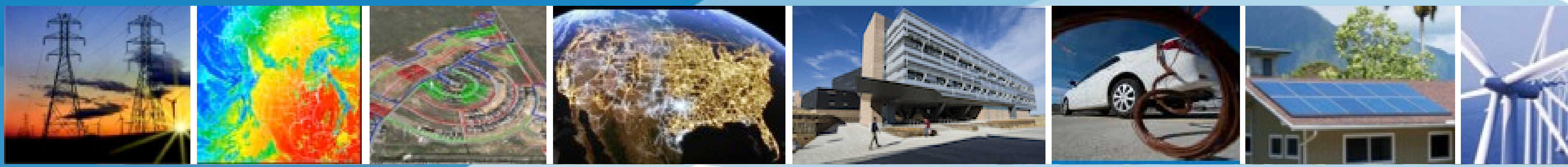
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Power Systems
Engineering Center



Seasonal Energy Storage

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https://www.nrel.gov/grid/

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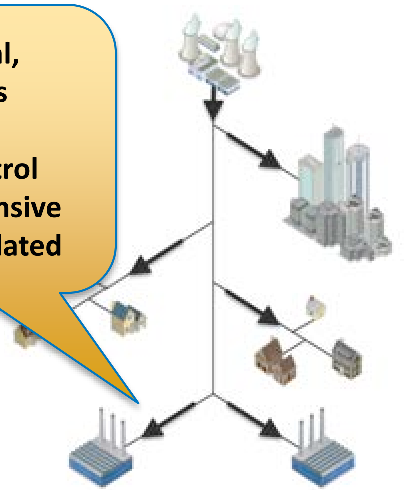
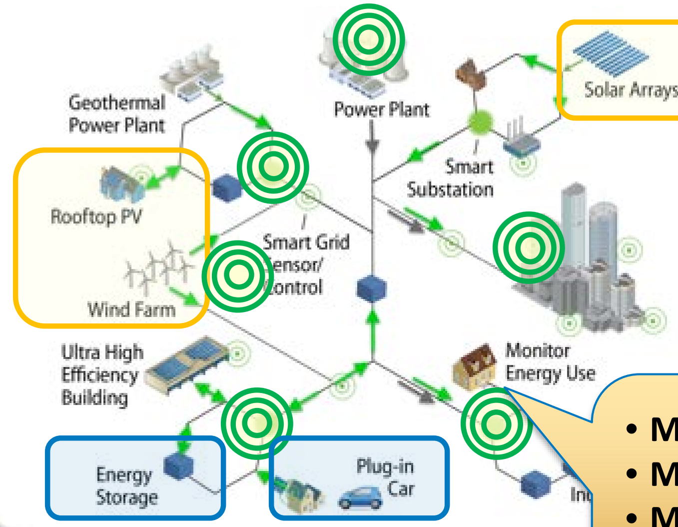
Evolution of the Power System

Current Power System



- Large Central, Synchronous Generation
- Central Control
- Carbon Intensive
- Highly Regulated

