

Grid Scale Electrolyzers: Enabling the 2045 Hawaii Vision

Stephen Szymanski, Director of Business Development, Nel Hydrogen
+1.203.678.2338 • sszymanski@nelhydrogen.com
December 6, 2018



Company Overview

Public Company, Pure H₂ Play

- 3 Manufacturing Sites
- 3,500+ Electrolyzers Installed
- 40+ H₂ Fueling Stations
- 90+ Years Experience



USA (Wallingford, CT)
PEM Electrolyzers



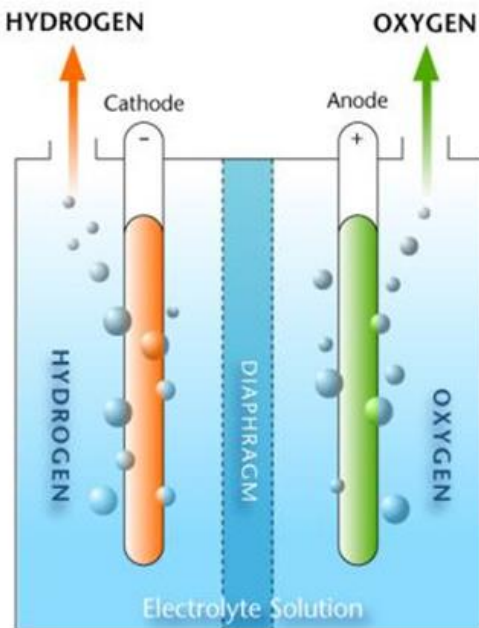
Denmark (Herring)
H₂ Fueling Stations



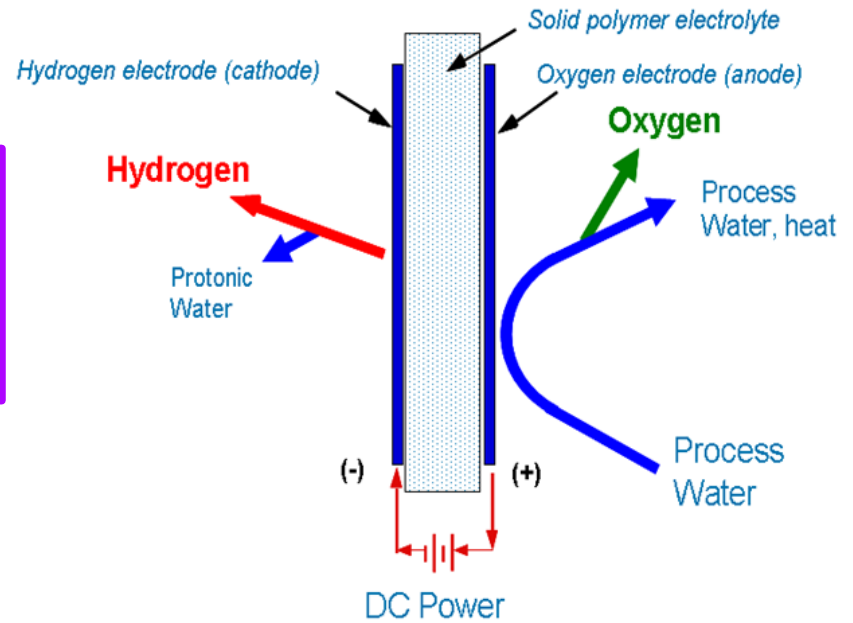
Norway (Notodden)
Alkaline Electrolyzers

What we do....

Our technologies produce pure hydrogen from electricity and water. When the electricity is from renewable energy, you have a carbon free source of hydrogen fuel.



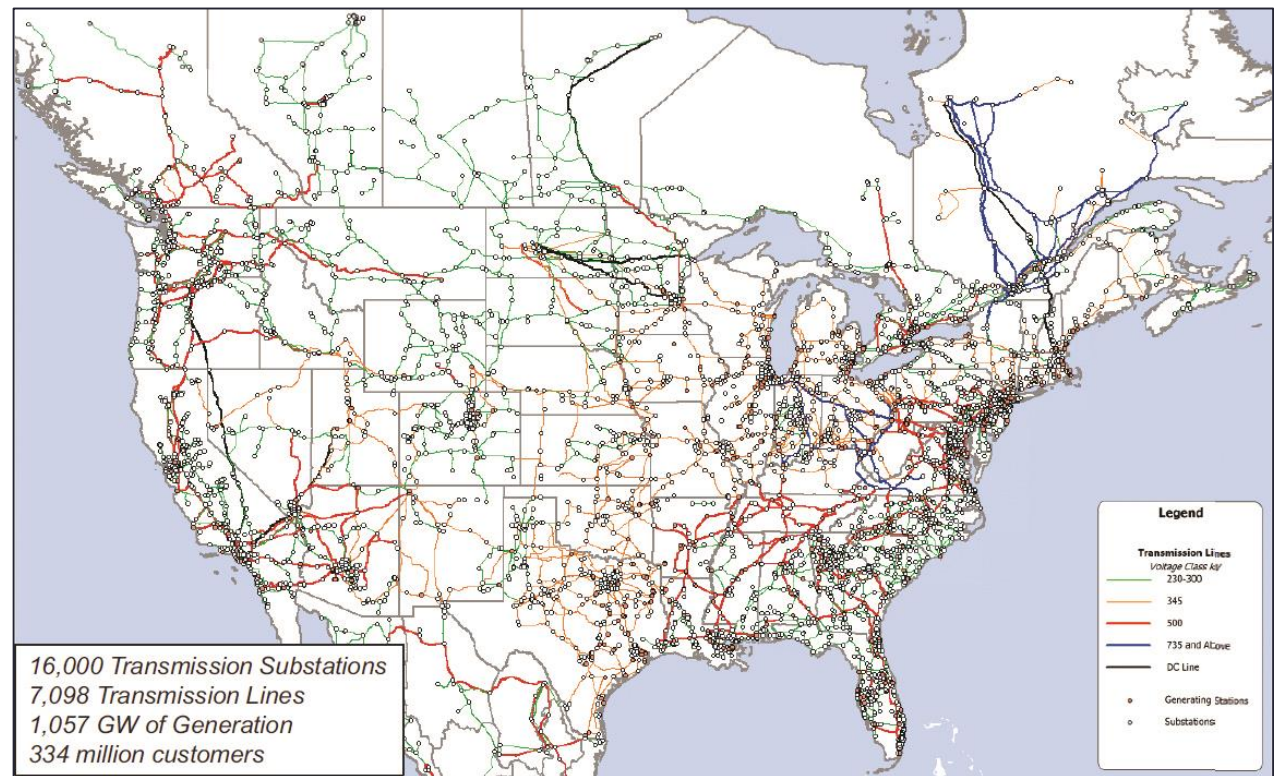
Liquid alkaline electrolyzer



PEM electrolyzer

Today's Electric Grid

- The US/Canadian electric grid is the World's Largest Machine*
 - Nodes
 - Connections
 - Inputs
 - Outputs



