Hydrogen Storage: Drivers and Near-Term Solutions

Presented by:

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80-year History of Turning Raw Technology into Practical Energy Solutions

FOR A BETTER ECONOMY AND A BETTER ENVIRONMENT

SUPPLY ▶ CONVERSION ▶ DELIVERY ▶ UTILIZATION

RESEARCH & DEVELOPMENT

PROGRAM MANAGEMENT

TECHNICAL/ ANALYTICAL

CONSULTING

TRAINING

COMMERCIALIZATION

400+ EMPLOYEES

World-class piloting facilities headquartered in Chicago area

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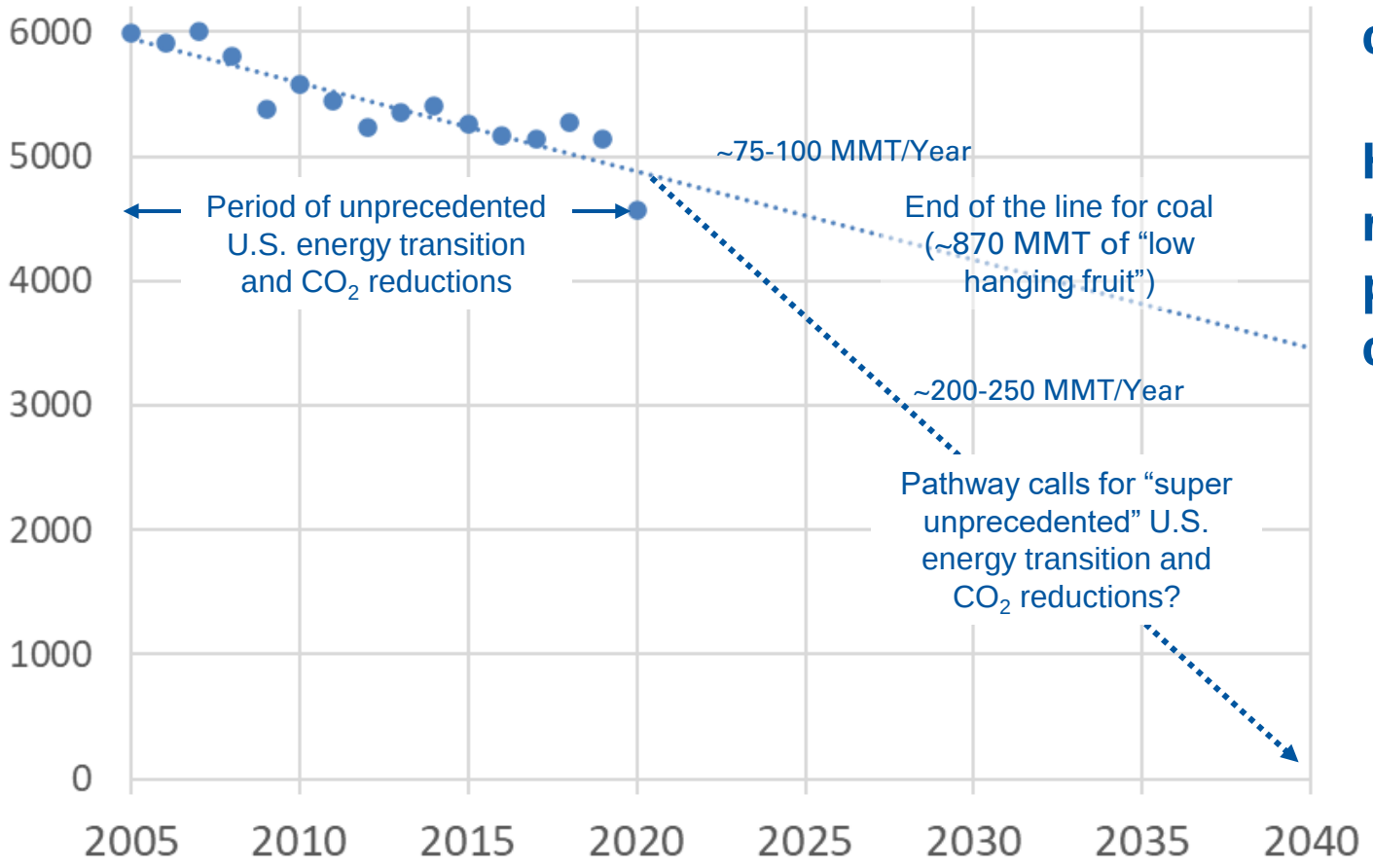
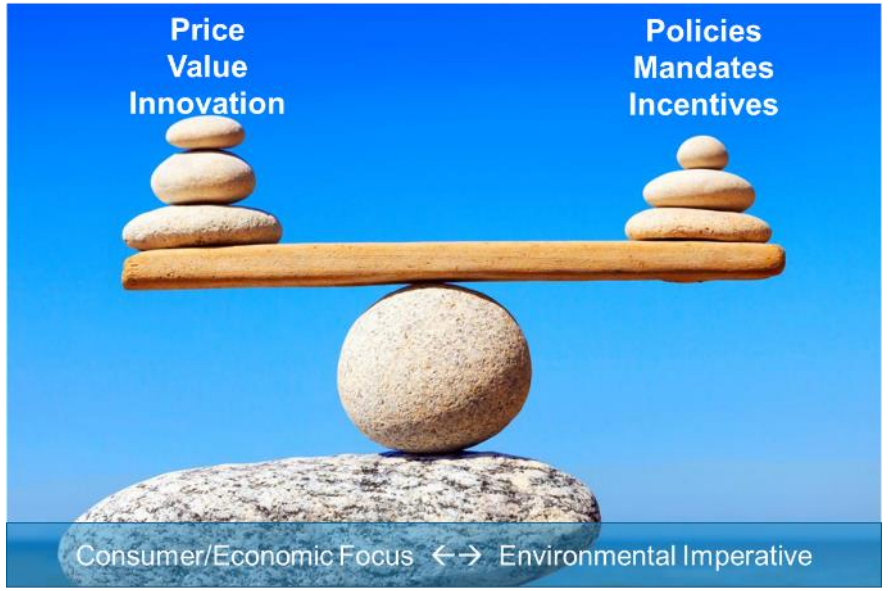
U.S. CO_2 Emissions (MMT/Year)