Future Power Systems

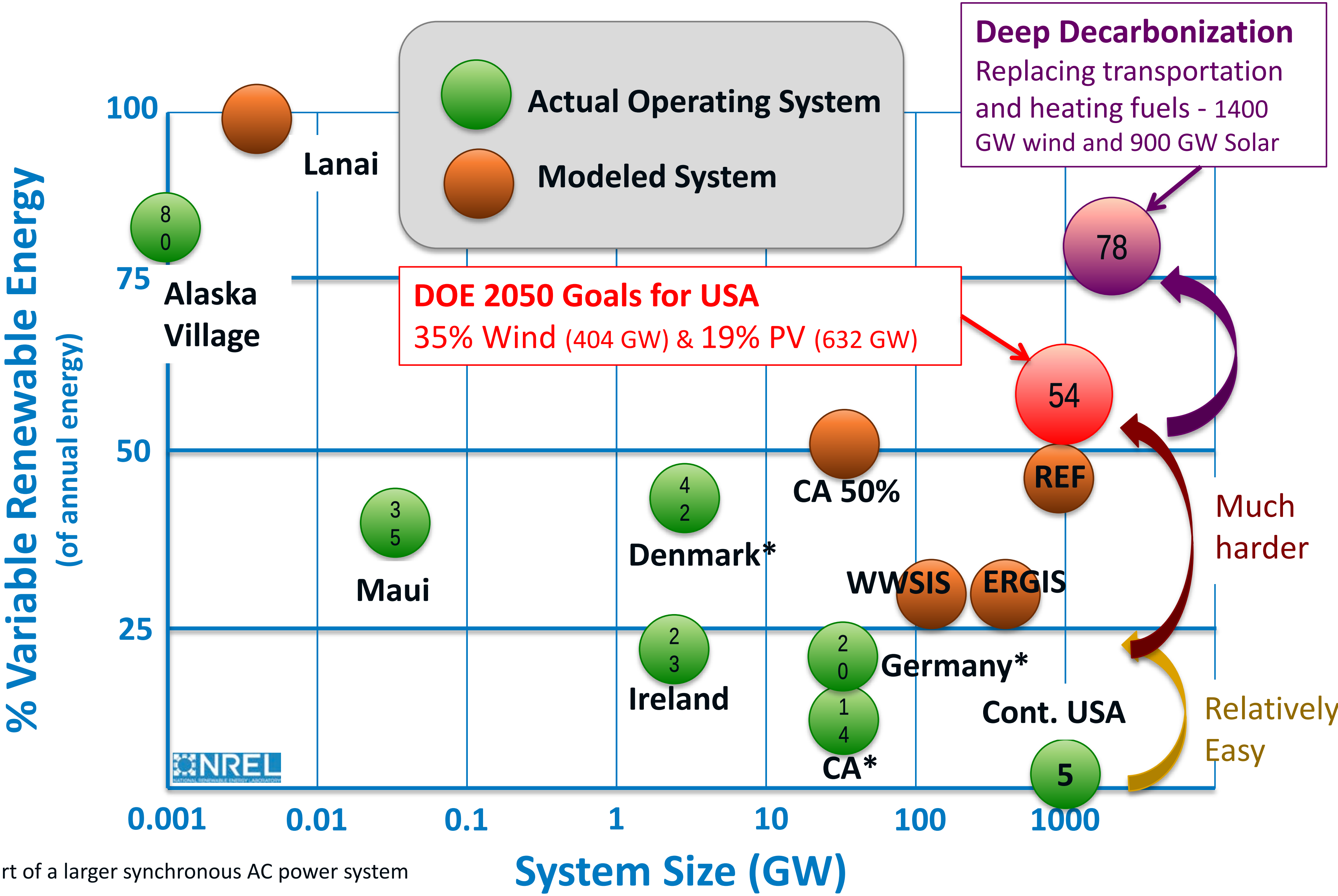


- More VRE
- More Info
- More Distributed
- Less Carbon

New Challenges in a Modern Grid

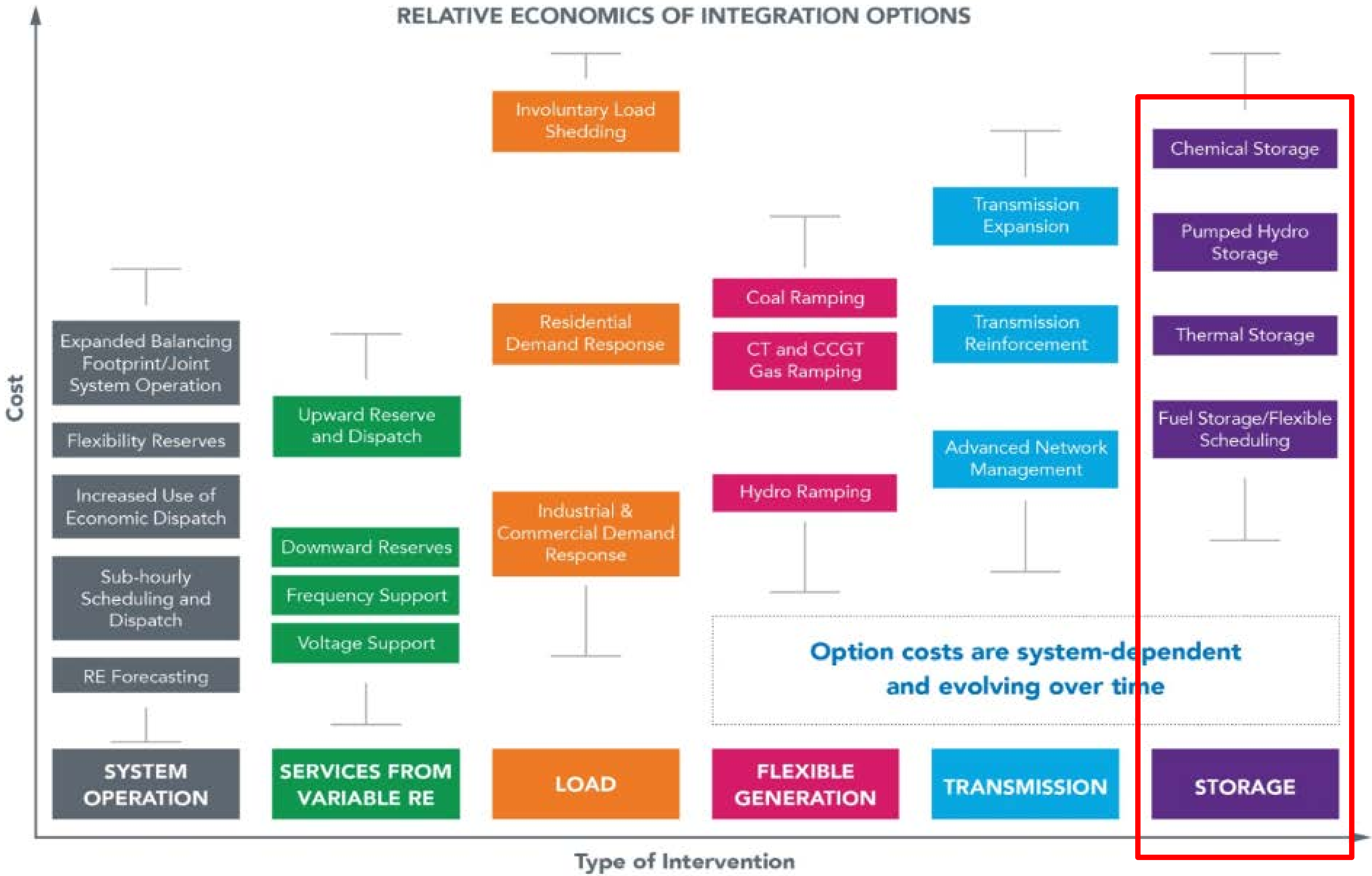
- Increasing levels of power electronics based variable renewable energy (VRE) – wind and solar
- More use of Communications, Controls, Data, and Information (e.g. Smart Grids)
- Other new technologies: EVs, Distributed storage, Flexible Loads
- Becoming highly distributed – more complex to control

How much storage do we need ?