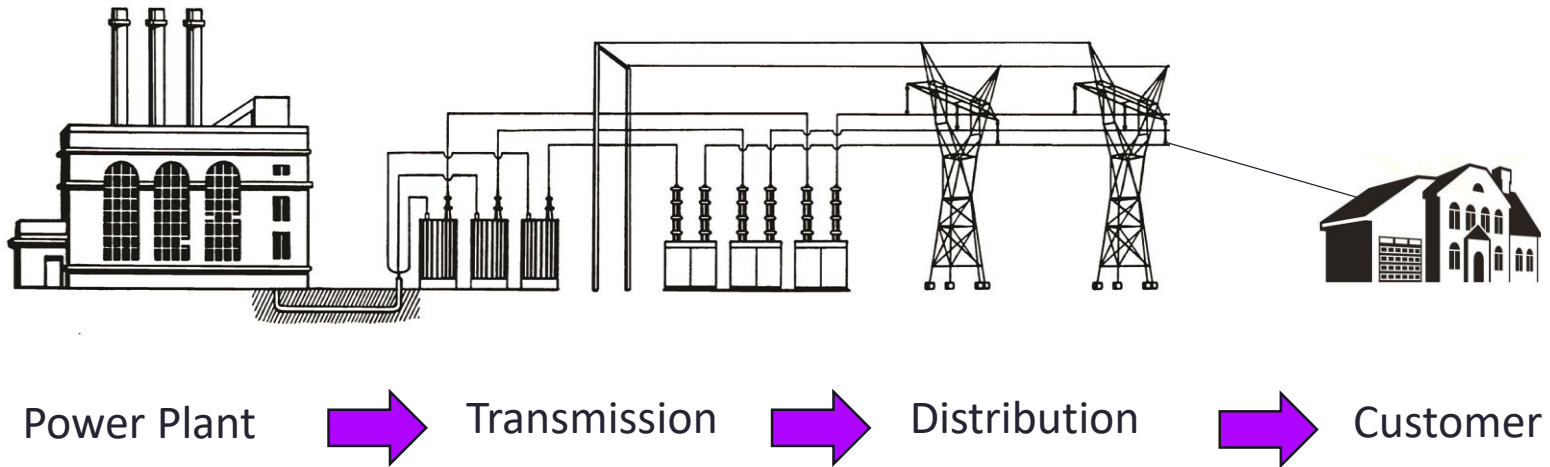
* www.livescience.com/48893-improving-efficiency-on-the-electric-grid.html

- The form and complexity of all electric grids increase every year
 - Longer lines
 - More nodes – suppliers and users
 - More complicated and demanding energy uses
 - Increased variety of energy sources
 - Two-way electricity movement



Early Electric Grids – One Way Power Movement

- Electric power flowed “downhill”



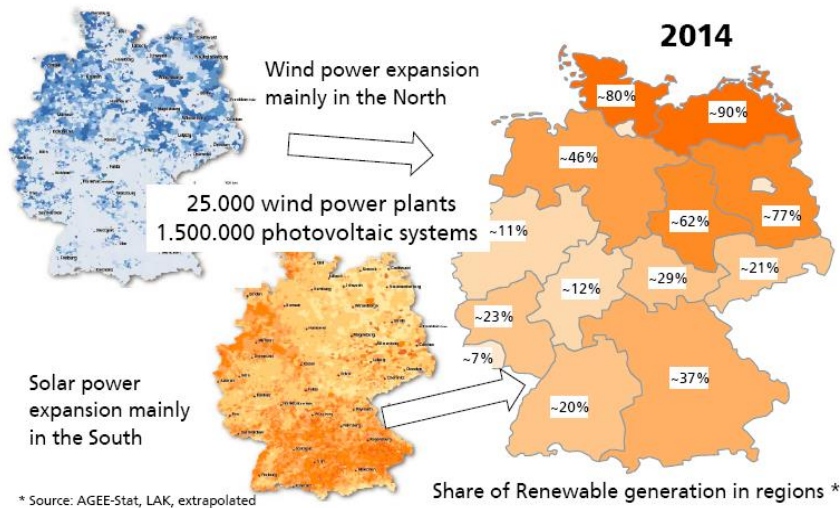
Non-Utility Generation – Upset the Orderly “Demand-pull” Approach to Capacity

- Created additional competition for conventional power plants
- Generation incentives helped obsolete the orderly demand-pull approach to capacity growth
 - 1978 – US – PURPA (Public Utilities Regulatory Policy Act)
 - Incentivized some generation approaches for societal benefit
 - Promoted energy conservation (reduce demand)
 - Promoted use of domestic and renewable energy (increase supply)
 - First widespread experience in the US with the concept of a “non-utility generator”.



- Several areas in Europe already experiencing critical levels leading to transmission issues and curtailment

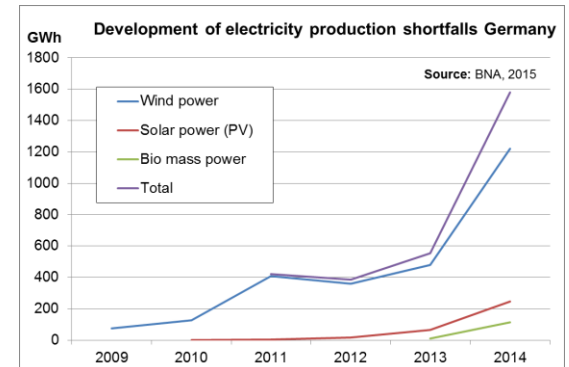
Wind and photovoltaic power generation in Germany



Denmark sets wind energy world record

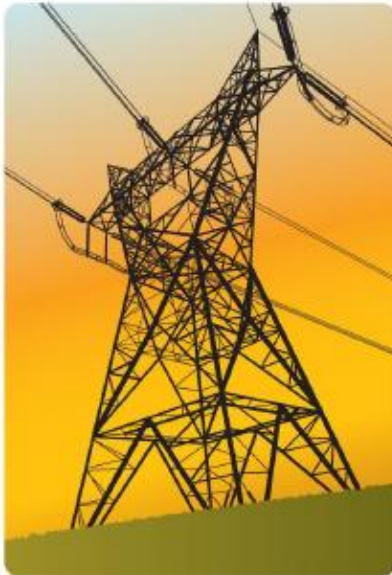


Denmark aims to generate 50 percent of its electricity from wind power by 2020



Excess Power versus Excess Oil

Electricity Consumption:
23,000,000* GWh



Energy Storage:
156 GWh* (0.0008%)