Most CO_2 emission reductions since 2005 due to shale gas cost-effectively displacing coal (and with minimal consumer energy cost impacts).

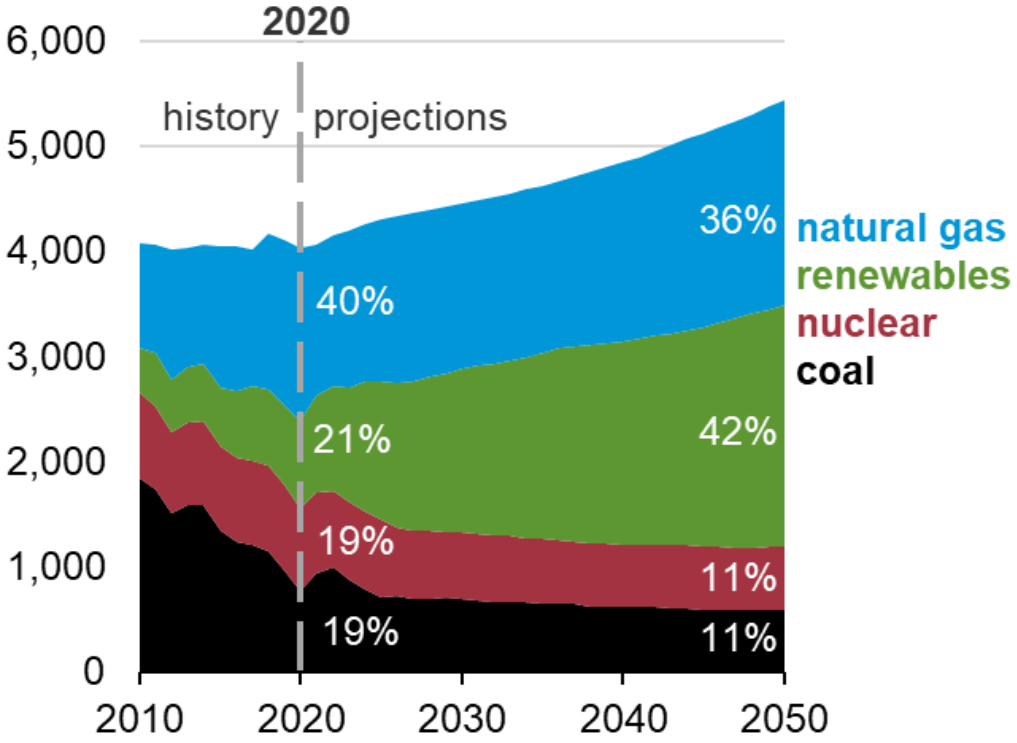
How do we achieve even greater rates of reduction after "low hanging fruit" is picked? What are the consumer energy cost and energy system implications?