* Part of a larger synchronous AC power system

Grid Flexibility Options

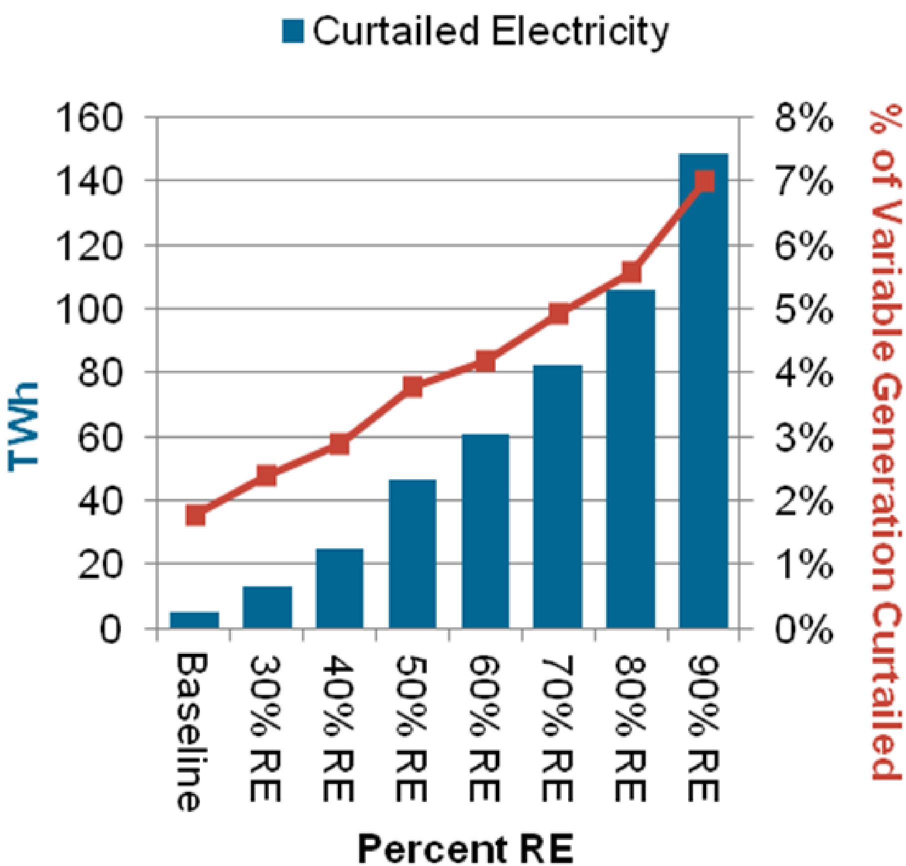


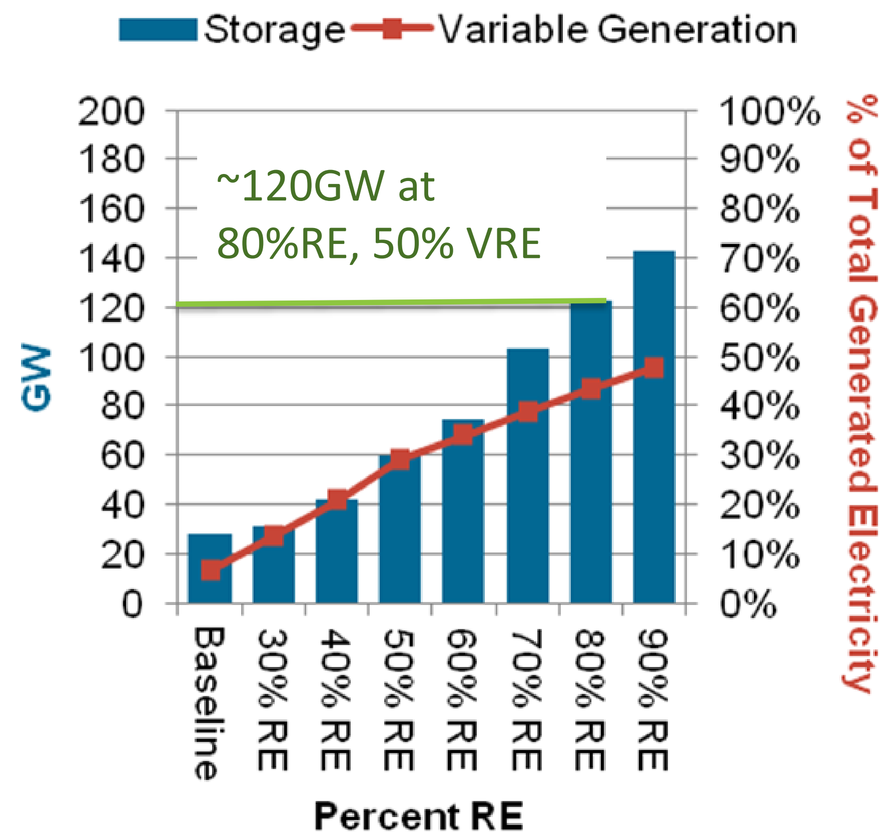
"Grid Integration and the Carrying Capacity of the U.S. Grid to Incorporate Variable Renewable Energy", J. Cochran, P. Denholm, B. Speer, and M. Miller, NREL/TP-6A20-62607 April 2015, http://www.nrel.gov/docs/fy15osti/62607.pdf

VRE Curtailment and Energy Storage – Renewable Electricity Futures

http://www.nrel.gov/analysis/re_futures/

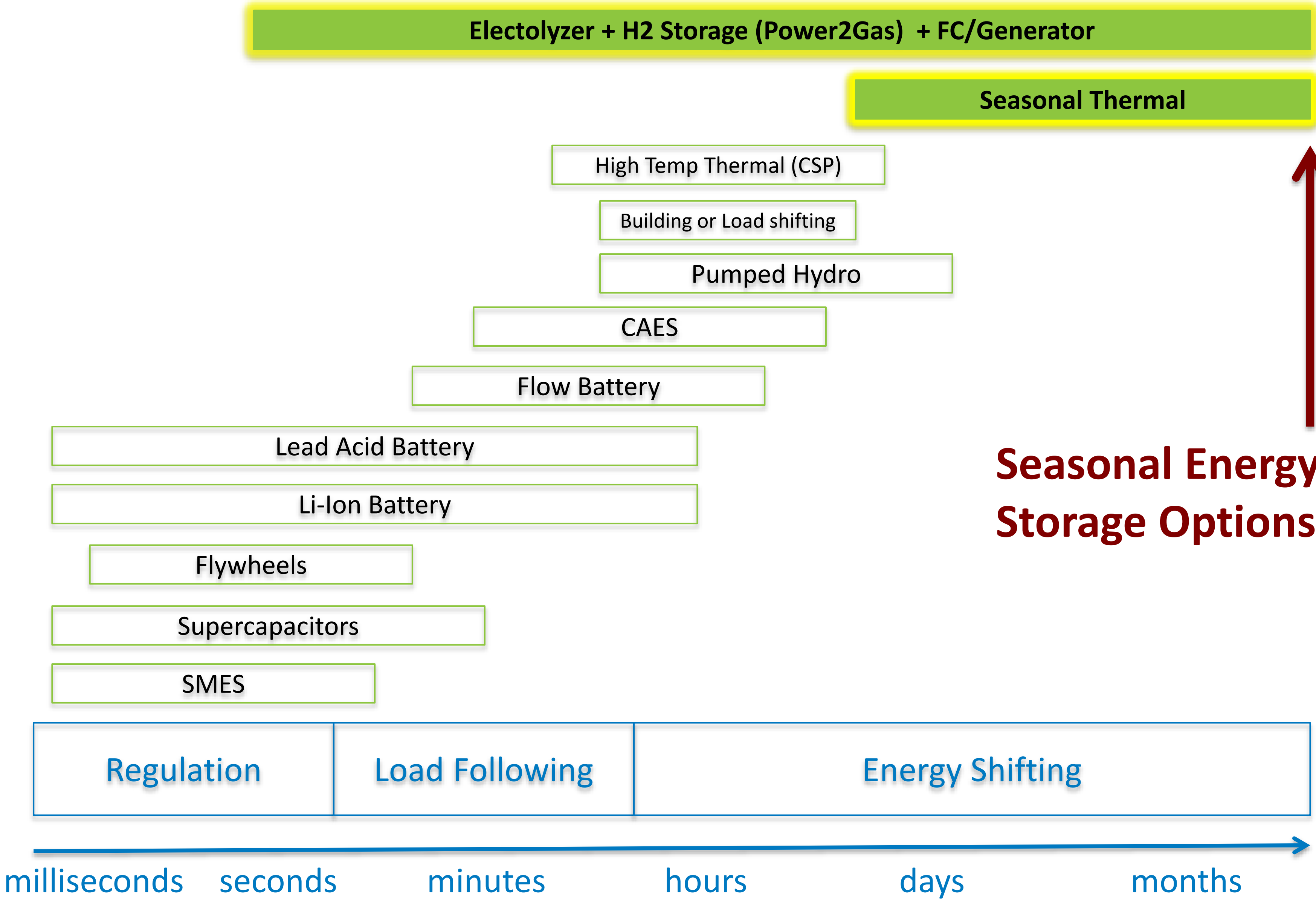
(assumed 8 hours of storage for PSH plants and 15 hours of storage for CAES plants.)



