **10 hours of power** connected to a floating solar array

  Two storage tanks that will hold 550 pounds of hydrogen

  To assist the project, OUC is signing a power purchase agreement with Invenergy for **150 megawatts of solar**, enough to power 13,500 homes.

  The system can be scaled

- The hydrogen equipment will cost **$5.5 million**.

- Additional information provided by **Giner**:

  With high penetrations of solar, a duck curve (as in California) is created, with very high power demand spikes in the evening, which can last eight hours. Giner says electrolyzers can eliminate 57 percent of that spike and use overproduced solar during the day to produce the hydrogen.

  The global hydrogen market is expected to grow to more than $180 billion in 2023, from $130 billion in 2018.

4. Texas hydrogen demonstration project and study

Background:

- Frontier Energy, the manager of California's Fuel Cell Partnership, initiated the **Demonstration and Framework for H2@Scale in Texas and Beyond** for the Port of Houston.

- The **H2@Scale** program is housed at the Department of Energy.

Project goals:

- **Design**, build and operate a dedicated renewable hydrogen network.

- **Conduct a study to:**

  Analyze the potential for hydrogen infrastructure and use in heavy industry at the Port of Houston.

  From that case study, identify the economics and policies required for a national strategic plan to deploy heavy-duty fuel cell transportation and energy systems.

Description of the project:

- Scope:

  Hydrogen produced by wind and solar power to power an onsite data center and fuel-cell-powered vehicles at the University of Texas at Austin.

A Port of Houston case study will assess wind and solar resources, salt-dome storage capacity, hydrogen pipelines (used now to supply refineries), natural gas infrastructure, the port operations, and the large concentration of heavy industry in the area to demonstrate the feasibility of hydrogen economy nationwide.

The project will cost **$10.8 million**, which includes funding from DOE.

- The project began in July 2020 and will take **three years** to complete. Projected timeline:

Year one – planning and construction of demonstration network at the University of Texas at Austin and Port of Houston study begins.

Year two – demonstration begins operation and the parameters of the are study finalized.

Year three – complete the demonstration and assess ability to provide cost-effective hydrogen.

- **Partners include:**

GTI
R&D and training on hydrogen technologies

University of Texas

Texas Gas Service

SoCalGas

Toyota
Supplier of fuel-cell-powered vehicles

Shell

Mitsubishi Heavy Industries

Air Liquide and PowerCell Sweden
Hydrogen-powered heavy-duty vehicles

OneH2
Hydrogen storage, dispensing

- Project components of the **Hydrogen Network** at the University of Texas:

Solar panel installation at the Texas Advanced Computing Center

Electrolysis to produce hydrogen using wind and solar sourced by GTI

Producing hydrogen with steam reforming using landfill methane

Onsite hydrogen storage

A fuel cell combined with solar and wind will power the data center

Onsite fueling of fuel-cell-powered light vehicles

5. Stone Edge Farm Microgrid (Sonoma, Calif.)

Background:

Stone Edge Farm is a vineyard and winery. In 2012, it installed its first microgrid on the 16-acre farm, with solar only. The management added battery and hydrogen storage and fuel cells for power generation and fueling four fuel-cell-powered light vehicles. In **August 2012**, all facilities on the farm began operating completely independent of the electric grid. Beginning in 2018, management added **300 kilowatts** of solar along with battery storage at its Silver Cloud vineyard.

Stone Edge Farm goals:

- 50 percent reduction achieved in first year with solar
- Thereafter, reducing carbon emissions as far **below zero** as possible

Project design:

- Initially, the aim was to **generate far more electricity with solar than was needed** (four times the farm's peak demand) to sell the power back to **Sonoma Clean Power**, a community choice aggregator. Various legal barriers prevented it, but negotiations continue with Sonoma that would create another revenue stream for the project.
- **With the excess power**, battery storage was added and finally a hydrogen electrolyzer to fuel three to four fuel-cell-powered light vehicles. Fuel cells

provide power to enable the system to operate independent of the grid permanently.

- The system also includes a small, external combustion **microturbine** that provides heat and power and can burn hydrogen or natural gas.
- Management is **adding another microgrid** to supply power to the vineyard operation with solar and battery storage.