Power Generation Market
Passing The Baton

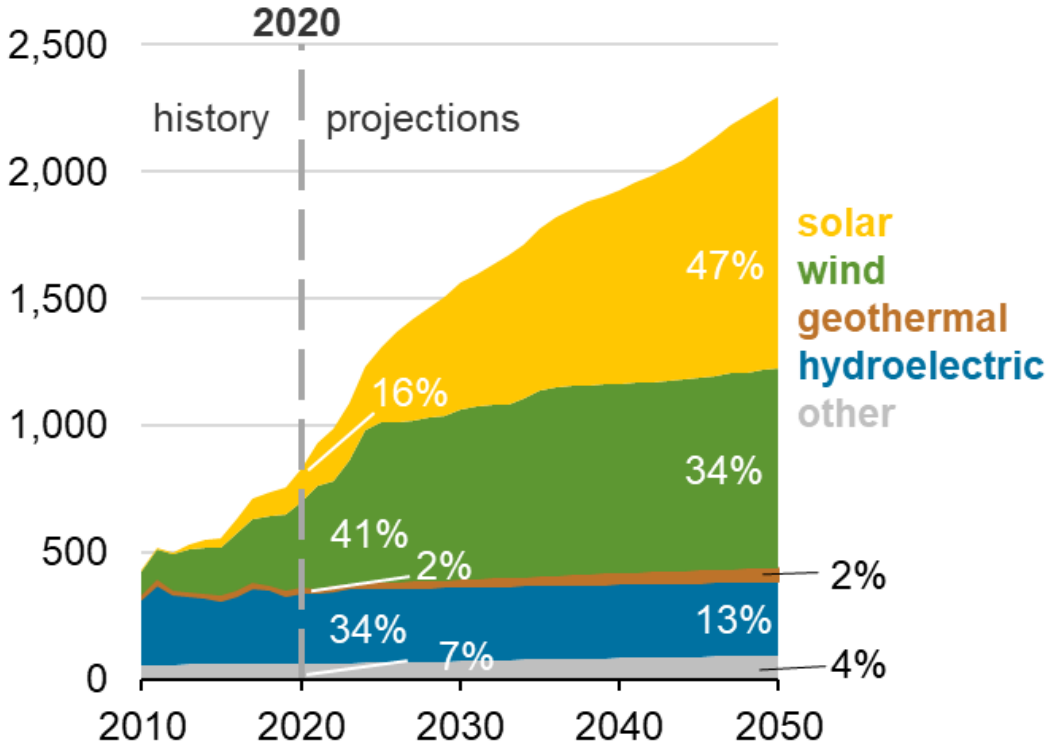
Coal to Gas + Renewables

U.S. electricity generation from selected fuels
AEO2021 Reference case
billion kilowatthours