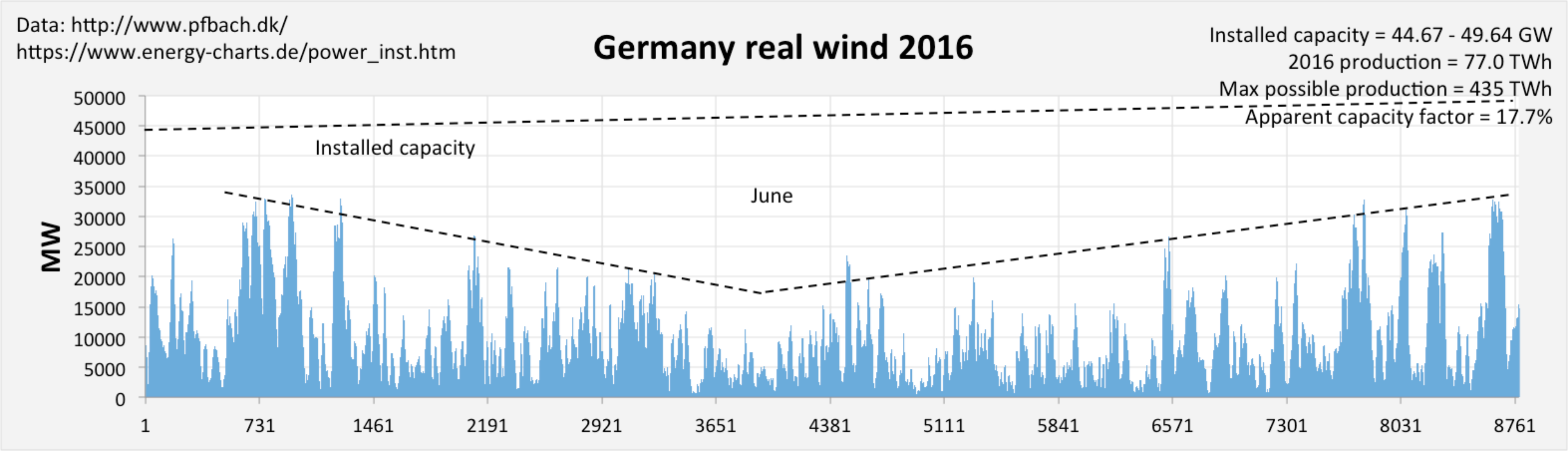


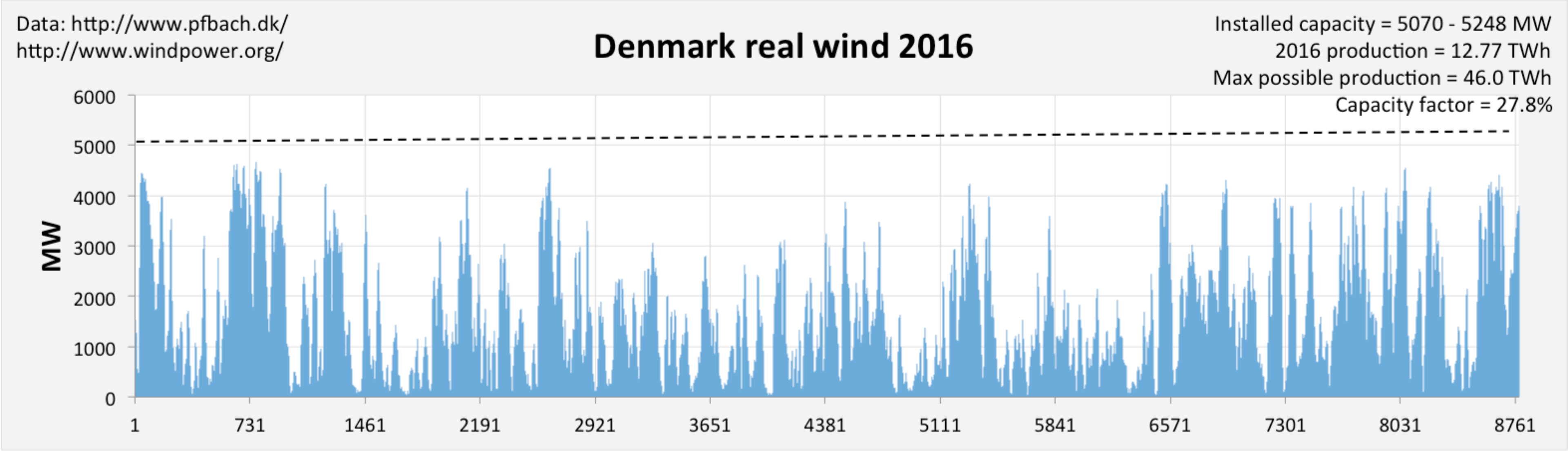
By 2050, storage capacity was estimated at 28 GW in the Low-Demand Baseline scenario, 31 GW in the 30% RE scenario, 74 GW in the 60% RE scenario, **and 142 GW in the 90% RE scenario.** Currently there is 21GW of pumped hydro in US.

Energy Storage – Technologies and Timescales

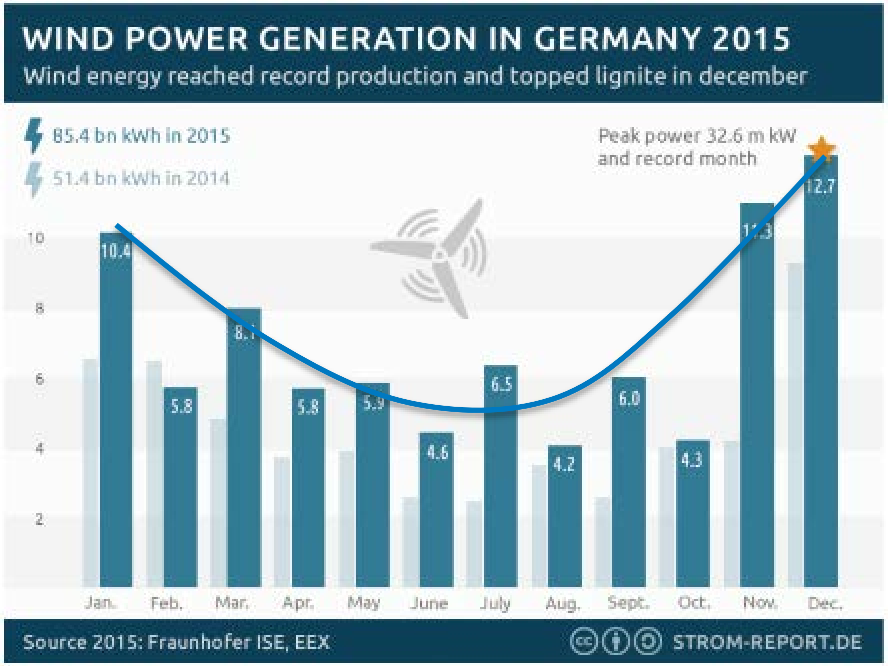


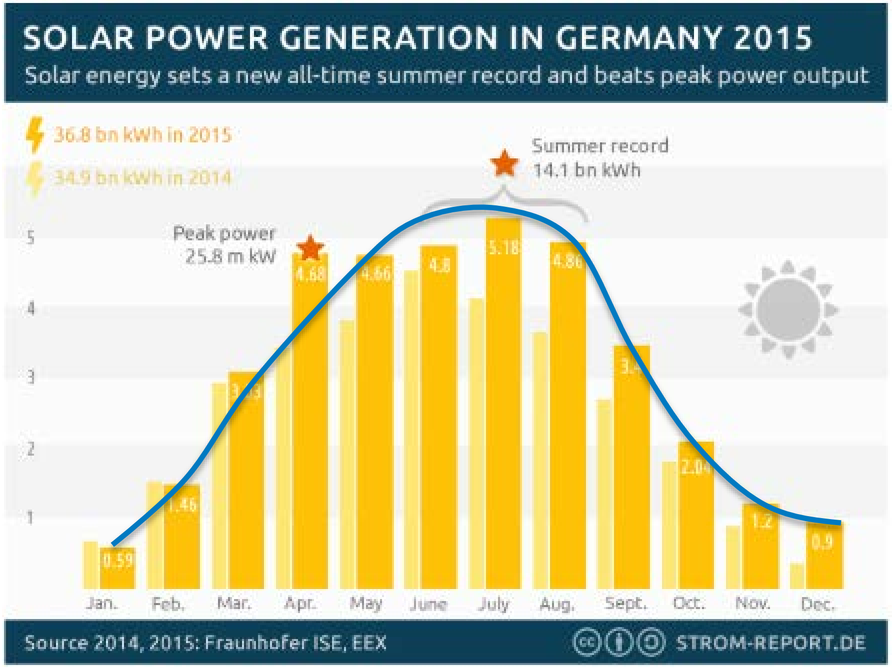
Understanding Resource Seasonality - Wind



