Is Clean Hydrogen Production a Good Fit for Questa?

Intermediate Feasibility Study Results

August 17, 2023

Kevin Topolski, Elaine Hale, Chrissy Scarpitti, Haider Niaz, Andre Fernandes Tomon Avelino, Alberto Franco

National Renewable Energy Laboratory

DOE/GO-102023-6016

Disclaimer

The following slides contain summary information and constitute a high-level overview of key questions and considerations related to clean hydrogen production, as well as technoeconomic feasibility study results. Additional analysis will be required to estimate economic impacts. The purpose of this presentation and the overall study is to provide information to the Questa Community Coalition. The authors, NREL, DOE, and Communities LEAP are not recommending any specific course of action. This deck is intended for discussion purposes only and should not be the sole basis of future design or investment decisions.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Communities LEAP (Local Energy Action Program) Pilot. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

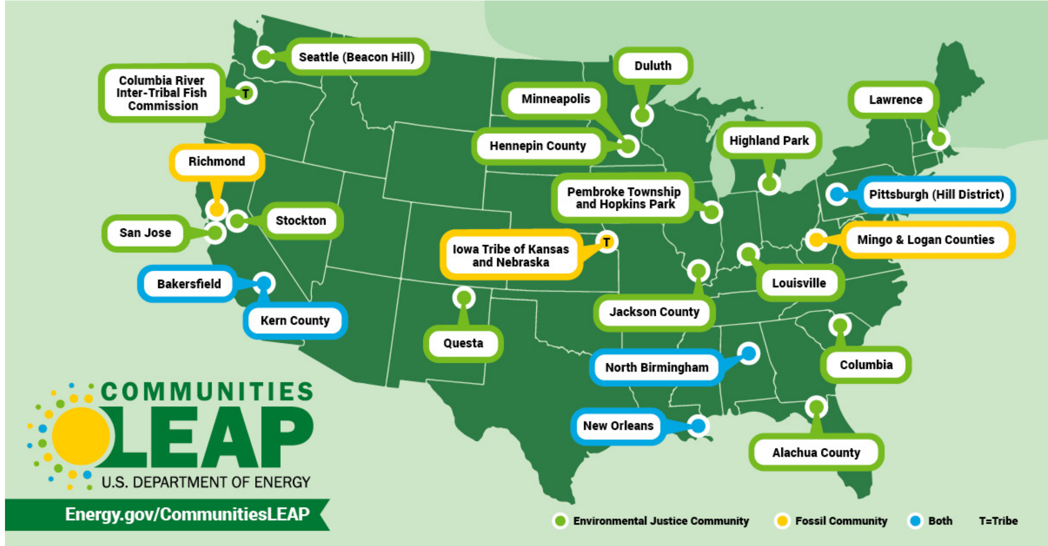
Contents

Project Context and History: Why Hydrogen? And How Did We Get Here?

Kit Carson Electric Cooperative (KCEC) has been exploring alternatives to meet its membership-driven 100% renewable energy goals in advance of the New Mexico legal mandate for rural co-ops to transition to carbon-free electricity by 2050. Questa Community Coalition members see potential economic development and brownfield reuse benefits of clean hydrogen production in Questa.

- The Communities Local Energy Action Program (LEAP) facilitates community-wide economic empowerment, local environmental improvements, and other benefits through clean energy deployment in communities that are low-income, energy-burdened, experiencing environmental justice impacts, or experiencing a shift away from economic reliance on fossil fuels.
- This coalition applied for a Communities LEAP technical assistance grant to study the feasibility and potential impacts of clean hydrogen development in Questa.
- Questa is one of the 24 communities selected for the inaugural class of Communities LEAP projects.

Questa LEAP Coalition members and NREL team visit the hydrogen test bed facility at the Flat Irons campus in Boulder County on December 9th, 2022. *Photo by Ryan Weeks, NREL*



Map of communities participating in the LEAP Pilot. *Illustration by DOE*

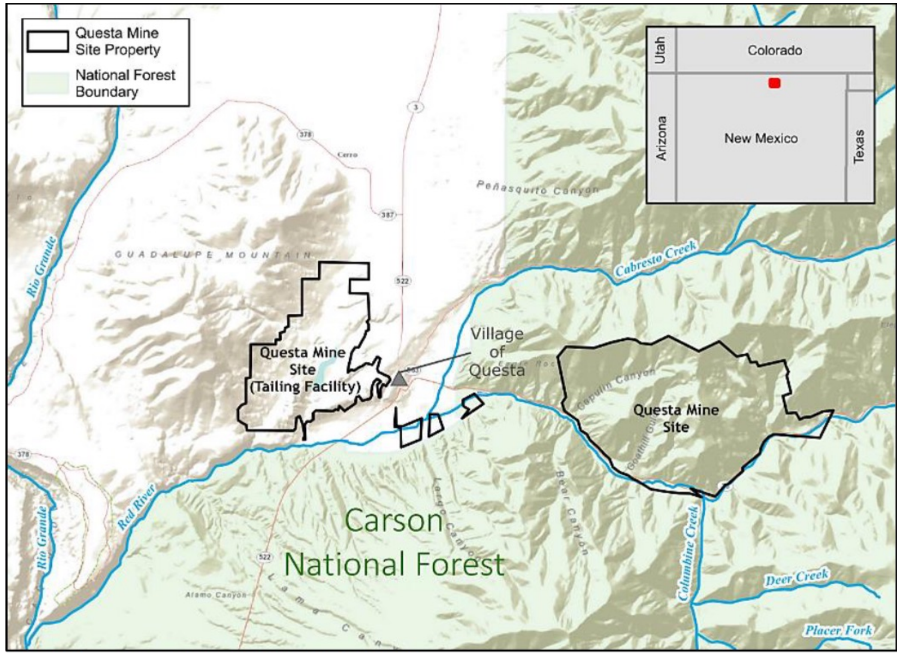
Questa's Communities LEAP Application

What?

- Study whether it would be beneficial to reuse mine and local resources (i.e., land, water) to produce electrolytic hydrogen.

Why?

- Deliver clean, reliable electricity during non-solar and other hard-to-serve times (KCEC)
- Create jobs in Questa (Village of Questa, Chevron)
- Attract more economic activity (Village of Questa, Chevron)
- Increase tax base (Village of Questa)
- Put existing assets to beneficial use (Chevron)
- Maintain affordable energy bills during the transition to clean electricity (KCEC, Village of Questa)
- Support corporate carbon reduction goals (Chevron)
- Be a replicable model for other rural and tribal communities (KCEC, Village of Questa).



Map of former molybdenum mine site and tailings facility located in Questa, New Mexico. *Map by EPA* https://onrt.env.nm.gov/wp-content/uploads/2018/05/Final-Questa_RPEA_5.21.18.pdf.

KCEC is looking beyond their 100% daytime solar goal.

Kit Carson Electric Coop (KCEC) solar panels generate daytime power. *Photo by KCEC* https://kitcarson.com/electric/100-daytime-solar-energy-by-2022/.

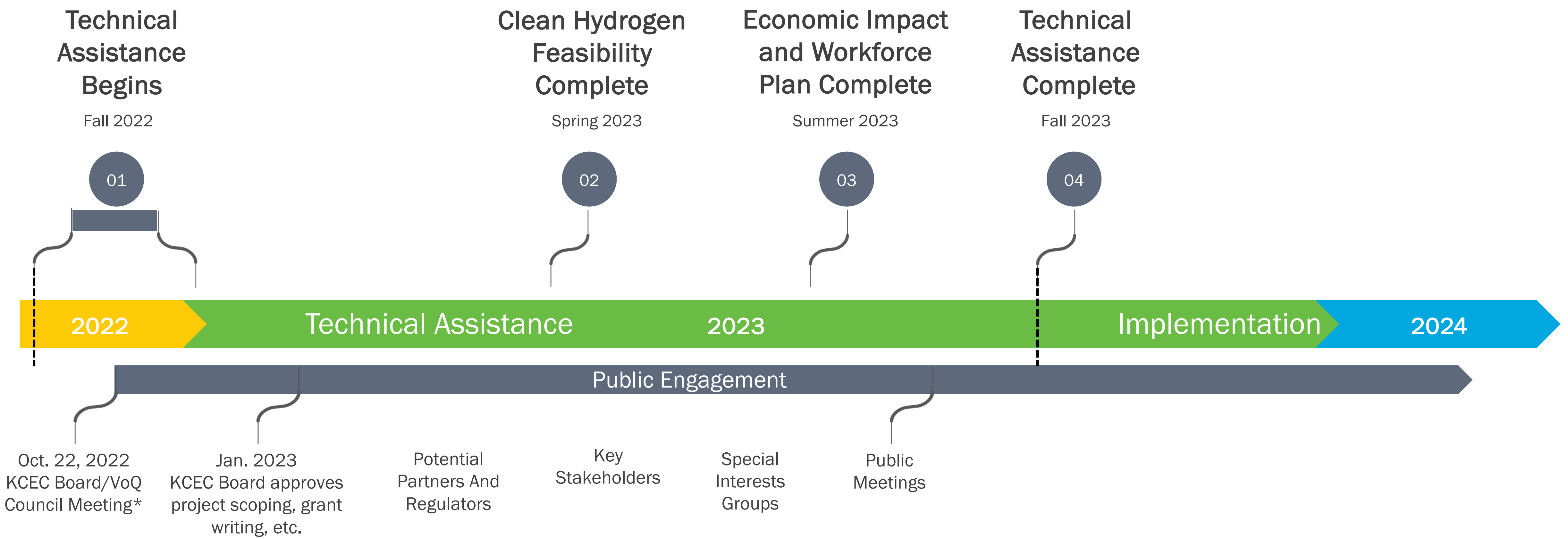
Questa Community Coalition and Technical Assistance Team

Community Coalition		
Name	**Title**	**Email**
John Ortega	Mayor, Village of Questa	jortega@villageofquesta.org
Jake Lafore	Project Manager, Village of Questa	jlafore@villageofquesta.org
Chris DeFillippo	Village Attorney, Robles, Rael & Anaya	chris@roblesrael.com
Luis Reyes	CEO and General Manager, KCEC	lreyes@kitcarson.com
Richard Martinez	Chief Operating Officer, KCEC	rmartinez@kitcarson.com
Lynn Skall	Director, Questa Economic Development Fund	lynn@questaedf.com
Gabriel Herrera	Public Affairs Advisor, Chevron	Gabriel.Herrera@chevron.com
Christian Isely	State Government Affairs Representative, Chevron	cisely@chevron.com
Mark Urfer	Site Manager, Chevron	Mark.Urfer@chevron.com

Technical Assistance (TA) Providers		
Name	**Role**	**Email**
Elaine Hale	Community Lead (NREL)	elaine.hale@nrel.gov
Chrissy Scarpitti	Community Lead (NREL)	chrissy.scarpitti@nrel.gov
Kevin Topolski	Hydrogen Infrastructure Analyst (NREL)	kevin.topolski@nrel.gov
Haider Niaz	Hydrogen Infrastructure Analyst (NREL)	haider.niaz@nrel.gov
Andre Fernandes	Economist (NREL)	andre.fernandestomonavelino@nrel.gov
Alberto Franco	Economist (NREL)	alberto.franco@nrel.gov
Patricia Sullivan	Associate Dean, Outreach and Recruitment, College of Engineering (NMSU)	patsulli@nmsu.edu
Kayla Copeland	Outreach Facilitator (Sundance)	kcopeland@sundance-inc.net
Riley Wittler	Outreach Facilitator (Sundance)	rwittler@sundance-inc.net
Duncan Mcbranch	New Mexico strategy development for WISHH (LANL)	mcbranch@lanl.gov

KCEC: Kit Carson Electric Cooperative
LANL: Los Alamos National Laboratory
NMSU: New Mexico State University
NREL: National Renewable Energy Laboratory
WISHH: Western Interstate Hydrogen Hub

Questa's Communities LEAP Timeline



Groups consulted to date

ED: NM Environment Department
EDD: NM Economic Development Department
EMNRD: NM Energy, Minerals and Natural Resources Department
LANL: Los Alamos National Laboratory
LOECC: Land of Enchantment Clean Cities

NMSU: New Mexico State University
RETA: New Mexico Renewable Energy Transmission Authority
WISHH: Western Interstate Hydrogen Hub
BLM: Bureau of Land Management
State Legislators

KCEC: Kit Carson Electric Cooperative Board
VoQ: Village of Questa Council
Taos County Commissioners
State Engineer
New Energy Economy
Western Environmental Law Center

Rio Grande Sierra Club
Renewable Taos
350.Org New Mexico
Amigos Bravos
Questa Independent School District
VFW: Veterans of Foreign Wars
Note: Others invited but did not attend.