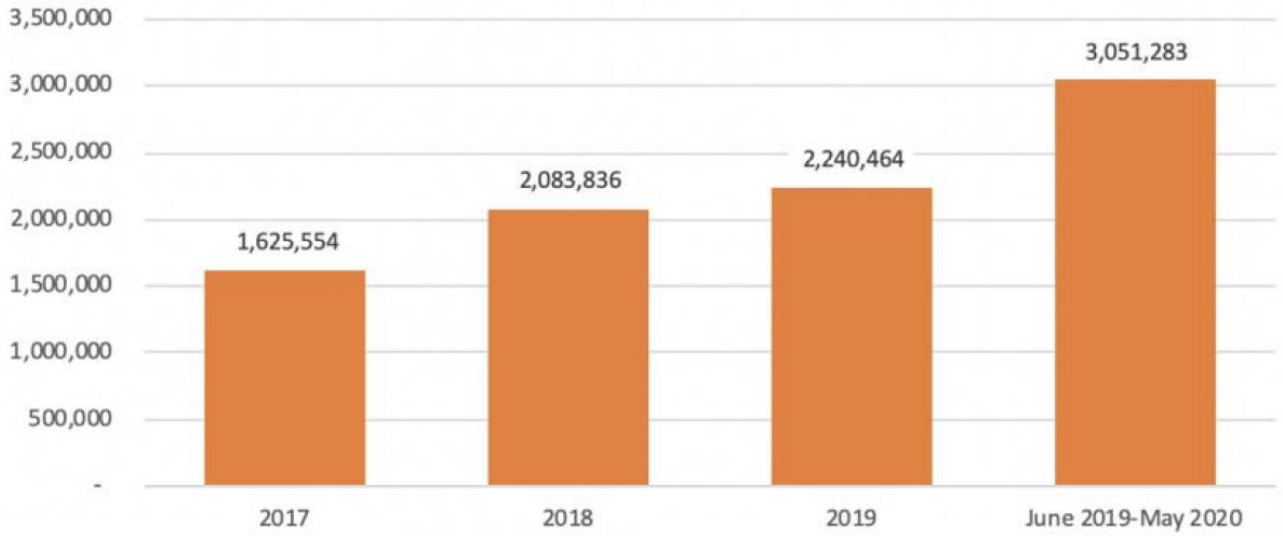
Wind to Solar

U.S. renewable electricity generation, including end use
AEO2021 Reference case
billion kilowatthours



DOE-EIA (AEO 2020)