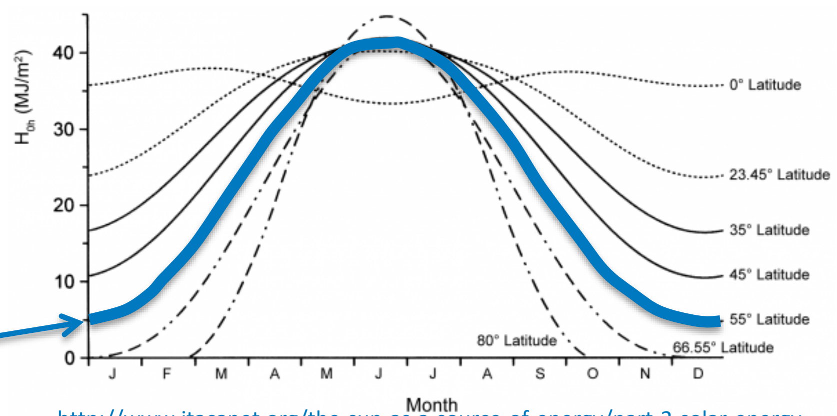


Understanding Resource Seasonality - Solar





Total daily amount of extraterrestrial irradiation on a plane horizontal to the Earth's surface for different latitudes (55deg Latitude highlighted in Blue)



http://www.itacanet.org/the-sun-as-a-source-of-energy/part-2-solar-energy-reaching-the-earths-surface/

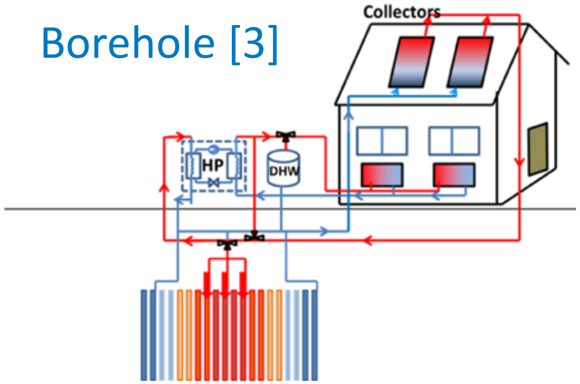
Seasonal Thermal Storage

Thermal Energy Storage Options

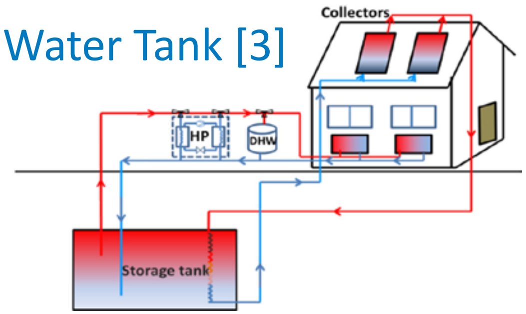
- Sensible Storage
  - Rocks beds (Thermal Blocks)
  - **Water (Aquifers, Tanks)**
  - **Ground (Borehole)**
  - storage efficiencies between 50-90%
- Latent Heat Storage
  - Phase Change Materials (PCM) (i.e. Paraffin)
  - storage efficiencies from 75-90%
- Thermo-chemical storage (TCS) using chemical reactions to store and release thermal energy
  - efficiencies from 75% to nearly 100%
- PCSM and TCS are general much more expensive, are economically viable only for applications with a higher number of cycles

References [3][4]

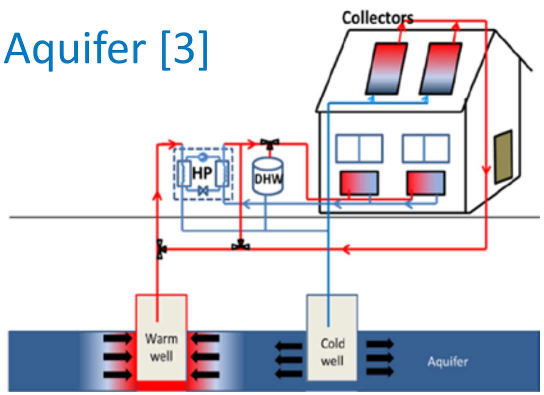
Borehole [3]



Hot Water Tank [3]



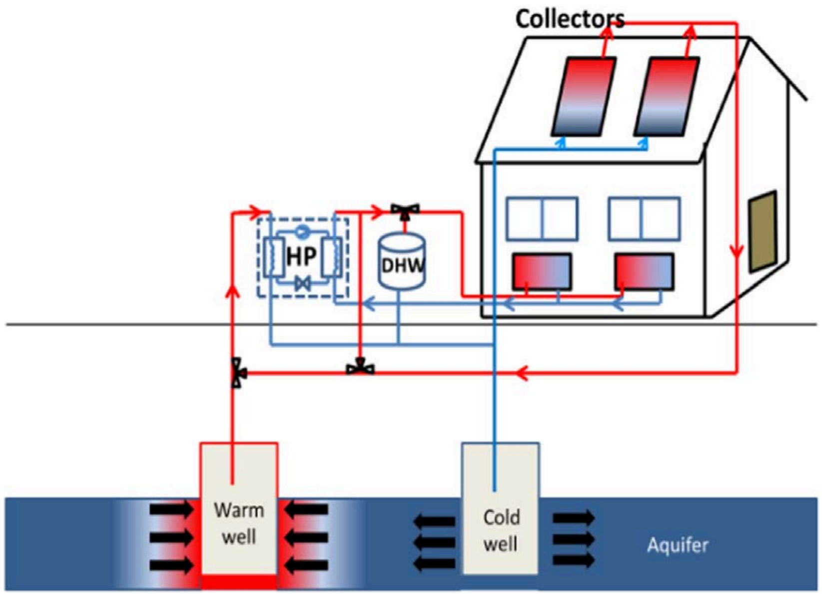
Aquifer [3]



Aquifer Thermal Energy Storage (ATES)

Aquifer Storage

- Typically cooling applications do better
- Ground is usually only 0-10deg different than cooling application whereas heating is 40-80deg different
- Some scaling and mineralization problems with hot storage which are less prevalent in cold storage
- Less universally applicable than borehole