* The slide deck presented at this meeting can be found online. See list of resources on page 41 of this deck.

What Is Hydrogen (H_2)?

- Hydrogen is an energy-carrying gaseous molecule that can be produced in multiple ways—for example, from:
  - Renewable electricity by electrolysis (or "Green H_2")
  - Natural gas by reforming:
    - without carbon capture (or "Gray H_2")
    - with carbon capture (or "Blue H_2").
  - Coal gasification (or "**Black H_2**").

- Hydrogen could be a clean alternative to methane (CH_4), also known as natural gas, because H_2 is a fuel that can be used for multiple purposes similar to methane [1]:
  - Vehicle fueling
  - Electricity generation
  - Other uses, as shown in Figure 1.

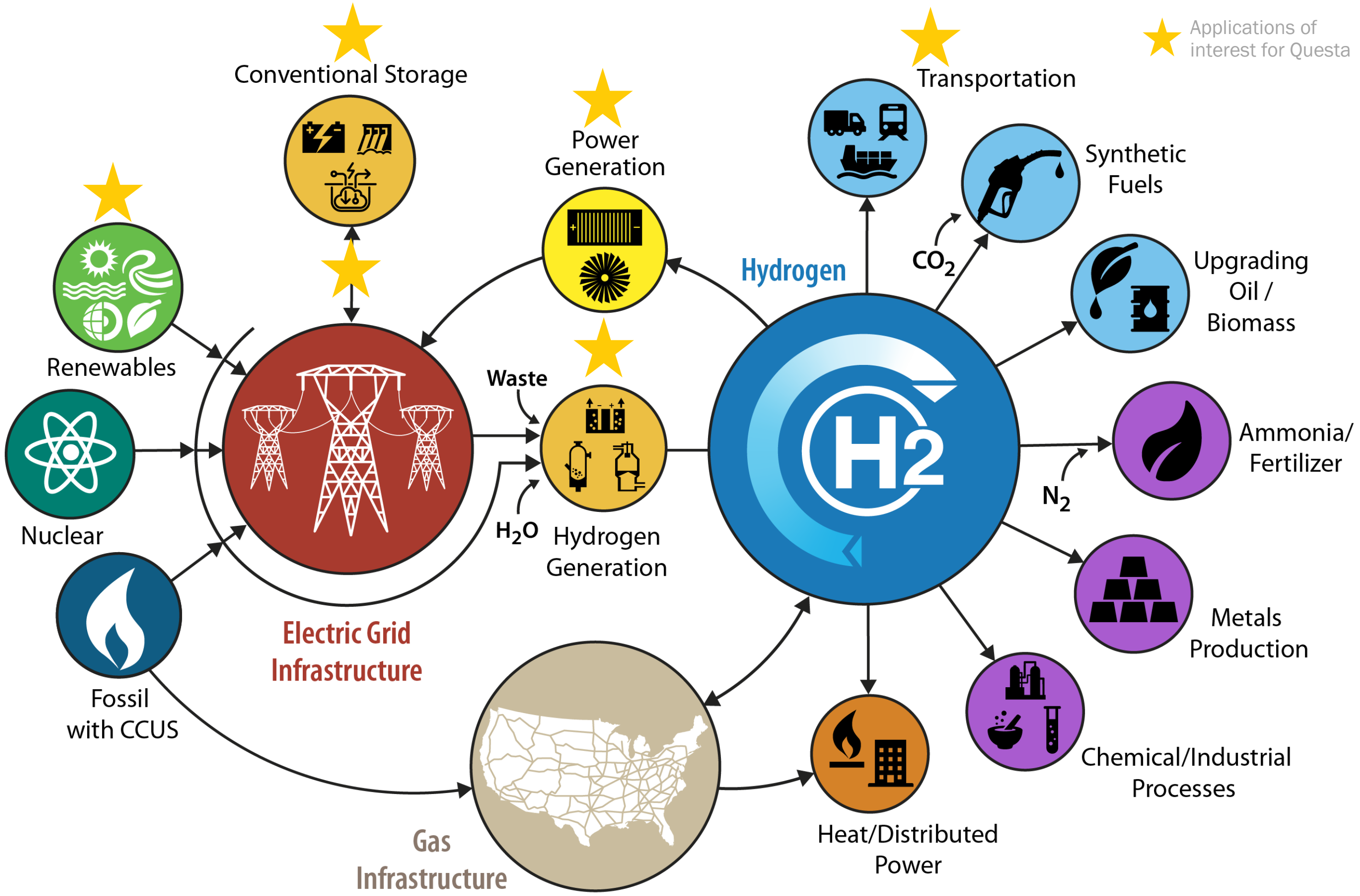
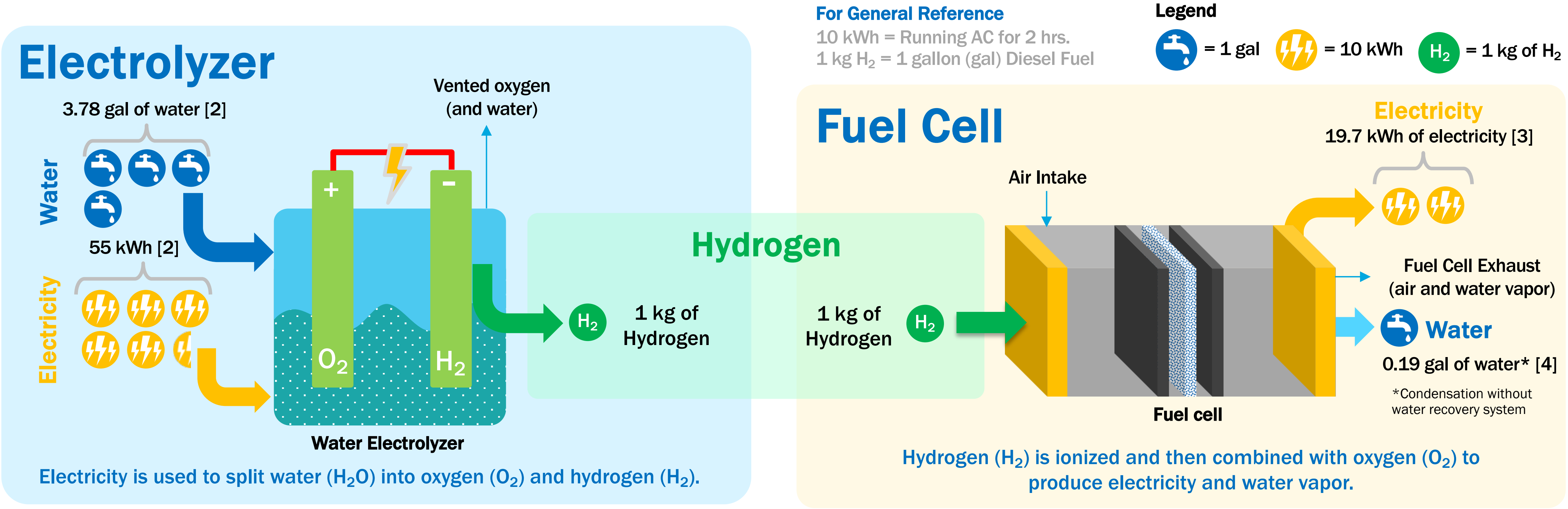


Figure 1. Various uses of hydrogen [1]

How Is Clean Hydrogen Made? How Is It Used?



This project focuses on clean H_2 production by electrolysis.

- Virtually no CO_2 or criteria air pollutant emissions are created by electrolytic H_2 production.
- Can be powered by any form of clean electricity (e.g., wind, solar, hydropower, nuclear, geothermal).

Clean H_2 could be used in fuel cells for grid power or vehicle mobility.

- No CO_2 or criteria air pollutant emissions are created.
- Could flexibly provide power when needed (e.g., winter peak times with no sun and little wind, vehicle fueling).

For Some End Uses, H_2 Storage Could Be More Cost-Effective Than Batteries

- This project examines two end uses that are challenging to decarbonize:
  - Electricity demand when there is little sunshine and wind
  - Off-road vehicle transportation.
- Batteries can partially meet these end uses with high energy efficiency but at limited scale (timescale of hours).
- Like batteries, hydrogen is a carbon-free energy carrier, but unlike batteries, it can be stored at scale (days to months timescale). This scaling is key for:
  - Electricity demand during prolonged periods of low wind and sun resource
  - Heavy-duty vehicles.
- Integrating batteries and hydrogen systems with clean energy generation can provide short- and long-duration storage across multiple scales of energy needs.