Increased Wind Curtailment is a growing Concern



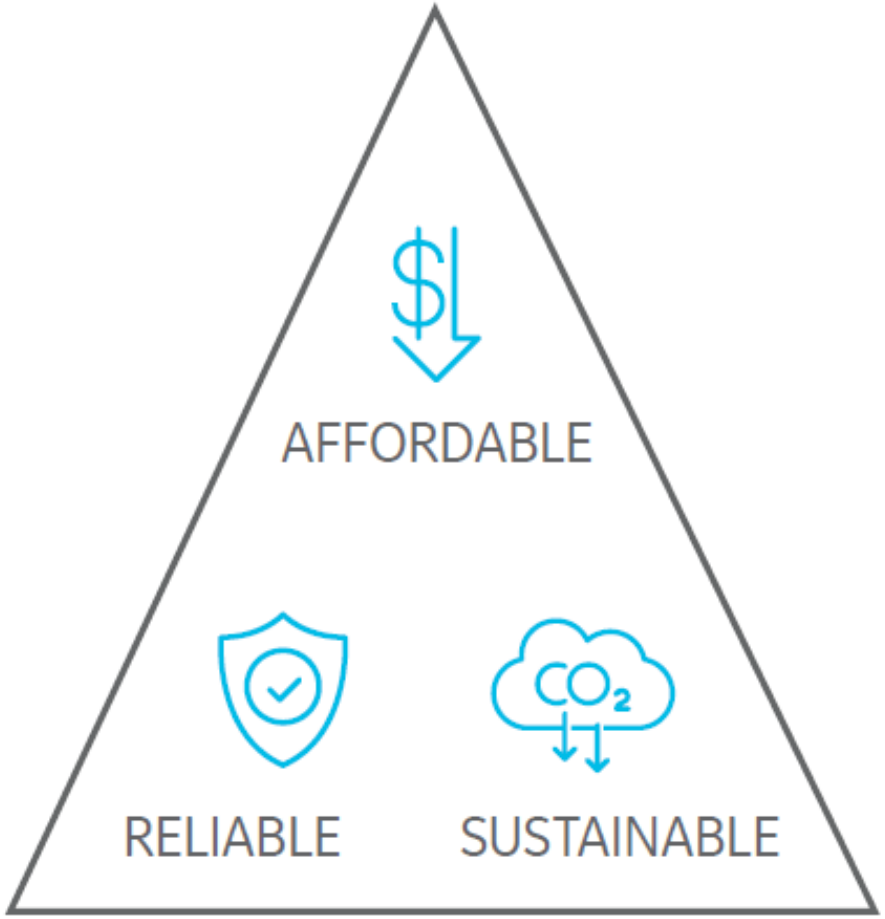
2017 – 2020 Actual Wind Curtailment MWh

Wind curtailments in ERCOT have almost doubled in the past 4 years

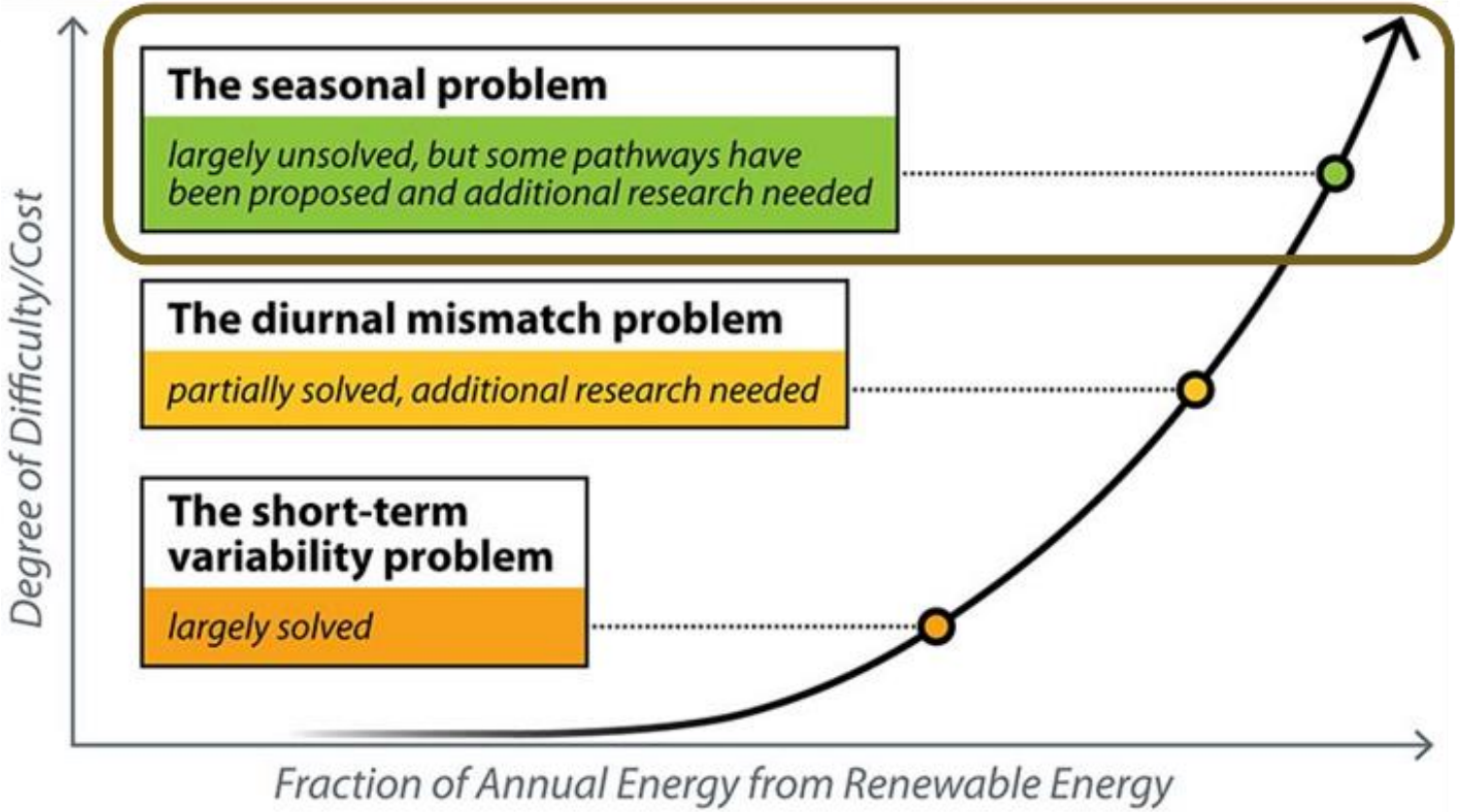
Source: Electric Reliability Council of Texas

The Concerns of the Power Industry Today

- The Climate Objective of the US Power Industry is to Reach Zero Carbon Output
- Eventually…….
- The Reality is that the Electric Industry Need to Satisfy this ENTIRE Triangle