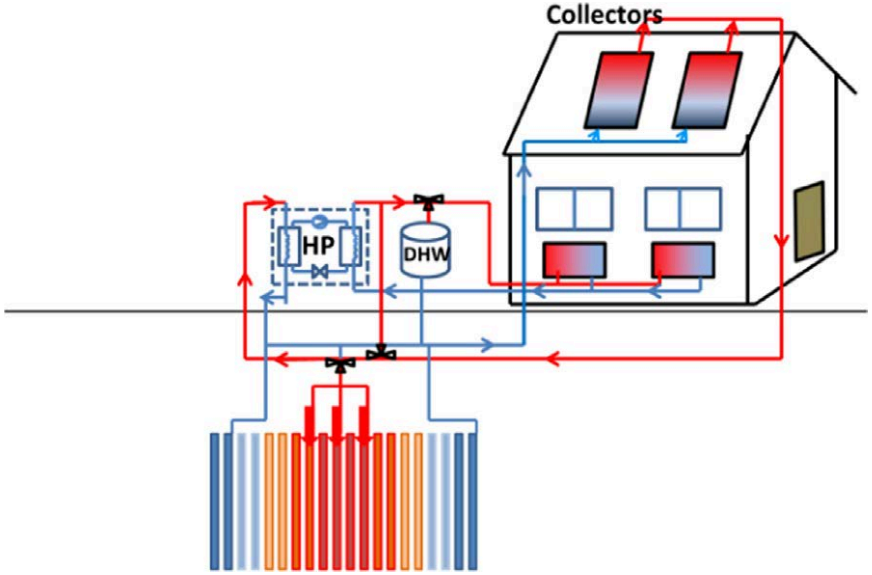
Aquifer [3]

References [3][5]

Borehole Thermal Energy Storage (BTES)

Borehole Storage

- An improvement on conventional closed-loop ground source heat pump (GSHP) geothermal systems
- The ground heat exchanger array for a BTES system is designed and operated in a manner such heat is stored seasonally, whereas conventional GSHP systems are designed to simply dissipate heat or cold into the subsurface.
- BTES essentially uses the Earth as a thermal battery, as opposed to a radiator.
- The capital cost of a large BTES system can be significant, as a large number of geothermal boreholes will need to be drilled, compared to just a few thermal wells for an ATES system.



Borehole [3]

http://www.underground-energy.com/BTES.html

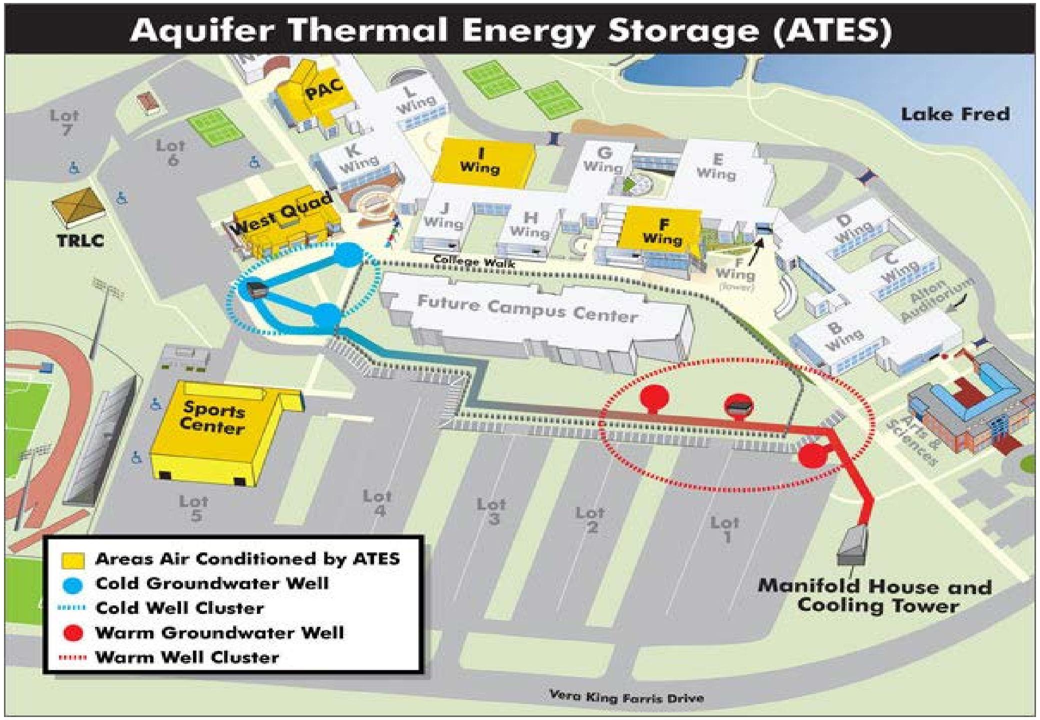
Seasonal Thermal Energy Storage in the US

Thermal Energy Storage Project in the Netherlands in 2010

Thermal Energy Storage Projects in US in 2015

Seasonal Thermal Energy Storage in the US

- **Richard Stockton College – New Jersey, USA**
  - Installed in 2008
  - Aquifer Thermal Energy Storage
  - 6 wells, Aquifer (100-200ft depth)
  - Used for cooling – 800 ton thermal capacity

