Economically Viable Intermediate to Long Duration Hydrogen Energy Storage Solutions for Fossil Fueled Assets

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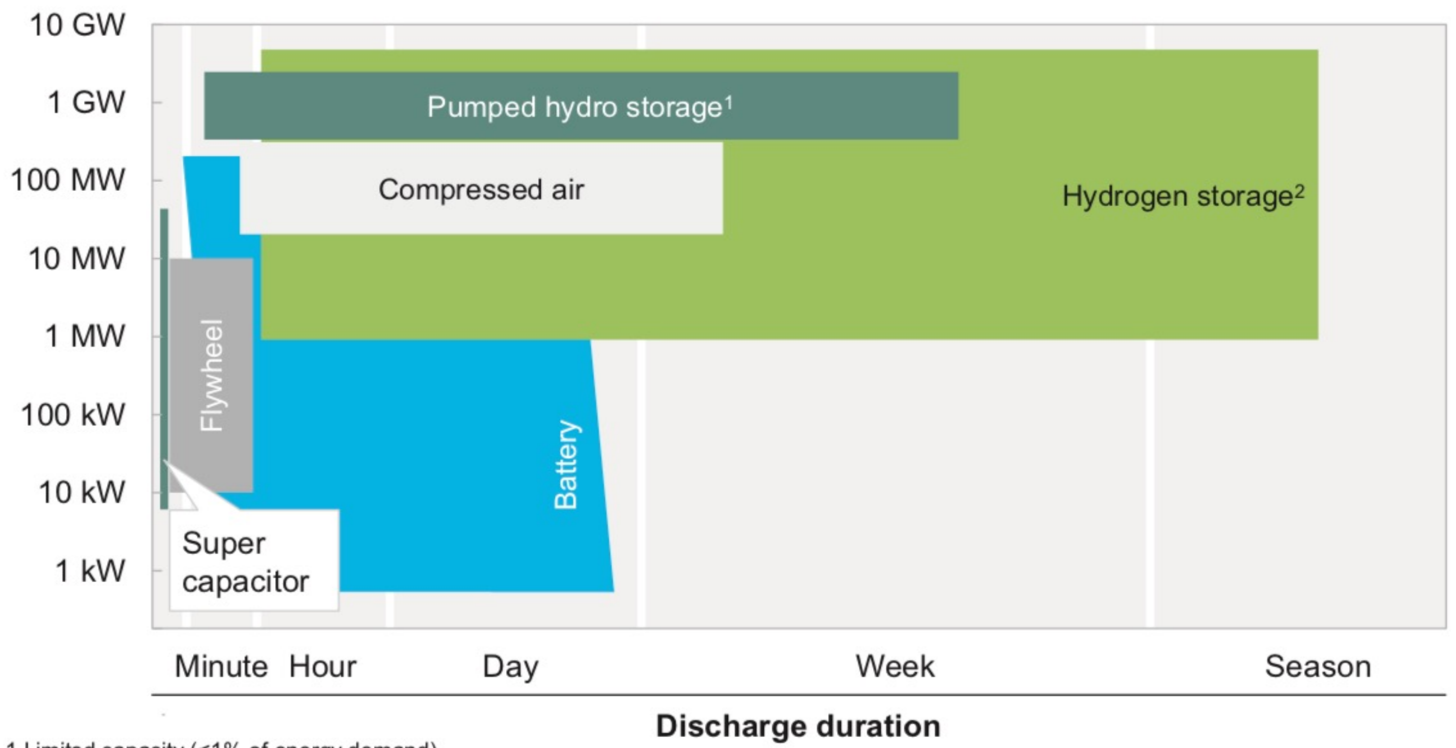
Hydrogen-based energy storage

One of the most suitable solutions for large scale long-duration energy storage needs

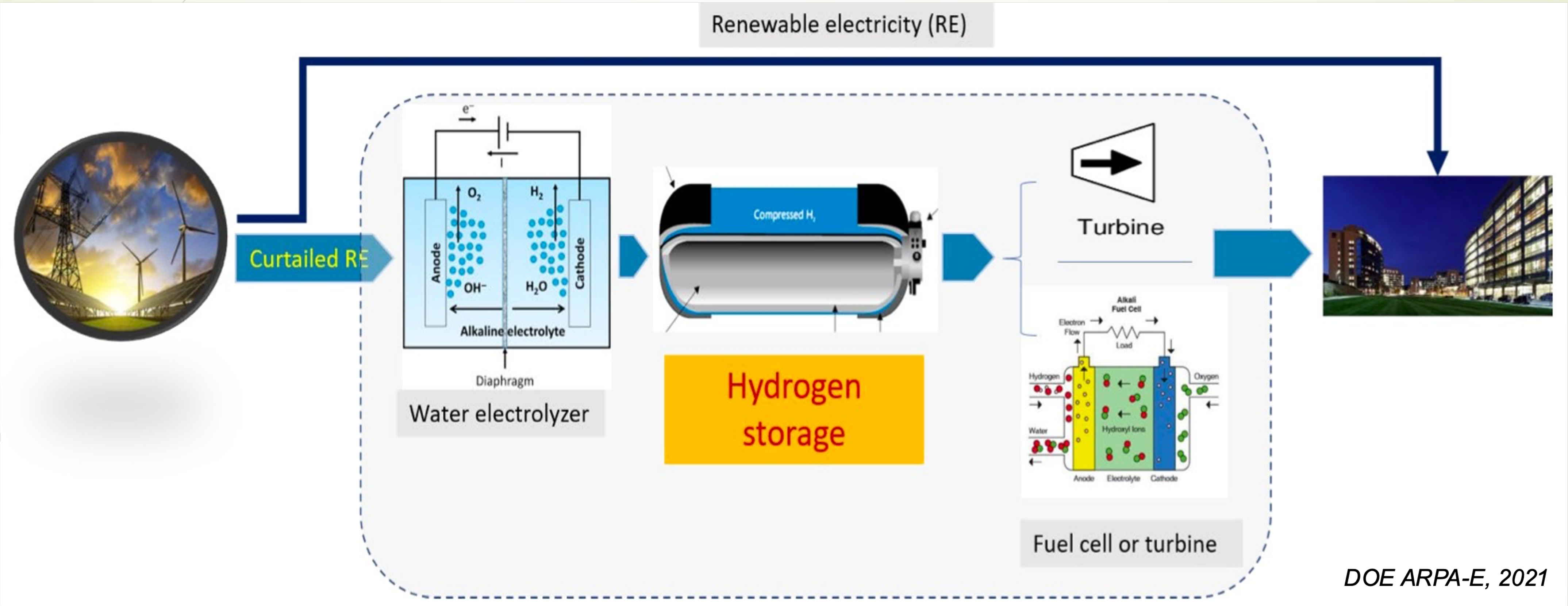
Technology overview in power and time



1 Limited capacity (<1% of energy demand)
2 As hydrogen or SNG

SOURCE: IEA Energy Technology Roadmap Hydrogen and Fuel Cells

Hydrogen-based energy storage systems for renewable energy power generation



- On-going demonstrations at multi-megawatt to hundreds megawatt-hour energy level
- Low round-trip efficiency compared to other technologies (battery, pumped hydro)