Project components that allow Stone Edge Farm to operate independent of the grid:

- 368 kilowatts of solar
- 400 Kilowatt electrolyzer
- 28 kilowatt fuel cell "hive"
- 324 kilowatts of various battery storage technologies
- 65 kilowatt microturbine
- A microgrid management system to balance power needs

Costs:

- Not disclosed
- However, commercial demand charges were significantly reduced.
- **California law** provides a $2.17 tax credit for each kilogram of hydrogen produced by a microgrid.

Project vendors and partners:

- **Wooster Energy Engineering**
  Principal engineer
- **Capstone**
  Microturbines
- **Tesla**
  Battery storage
- **Enphase Energy**
  Solar installation/microinverter manufacturer
- **PlugPower**
  Electrolyzers/fuel cells
- **Sony**
  Battery storage
- **Simplifi Power**
  Battery storage
- **Redflow**
  Battery storage
- **Sonoma Clean Power**
  Municipal aggregator
- **PG&E**

Other developments:

- As a working laboratory, Stone Edge hosted **80 interns** between 2012 and 2017.
- **During the 2017 wildfires** and before leaving the grid permanently, the microgrid operated for 10 days remotely, without electric system support.

6. Hannibal Port Power Project (Hannibal, Ohio)

Background:

- **485-megawatt natural gas plant** on a brownfield site **near the Ohio River**
- Approved by the Ohio Siting Board **in 2017**
- **Financing** approved in February 2019
- Project partners **announced in October 2020** that hydrogen would be blended with natural gas.
- 2030 target date for **100 percent hydrogen**
- Project will use **hydrogen from a nearby industrial facility** for testing and switch to green hydrogen using Ohio River water.
- The facility is scheduled to begin operation by **November 2021, burning 20 percent hydrogen**
- Hydrogen will eventually be **stored in underground salt dome formations**.

Project partners:

- **New Fortress Energy (NFE)**
  Providing electrolyzers that require **30 percent less energy** than current technology
- **Long Ridge Energy Generation, owned by NFE**
  Plant operator and manager

- **GE**
  Providing hydrogen ready turbines

- **Black & Veatch**
  Engineering for hydrogen handling and integration with natural gas

Cost:

- **$588 million** for the plant itself

- Costs of hydrogen technology not available at this time

Power plant jobs:

- 300 to 350 construction jobs

- 20 permanent jobs

- Hydrogen-related jobs unavailable

7. SunLine Transit Agency Program for zero-emissions buses (Coachella Valley, Calif.)

Background:

- **SunLine Transit Agency** operates 120 miles east of downtown Los Angeles, providing provides service to nine cities in an 1,100 square mile area, including Palm Springs.

- SunLine purchased its **first hydrogen-powered bus** in 2000. Since then it has added 19 fuel-cell- and battery-powered buses.

- In July, SunLine's **board of directors approved its plan** for all buses and other agency vehicles to be emissions-free by 2025.

General information on fuel-cell-powered and electric buses:

- On average, fuel cell buses require 66 pounds of hydrogen per day.

- It takes seven to 10 minutes to fuel them, which is equivalent to diesel buses.

Current system:

- A **2-megawatt Nel electrolyzer** – the **largest in the country** for transportation – that produces enough hydrogen daily for **32 buses**, about 2,000 pounds per day, installed this year

- 24 percent of large, fixed route buses are zero emissions

- 15 fuel cell fixed route electric buses.

- Four fully fixed route electric buses.

- 39 compressed natural gas paratransit buses

- Phasing out natural gas to produce hydrogen this year

- Fuel-cell buses cost **56 cents per mile** to operate, equivalent to 6 miles per gallon of gasoline

2020-2022 planned zero-emission investment:

- All purchases of fixed route buses will be zero-emissions buses, or ZEB, from now on.

- 50 percent of fixed route fleet will be ZEB by 2025.

- Microgrid will eventually consist of **4 megawatts** of solar and 2 megawatts of battery storage.

2020-2022 Costs

- Hydrogen fueling state – $400,000

- Replacing 15 fuel-cell-powered buses – $15 million

- Replacing two electric buses – $2 million

- Beginning solar and battery storage micro grid to hydrogen – $4 million

- Workforce training – $680,000

Capital cost of planned system (2020-2040):

- $173.4 million

- $106 million from targeted federal and state support funds

Planned system:

- All fixed route and paratransit buses will be 100 perent ZEB by 2035.