Oil Production:
27.76B Barrels/Year*

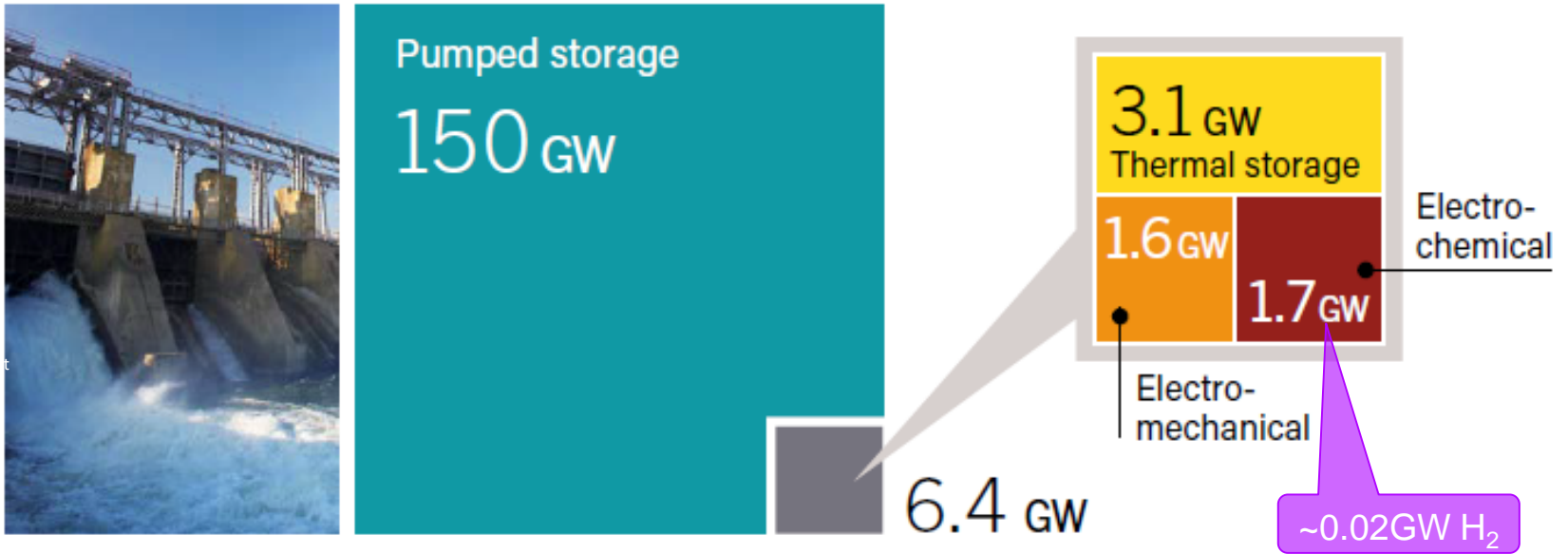


Oil Reserve:
4.1B Barrels* (14.8%)

Oil reserves: 54 days
Electricity: 4 minutes
19,000x differential

*2013 numbers, www.eia.gov,
www.energystorageexchange.org (DOE),
www.iea.org, www.worldenergy.org

Where is Storage Today?



“Excess” Power – Key to Mainstream Electrolysis

- The Hydrogen Electrolyzer
 - Proven technology
 - Reliable
 - Easy-to-operate
 - Load-following
 - Easy to maintain
 - Relatively low capital cost
 - Very dependent on “fuel” cost (electricity)
 - Ideal user of “excess” power



M400, 2.2 MW electrolyzer

- Effect of electricity pricing variability on the cost of hydrogen generated via electrolysis:

| Grid price (cents/kWh) | Hydrogen variable price (\$/100 scf) |
|------------------------|--------------------------------------|
| 10 | \$1.50 |
| 8 | \$1.20 |
| 6 | \$0.90 |
| 4 | \$0.60 |
| 2 | \$0.30 |

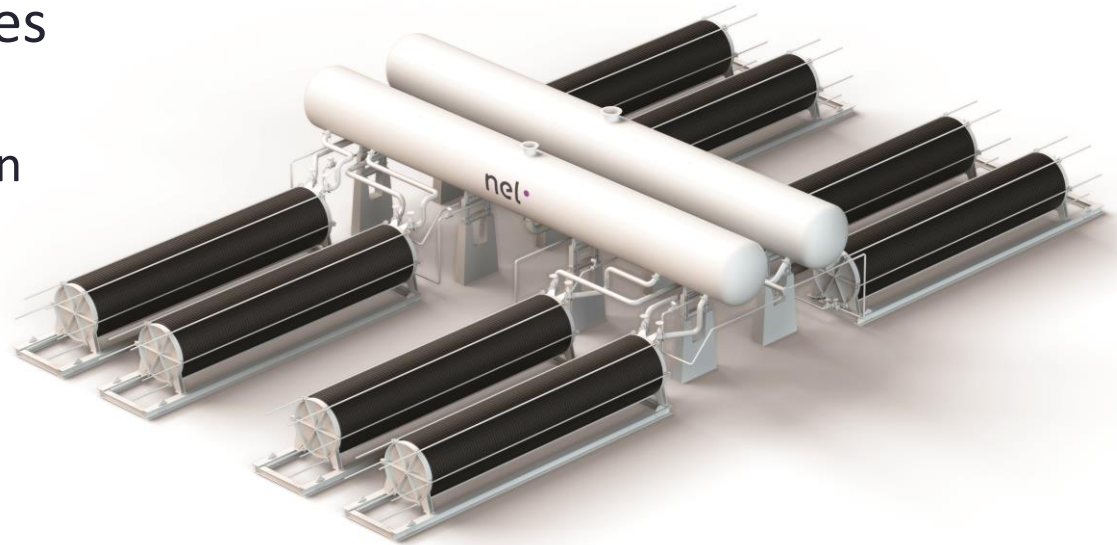
Large-scale delivered hydrogen price

Current cost of SMR hydrogen

NREL – Economic Assessment of Hydrogen Technologies Participating in CA Electricity Markets*



- Electrolyzers can:
 - Smooth renewable generation
 - Provide grid services
 - Operating reserves
 - Frequency regulation
 - Load following
 - Benefit from electricity price swings



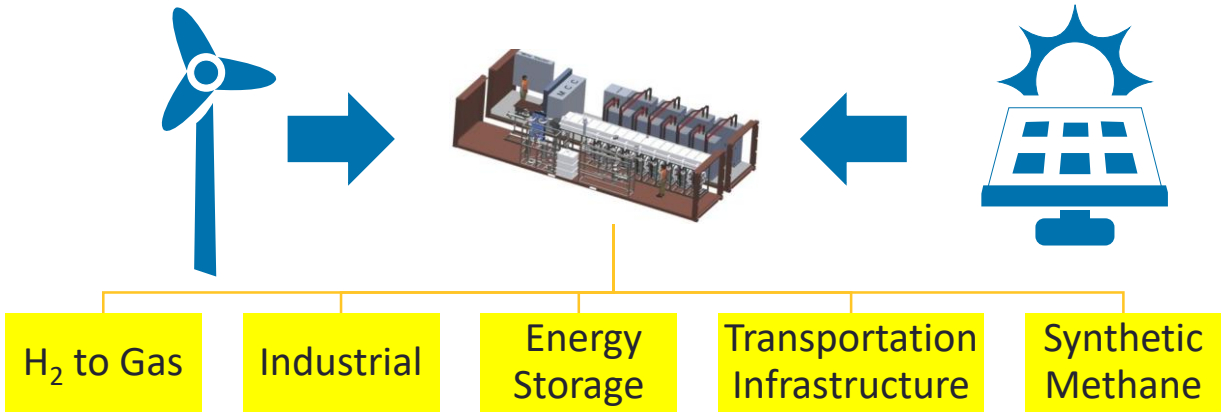
A3880, 18 MW electrolyzer

* NREL Contract #DE-AC3608GO28308

Grid scale electrolysis is ideally suited to optimize renewable power storage

Wind and solar production mismatch can cause up to **30%** of electricity to become stranded