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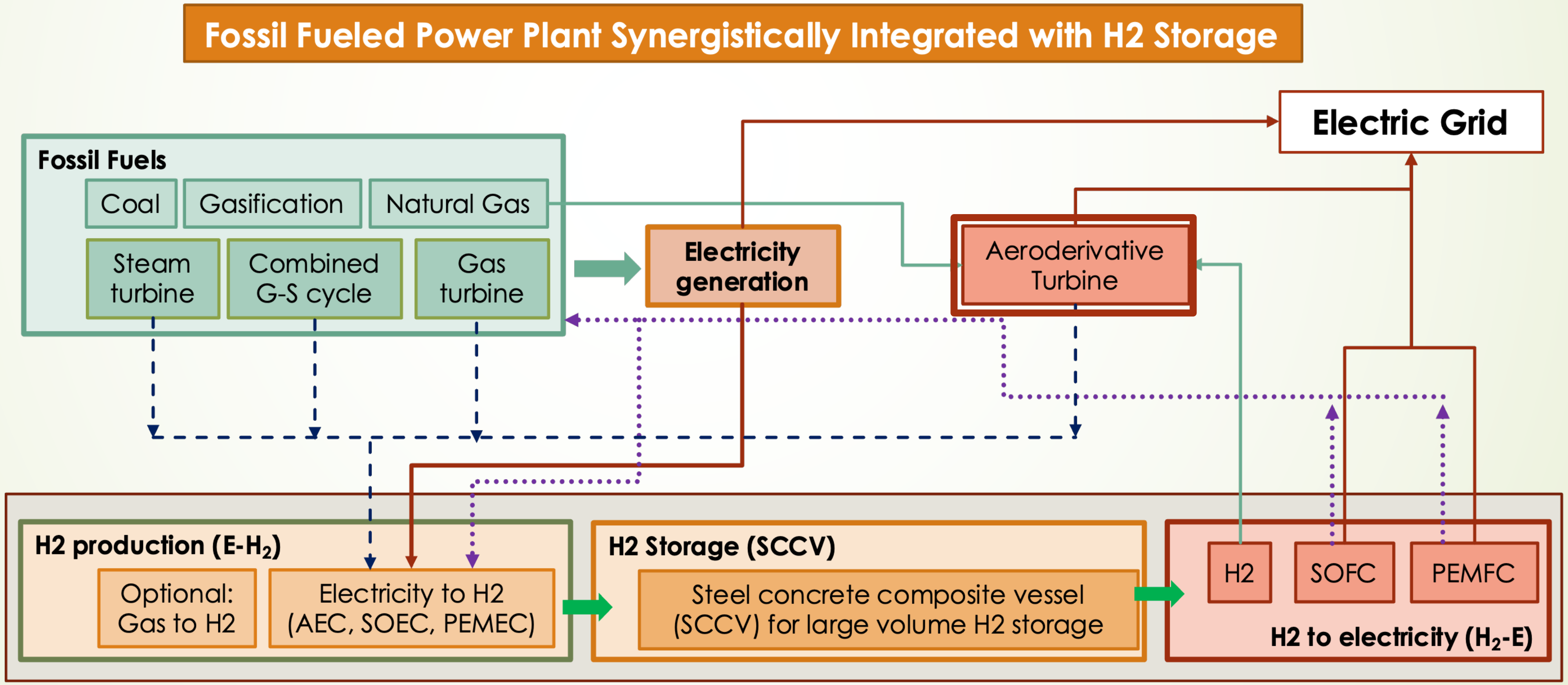
Unique Options, Opportunities and Challenges for Hydrogen Storage System for Fossil Power Plants

- Both E-H2 and H2-E processes involve heat or thermal energy
- **S**ynergistically **I**ntegrating low-cost **H**ydrogen **E**nergy **S**torage system with fossil-fuel assets – The **SIHES**



Dashed lines show flow of the by-product heat from one subsystem to others to improve the overall efficiency of power generation.

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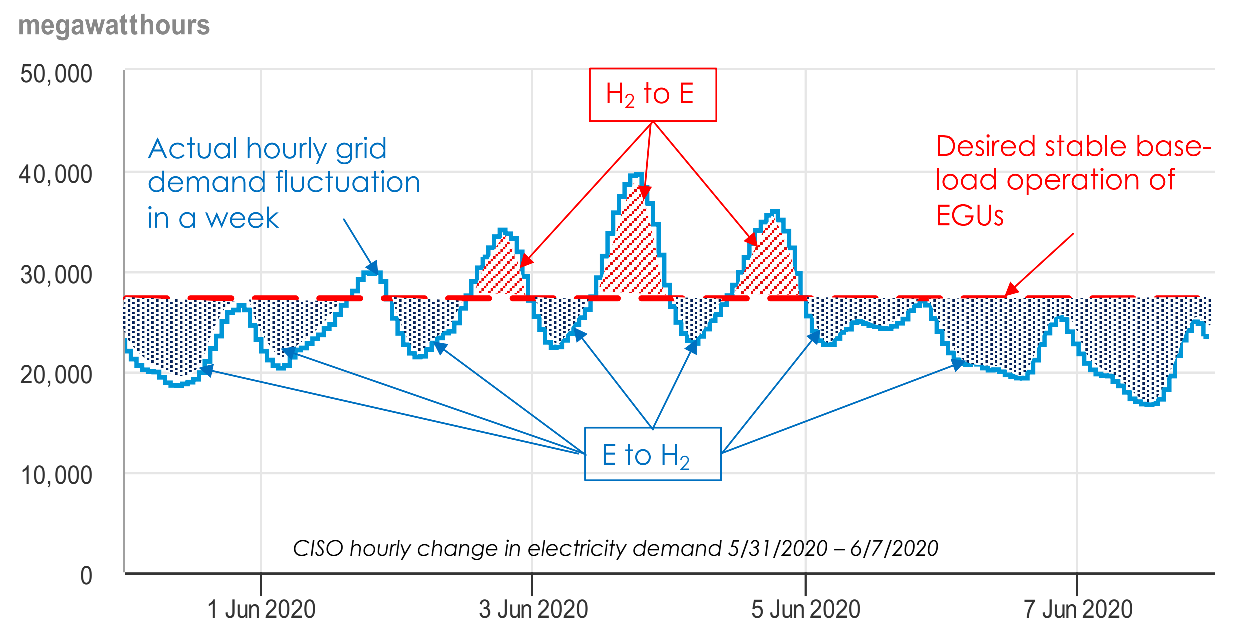
Concept of SIHES: Operation

- Allow fossil power plant to run at relatively stable optimal base-load conditions to mitigate inefficient, off-design and deep cycling operations and to improve the economics of power plant
- Electricity price is inherently proportional to the demand
  - E -> H_2 at low price and H_2 -> E at high price.
  - Opportunity for optimization of SIHES for profitability (site specific capacity, and operation profile).
- Operation profile strongly influence the design and sizing of subsystem of SIHES
  - Require use of *sufficiently large* hydrogen energy storage system to manage the dynamic changes in electric grid demand and electricity price over intermediate to long-durations.