- 67 fuel-cell or electric buses

- 18 electric buses

- 39 paratransit ZEB vehicles

Other aspects of SunLine's system:

For additional revenue, SunLine will allow access for heavy and light fuel-cell-powered vehicles to its fueling station, as the electrolyzer produces excess hydrogen.

8. Nikola Motor hydrogen fueling station pilot and planning

Background:

- Nikola Motor was formed **in 2015** to produce heavy electric and fuel-cell/electric trucks.
- This year the firm was **accused of misleading investors** about the company's viability and planned rollouts. The accusations were brought by a watchdog that benefited – it bet on the stock to drop – when Nikola's stock price plummeted. The SEC is still investigating.
- GM recently **backed out of an 11 percent stake in Nikola**, a $2 billion deal, for various reasons but may supply fuel cells and batteries for Nikola's semis. Since GM's fuel-cell system was initial designed for passenger cars, it must be redesigned.
- However, Nikola's third-quarter earnings **call** indicates it is moving forward with heavy electric and fuel cell trucks, as well as initial buildout of hydrogen fueling stations.

Partners (investments from these partners total **$480 million**):

- **Nel** – supplies electrolyzers for hydrogen fuel stations
- **Bosch** – supplies fuel cells for the semis
- **CNH** – joint venture with Nikola to manufacture heavy-truck electric vehicles in Germany for regional runs
- **Hanwha solar** – supplies solar panels for green hydrogen production at fueling stations

Nikola/Nel pilot:

- **Nikola bought electrolyzers** to supply five stations in multiple states and trucking routes.
- The $30 million **purchase** is for 85-megawatts of electrolyzers that will produce eight tons of hydrogen per day for each station, which will **support 210 trucks daily.**
- Solar arrays will power the electrolyzers.
- Among the early stations there will be **two** at either end of a 400-mile route for Anheuser-Busch, from its brewery in Van Nuys, Calif., to a distribution center in Chandler, Ariz.
- The stations can be sized to fuel from 200 to 1,000 semi-sized trucks per day.
- Busch has **ordered 800 trucks**.
- Construction of the **first station** will begin in the second quarter of 2021.
- Station components are projected to last **21 years**.

Fuel-cell and electric truck capabilities and costs, per Nikola:

- Nikola plans a seven-year, 700,000-mile leasing arrangement at $665,000 per truck.

Truck costs – $188,000
Hydrogen per truck (including station costs) – $231,000
Service and maintenance costs – $47,000
Station capital costs per lease – $26,000
Profit per track lease – $173,000

- The cost per mile is projected to be slightly less than a diesel truck, whose fuel will be subject to more price volatility – 95 cents, compared to 97 cents per mile.
- Per station, total costs estimated at $16.6 million
- Truck range is estimated to be 500 to 750 miles
- Fueling time comparable to diesel at 15 minutes
- Charging time for comparable fully electric semi:

According to Nikola, it would charge in an hour or more
According to Tesla, it would take 30 minutes for its semi with its solar-powered mega-charger.

Current situation:

- Nikola's planned fuel-cell-powered truck assembly plant in Arizona:

  Production trials in mid-2021.

  Limited production ramp-up by the end of 2021.

  Tests of prototypes will begin in 2021.

  Production of its fuel-cell hybrid trucks will begin **later this year**.

  Assembly plant projected to be at **full production** in 2023.

  The facility will be 1 million square feet and **cost $1 billion**.

  Estimated employment at the facility will be **2,000** jobs.

- Trucks will be tested in 2022.

- Nikola says it has **orders for 14,600 trucks**, valued at more than $10 billion.

  65 percent are large corporate customers.

  34 percent are large fleet owners.

  Busch has placed 6 percent of all orders.

- Nikola has **joined a consortium** with Hyundai, Toyota, Shell, Nel and Air Liquide to standardize fuel cell pumps and vehicle receptacles.