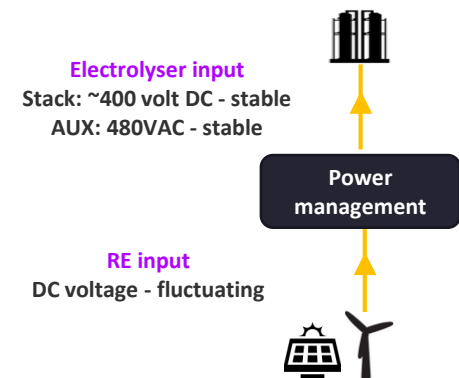
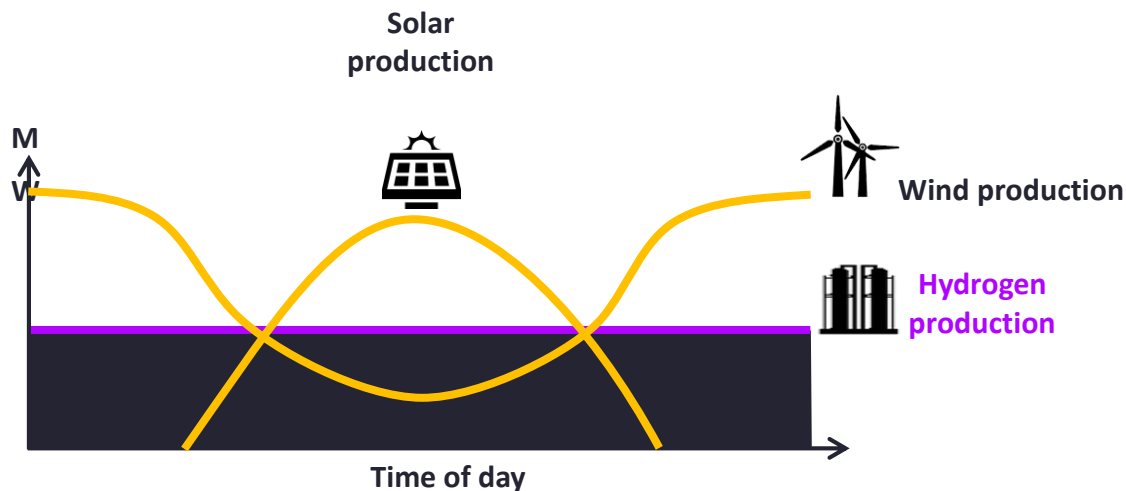
Value of this stranded renewable energy represents a TAM of over **\$12B⁽¹⁾**



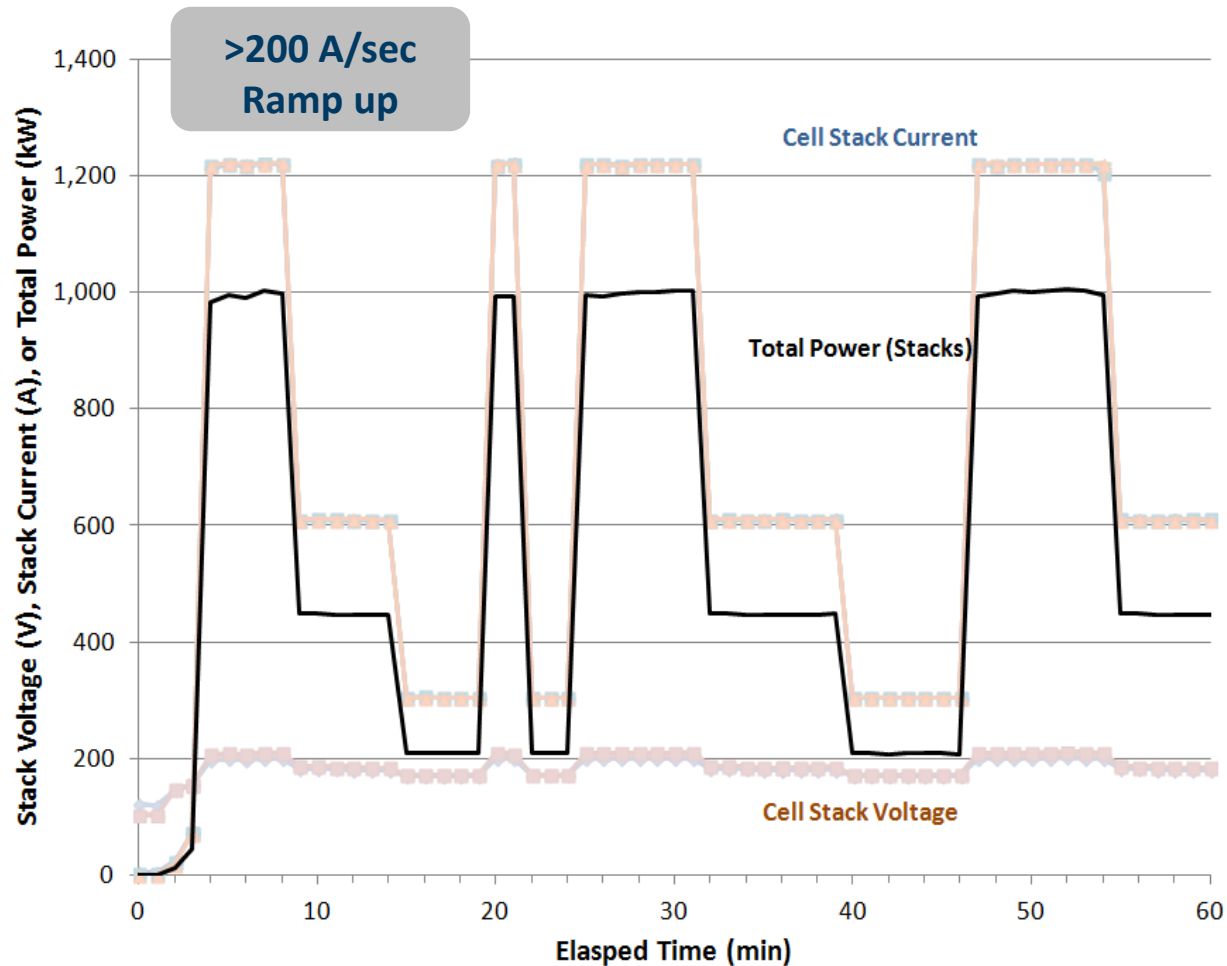
(1) Addressable market size based on management's internal estimates for Germany.