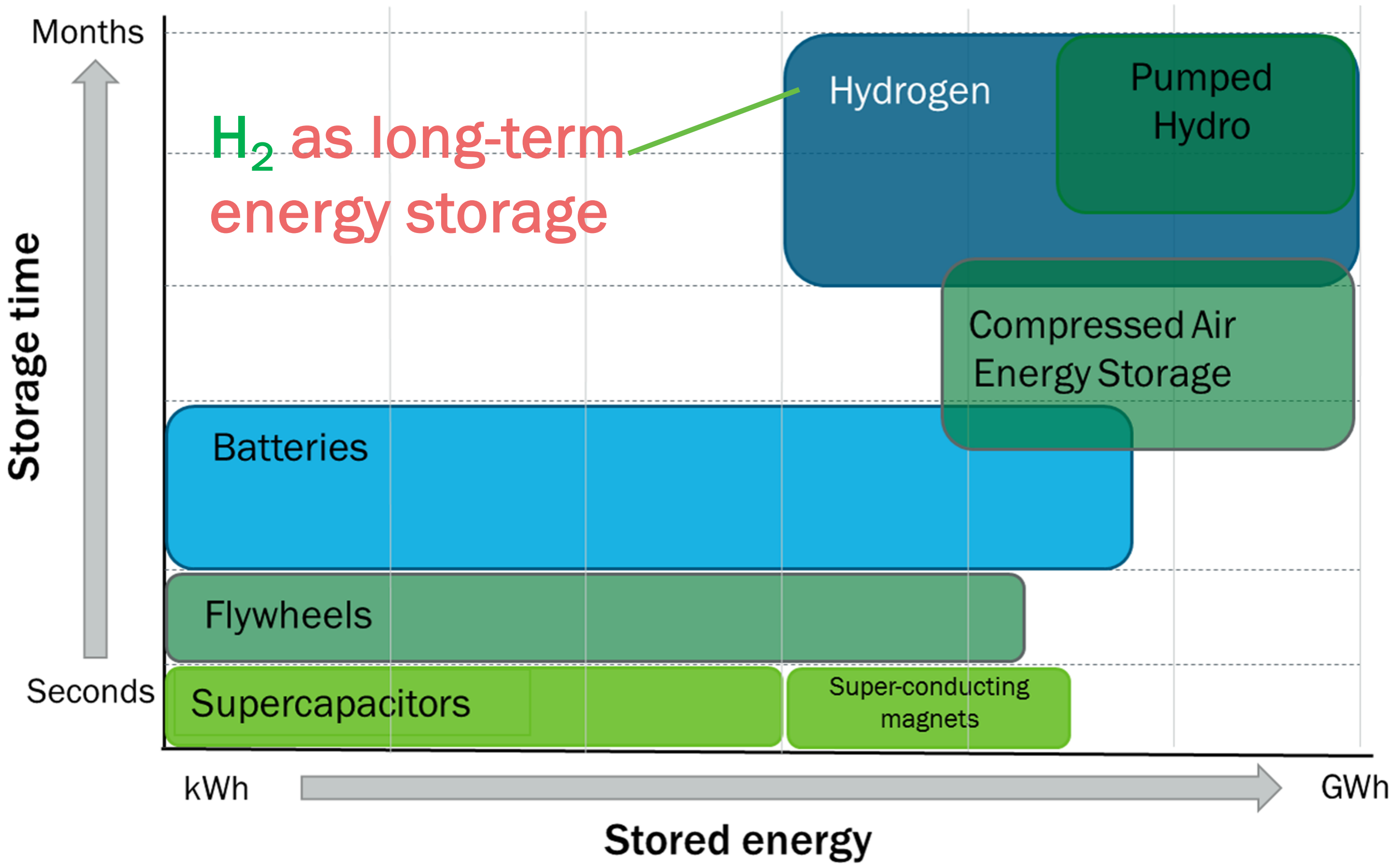
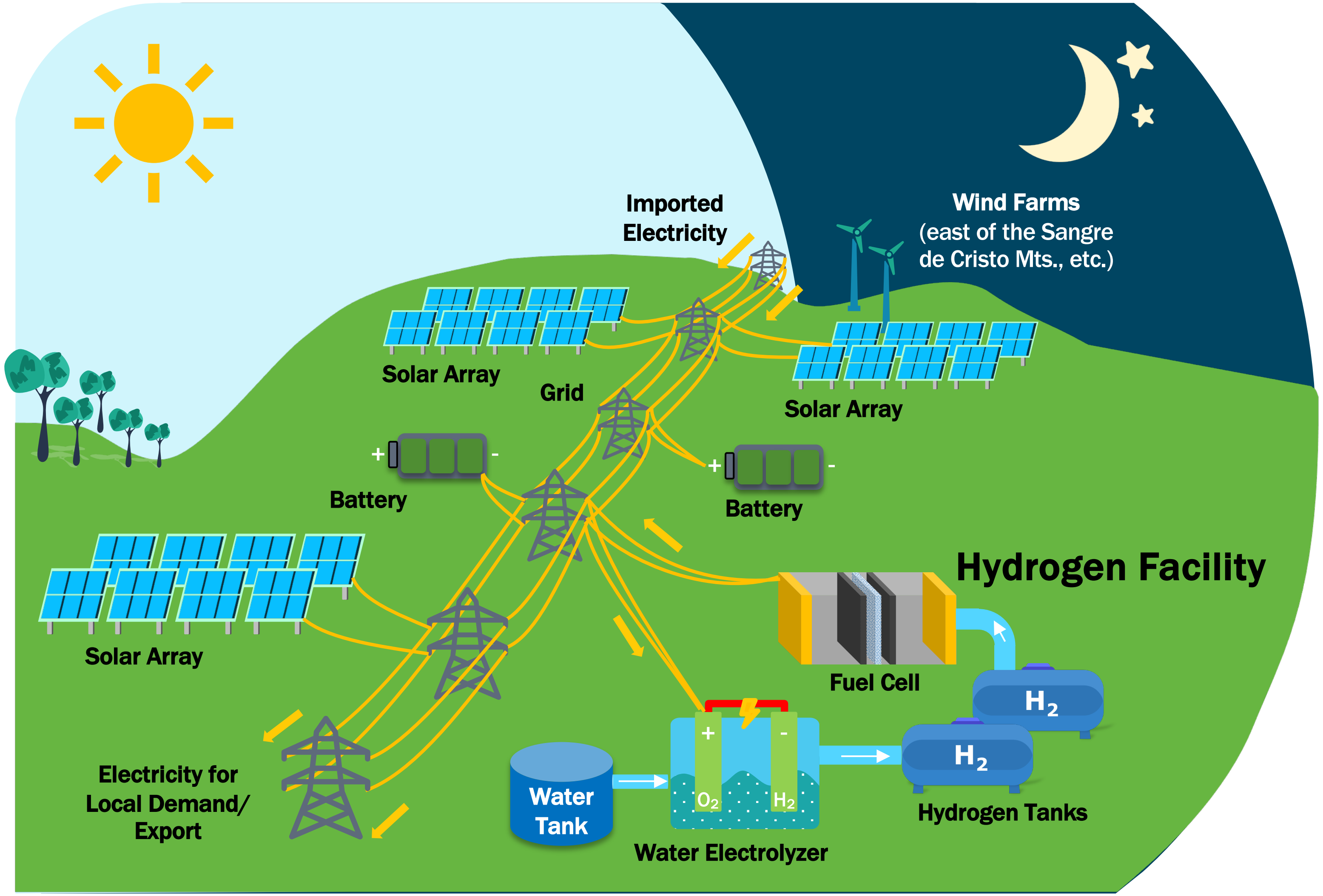


Figure 2. Hydrogen versus other energy storage options in context of amount of stored energy and storage duration [5]

Grid-Connected Application: Under Consideration by KCEC as the Co-op Plans for 100% Clean, Resilient Electricity



Solar and wind are fundamental technologies:
Clean electricity plans, including KCEC's, start with solar and wind. Solar photovoltaics (PV) arrays are well-accepted in the Taos county area and are being deployed locally.

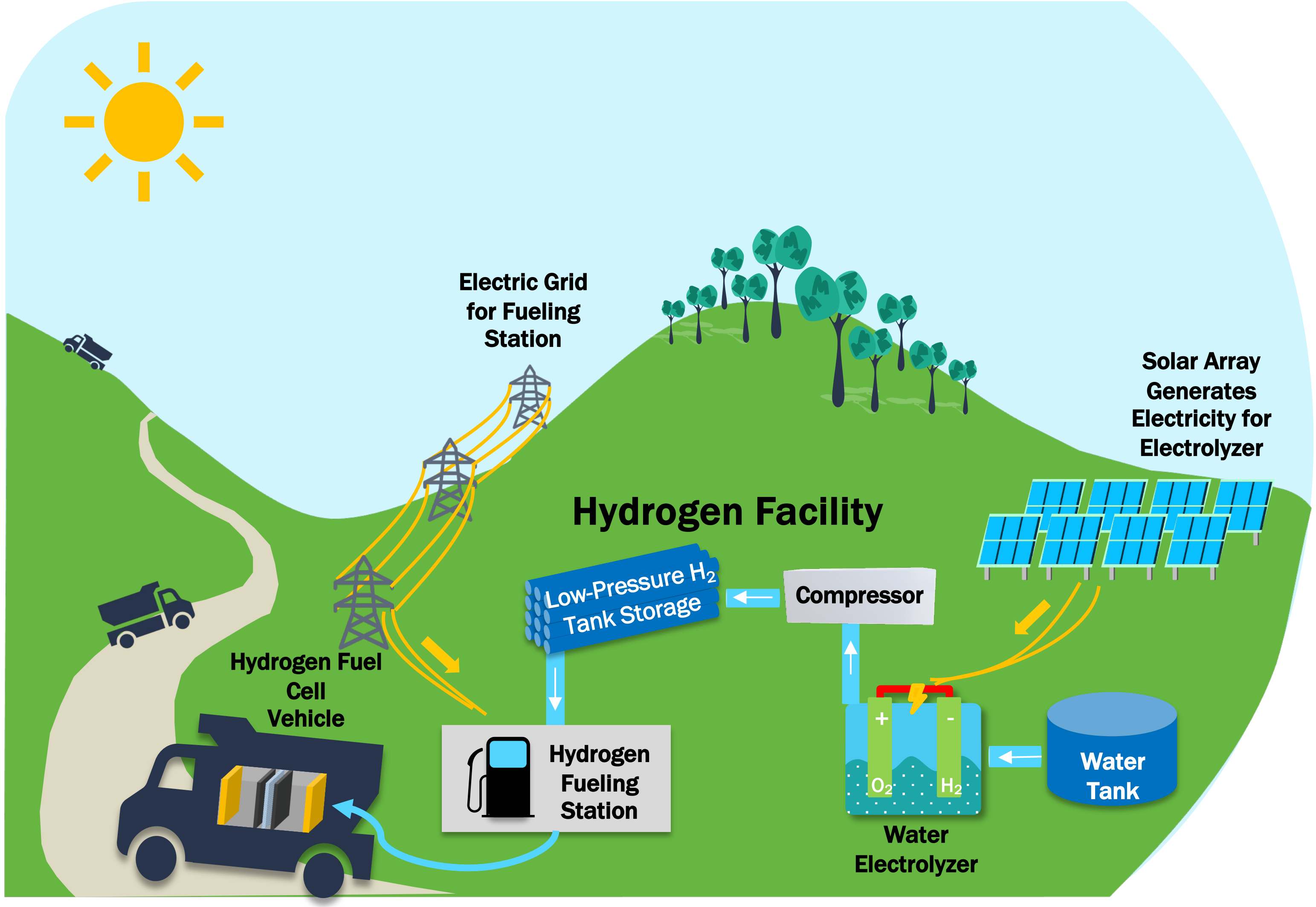
Transmission facilitates clean-energy imports:
Taos county is more sunny than windy, so KCEC has been exploring how to access wind by building more transmission.

Complementary technologies:
Detailed clean energy plans deploy multiple technologies to complement solar and wind [6]. KCEC is deploying batteries to better align electricity supply with demand.

Hydrogen long-term energy storage:
Detailed clean energy plans also find prolonged periods of low solar and wind availability [6]. Emerging technologies like hydrogen energy storage will be needed to keep the lights on (e.g., after batteries have been discharged).

Thoughtful deployment can increase resilience:
Distributing, for example, solar, battery, and long-term hydrogen storage throughout KCEC territory could provide more power to more people during wildfires and other stressful conditions.

Heavy-Duty, Off-Road Vehicle Fueling Application: Under Consideration by Chevron in Support of Corporate Carbon Reduction Goals



Stand-alone solar array, electrolyzer, and hydrogen storage: The electricity produced by an off-grid solar array runs an electrolyzer. Hydrogen storage is sized to serve a flat weekly demand despite higher production rates in the summer.

Hydrogen fueling station: The hydrogen storage facility connects to a fueling station that heavy-duty, off-road vehicles visit once per day.

Diesel fuel offset: The heavy-duty, off-road vehicles move rock as part of mine site remediation. Trucks with diesel internal combustion engines are the traditional alternative to hydrogen fuel cell vehicles.

Decrease emissions: Fuel cells do not generate greenhouse gas emissions, nitrous oxides (NO_x), or particulate matter that can cause climate change and respiratory illness [7]. Hydrogen combustion engines generate NO_x [7], but are not considered in this study.

Potential Hydrogen Facilities for Questa

Facility A: Grid-Connected Storage Application (KCEC)

Conceptual Design and Purpose

- Location: Chevron Tailing Facility under consideration
- Equipment configuration and size:
  - 32-MW PEM* electrolyzer
  - 14-ton compressed hydrogen gas storage
  - 7.5-MW PEM fuel cell
  - 15-MW solar PV array.