Remaining Challenges for Grid-Scale Storage



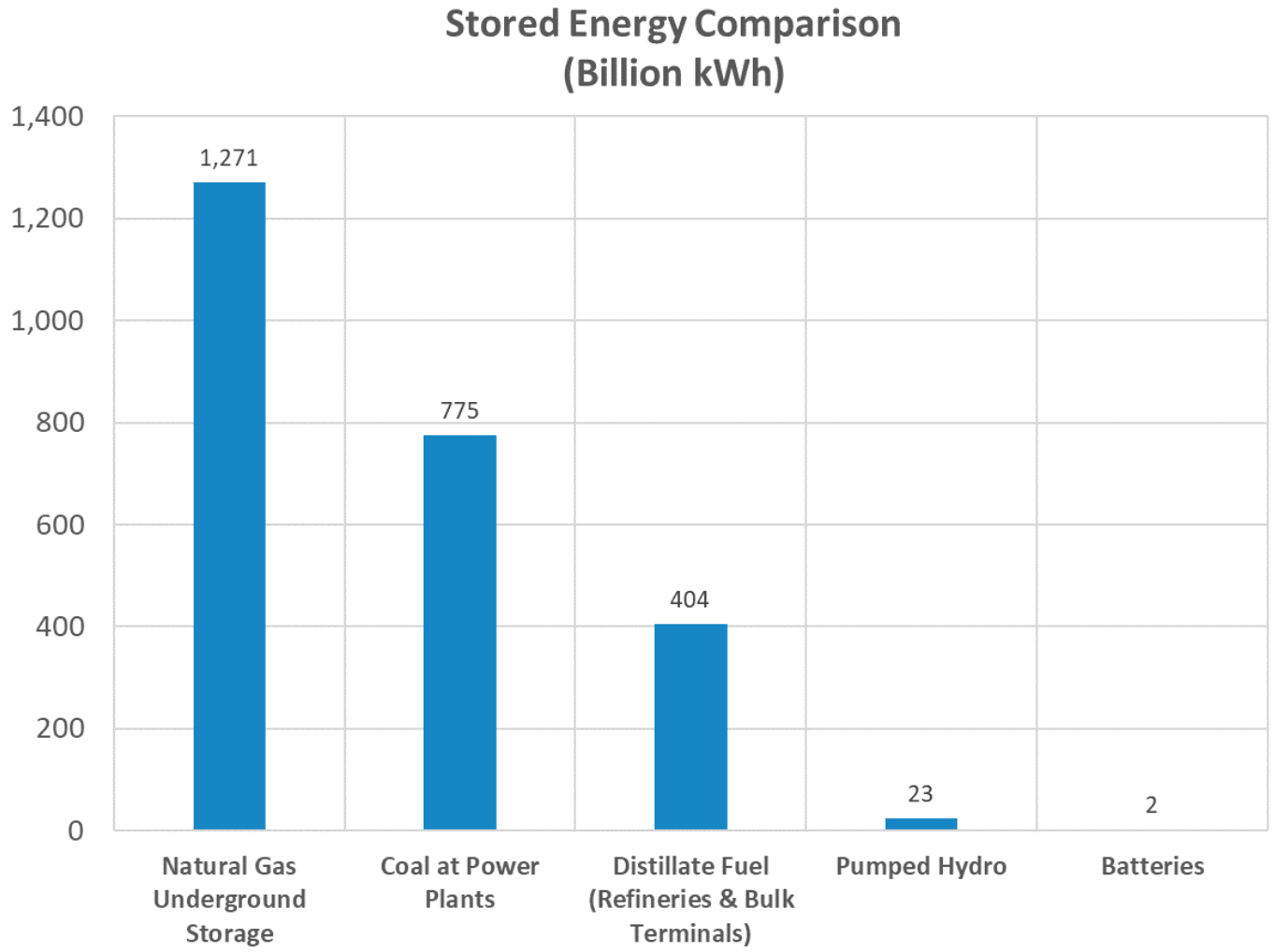
DOE/NREL
Seasonal generation and demand challenges are the most difficult, most costly, and largely unresolved issue with renewable energy.

Underground Natural Gas Storage – aboveground compressors and dehydration equipment and underground gas storage. Expected lifetime of 30-50+ years.