Grid fluctuation for illustration only

Project Objective

- **Technical Viability**: Enables EGUs to operate at optimal baseload operation conditions through use of *sufficiently large* storage system to manage the dynamic changes in electric grid demand and electricity price over intermediate to long-durations (i.e., ***from 12 hours to weeks***).
- **Economic Viability**: Target *added* round-trip levelized cost of energy (LCOE) no greater than 10% of LCOE of today's fossil plant for 30 years operation (**$5-10/MWh**).
- **Phase I**
  - Focus on a site-specific *conceptual design* for a fossil power plant selected from the Exelon fossil fleet, to demonstrate both the technical and economic feasibility of SIHES.
- **Phase II**
  - subsequent Pre-FEED, site demonstration, and eventual deployment of SIHES in fossil power generation.
- DOE FOA Requirement on H2 Storage System: **>10MWh**

R&D Plan, Approach and Tasks

Drastically reduce the cost of hydrogen storage subsystem

- Further develop our ultralow cost steel concrete composite vessel (SCCV) for tailored use in SIHES
- Scalability
  - 500-1000 kg H2 vessels mass-produced in shop (vs 30-50kg of today's vessels)
  - Tens to hundreds tons of H2 by on-site construction

Effectively integrate hydrogen energy storage system with fossil assets

- Considerable room and **unique opportunities** exist in optimal integration of SIHES into fossil assets

Techno-economic optimization

- Optimize both system design and operation of SIHES for the dynamic storage demands and electricity fluctuations

Site Specific Target level of performance

- Baseline design for a specific type fossil power plant selected by utility team member
- Target hydrogen energy storage parameters
  - Cost : added round-trip E-H_2-E LCOE in the range of 10% of base LCOE of today's fossil plant (i.e. $5-10/MWh)
  - 30-500MWh for 1-10 days designed for 30-year service

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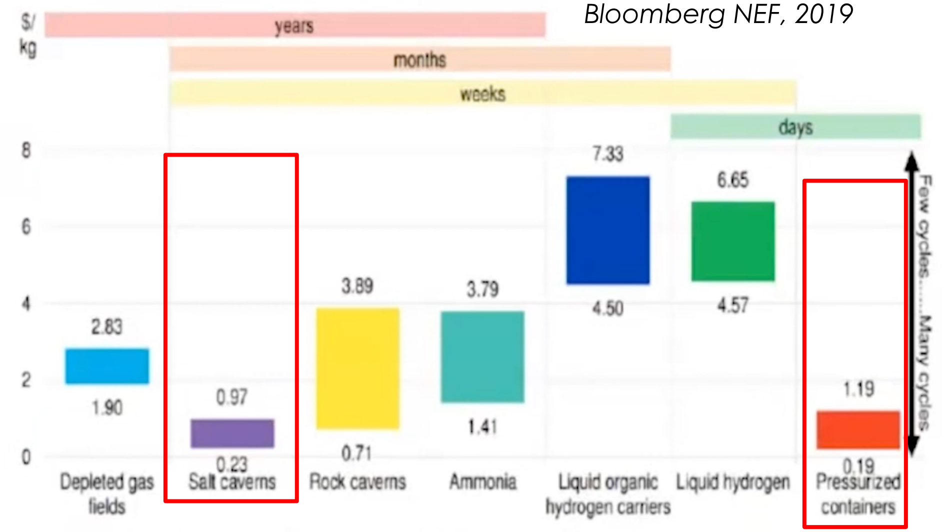
Options for H2 storage subsystem:

- High pressure H_2 vessel storage is one of the mature and cost-effective options, but **limited by volume**

Figure 1: Levelized cost of hydrogen storage (LCOS) and typical storage duration, 2019

Bloomberg NEF, 2019



Source: BloombergNEF. Note: ammonia, LOHCs and liquid hydrogen are mainly media for long-distance transport.

Table 1: Hydrogen storage options *BloombergNEF, Hydrogen Economy Outlook 2020*

	Gaseous state				Liquid state			Solid state
	Salt caverns	**Depleted gas fields**	**Rock caverns**	**Pressurized containers**	**Liquid hydrogen**	**Ammonia**	**LOHCs**	**Metal hydrides**
Main usage (volume and cycling)	Large volumes, months-weeks	Large volumes, seasonal	Medium volumes, months-weeks	Small volumes, daily	Small - medium volumes, days-weeks	Large volumes, months-weeks	Large volumes, months-weeks	Small volumes, days-weeks
Benchmark LCOS ($/kg)[1]	$0.23	$1.90	$0.71	$0.19	$4.57	$2.83	$4.50	Not evaluated
Possible future LCOS[1]	$0.11	$1.07	$0.23	$0.17	$0.95	$0.87	$1.86	Not evaluated
Geographical availability	Limited	Limited	Limited	Not limited	Not limited	Not limited	Not limited	Not limited

Source: BloombergNEF. Note: [1] Benchmark levelized cost of storage (LCOS) at the highest reasonable cycling rate (see detailed research for details). LOHC – liquid organic hydrogen carrier.

"Salt cavern and <u>high-pressure tank storages</u> are mature technologies, while the other options are, for the most part, at lab scale."

(Source: ARPA-E RFI "Stationary Hydrogen Storage Technology Development", Jan, 2021)

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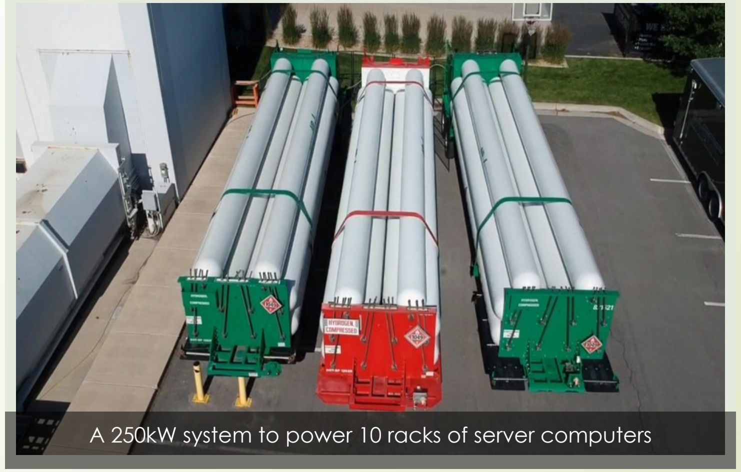
Today's high-pressure H2 storage vessels

- Small volume Tubes/vessels
  - Commercially available and widely used for H2 refueling stations
  - Limited by size such as lengths and diameters (up 20-30 inches) **20-50kg** per vessel/tube
  - Made of structural steels for cost
- Hydrogen embrittlement concerns (especially under cyclic loading conditions)
  - No high-strength steels
  - **Welding not allowed,** limiting the size of tubes (seamless tubes). Difficult to scale up for large scale storage needs
- "For an LM6000 aero-derivative (50 MW) firing 100% H2 that is about **950 tons** of storage capability a year". By AEP attendee
  - Today's tubes are not suitable for H_2 storage at electric utility scale.