- Application: Long-duration storage facility for the local power network:
  1. Converts solar power in excess of local demand to hydrogen gas via water electrolysis ✢
  2. Stores hydrogen on-site via steel pipe storage
  3. Fuel cell uses stored hydrogen to generate electricity when solar and batteries cannot meet power demand. ✢

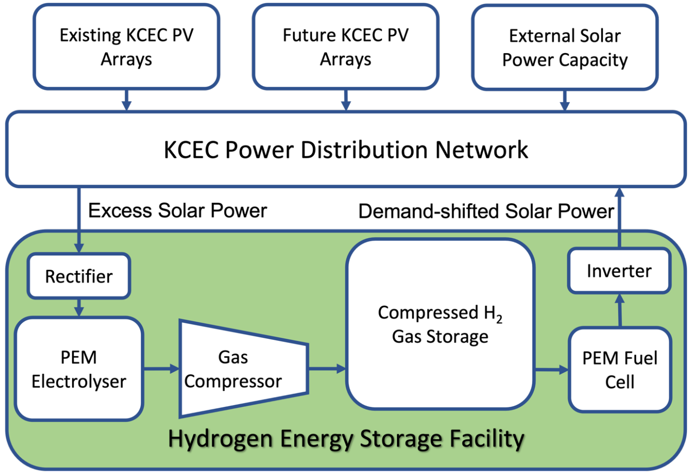


Figure 3. Grid-connected storage facility flow diagram

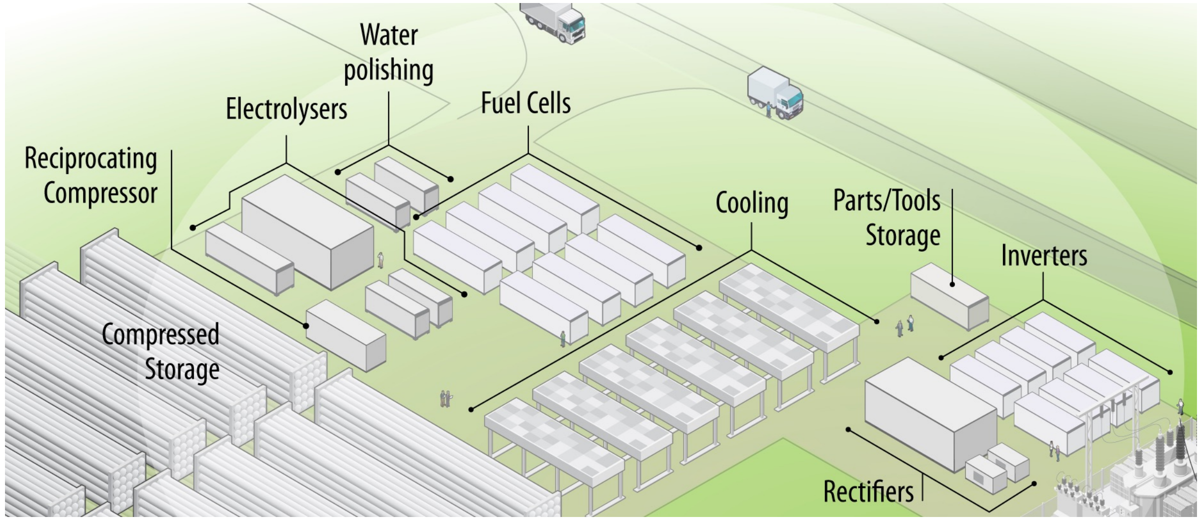


Figure 4. Conceptual rendering. *Illustration by Alfred Hicks, NREL*

* PEM: Polymer Electrolyte Membrane

✢ The feasibility study makes these simple assumptions, but realistic operations will likely be more complex (e.g., produce hydrogen with low-cost electricity [excess local solar or other] and only run the fuel cell if other clean electricity options [including imported wind] are unavailable or very expensive).

Facility A: Inputs and Outputs

1 acre foot = 1 year of indoor water use for 4 New Mexican households [8]

1 GWh = 1 year of electricity use for 129 New Mexican households [9]

Design Inputs

Direct Inputs

- 5.34 acre-ft/yr of water withdrawn*✢
- 25.9 GWh/yr of solar electricity in excess of local demand*
- 90–105 acres of land for 15 MW of solar PV and H_2 facility
- 10 permanent jobs.

Indirect Inputs

- 143–166 acres of land (for additional planned non-collocated 24 MW of KCEC solar capacity).

Design Outputs

Direct Outputs

- 9.0 GWh/yr electricity to directly supply demand*
  - 460 tons/yr of H_2 produced and temporarily stored.
- 0.27 acre-ft/yr of condensed water (for return).

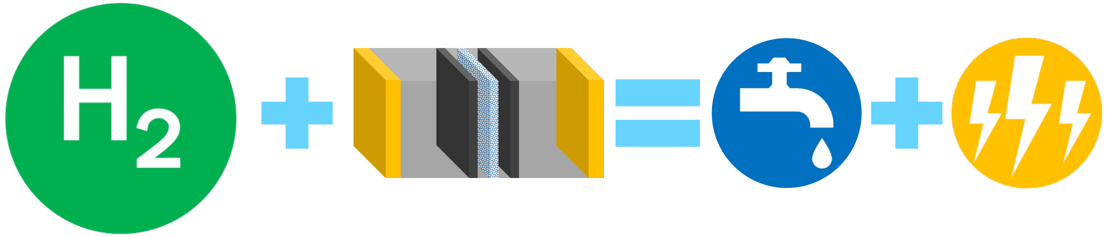
Indirect Outputs

- 456 metric tons CO_2e/yr avoided [10].**

Grid-connected **electrolyzer** annual summary

32-MW electrolyzer + 5.34 acre-ft of water/year + 25.9 GWh/yr of excess electricity = 460 metric tons of H_2/year

Grid-connected **fuel cell** annual summary



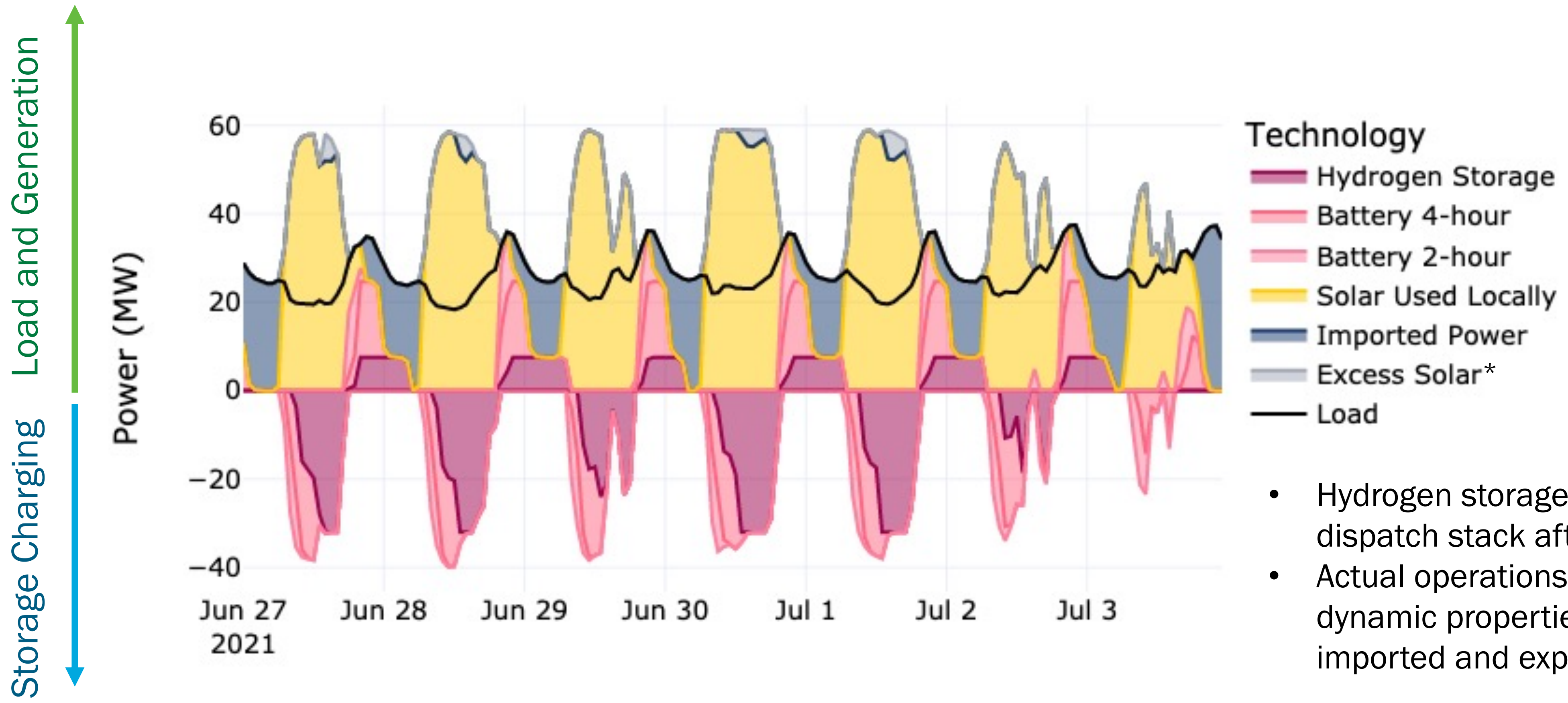
460 metric tons of H_2/year + 7.5-MW Fuel Cell = 0.27 acre-ft of water/year + 9 GWh/yr of round-tripped electricity

* This assumes a simple dispatch strategy for KCEC's local PV, batteries, and hydrogen storage assets, where the electrolyzer is last to charge and the fuel cell is the last to discharge.

✢ Estimate excludes water use for facility cooling. See lessons learned from https://www.nrel.gov/docs/fy23osti/83885.pdf.

** We assume that fuel cell generation avoids emissions at the long-run marginal emission rate for northern New Mexico over the 30-year project lifetime, starting in 2027.

Modeled KCEC Dispatch Approach Maximizes Local Use** of Solar



- Hydrogen storage is last in the local dispatch stack after solar and batteries.
- Actual operations would factor in dynamic properties of markets for imported and exported power.

*Excess solar is solar generation beyond what is used to directly meet load, charge batteries, and generate hydrogen.
**"Local use" implies use within KCEC service territory.

Facility B: H_2 Fuel Cell Vehicle Fueling Application (Chevron)

Conceptual Design and Purpose

- Location: Chevron former molybdenum mine site
- Equipment configuration and size:
  - 4.2-MW solar PV array
  - 4.2 MW PEM electrolyzer
  - 16.1-ton compressed H_2 gas storage
  - Hydrogen fuel cell vehicle refueling station.

- Application: Heavy-duty fuel cell vehicle fueling facility for Chevron's mine reclamation operations:
  - Dedicated solar PV array supplies power to generate hydrogen gas via water electrolysis
  - Steel pipe storage stores hydrogen on-site
  - Sizing supports refueling assuming constant daily demand and variable solar generation.*

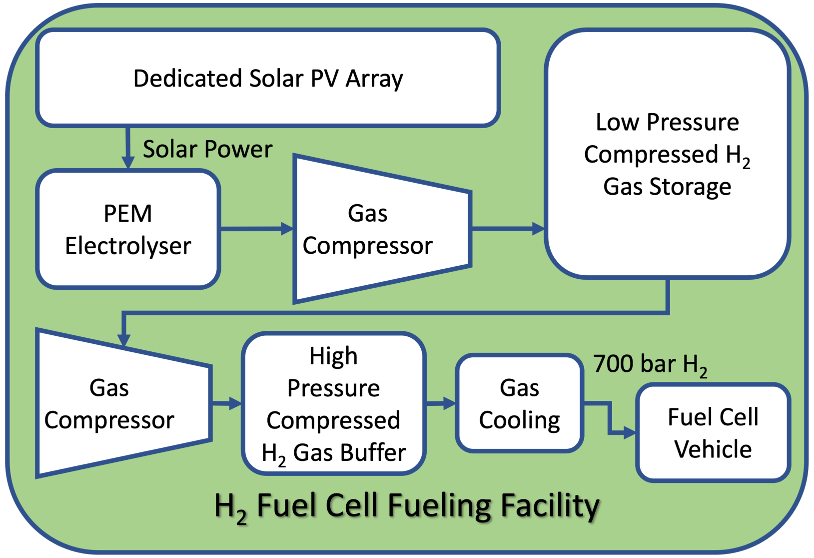


Figure 5: H_2 fuel cell vehicle fueling facility flow diagram

Figure 6: Light-duty H_2 fueling facility in La Cañada, CA.