Pumped Hydro Storage – water pumps and power turbines with elevated water storage. Expected lifetime of 30-50+ years.

Battery Energy Storage – multiple batteries in storage containers. Expected battery life of 10-20 years.

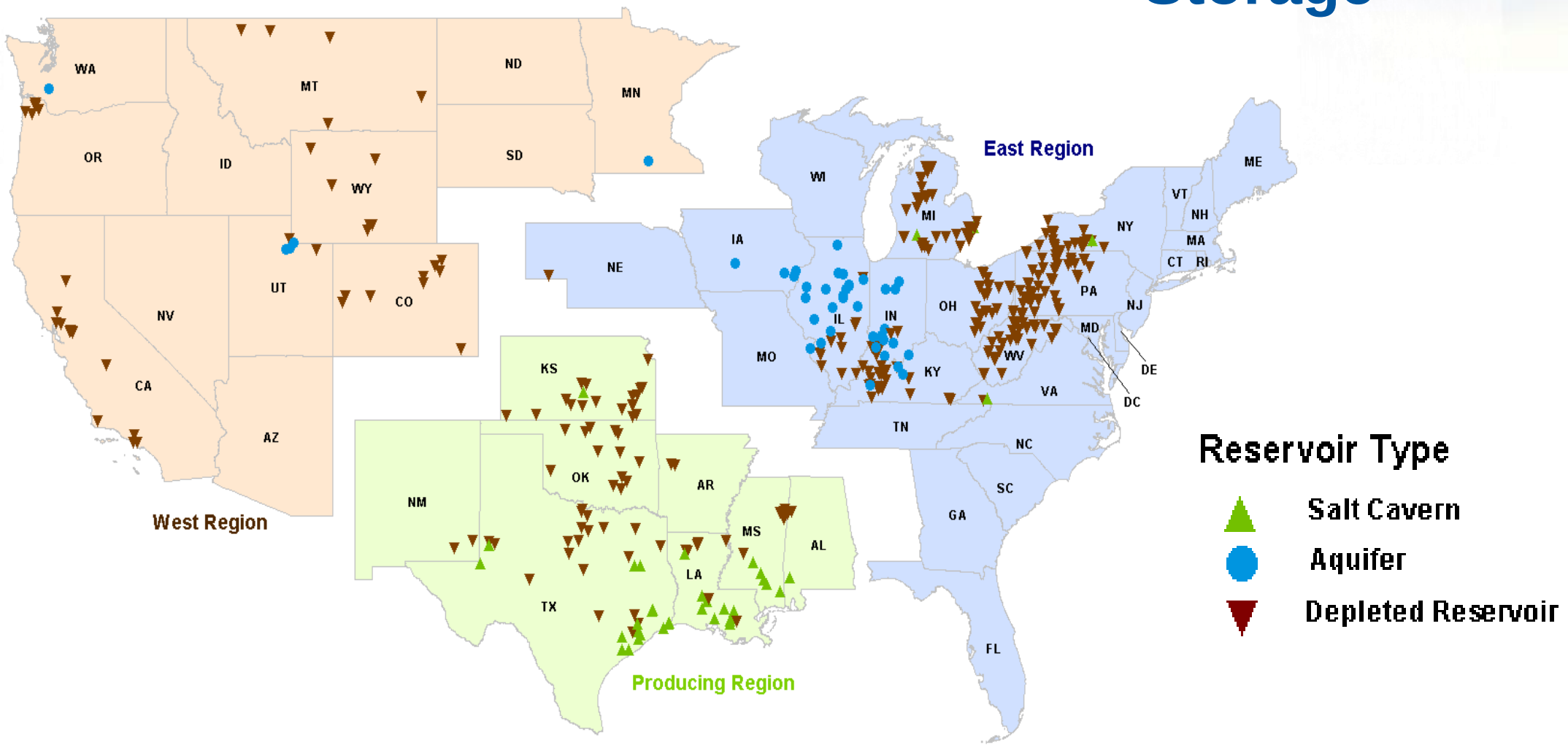
Energy Storage Options – U.S. Capacities



- Many energy storage options currently used in today's energy market
- Different forms suited for different uses
  - Electricity
  - Chemical energy carriers
- Other Distributed Energy Storage
  - LNG Plants
  - CAES
  - Flywheel