H2 Refueling station in CA

Microsoft uses hydrogen fuel cells to power servers for 48 hours straight (July 27, 2020)



A 250kW system to power 10 racks of server computers

Large volume high-pressure steel vessels for non-hydrogen applications are routinely made, but require welding and different manufacturing technologies

Source: M Jawad, Nooter Co

- 96-ft Long high-pressure steel vessel for ammonia conversion manufactured in the US in 1970s.
- **Must address the safety concerns of hydrogen embrittlement for hydrogen storage**

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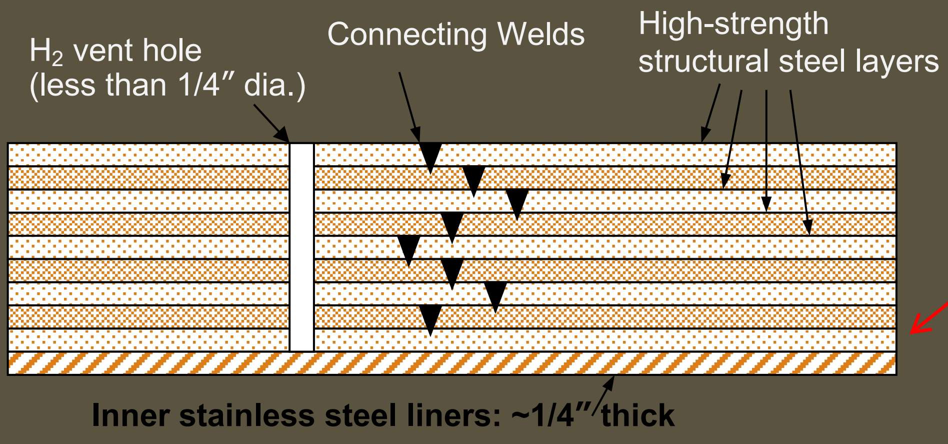
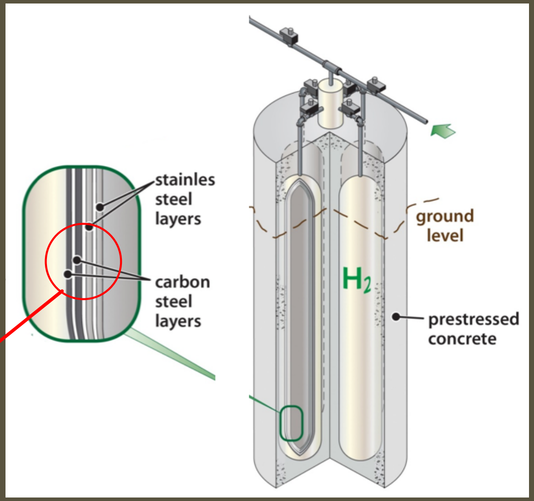
Our Technology: Low-Cost Steel Concrete Composite Vessel (SCCV) for Large Scale Stationary Hydrogen Storage

- Eliminating HE by Design" A multi-layer design with strategically placed vent holes to prevent the intake and accumulation of hydrogen in the steel layers except the innermost layer





- Small vent ports are created on the 2nd and all the outer layers of the vessel without sacrifice of the structure mechanical integrity.
- Hydrogen mitigated through the innermost layer will pass through the vent ports and will accumulate little or no pressure, hence hydrogen embrittlement effect on the outer low allow steel shells is minimized.

Key Technology
Low-Cost Steel Concrete Composite Vessel (SCCV) for Stationary High-Pressure Hydrogen Storage

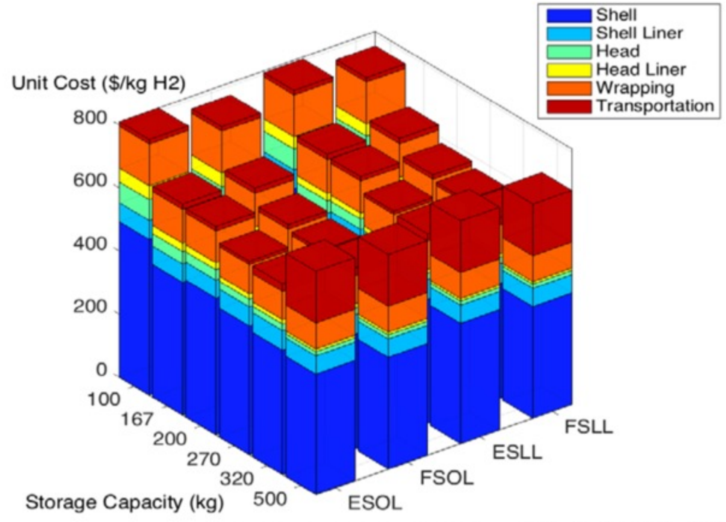
- SCCV is an innovative solution specifically designed and engineered for stationary high-pressure gaseous **hydrogen** storage applications
  - Addressing the two critical challenges: **high capital cost** and **safety** concerns of hydrogen embrittlement of high-strength steels.
  - US Patent 9,562,646 B2
  - **ASME Pressure Vessel Code Case 2949**
- Novel design
  - Eliminate hydrogen embrittlement problem **by design**
  - Enable use of cost-effective commodity materials (concrete and steels)
- Advanced **welding**, manufacturing and sensor technologies for reduced cost and improved safety
  - Can be fabricated with today's commercially ready manufacturing technologies in the US
- Scalability enabled by advanced welding technologies:
  - 500 – 2000 kg H_2 vessels mass-produced in shop vs today's seamless tube at 20-50kg H_2
  - Even larger, super sized H_2 vessels by on-site construction


Manufacturing of first demonstration SCCV

SCCV is cost competitive

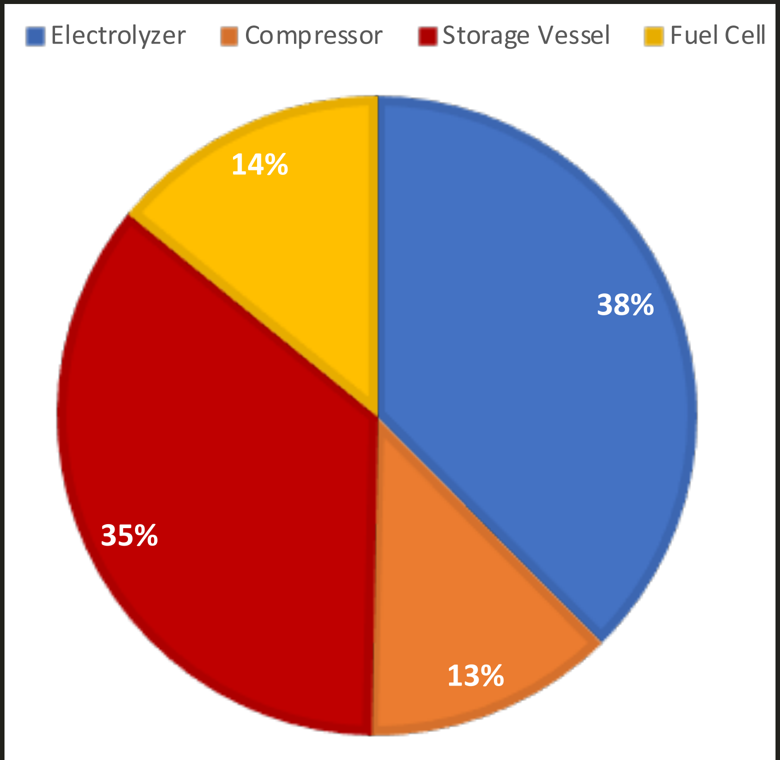
- Today's vessel cost: \$1000-1500/kg H_2
- Our technology:
  - \$500-600/kg H2 at 875 bar (US price).
  - Reference SCCV design: 1500kg H_2 in moderate volume production (24 identical vessels per order)
- Improvement in design, manufacturing and economics of scale would further reduce the cost to ***\$200-300/Kg H_2 at high volume production***