Photo by Dennis Schroeder, NREL

* Sizing assumed 2021 weather data (e.g., solar irradiance, temperature), which results in a solar PV capacity factor of 23.8%. If this project is pursued, the sizing should be refined to account for year-to-year solar generation variability and uncertainty.

Facility B: Inputs and Outputs

1 acre foot = 1 year of indoor water use for 4 New Mexican households [8]

1 metric ton H_2 = 1,250 gallons of diesel fuel

Design Inputs

Direct Inputs

- 8.84 GWh/yr renewable electricity from solar PV
- 1.82 acre-ft/yr water withdrawn and consumed†
- 1.25 permanent jobs
- 25.2–29.4 acres of land (for solar PV siting)
- 1.11 GWh/yr grid electricity (for fueling station*).

Design Outputs

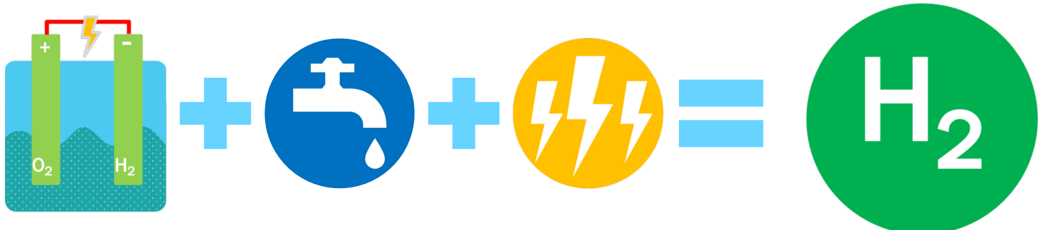
Direct Outputs

- 157 tons/yr of on-demand 700-bar hydrogen gas for heavy-duty fuel cell vehicle refueling.

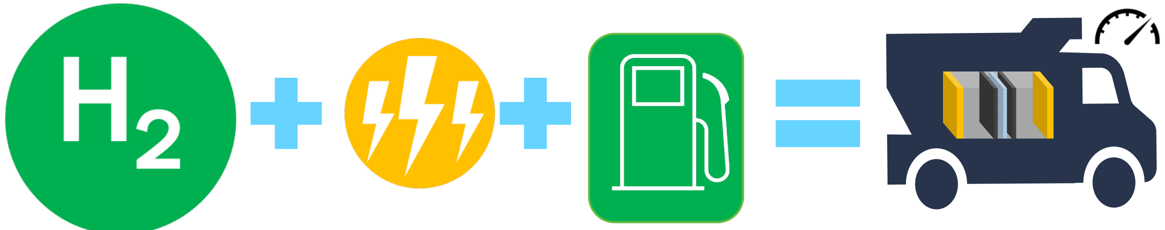
Indirect Outputs

- 195,690 gal/yr of diesel use displaced, avoiding**:
  - 1,992 metric tons/yr CO_2
  - 17.81 metric tons/yr CO
  - 1.05 metric tons/yr NO_x
  - 31 kg/yr $PM_{2.5}$.

Annual **Islanded Electrolyzer** Operation

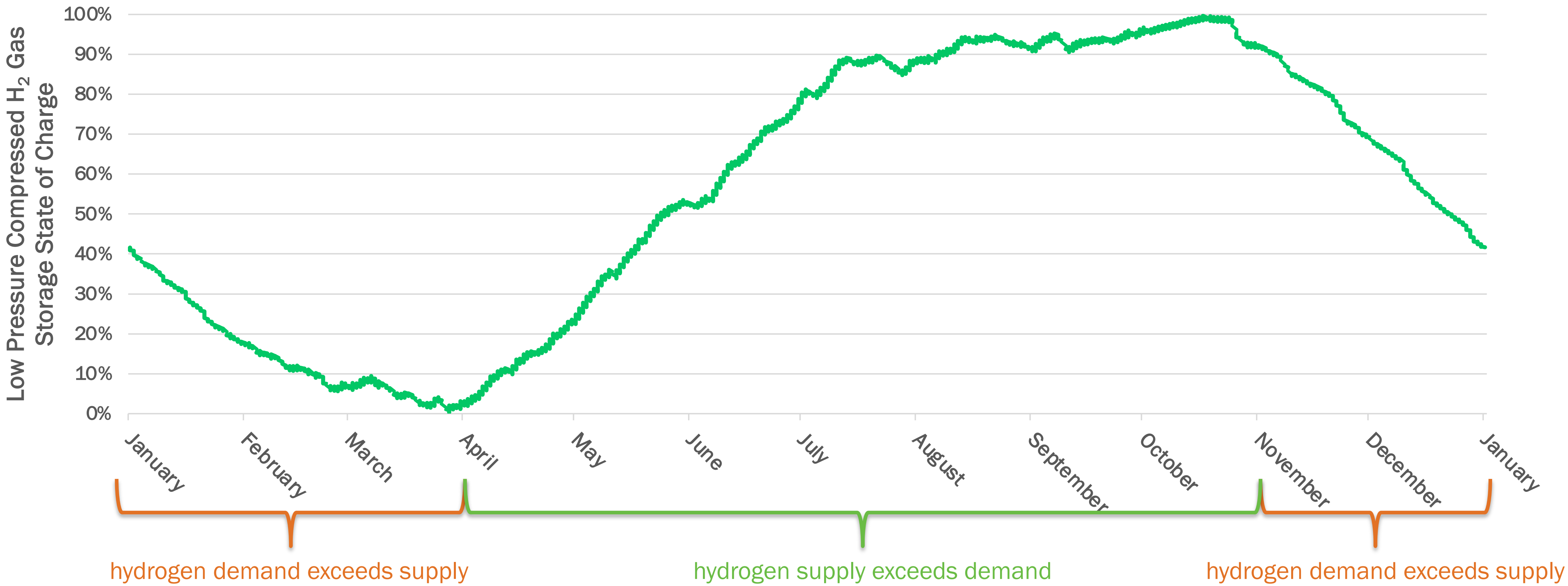


Annual **Fueling Station** Operation



† Estimate excludes water use for facility cooling. See lessons learned from https://www.nrel.gov/docs/fy23osti/83885.pdf.
* The H_2 fueling station has an electricity demand to compress H_2 for vehicle fueling. This electricity demand may not align with solar power generation. We therefore assume local grid support.
** Avoided emissions does not account for grid-emissions from powering fueling station

Hydrogen Storage Is Sized To Buffer Supply/ Demand Imbalances for Fueling



- Hydrogen storage is used to resolve daily and seasonal supply and demand mismatches for vehicle refueling.
- Refined sizing would factor in year-to-year weather variation and fuel demand uncertainties.

What Are Concerns About Clean Hydrogen for Northern New Mexico?

Environmental, Health, and Safety

- Storage and leaks
- Public health and safety
- Climate and environment
- Technology readiness and commercial availability.

Water Use

- Water consumption and quality
- Water cost
- Water rights and displacement of current uses
- Water reuse, treatment, and discharge.

Visual Impacts

- What might it look like?
- Traffic, noise, and light
- Hours of operation.

Costs and Alternatives

- Capital construction cost
- Operation and maintenance cost
- Ownership and rate payer impacts
- Carbon-free electricity and fuel alternatives.

What Are *Environmental, Health, and Safety Concerns*?

How is hydrogen stored and what if it leaks?

- Hydrogen is stored in pressurized tubes equipped with leak detection monitoring devices [11]. Hydrogen transport is not anticipated for this project, but industrial supply chains are established, and protocols follow similar procedures to other flammable gases such as natural gas or propane [12].
- Estimated leakage rates for hydrogen in steel pipe is between 0.0004%/day and 0.19%/day [13].
- Small leaks are common because hydrogen is a small molecule. Such leaks do not cause a flammable mixture in open air because hydrogen is light and tends to dissipate quickly [11]. In order to cause a fire, concentrated hydrogen would need to be exposed to an ignition source, similar to gasoline, natural gas, or propane.

What are the potential public health and safety impacts?

- If confined in high enough concentrations, hydrogen can be explosive if ignited [11, 14, 15]. Fire and explosion can cause loss of life, injury, and property damage.
- Because it dissipates quickly, risk of a flammable mixture or asphyxiation is greatest in confined areas [11]. Note that it is impractical to disperse hydrogen quickly enough in the event of a massive release in an enclosed building [12].
- Hydrogen flames are nearly invisible to the human eye in daytime and generate less radiant heat than other fuels such as propane [10, 15]. Hydrogen is odorless, colorless, and tasteless [16], making it difficult to detect.
- Workers exposed to high concentrations of hydrogen, similar to other gases, can suffer from asphyxiation (lack of oxygen). Otherwise, hydrogen gas is not toxic [11, 16].
- Electrolyzers and pressurized storage systems present hazards to facility workers due to risk of shock, chemical exposure, or rupture if systems are not properly designed and maintained [17].
- When burned, hydrogen generates NO_x [7], which can cause human respiratory illness and contributes to climate change [18]. NO_x forms when fuels are burned at high temperatures and are primarily generated from motor vehicles and other fuel combustion applications. NO_x reacts with other chemicals in the atmosphere to form particulate matter and ground-level ozone, which are also harmful to humans and the planet [18, 19].

What Are *Environmental, Health, and Safety Concerns*?

What are the potential climate and environmental impacts?

- Hydrogen is an indirect greenhouse gas that has stronger warming effects, but is shorter-lived, than other greenhouse gases. If leaked, it causes atmospheric warming [20]. If burned, hydrogen generates NO_x, which contributes to climate change [18].

Has this been done before? Is this technology sound and commercially available?

- Hydrogen has been used in industrial applications for over 80 years and can be used as safely as gasoline, natural gas, or propane [12]. Industrial supply systems are well established.
- Pure hydrogen is currently used at scale in oil refining and ammonia production. Thus, there are already standards for safe handling and transport of hydrogen. Electrolyzers and fuel cells are newer technologies based on PEMs. These technologies are currently scaling up, but in their fundamentals are cleaner than legacy hydrogen production and combustion processes. We will provide a few examples of existing systems using electrolyzers and fuel cells in the upcoming slides [17].

Feasibility Study Intermediate (Pre-Economic Impacts Analysis) Results

Facility A: Grid-Connected Storage

- $44.5 MM overnight capital cost (without incentives)
- Levelized cost of electricity = $0.45/kWh of round-tripped electricity (with incentives)
- Power generation to supply 3.1% of KCEC annual electricity demand during hard-to-serve times
- Key assumptions:
  - 2027 electrolyzer and fuel cell technology costs
  - Full value of Inflation Reduction Act incentives (below)
  - Dispatch strategy that maximizes local use of local solar generation (77 MW KCEC new and existing PV)
  - Projection of 2027 KCEC net load, 2021 PV profiles.