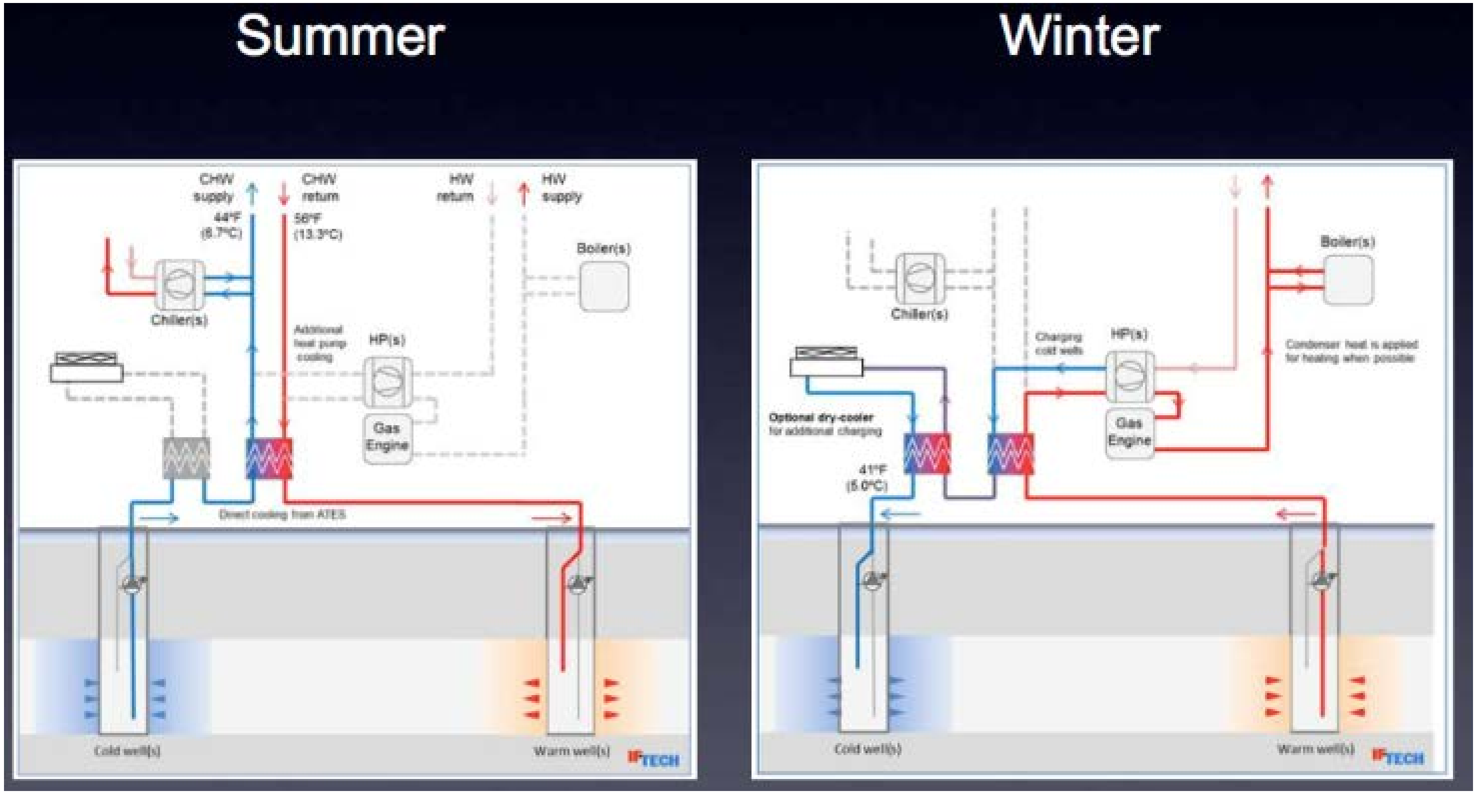


http://intraweb.stockton.edu/eyos/page.cfm?siteID=82&pageID=40

http://www.underground-energy.com/Aquifer_Thermal_Energy_Cold_Storage_System_at_Richard_Stockton_College.pdf

Seasonal Thermal Energy Storage in the US

- **Veteran Administration Hospitals – Chillicothe and Columbus, OH**



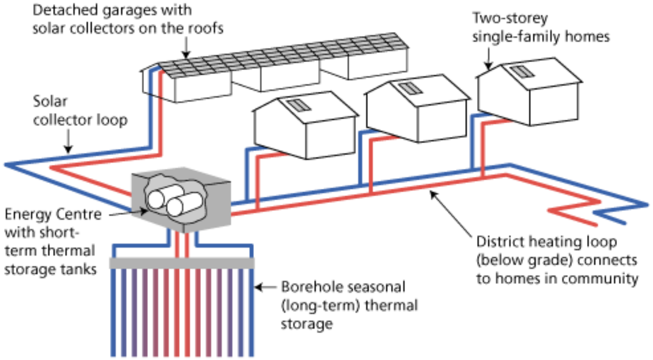
"In Depth Feasibility Studies Aquifer Thermla Energy Storage (ATES) VA Hospitals in Columbus and Chillicothe, OH", M. Worthington and M. Spur, June 2015, http://www.districtenergy.org/assets/pdfs/2015-Annual-Boston/Proceedings/Tuesday/4C.1Worthington-Spurr.pdf

Seasonal Thermal Energy Storage Example – Drake Landing, Canada

Drake Landing Solar Community, Alberta, Canada

- 52 homes with 800 solar collectors on garage roofs
- Glycol solution is heated, then heat is transferred to water for short term storage
- Heat is then stored for long term periods using BTES (144 6-inch boreholes)
- 10th year of reliable operation with no unscheduled interruptions in heating delivery operations
- 100% solar fraction in the 2015-2016 heating season, meaning all the heat required by the houses for space heating was supplied by solar energy
- Consistent solar fractions above 90% over the last 5 years, with an average of 96% for the period 2012-2016