Combining solar and wind increases electrolyzer utilization

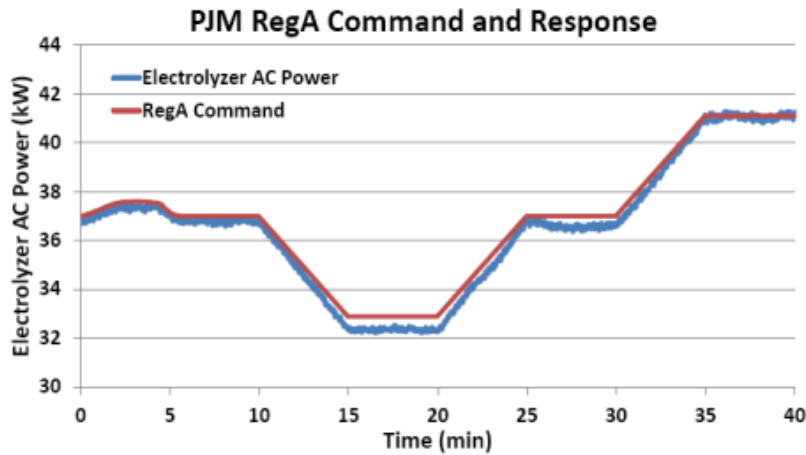
- Combining solar and wind can increase electrolyzer capacity factor – particularly for off-grid applications.
- Depending of site location – wind production typically happens during night and solar during day.
- Optimization of solar/wind and electrolyzer capacity may enable up to 65% electrolyzer utilization off-grid.
- Local power management will be required when operating off-grid – to ensure sufficiently stable power supply.



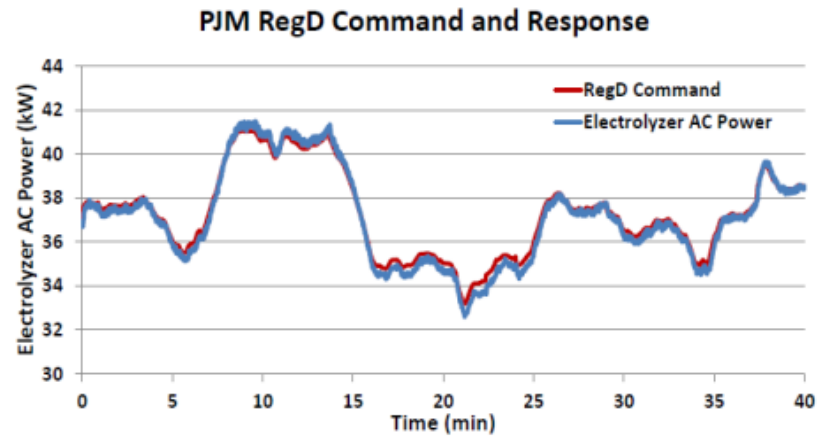
Fast ramping capability is well suited for renewable energy profiles



- Standard test methods available for ancillary services market
 - *Electrolysis meets regulation market tests*



Traditional Regulation Signal Test

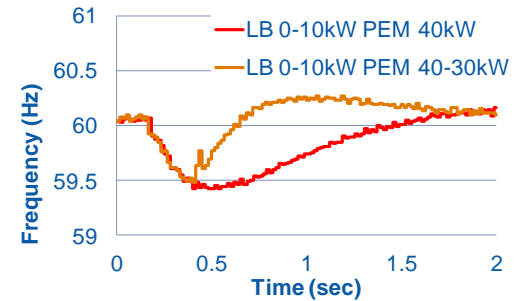
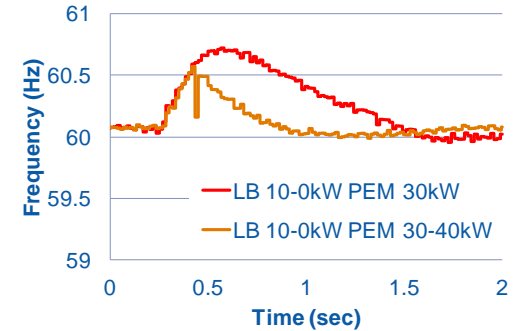
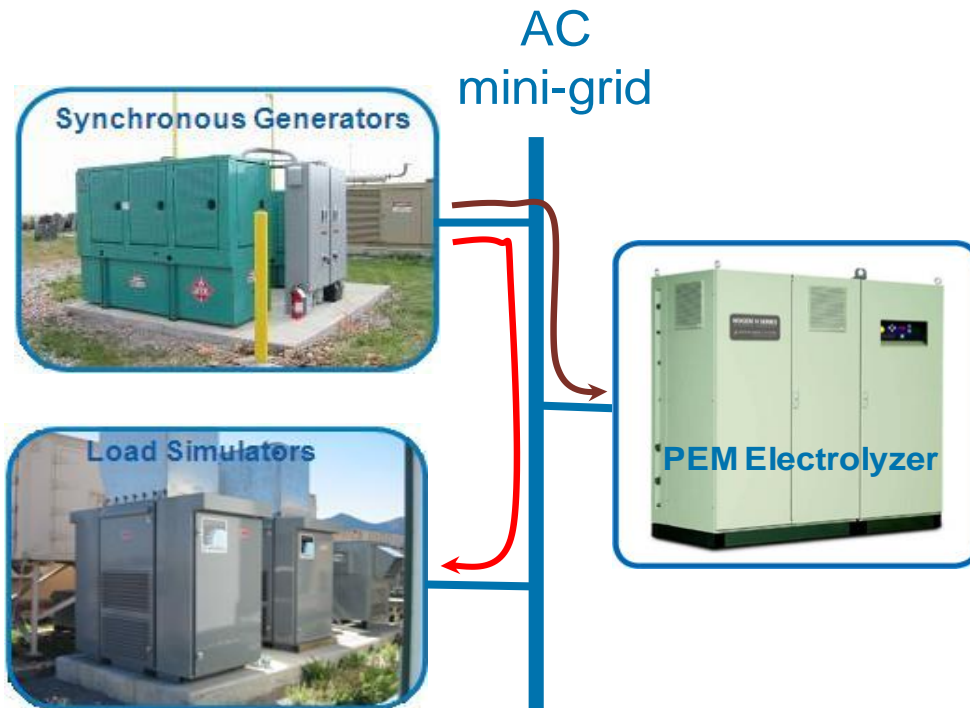


Dynamic Regulation Signal Test

Courtesy of K. Harrison, NREL

PEM electrolyzers for grid services:

NREL Wind-to-Hydrogen Project shows ability to provide both up and down regulation services in a simulated AC grid



Red line – Without PEM Load
Gold line – With PEM load

- PEM electrolyser triggered to provide frequency regulation (59.5 or 60.5Hz)
- Electrolyzer adds or sheds 10kW load to stabilize AC grid in milli-seconds
- Confirmed the ability of PEM electrolysis to increase grid stability

There is a precedent for large scale hydrogen production from renewable electrolysis....