	100 kg	167 kg	200 kg	270 kg	320 kg	500 kg
FSOL	771	639	585	568	574	680
FSLL	765	635	583	566	572	679
ESOL	810	669	660	613	604	707
ESLL	805	665	658	611	603	706

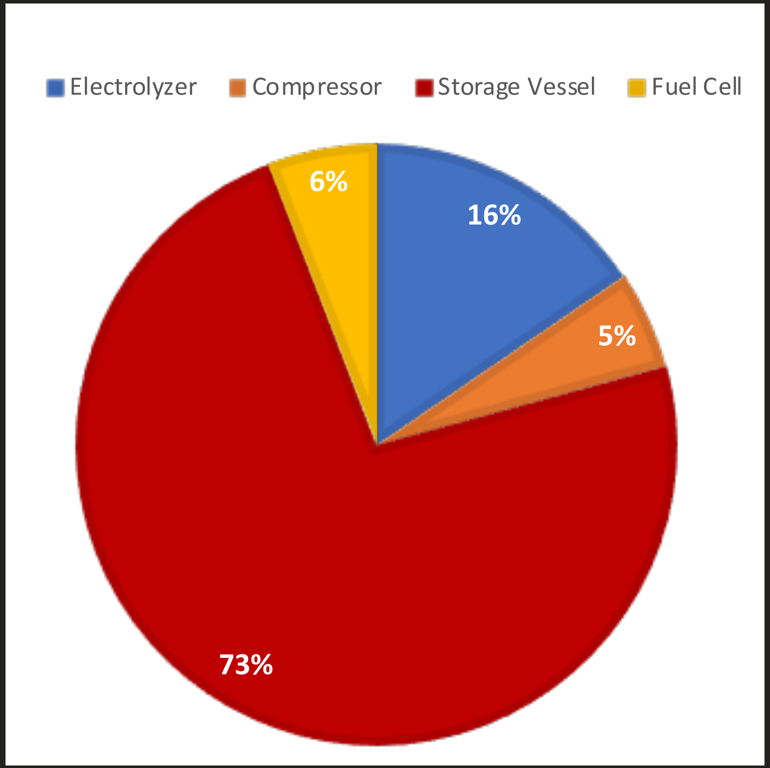


SIHES could drastically reduce the capital cost of H_2 energy storage, potentially economically viable

Our E-H_2-E technology



Today's technology



Energy Plant Type	LCOE $ per MWh
Offshore Wind	130.40
Coal with 30% CCS	104.60
Coal with 90% CCS	98.60
Biomass	92.20
Advanced Nuclear	77.50
Nat Gas Combined Cycle with CCS	67.50
PV Solar	60.00
Hydro-electric	39.10
Land Based Wind	55.90
Natural Gas Combined Cycle	**41.20**
Geothermal	41.00
Energy Storage System	**Additional LCOE $ per MWh**
Li-ion Battery	100-300
Today H2 based	50-60
Our H2 based	**5-20**

Data source: EIA, NREL, solarcellcentral.com 7/2020

- Basis for analysis:10MW, 7-day storage. 30-year operation life for hydrogen system, and 10 years for Li-ion battery
- Same cost figures for all components other than storage vessels

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Two Potential Scenarios for Fossil Power Plants

- Baseload units (500 – 1500 MW typical)
- Peaker generation units (10-60 MW typical)

- Mystic Generating Station: Near Boston, part of ISO-NE
- Units 8 and 9: combined cycle gas turbines. 703MW/710 MW
- **Mystic Jet: a 9 MW oil fueled peaking unit run** during high demand

- Southeast Chicago Energy Project Generation Station: near Chicago part of PJM
- **Peak generation plant** at 296MW, with 8 units rated at **37MW** running on natural gas

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Initial Market Entry Point:

HyPeaker

(Hydrogen based peaking power generation units)

- **Peakers (Peaking power generation units)**
  - TVA Johnsonville Combustion Turbine Plants (50-60MW/unit)
  - Exelon Southeast Chicago Energy Project Generation Station (37MW/unit)
- Compared to baseload units
  - Peakers are much smaller – more manageable for **early adoption** from both technical and capital investment perspectives.
  - More expensive and inefficient to run, on MWh basis, than the baseload plants.
  - Emit higher rates of CO_2 and health-harming air pollutants.
- Run infrequently during periods of high peak demand. Only used for a few hours at a time, with capacity factor of 0.1 or less.
  - The Mystic Jet unit has a much lower capacity factor, in the range of 1-3%.
- **Such low-capacity factor and intermittent operation allows a HyPeaker to generation H2 when the electricity price is low or even negative, and supply the peak demand at a prime price.**
- More than 1,000 natural gas- and oil-fired peaker plants in the US. A sizable market.
  - Disproportionately located in disadvantaged communities, significant societal benefits

Techno-economic analysis (TEA)

System considerations

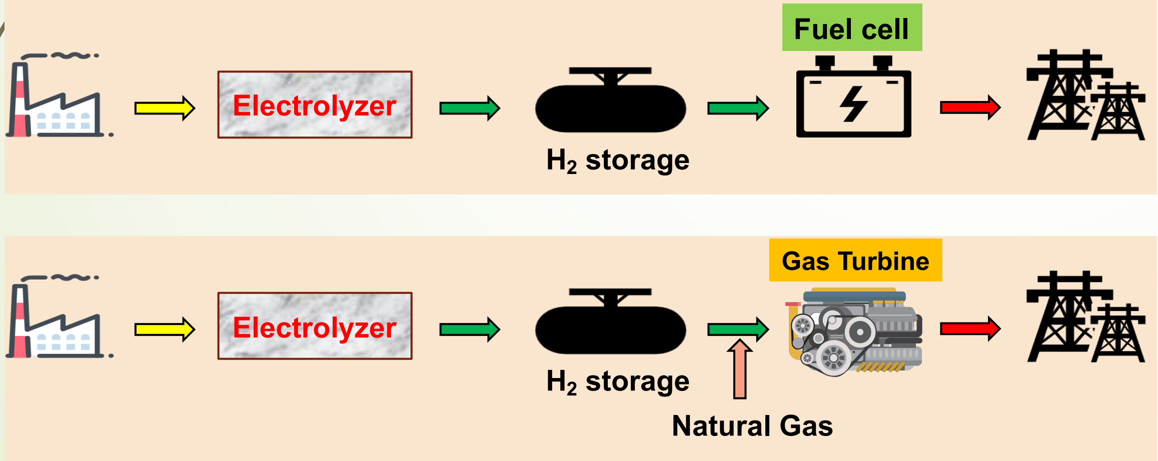
Electricity grid

E-H2
Type: Alkaline Electrolyzer, 70% efficiency
Cost:
high: $1000/kW
Low: $400/kW
Capacity:
TBD from TEA (1MW-30MW)