Incentive	Assumed Value	Equipment Covered
IRA PTC	$3/kg H_2 produced	Electrolyzer, Rectifier
IRA ITC	40% investment tax credit	H_2 Storage, Fuel Cell, Inverter

Facility B: Heavy-Duty Vehicle Fueling

- $22.7 MM overnight capital cost (without incentives)
- Levelized cost of hydrogen = $6.06/kg of 700 bar H_2 ($4.86/gal diesel equiv., with incentives)
- Fueling capacity to support Chevron's reclamation efforts at the former molybdenum mine site
- Key assumptions:
  - 2027 PV and electrolyzer technology costs
  - Full value of Inflation Reduction Act incentives (below)
  - Constant hydrogen demand throughout the year, 23.8% capacity factor (2021 weather) for solar PV.

Incentive	Assumed Value	Equipment Covered
IRA PTC	$0.026/kWh produced	PV
	$3/kg H_2 produced	Electrolyzer, Rectifier
IRA ITC	40% investment tax credit	H_2 Storage

How Can *Environmental, Health, and Safety Impacts* Be Mitigated?

How is hydrogen stored and what if it leaks?

- Use design best practices: Production, storage, transport, and dispensing equipment should be sited and built to national standards (International Fire Code and NFPA 2 Hydrogen Technologies Code)--use of non-corrosive and non-flammable materials; properly ventilated; equipped with seals, backflow pretension, impact sensors, leak detection, thermal and optical flame detection, isolation valves, emergency/automatic shut off, and audible and visual alarm systems [11] [21].
- Ensure active ventilation at all times for enclosed buildings to prevent accumulation of flammable mixture.
- Decrease risk of ignition in event of hydrogen buildup through design and maintenance of systems [21].
- Manage risks: Like all flammable gases, safety relies on assessing and managing hazards, monitoring systems to ensure integrity, maintaining proper ventilation, managing discharges, detecting and isolating leaks, and having trained personnel [21].

What are the potential public health and safety impacts?

- Regularly train emergency management, response, and facilities staff in hydrogen-specific safety [21]. Maintain an active emergency response plan, practice drills and review protocols, and conduct public outreach to ensure staff and community are aware of risks and response procedures. See list of training resources.
- NO_x is generated primarily from the burning of fuel at high temperatures [7]. The vehicle application in this study assumes use of fuel cells to convert hydrogen to electricity, which does not generate NO_x, CO_2, or particulate matter [7]. The vehicle application could generate NO_x and particulate matter if hydrogen is combusted with combustion engines rather than fuel cells.

What are the potential climate and environmental impacts?

- Ensuring that systems are built and maintained to have low leakage rates reduces climate, as well as safety and economic, impacts.

Example Project: Cal State Green H_2 Production and Fueling

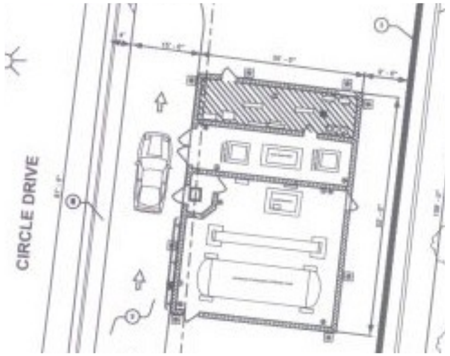
Operational since 2014

- Located 6 miles from downtown Los Angeles, near freeway
- Considered first in the world to sell hydrogen fuel by the kilogram directly to retail customers [22]
- Capable of producing and storing 60 kg of hydrogen on-site from renewable energy sources, per day
- Construction began in late 2010 as a design-build process; opened on May 7, 2014
- Equipped with leak sensors, flame detectors, and other safety devices
- Utilizes a Hydrogenics electrolyzer, first- and second-stage compressors enabling 350- and 700-bar fueling, 60 kg of hydrogen storage, water purification, and equipment cooling system, grid-tied.

Point of contact: Dr. David Blekhman. blekhman@calstatela.edu
Technical Director, Hydrogen Research and Fueling Facility
California State University, Los Angeles

Aerial view of fueling station. *Picture from Google Streetview*

Vehicle refueling. *Picture from Cal State* https://www.calstatela.edu/ecst/h2station



Construction drawing. *Image from Cal State* https://www.calstatela.edu/ecst/h2station/history

What Are the *Water Use Concerns*?

How much water will be needed?

- It takes 3.78 gallons of water to generate 1 kg of hydrogen [2]. After hydrogen is converted to electricity using a fuel cell, 5% of this water is estimated to be "recovered" from the fuel cell exhaust [4] without a dedicated cooling system.
- We estimate that the grid-connected storage application would withdraw 5.34 acre-feet of water per year and return 0.27 acre-feet, which works out to about 0.18 gallon of water consumed per kWh of power put back on the grid.
- Approx. 1.82 acre-feet of water per year needed for vehicle fueling application. None returned.
- 1 acre foot = 1 year of indoor water use for 4 New Mexican households [8].

Where will it come from and how much will it cost?

- The source of the water rights has not been determined but will impact project economics. Potential sources of water rights being explored include purchase/transfer/trade of Chevron water rights or other partners.

What quality is needed for electrolysis, and can non-freshwater be used?

- Water quality needed for electrolysis is ASTM Type II [23]. Any water could be used as input, but non-potable water would require more treatment and increase costs.

Can water used for hydrogen production be reused? Where will it be discharged, and how will it be treated before it is discharged?

- When hydrogen is converted to electricity by fuel cell, water is the primary byproduct. This water can be captured and reused or discharged in a body of water. However, treatment may be required prior to discharge into water bodies because it contains impurities such as aluminum, nickel, nitrite, and manganese above U.S. Environmental Protection Agency (EPA) drinking water limits [4]. Nitrates are essential plant nutrients, but can be toxic to warm-blooded animals. They are common in effluent of wastewater treatment facilities and can cause significant water quality problems when accumulated in high concentrations [24].
- Hydrogen gas is not toxic or poisonous [16]. It will not contaminate water sources.
- Permits and quality standard compliance will be required by the NM State Engineer, NM State Environmental Department, and the EPA.

How Can *Water Impacts* Be Mitigated?

How much water will be needed?

- This project considered water recovery and treatment equipment. Current findings show that water-recovery equipment is not cost-effective or water-efficient. Thus, water capture is not included in grid-connected energy storage project cost. Further study is needed to bring cost-effective water recovery to market.
- Water consumption for this facility without recovery is comparable to natural gas power plants and less than coal power plants, both equipped with recirculating cooling systems [25, 26].
- The best available information was used to estimate water consumption for this project, but more research is required to increase accuracy of estimated water use of all system components.

Where will it come from, and how much will it cost?

- The coalition is exploring potential sources of water/water rights. Chevron rights are being considered. No village rights are being considered.

What quality is needed for electrolysis, and can non-freshwater be used?

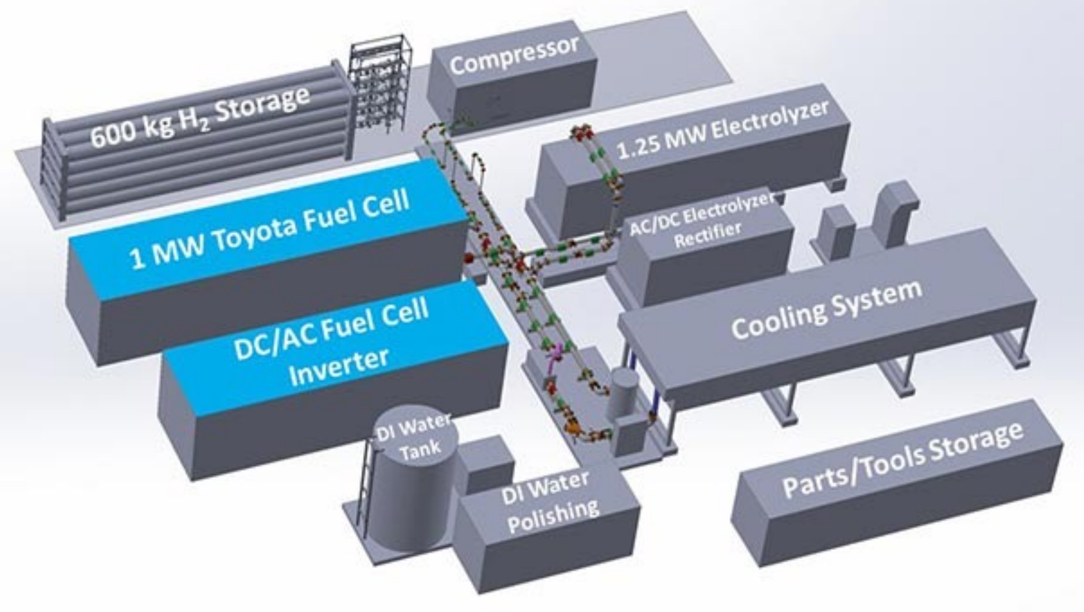
- Non-potable water sources are being considered by the Village of Questa.

Can water used for hydrogen production be reused? Where will it be discharged, and how will it be treated before it is discharged?

- Project will need to meet state and EPA standards for water quality. System should be designed to allow for monitoring of water quality.
- Water treatment and discharge costs are not included in the feasibility study, but they are expected to be low [23].

Example Project: NREL Test Facility

- Located in Boulder County, Colorado.
- Independent research facility testing performance in grid-interconnected system.
- Future test facility studies may assess water efficiency and recapture.
- Site design and permitting process included setback distances and fire code requirements, high-level electrical system design, process hazard analysis safety evaluation of storage system, compressor, and gas management panel.
- Not fully operational as of August, 2023. Pending commissioning.
- 1.25-MW PEM electrolyzer, 1-MW fuel cell, 600-kg H_2 storage equivalent to 20 MWh of storage [27].



Conceptual hydrogen system design. *Illustration by Alfred Hicks, NREL*

Installed hydrogen system at NREL's Flat Irons Campus. *Photo by Josh Bauer/Bryan Bechtold, NREL 73051*

What Are the *Land Development Impact Concerns*?

What might it look like?

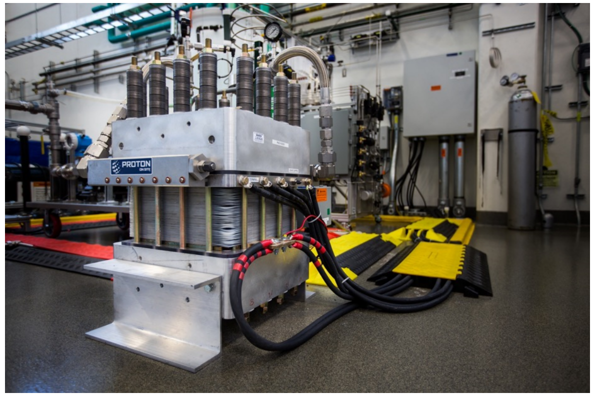
- Utility-scale solar generation facilities require substantial land but are generally low profile.
- PEM hydrogen production facilities look much like light industrial buildings.
- Hydrogen fueling stations look much like gasoline stations.

How much land would be required?

- KCEC approximates 6-7 acres per 1 MW of solar PV power generation capacity.
- The overall facility size estimate is 90–105 acres of land for 15 MW of on-site solar PV, electrolyzer, fuel cell, and belowground hydrogen storage (in compressed tubes). At most, 2 acres would be required for all non-PV components.
- Aboveground compressed storage tubes are typically stacked in rows approximately the size of a 40’ long by 10’ tall shipping container. This project could require approx. 28 stacks of tubes of compressed storage (or 14 stacks of 80’ tubes, as illustrated on slide 32).

What hours will it operate, and will there be traffic, noise, or light impacts?

- Hydrogen facilities often operate 24 hours per day, 7 days per week with at least one staff person present. This may generate noise, nighttime light, glare, and traffic.
- Traffic would be generated in an alternative fuel application. Earth-moving equipment and long-haul trucks are the most likely consumers of hydrogen fuel. The location of the fueling facility is yet to be determined but would be near the mine site.