Rjukan, Norway; 1927 – 1970's

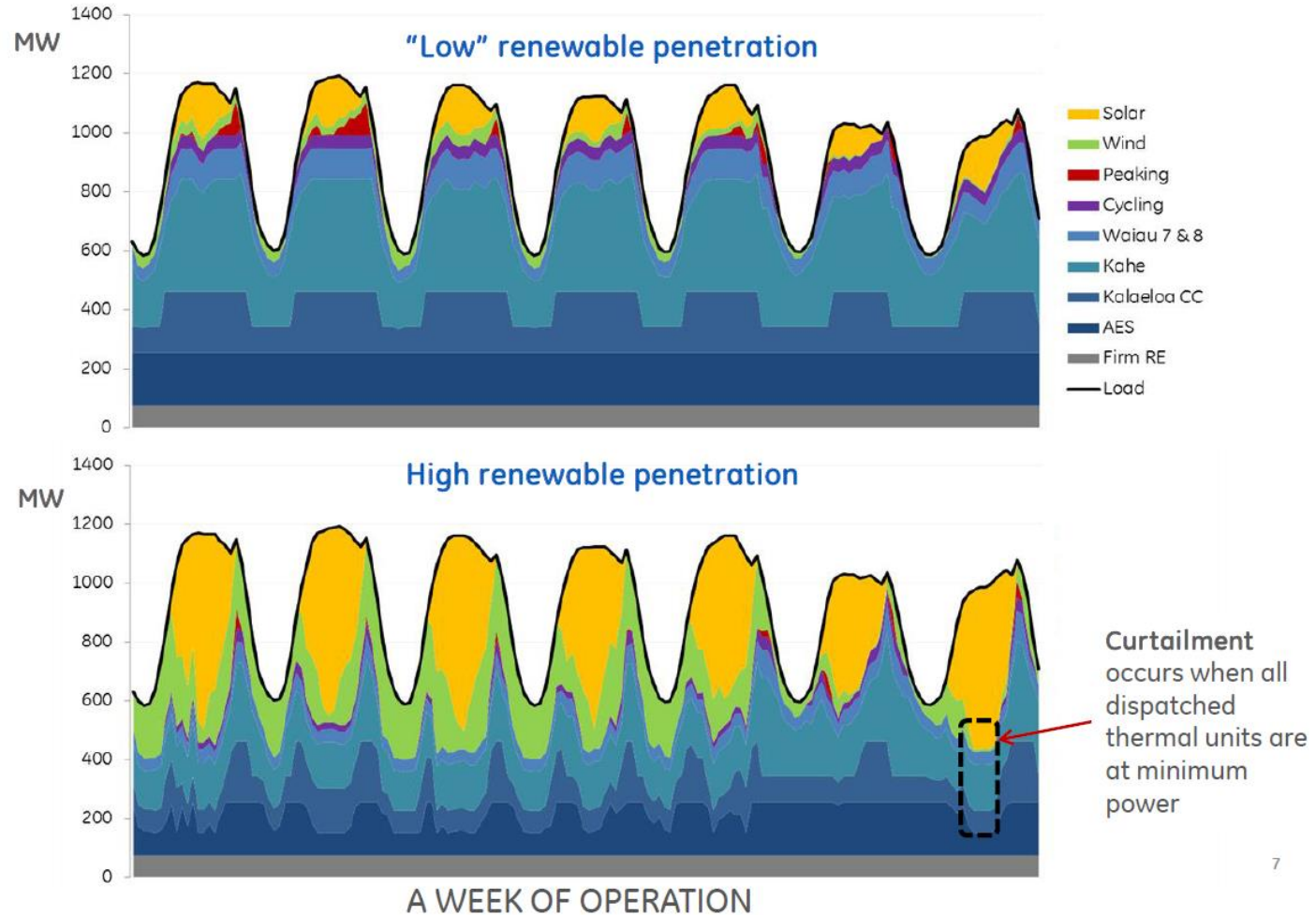


Glomfjord, Norway; 1953 – 1991

- Two largest electrolyser plants worldwide
- Capacity: 30 000 Nm³/h each
- Energy consumption: approximately 135 MW each
- Supplied by renewable hydro power

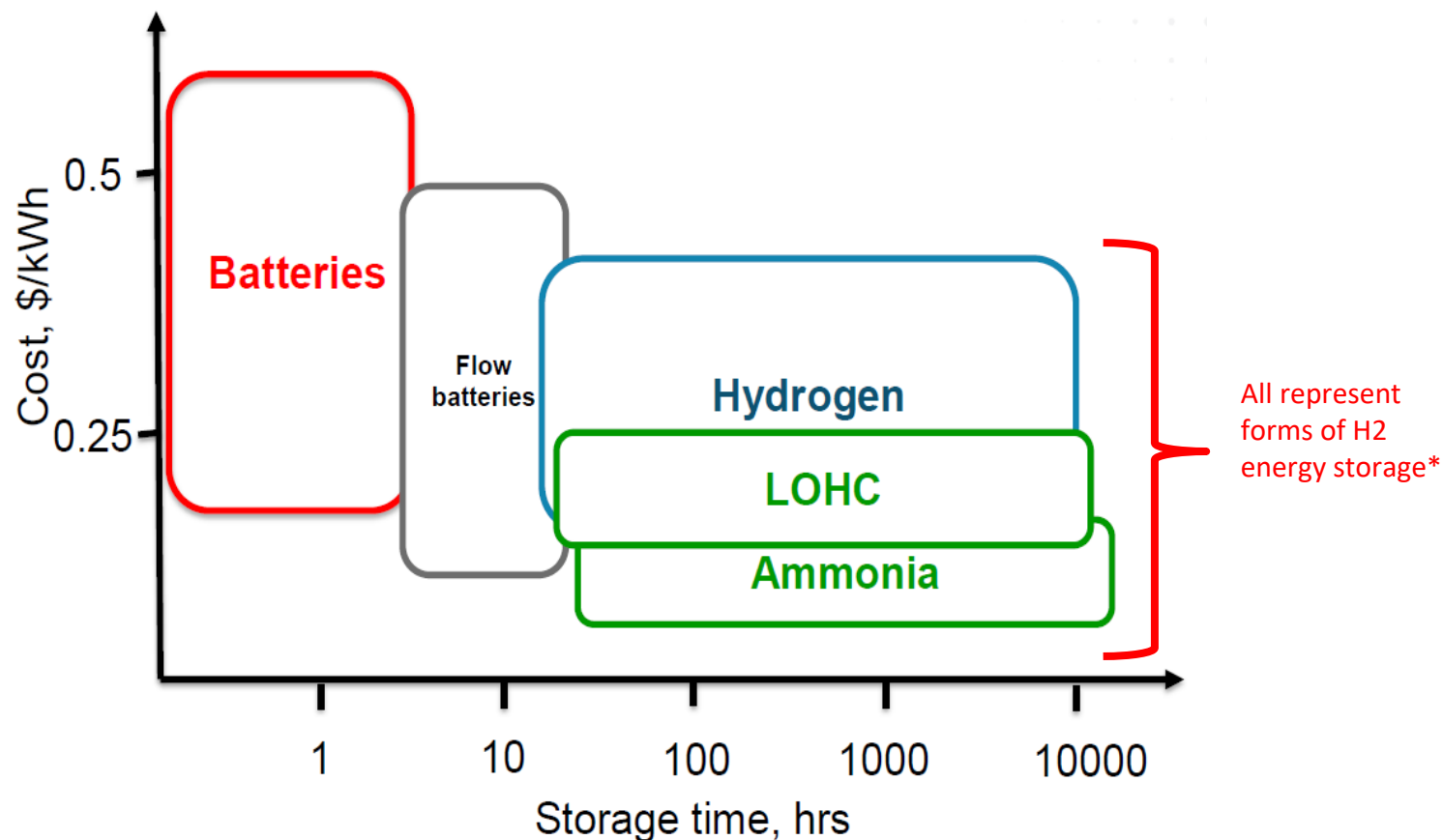
Hawaii needs energy storage on a massive scale to achieve their 100% RPS objective:

Dispatch to meet load and accept renewables



Source: HNEI, Hawaii RPS Study, May 2015

Hydrogen storage dominates long duration use cases that will enable the high penetration of renewables:

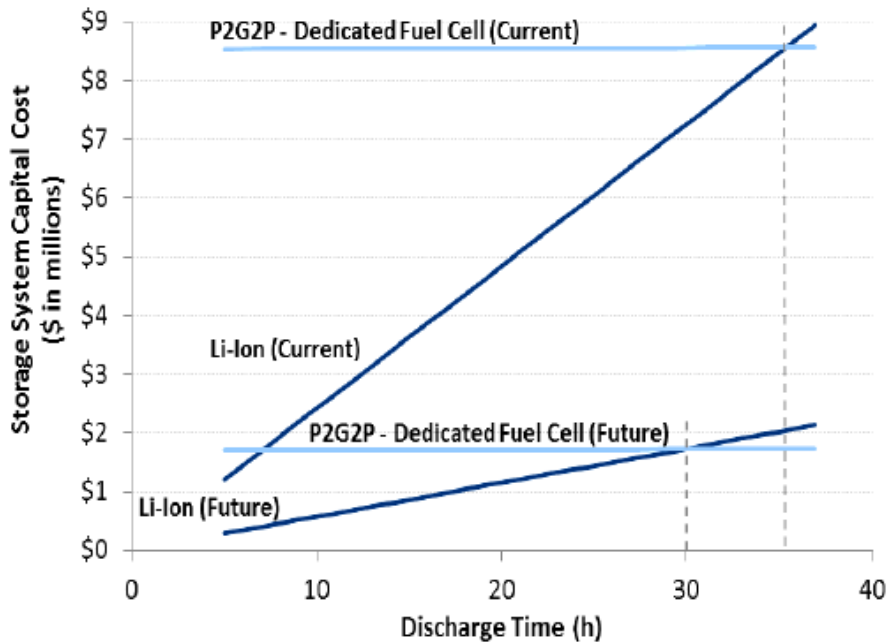


Source: Soloveichik, NH3 Fuel Conference 2016

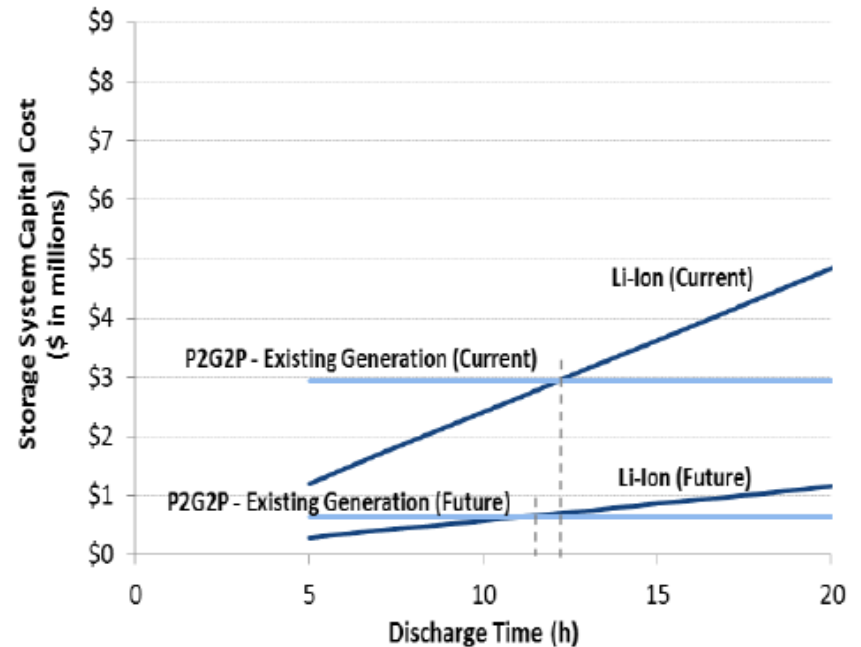
* LOHC (liquid organic hydrogen carrier) and ammonia are both produced with hydrogen as an input

Hydrogen energy storage (P2G2P) cost comparison to Li-Ion batteries

Case 1: Dedicated fuel cell for converting stored energy back to electricity.



Case 2: Hydrogen is transported via CNG distribution system and used in existing generation asset.



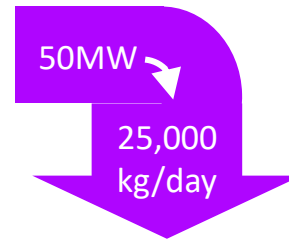
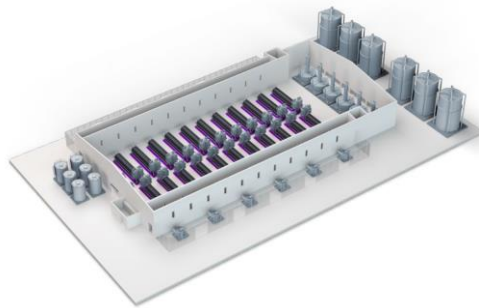
CHBC White Paper, [Power-to-Gas: The Case for Hydrogen](#)

Key Takeaway:

Even with a dedicated fuel cell for converting the stored energy back to electricity, P2G is cost effective at longer discharge times.

HDV's and buses can help provide scale to hydrogen

HDV's consume much more hydrogen than LDV's and fleet operation enables high fueling equipment utilization.