Storage Vessel + Compressor
SCCV (our technology)
Cost: $200-$400/kgH2 ($6-$12/kWh)
Today's market as reference
Cost: $1000-$1500/kg-H2 ($30-$45/kWh)
Capacity:
TBD from TEA, no other restriction
DOE AOP requirement: >10MWh
Likely in the range of 50-500MWh

H2-E
PEM Feul Cell (Option 1), 65% efficiency
Cost: $300-$600/kW
Aeroderivative Turbine, 45% efficiency
Cost: $0, using existing unit
H2/NG mix: 20% H2 now, 100% future
Capacity:
30-50MW

Electricity grid



Factors Evaluated in Phase I TEA

- Gas Turbine vs. Fuel Cell System
- Reversible vs. Conventional Fuel Cell Systems
- Options of Hydrogen Storage
- H2 to E Unit Efficiencies
- Locational Marginal Price (LMP) Variations

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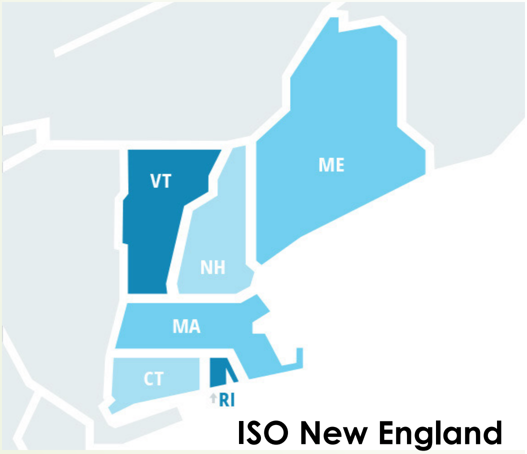
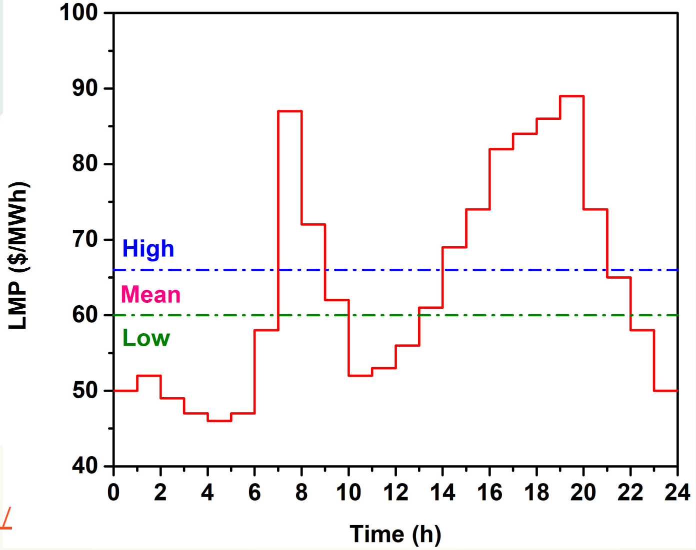
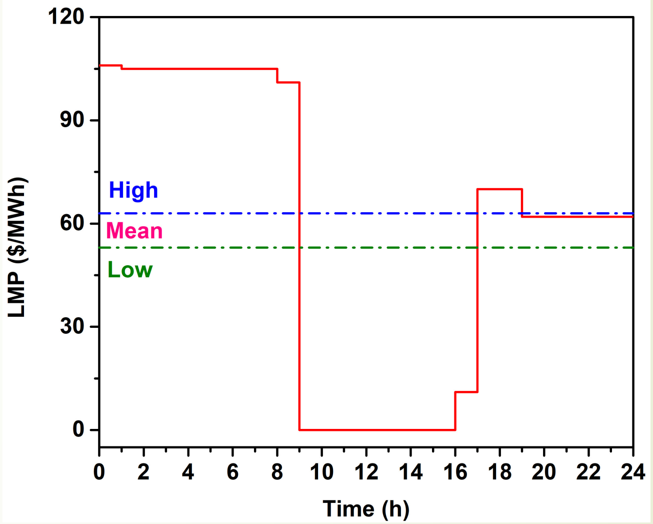
Locational Marginal Price (LMP) Variations

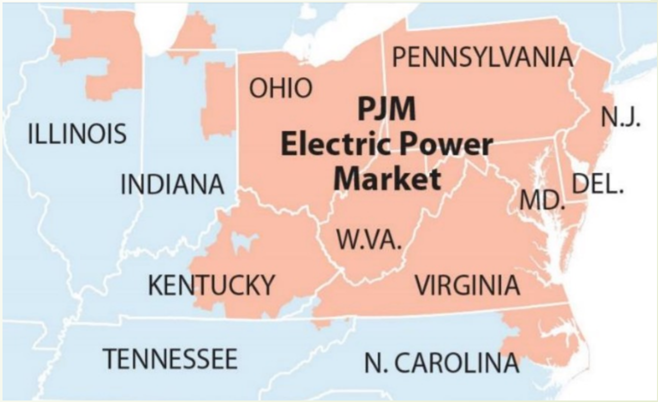
- Operational modes:
  - Low LMP: electricity to hydrogen (via electrolyzer)
  - Mean LMP: Idling
  - High LMP: hydrogen to electricity (Fuel cell or **gas turbines**)