Example electrolyzer. *Photo* by John De La Rosa, NREL 34729


Example above ground hydrogen storage. *Photo by Werner Slocum, NREL 72174*

How Can *Land Development Impact* Be Mitigated?

- Storage tanks are proposed to be underground to reduce visual impact, but above ground storage could be required pending final site soil characteristics. Aboveground storage would be stacked in high-pressure pipes.
- The solar PV arrays and hydrogen production facility could potentially be located on Chevron's Tailing Facility site west of Questa. This would put a brownfield site to beneficial use, limit the disturbance of natural lands, and reduce visual impact by siting the PV array at a lower elevation. Visual impacts of PV arrays can be further mitigated through vegetation and fencing.
- A refueling station could be co-located on Chevron's mine remediation site, limiting the impact of traffic for refueling.
- The jurisdiction could require the developer to demonstrate operational performance standards (post-commissioning) as a condition for permit approval. Other development agreements, such as local hiring commitments, training programs, local materials sourcing, economic/environmental remediation funds, special tax assessments, or other community benefits agreements could similarly be negotiated during the development review [28].
- The village could adopt an ordinance to regulate hours of operation, traffic, noise, and lighting to protect night skies, animal migration, and quality of life for residents.
- Transmission and distribution infrastructure is largely already in place or would utilize existing corridors (including Tailing Facility). A new substation and short transmission line for interconnection may be required.

Example Project: Shell’s Rhineland Refinery

- **10-MW** PEM electrolyzer located in Wessling, Germany [29].
- Europe’s largest PEM and the first to apply it at such a large scale in a fuel refinery.
- Operated by Shell, beginning July 2, 2021.
- Uses renewable electricity to produce up to 1,300 metric tons of green hydrogen a year.
- PEM electrolyzers, which are more compact than conventional alkaline electrolyzers, can operate dynamically with varying load, making them well-suited for renewable energy.

(Questa’s proposed facility would utilize a 32-MW electrolyzer.)

Birds eye view of Shell’s PEM green hydrogen production facility. *Image by Shell Photographic Services.*

What Might the Questa Grid-Tied Clean Hydrogen Facility Look Like?

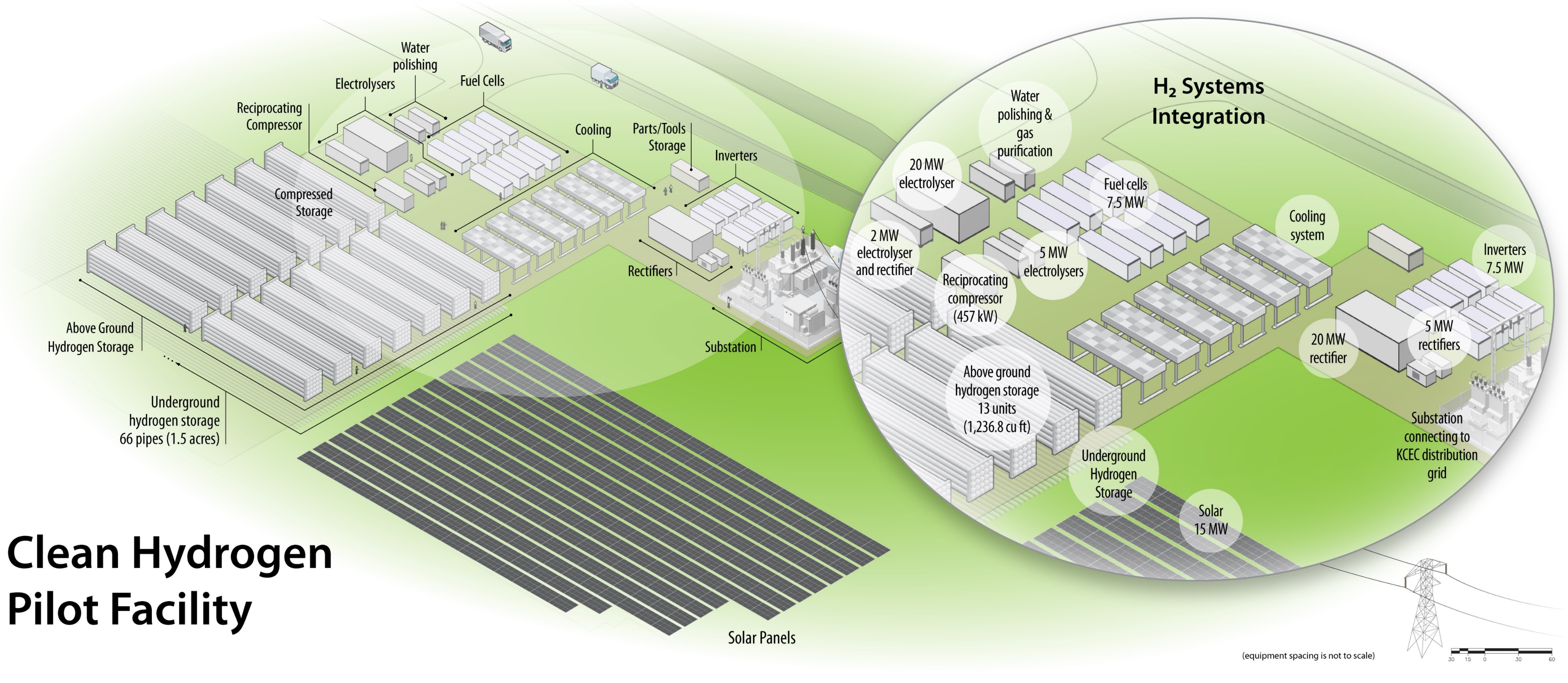


Illustration by Al Hicks, NREL

What Are the Concerns About *Costs and Alternatives*?

What are the alternatives for carbon-free electricity and fuel? Why not use batteries, wind, or pumped hydro?

- Energy decarbonization is required by New Mexico Law (2019 Energy Transition Act requires rural co-ops to transition to carbon-free electricity by 2050 and 50% clean electricity in 2030) [30].
- KCEC is deploying multiple existing technologies to meet its 100% renewable generation goal, including solar, batteries, and transmission (to import wind) [31].
- Other long-duration storage alternatives (bio-fuels, natural gas, pumped hydropower), rely on fossil fuels or scarce resources [32].

What would it cost to build, operate, and maintain?

- Ultimate cost will be determined by financing approach. Project is pursuing grant funding and tax credits. Could enter into partnerships to reduce costs. Could finance remaining portion of project through low-cost loans, green banks, bonds, or private financial institutions [31].

Who will pay for it, and how will it impact rate payers?

- As designed, the Facility A hydrogen storage system would only supply 3.1% of KCEC net energy demand in 2027, which naturally limits rate impacts (because 96.9% of demand is supplied by other, typically lower-cost, resources). Rate impacts will also depend on coalition success in securing tax credits and/or grant funding [31].
- Chevron is the entity that would decide whether and how to build the Facility B heavy-duty vehicle fueling application to support former mine site remediation efforts.
- Neither the grid-tied nor alternative fueling application proposed facilities' ownership has been determined at this time.

Won't this project use renewable energy that could be utilized elsewhere? Would this slow progress toward direct electrification?

- Electrolyzers would convert surplus solar power from daytime generation into stored energy in the form of hydrogen for future use.

How Are *Costs and Alternatives* Being Addressed?

- There are few alternatives to address times with low solar and wind availability[32].
- There are few alternatives to provide long-duration resilience[32].
- KCEC is creating a deployment strategy to combine various resources to maximize the benefit to co-op members as the demand for renewable energy increases.
- Energy-economy models often underestimate technology deployment, and thus underestimate cost reductions for new technology. Cost of technology is expected to drop over time, due to anticipated learning from technology deployment [33].
- Transition to net-zero emissions can provide net economic benefits, compared to no transition [33].

Western Environmental Law Center: Key Principles and Guardrails*

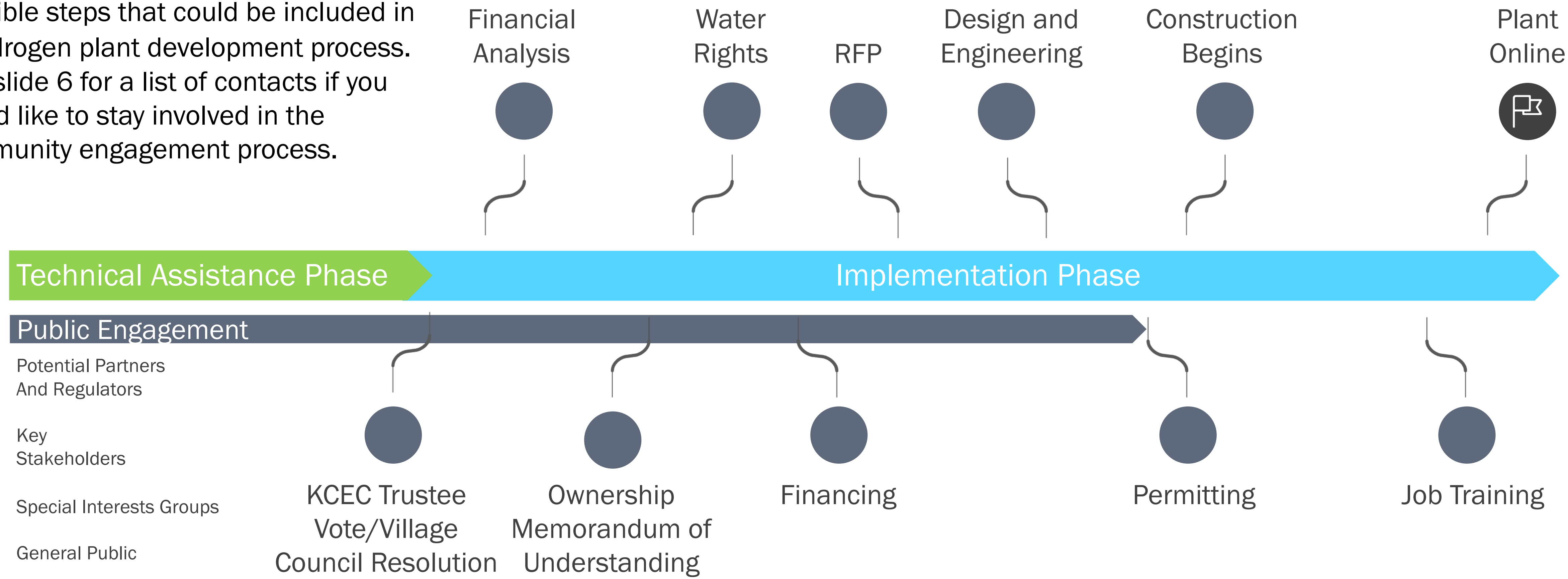
How many of these principles are met by the proposed facilities?

Principle	Strategies	Questa?	Explanation
Production	• Prioritize green electrolytic hydrogen • Use additional and hourly matched renewable energy • Address environmental and public health risks of new infrastructure, uncaptured emissions, upstream emissions, methane leakage, and air pollution linked to gas processing and combustion • Utilize additional renewable energy (i.e., renewable energy that would not have existed on the grid but for the new hydrogen demand) • Apply strict water quality and water efficiency standards utilizing advanced water efficiency electrolyzers.	Y TBD Y N/A Y	Electrolytic hydrogen plant expected to use excess renewable electricity Utilizes fuel cells, leak monitoring at production facility, water recapture Storing excess renewable electricity to meet power demand at times with low solar (and wind) generation Considers best available technology.
Transportation and storage	• Co-location of hydrogen production and use • Embed hydrogen leakage monitoring in pipelines and storage • 100% hydrogen pipelines, no blended fossil gas.	Y Y N/A	Storage at production site No distribution of hydrogen
End uses	• Directed to hard-to-electrify applications • Deployment does not inhibit or redirect progress on direct electrification • Should not be used in applications where direct use of electricity produced from renewable energy offers a better alternative • Should not be used to generate baseload power.	Y Y Y Y	Facility A utilizes excess renewable electricity by shifting it to hard-to-serve times. Facility B uses an off-grid solar array to decarbonize heavy-duty vehicle use.
Community involvement and risk mitigation	• Community members and stakeholders engaged throughout entire process • Opportunity to give meaningful feedback on project selection, concepts, and details • Potential harms identified and mitigated (production, transportation, storage and use, including NO_x emissions).	TBD TBD TBD	Scoring in this area dependent on public engagement moving forward. Scoring in this area depends on final design, implementation, and operation.