500/year



High fueling equipment utilization (fleet)

1,000/year



Low fueling equipment utilization (network)

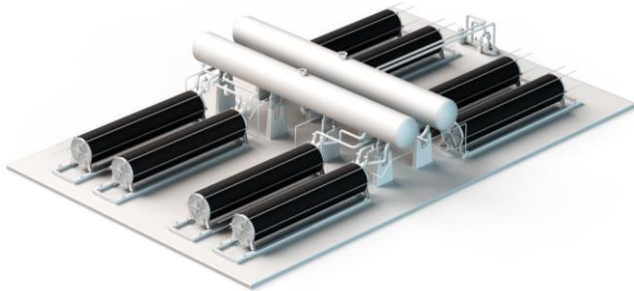
40,000/year



New alkaline system configurations can already address grid scale applications

NEL is developing a GIGA factory concept for REH2 production to achieve fossil cost parity

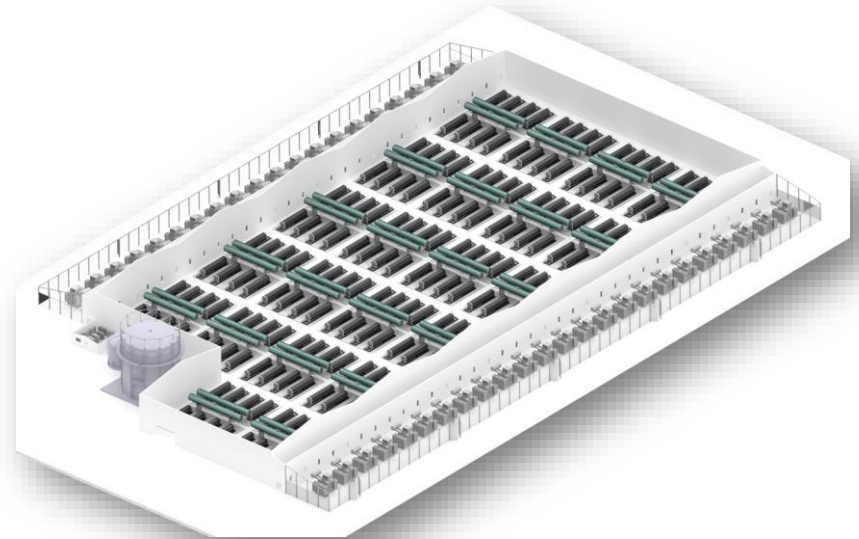
- New cluster concept where electrolyser stacks share balance of plant components
- 8 stack cluster (2.25 MW per stack) provides the basis for grid scale plants
- Target is to reach <\$500/kW and manufacturing scale to supply hundreds of MW
- Work in process with clients on large-scale plant concepts



8 cluster electrolyser

Sharing balance of plant

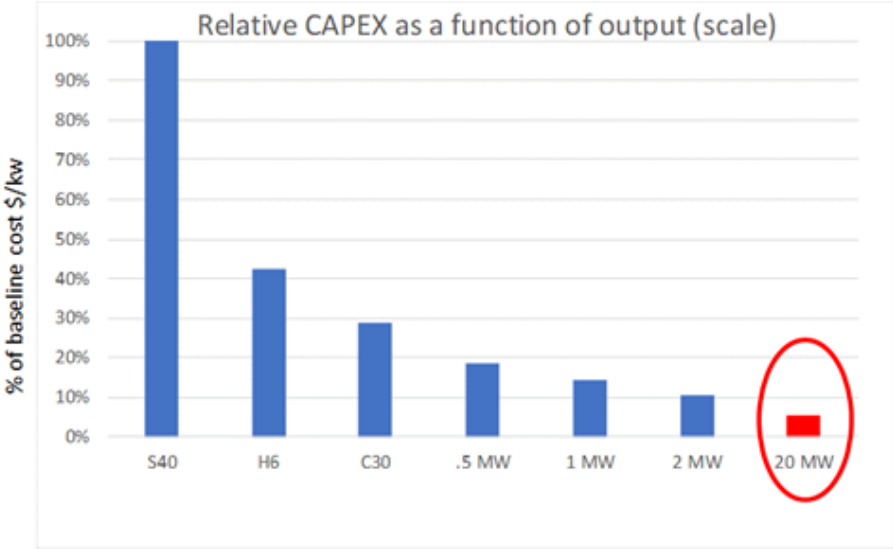
~ 18 MW



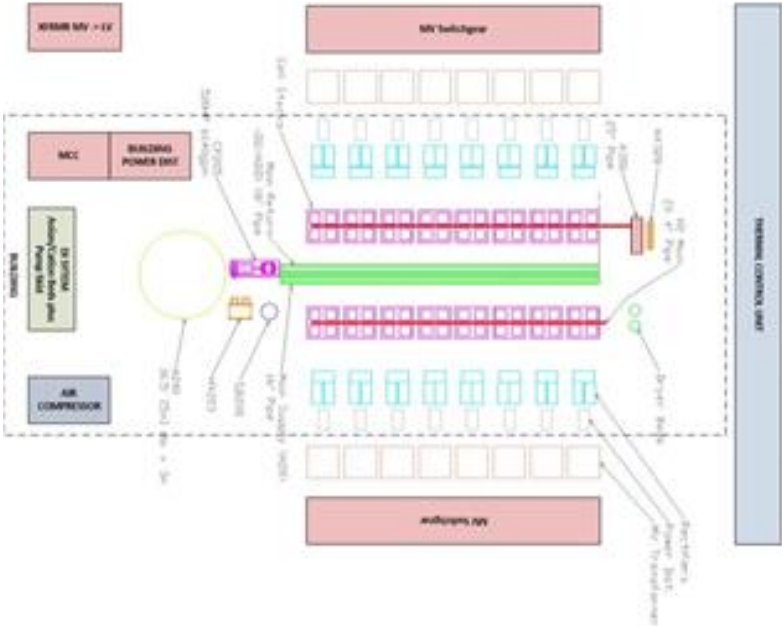
Multiple clusters for large scale plants

100's of MW to GW size

Similar cost reduction can be achieved for 20 MW PEM array: “M4000” platform



20 MW CAPEX is approximately half of 2 MW system on a \$/kW basis.



Nel’s M4000 PEM system layout in development.

Case Study: How volume can drive cost reduction



Nikola Motors supply agreement will enable automation, scale-up, and cost reduction



OVER 8,000 TRUCKS
ON ORDER
800 TRUCK ORDERS
FROM ANHEUSER-
BUSCH INBEV
TRUCKS ARE LEASED
ACCORDING TO
MILEAGE WITH ALL
FUEL INCLUDED



Source: Nikola



Nel's 8 ton/day (18 MW) electrolyzer plant provides the hydrogen production for each station site. New factory in Norway will enable 40% reduction in stack cost.

Mahalo!

www.nelhydrogen.com

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