Date: 10/10/2021
Source: https://www.iso-ne.com/isoexpress/

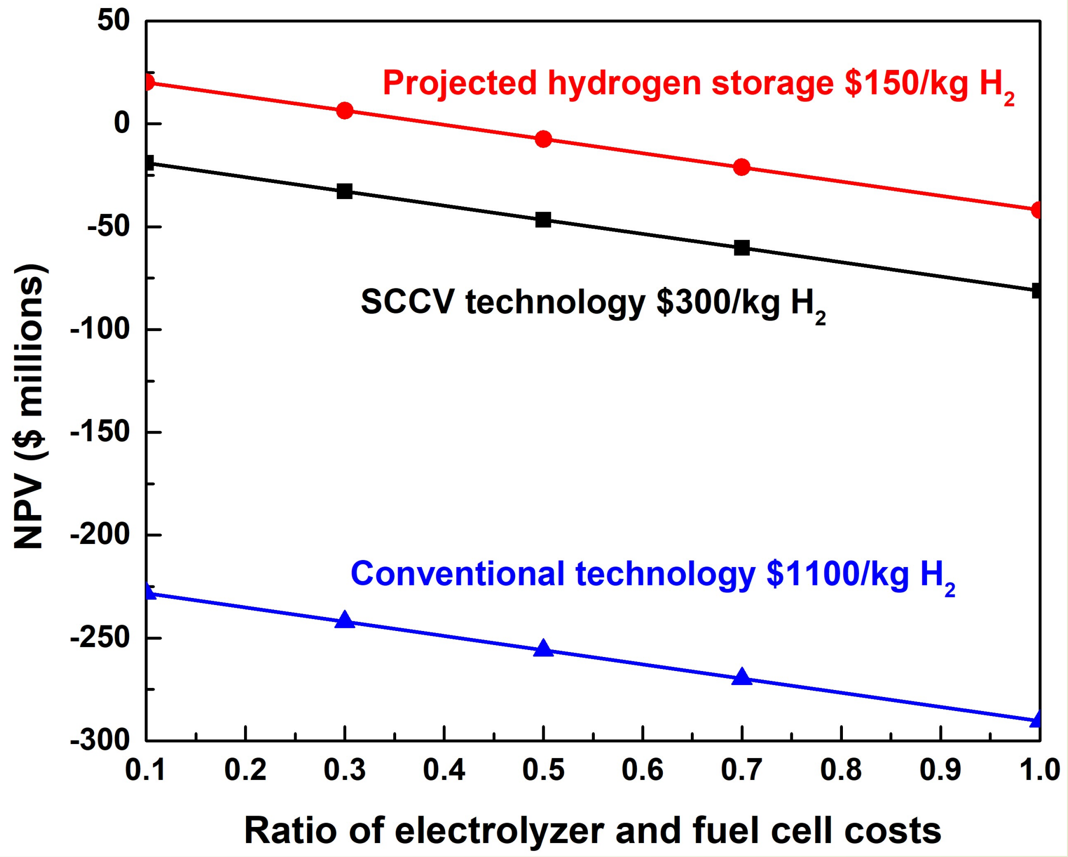




Date: 1/15/2035 (projected)
Source: https://data.nrel.gov/submissions/181

Comparison of Hydrogen Storage Cost (PJM)

- NPV is compared between SCCV ($300/kg, $150/kg H2) and conventional ($1100/kg H2) hydrogen storage technologies
  - Considerable cost benefits from SCCV
  - The NPV of new SCCV technology ($150/kg H2) reaches $20.25 MM



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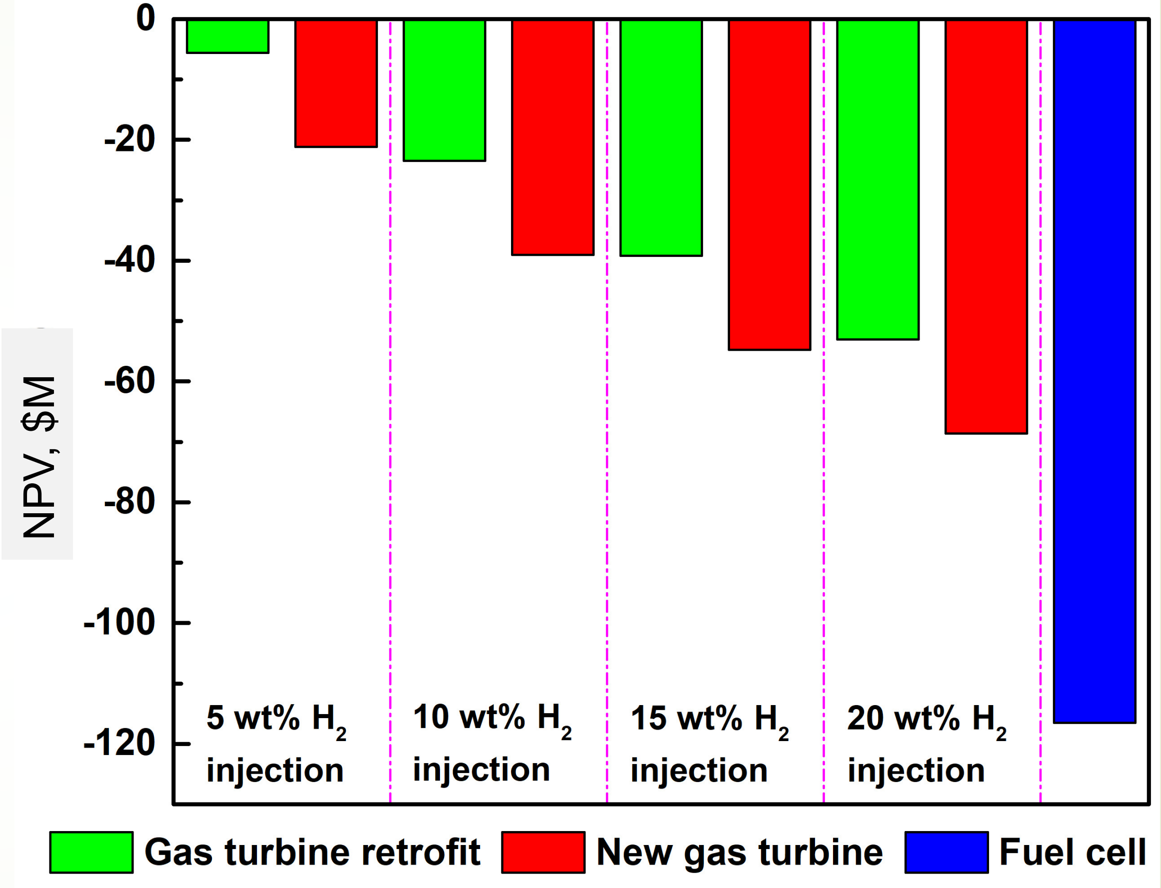
Gas Turbine vs. Fuel Cell Systems (PJM)

- Using existing gas turbine system (5-20 wt% H_2 co-firing with natural gas) is more economical than fuel cell system
  - At 5 wt% H_2 blend, the net present value (NPV) difference is $110 MM in comparison with fuel cell system
- Emissions of CO_2, NOx from natural gas combustion would require capture/management
  - Will be included in next phase of study



Conditions:
- Hydrogen Storage Tank - $300/kg

National Energy Technology Laboratory, Cost and performance baseline for fossil energy plants Volume 1: bituminous coal and natural gas to electricity, U.S. Department of Energy, Pittsburgh, PA, 2019

Baseline **HyPeaker** design metrics based on selected sites

System Design: 30-year life, 50x50x20m footprint

Electricity generation unit: 30MW unit for first demonstration

- PEM based hydrogen fuel cell
- **Retrofitting existing gas turbines with mixed H2 and gas fuel, initially less than 20%**

Hydrogen storage system:

- SCCV at 3000psi pressure with sufficient storage capacity for 20 hours operation (300MWh or 8000 kg H2 storage).