https://www.dlsc.ca

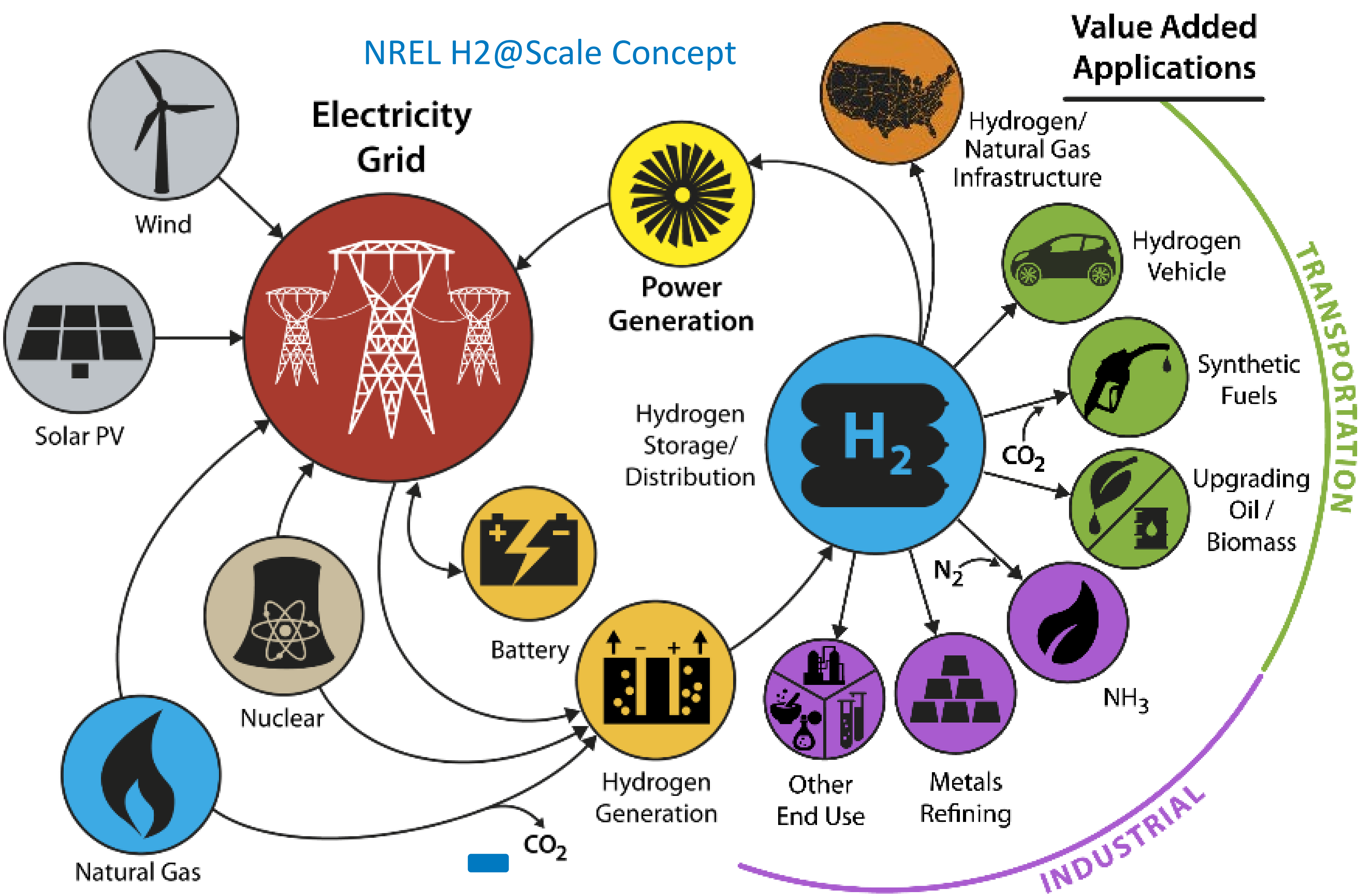


Seasonal Thermal Energy Storage Example – Munich, Germany

Construction of the seasonal heat storage in Munich, 5700 m³, 2007

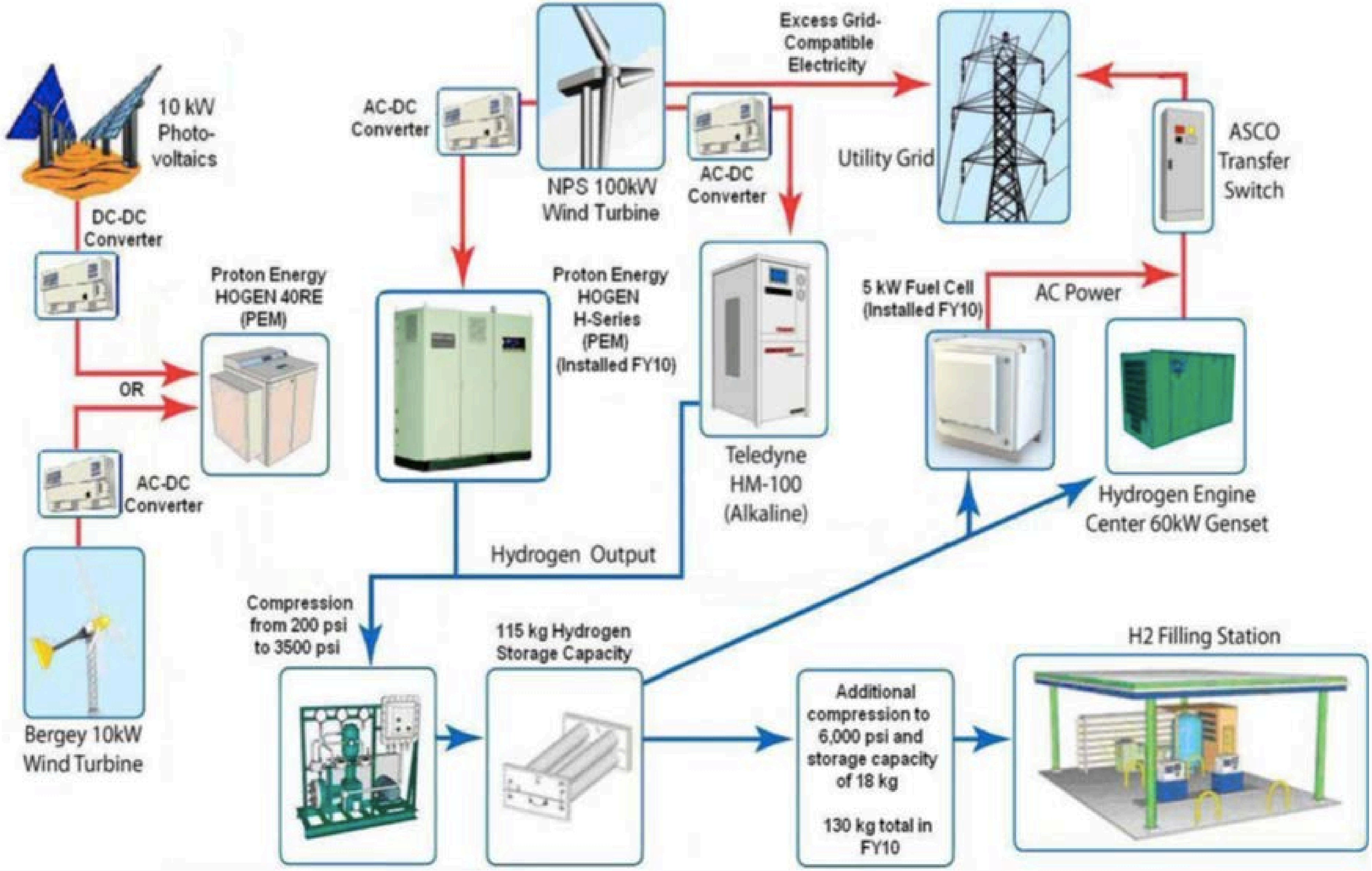
Hydrogen

H2@Scale – Connecting Electricity and Hydrogen



http://www.nrel.gov/docs/fy16osti/66246.pdf

NREL Wind and Solar to H2 Experiments

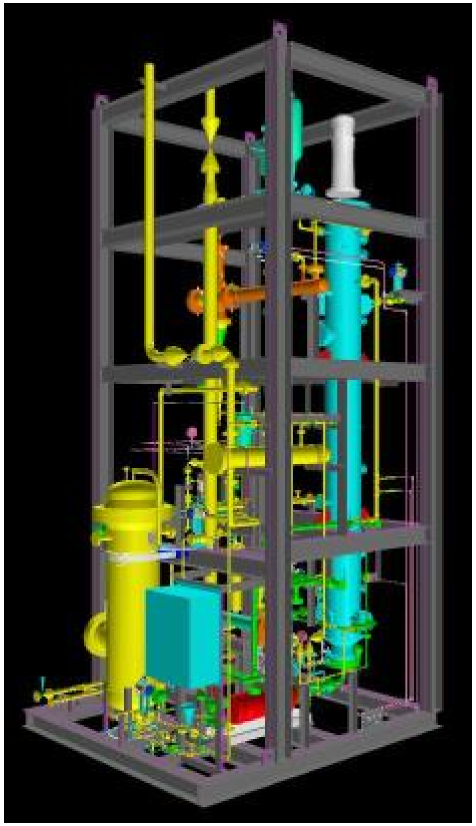


Southern California Gas

SoCalGas
A Sempra Energy utility

Power-to-Gas (H_2, CH_4): Taking the next step towards GW-scale energy conversion via Hydrogen with multiple end-uses

Archaea converts up to 5 kg/h H_2 into 4 – 8 scfm of CH_4



Novel Bioreactor to convert H_2 + CO_2 > CH_4

Impact Expand operational testing and measurement of mass and energy balances, efficiencies to compare economics and show the potential of P2G systems to enable high levels of renewable energy penetration.

Goals End-to-End system-level optimization to enable high levels of PV-to-H2-to-NG for energy storage and demonstrate first bioreactor in the USA

Project Description Expanded operations to inform modeling and economic modeling to; (1) suggest optimal P2G site selection within the WECC, (2) develop tariffs that could be adopted to advance P2G services and (3) inform public policy and energy leaders about the features and benefits of P2G

This work at NREL will lay the foundation for commercial P2G (10 – 100 MW) pilot demonstrations

https://www.nrel.gov/esif/partnerships-southern-california-gas.html

NREL Power Systems Engineering Center
https://www.nrel.gov/grid/

NREL … Providing Solutions to Grid Integration Challenges

Thank You!

www.nrel.gov

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Additional References

1. “Grid Integration and the Carrying Capacity of the U.S. Grid to Incorporate Variable Renewable Energy”, J. Cochran, P. Denholm, B. Speer, and M. Miller, NREL/TP-6A20-62607 April 2015, http://www.nrel.gov/docs/fy15osti/62607.pdf
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5. “State of the Art Review of Aquifer Thermal Energy Storage Systems for Heating and Cooling Buildings”, H. Paksoy et al.
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