* Principles extracted from [34].

Potential Next Steps for Building a Hydrogen Production Facility

Any hydrogen project undertaken by one or more Questa Community Coalition members will involve several steps. This graphic is an illustration of possible steps that could be included in a hydrogen plant development process. See slide 6 for a list of contacts if you would like to stay involved in the community engagement process.



Thank you

www.energy.gov/communitiesLEAP

Publication Number: DOE/GO-102023-6016

References

[1] Ruth, M. F. et al. (2020). *The Technical and Economic Potential of the H2@ Scale Hydrogen Concept within the United States.* NREL/TP-6A20-77610. National Renewable Energy Lab.(NREL), Golden, CO (United States).

[2] Penev. (2022). “H2A-Lite: Hydrogen Analysis Lite Production Model.” https://www.nrel.gov/hydrogen/h2a-lite.html.

[3] Hunter, C. A., Penev, M. M., Reznicek, E. P., Eichman, J., Rustagi, N., & Baldwin, S. F. (2021). “Techno-economic analysis of long-duration energy storage and flexible power generation technologies to support high-variable renewable energy grids.” *Joule*, *5*(8), 2077-2101.

[4] Tibaquirá, J. E., Hristovski, K. D., Westerhoff, P., & Posner, J. D. (2011). “Recovery and quality of water produced by commercial fuel cells.” *International Journal of Hydrogen Energy*, *36*(6), 4022-4028.

[5] Wieliczko, M., & Stetson, N. (2020). “Hydrogen technologies for energy storage: A perspective.” *MRS Energy & Sustainability,* 7, E41.

[6] NREL. “LA100: The Los Angeles 100% Renewable Energy Study and Equity Strategies.” https://maps.nrel.gov/la100/la100-study/report.

[7] Lewis, A. C. (2021). “Optimising air quality co-benefits in a hydrogen economy: A case for hydrogen-specific standards for NOx emissions. *Environmental Science: Atmospheres*, 1(5), 201–207. https://doi.org/10.1039/D1EA00037C.

[8] New Mexico Office of the State Engineer. (2015). New Mexico Water Use By Categories 2015. https://www.ose.state.nm.us/WUC/wucTechReports/2015/pdf/2015%20WUR%20final_05142019.pdf.

[9] U.S. Energy Information Administration. (n.d.). 2021 Average Monthly Bill—Residential. https://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf.

[10] Gagnon, P., Cowiestoll, B., & Schwarz, M. (2023). *Cambium 2022 Scenario Descriptions and Documentation.* NREL/TP-6A40-84916. National Renewable Energy Lab.(NREL), Golden, CO (United States).

[11] H2 Tools. “Hydrogen Leaks.” https://h2tools.org/bestpractices/hydrogen-leaks.

[12] Barilo, N. (2018). *Introduction to Hydrogen and Fuel Cell Technologies and Safety Considerations*. PNNL-SA-137745. Pacific Northwest National Laboratory, Richland, WA. https://h2tools.org/sites/default/files/IntroToH2FCandSafetyConsiderations_Sept2018.pdf

[13] Feng, Z., Anovitz, L. M., Blencoe, J. G., Babu, S., & Korinko, P. S. (2005). *Hydrogen Permeability and Integrity of Hydrogen Delivery Pipelines*. U.S. Department of Energy: Washington, D.C.

[14] H2 Tools. “Hydrogen Explosions.” https://h2tools.org/hydrogen-explosions.

[15] H2 Tools. “Hydrogen Flames.” https://h2tools.org/hydrogen-flames.

[16] H2 Tools. “Gaseous Hydrogen Properties and Behaviors.” https://h2tools.org/gaseous-hydrogen-properties-and-behaviors.

[17] Totalshield. (2023). “Electrolyzer and Hydrogen Fuel Safety.” https://totalshield.com/blog/electrolyzer-and-hydrogen-fuel-cell-safety/.

[18] Lammel, G., & Graßl, H. (1995). “Greenhouse effect of NOX.” *Environmental Science and Pollution Research*, 2(1), 40–45. https://doi.org/10.1007/BF02987512.

References (cont.)

[19] EPA. “Basic Information About NO2.” https://www.epa.gov/no2-pollution/basic-information-about-no2.

[20] Ocko, Ilissa, & Hamburg, Steven. “Climate consequences of hydrogen emissions.” *Atmos. Chem. Phys.*, 22, 9349-9368. https://acp.copernicus.org/articles/22/9349/2022/.

[21] H2 Tools. “Introduction to Hydrogen and Fuel Cell Technologies and Safety Considerations.” https://h2tools.org/sites/default/files/IntroToH2FCandSafetyConsiderations_Sept2018.pdf.

[22] Cal State LA. “CAL State LA Hydrogen Research and Fueling Facility (H2 Station).” https://www.calstatela.edu/ecst/h2station.

[23] Winter, L. R., Cooper, N. J., Lee, B., Patel, S. K., Wang, L., & Elimelech, M. (2022). “Mining Nontraditional Water Sources for a Distributed Hydrogen Economy.” *Environmental Science & Technology*, *56*(15), 10577-10585.

[24] EPA. “5.7 Nitrates.” https://archive.epa.gov/water/archive/web/html/vms57.html.

[25] Macknick, J., Newmark, R., Heath, G., & Hallett, K. C. (2011). “Review of operational water consumption and withdrawal factors for electricity generating technologies.” *Environmental Research Letters,* 7, 4. https://iopscience.iop.org/article/10.1088/1748-9326/7/4/045802/meta.

[26] Torcellini, P., Long, N., & Judkoff, R. (2003). *Consumptive water use for US power production.* NREL/TP-550-33905. National Renewable Energy Lab., Golden, CO (U.S.).

[27] Leighton, Daniel, Mohr, Jeffrey, & Hanna, Tavis. (2022). “ARIES/Flatirons Facility-Hydrogen System Capacity Buildout.” https://www.hydrogen.energy.gov/pdfs/review22/ta048_leighton_2022_o.pdf.

[28] DOE. “Community Benefit Agreements: Frequently Asked Questions (FAQs).” https://www.energy.gov/sites/default/files/2017/09/f36/CBA%20Resource%20Guide%20FAQs.pdf.

[29] Shell Global. (2021). “Shell starts up Europe’s largest PEM green hydrogen electrolyzer.” https://www.shell.com/media/news-and-media-releases/2021/shell-starts-up-europes-largest-pem-green-hydrogen-electrolyser.html.

[30] State of New Mexico. “Senate Bill 489.” https://www.nmlegis.gov/Sessions/19%20Regular/bills/senate/SB0489.pdf.

[31] Personal communication with Luis Reyes, CEO and General Manager of Kit Carson Electric Co-op.

[32] Trieu Mai, Paul Denholm, Patrick Brown, Wesley Cole, Elaine Hale, Patrick Lamers, Caitlin Murphy, Mark Ruth, Brian Sergi, Daniel Steinberg, Samuel F. Baldwin. (2022). “Getting to 100%: Six strategies for the challenging last 10%.” *Joule*, 6(9), 2542-4351.

[33] Way, R., Ives, M. C., Mealy, P., & Farmer, J. D. (2022). “Empirically grounded technology forecasts and the energy transition.” *Joule*, *6*(9), 2057-2082.

[34] Letter to the Western Hydrogen Hub coalition from the Environmental Defense Fund, GreenLatinos, Natural Resources Defense Council, Colorado Sierra Club, Western Environmental Law Center, and Western Resource Advocates. February 27, 2023. Received via Luis Reyes, April 11, 2023, and forwarded to NREL.

Resources

Questa Green Hydrogen Presentation from the KCEC Board Meeting/Village of Questa Council Meeting on October 22, 2022.

Is clean hydrogen production a good fit for Questa? Project Introduction.

https://www.nrel.gov/docs/fy23osti/84348.pdf.

Hydrogen Concepts

Green Hydrogen: A Briefing for Land Managers. May 2023.

https://www.nrel.gov/docs/fy23osti/83885.pdf.

NACFE. “Hydrogen Trucks: Long-Haul Future?”

https://nacfe.org/research/electric-trucks/hydrogen/.

“Demonstration of Hydrogen Flames (video).”

https://h2tools.org/sites/default/files/barilo/BurnDemo.mp.4.

Hydrogen Safety

Totalshield. “Electrolyzer and Hydrogen Fuel Cell Safety.”

https://totalshield.com/blog/electrolyzer-and-hydrogen-fuel-cell-safety/.

Safety training materials for first responders: https://h2tools.org/training-materials.

Hydrogen standards: https://safehydrogenproject.org/.

Hydrogen codes and standards: https://h2tools.org/codes-standards.

Introduction to hydrogen for code officials: https://www.hydrogen.energy.gov/codes_standards.html.

Hydrogen Water Use

Izenson, M. G., & Rozzi, J. C. (2009, January). “Demonstration of Efficient Water Recovery for Fuel Cell Power Systems.” In *International Conference on Fuel Cell Science, Engineering and Technology* (Vol. 48814, pp. 199-208).

Local Nuisance Regulation Examples

New Mexico Night Sky Protection Act and example city ordinances: http://www.darkskynm.org/lightinglaws.html.

Taos County Ordinance 2006-9 Night Sky Protection Act: https://www.taoscounty.org/DocumentCenter/View/1157/Ordinance-2006-9-Night-Sky-Protection-Act?bidId=.

City of Albuquerque Noise Control Ordinance: https://www.cabq.gov/environmentalhealth/noise.

City of Hobbs Uniform Traffic Ordinance: https://www.hobbsnm.org/files/Uniform%20Traffic%20Ordinance.pdf.

Resources

Hydrogen

H2@Scale Report:

https://www.nrel.gov/docs/fy21osti/78956.pdf

H2A-Lite: Hydrogen Production Analysis Lite Model
https://www.nrel.gov/hydrogen/h2a-lite.html

Fuel Conversion Factors to Gasoline Gallon Equivalents

https://epact.energy.gov/fuel-conversion-factors

New Mexico's Clean Energy Plans

Executive Order 2021-003:

https://www.governor.state.nm.us/wp-content/uploads/2019/01/EO_2019 003.pdf

Executive Order 2022-013:

https://www.governor.state.nm.us/wp-content/uploads/2022/03/Executive-Order-2022-013.pdf

New Mexico Hydrogen Hub Roadmap:

https://www.env.nm.gov/wp-content/uploads/2022/01/Defining-and-Envisioning-a-Clean-Hydrogen-Hub-for-NM.pdf

Relevant Federal and State Actions

Bipartisan Infrastructure Law Programs:

https://www.energy.gov/bil/bipartisan-infrastructure-law-programs

Inflation Reduction Act:

https://www.congress.gov/bill/117th-congress/house-bill/5376/text

New Mexico EDD Business Incentives:

https://edd.newmexico.gov/choose-new-mexico/competitive-business-climate/incentives/

New Mexico EMNRD Tax Incentives:

https://www.emnrd.nm.gov/ecmd/tax-incentives/

New Mexico EMNRD Grid Modernization Grant Program:

https://www.emnrd.nm.gov/ecmd/grid-modernization-grant-program/

New Mexico ED Funding Opportunities:

https://www.env.nm.gov/funding-opportunities/#