Hydrogen production unit from electricity:

- Alkaline electrolyzer, rated at 8 to 10MW (½ to 1/3 of electricity generation capacity)

Intentionally overmatch the capacity of ultra-low cost SCCV

- Provide the extra storage capacity for low electricity price over a long period of time such as in several weeks
- Reduce the capacity of the electrolyzer, the highest cost item in the system.
- This aspect is unique to the fossil power plant application

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Phase I Project Summary

- Deployment site selected, and identified early market entry point for long duration hydrogen storage system:
  - Peaking power generation: HyPeakers
- Developed TEA model tool and completed initial TEA for HyPeaker
  - Quantified the significant economic benefits of SCCV
  - Evaluated options of HyPeaker system design
  - Identified scenarios for HyPeaker operation
- Completed the **site-specific concept** HyPeaker system design and operation metrices
  - HyPeaker is technically feasible and economically advantageous
- Solid foundation for Phase II Pre-FEED
  - Technology Readiness
  - Partners for Phase II and future deployments
  - System and operation optimization based on economics

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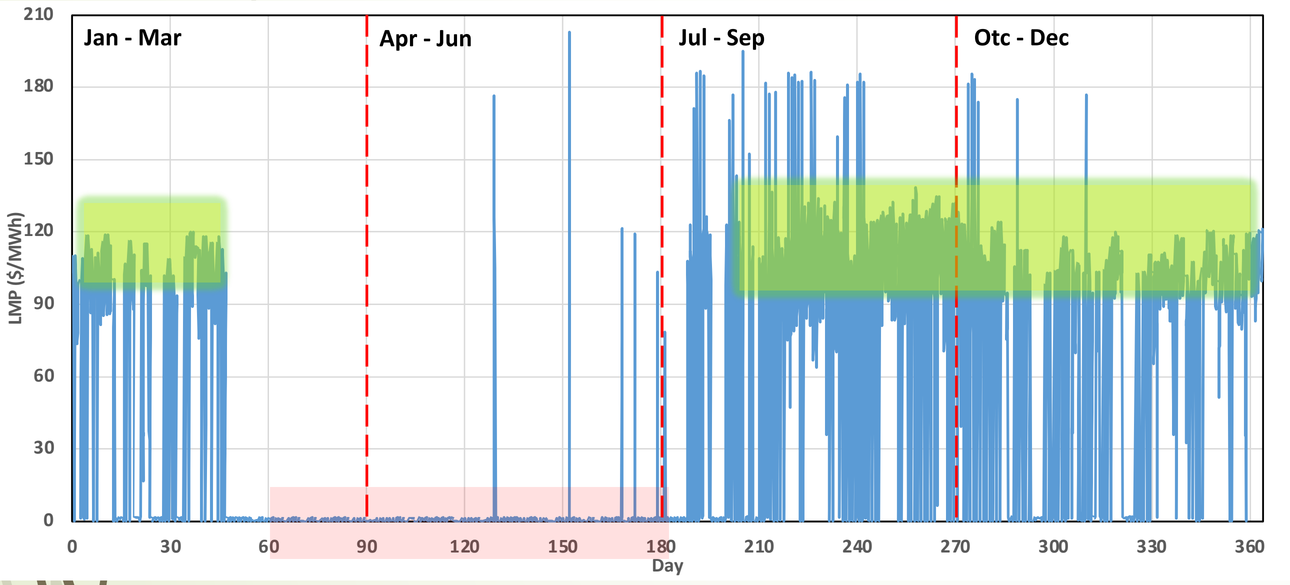
Phase II Plan

- Phase II Awarded
- Complete a preliminary front-end engineering and design (Pre-FEED) study of HyPearker integrated with a site-specific fossil asset
  - Based on TVA Johnsonville Combustion Turbine Plants, 50 MW Aeroderivative gas turbine unit
  - Detailed technoeconomic study to further optimize the HyPeaker for such site and applications
    - Manufacturing capability of storage systems in the US and internationally
      - 500 kg – 2000 kg shop fabricated and transported to site
      - On-site construction of larger vessel system
    - Seasonal long-duration consideration
- Demonstrate the technical feasibility and economic viability of HyPeaker

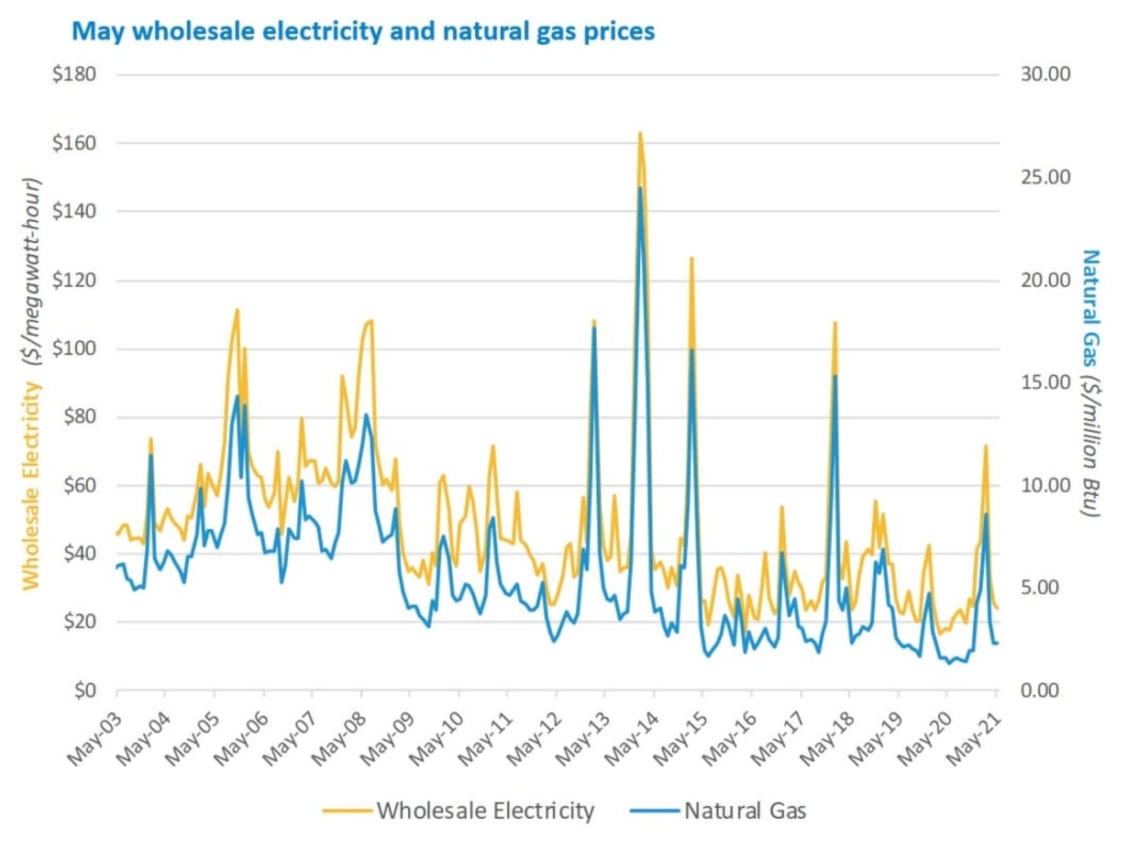
Seasonal Long-Duration Considerations

Yearly LMP for CAISO-150



https://data.nrel.gov/submissions/181

Monthly wholesale electricity prices and demand in New England, May 2021



https://isonewswire.com/2021/06/24/monthly-wholesale-electricity-prices-and-demand-in-new-england-may-2021/

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Thank you!

About WE New Energy

- WE New Energy Inc (WENE) is a hydrogen energy storage technology company serving the rapid growing clean renewable energy market. We design, engineer and support integrated hydrogen energy conversion and storage system/products, and contract manufacturing companies to produce sub-systems and final assembly based on our designs and specifications.

- WENE"s core technology includes patented highly cost competitive large scale stationary high-pressure hydrogen storage system, and other related hydrogen storage and testing technologies. WENE and Oak Ridge National Laboratory (ORNL) have exclusive IP licensing agreement on hydrogen energy storage technologies.

- We are involved in several large-scale hydrogen storage projects for clean renewable energy transition

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