Goals by 2030, though timing could be delayed, according to the company's third-quarter earnings call):

- **700 fueling stations** by 2028

- 30,000 fuel-cell-powered trucks **produced by 2027**

Other fuel-cell-powered heavy-vehicle partnerships/developments:

- **Kenworth and Toyota** have designed fuel cells into a Kenworth model.

- Toyota and its subsidiary **Hino Motors** (maker of diesel engines) will test a fuel-cell-powered semi in 2021.

- **Daimler and Volvo** formed a partnership in 2020 to design a fuel-cell-powered heavy vehicle, with production slated to begin in 2024.

- Hyundai has targeted 2022 to begin marketing its fuel-cell-powered semi.

- **Cummins and Hyundai** will collaborate on fuel-cell and battery electric powertrains for commercial vehicles in the U.S. market.

- **Cummins and Navistar** have partnered to convert an International semi model to hydrogen:

  Cummins received $7 million from the DOE for the design.

  The truck will have a 300-mile range and be road-tested for 1 year.

  Werner Enterprises out of Fontana, CA will integrate the truck into its fleet.

  33 percent of transportation hydrogen must be produced from renewable sources in California.

9. Douglas County Public Utility District Hydrogen Project (Washington)

Background:

- Douglas County Public Utility District, or PUD, is powered almost exclusively – 97 percent – by the **840-megawatt Wells Dam** located on the Columbia River, 200 miles east of Seattle.

- At the request of its local state representative, the **Washington legislature passed bills** in 2019 to:

  Allow PUDs to produce and distribute green hydrogen.

  Provide incentives for building a renewable hydrogen transportation infrastructure.

- In 2020, the legislature provided $250,000 for Douglas County to procure expertise for the design and engineering of the project.

- Also in 2020, Douglas County received a $1.9 million grant from the **Centralia Coal Transition Board** (funded by a U.S. subsidiary of **TransAlta**, a Canadian hydro, geothermal, biomass and wind utility) to construct a demonstration hydrogen fueling station, using hydrogen produced by the Wells Dam.

- In April 2020, the **Douglas County public utility district commissioners approved $9.5 million** for the purchase of the electrolyzer and attendant facilities.

Goal:

Gain experience for future expansion of infrastructure for passenger and heavy-vehicle fuel-cell-powered vehicles.

Partners:

- **RH2 Engineering** – design and engineering consultant

- **Hydrogenics**, a Cummins subsidiary – supplier of the electrolyzer

- **Toyota** – supplier of 10 fuel-cell or electric passenger vehicles

- **Bonneville Environment Foundation**, collaborating on the hydrogen fuel station

- **Renewable Hydrogen Alliance** – collaborating on the hydrogen fuel station

The project:

- The PUD will use excess electricity from Wells Dam to generate hydrogen.

- A 5-megawatt electrolyzer **located 50 miles from the dam** at an **industrial park** on the Columbia River in Douglas County will produce the hydrogen, until now the **largest of its type deployed in the U.S.**

- The **hydrogen will be transported by a diesel** semi to a hydrogen fueling station between Seattle and Portland.

- The station will serve a **fleet of 10 Toyota Mirai fuel-cell-powered passenger vehicles** with a 300-mile range that can be fueled in less than five minutes.

- **An added benefit** is that instead of changing the dam's electric output to balance the grid, the electrolyzer will be ramped up or down as needed. The electrolizyer is a flexible resource and can be ramped up in microseconds and can reduce the need for reserve power.

Timeline:

Both the **electrolyzer** and the **fuel station** are expected to be operational some time in 2021.

Hydrogen projects in early stages in Washington:

- **Tacoma Power**, a municipal utility, has created the first electric rate for hydrogen production in the country, which will be capable of interrupting that electric demand when power is needed or prices high, and wants to attract to the area companies that would generate hydrogen with electrolyzers.

> Hydrogen supplies more than 80 percent, nuclear 7 percent and wind 6 percent of **Tacoma's power**.

- **Eugene Power & Electric**, a municipal utility, signed a memo of understanding with Bonneville Environmental Foundation and NW Natural, a gas utility, to explore an electrolyzer up to 10 megawatts to produce hydrogen, mainly with renewables.

> The hydrogen could be used many ways, including mixed with natural gas in NW Natural's pipelines or buses.