Source: DOE-EIA

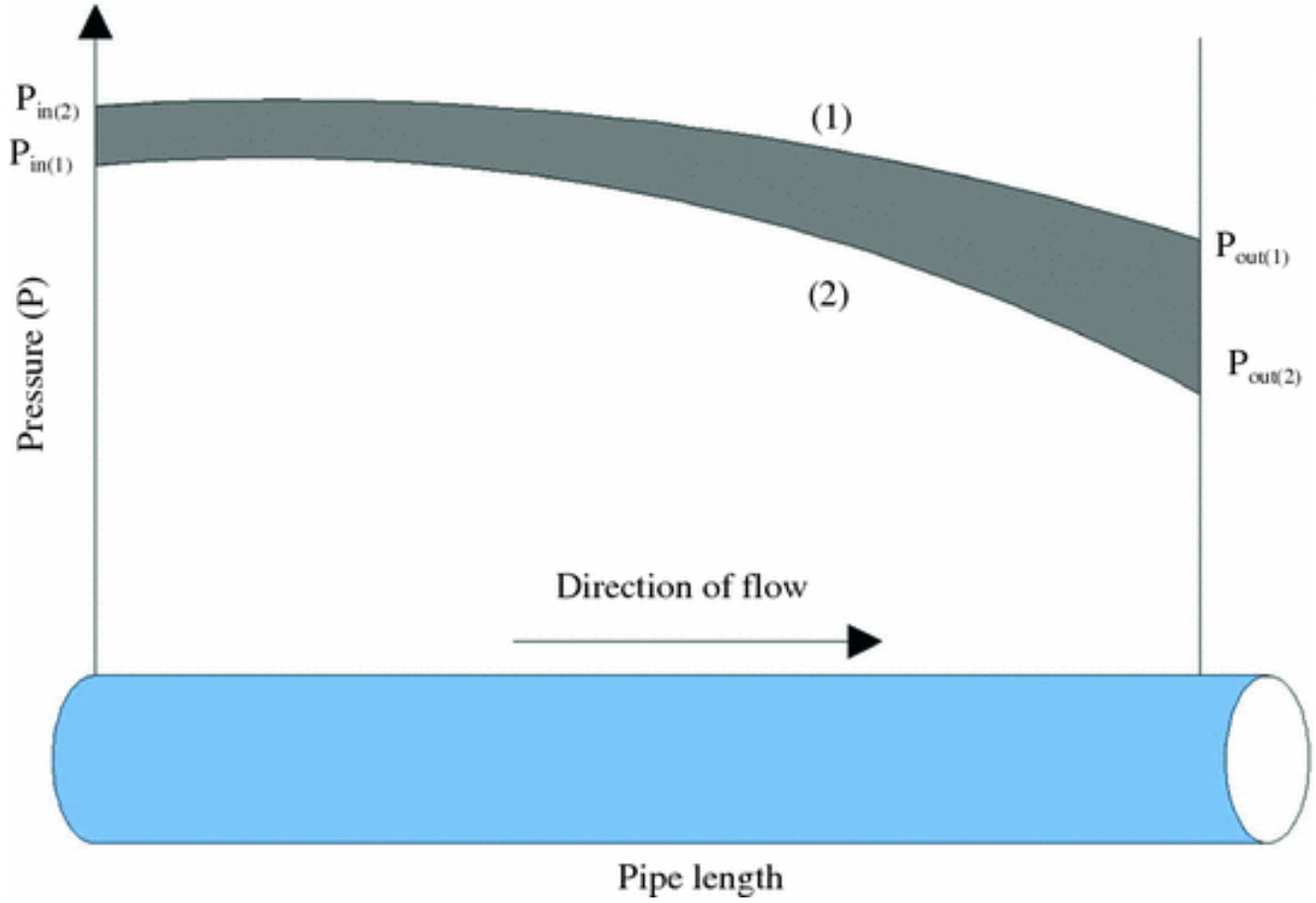
Storage



Note: Locations of storage facilities presented in the map are approximate. Some symbols representing storage facilities may overlap.
Source: U.S. Energy Information Administration, Form EIA-191A, "Annual Underground Gas Storage Report"

Picture Courtesy of EIA

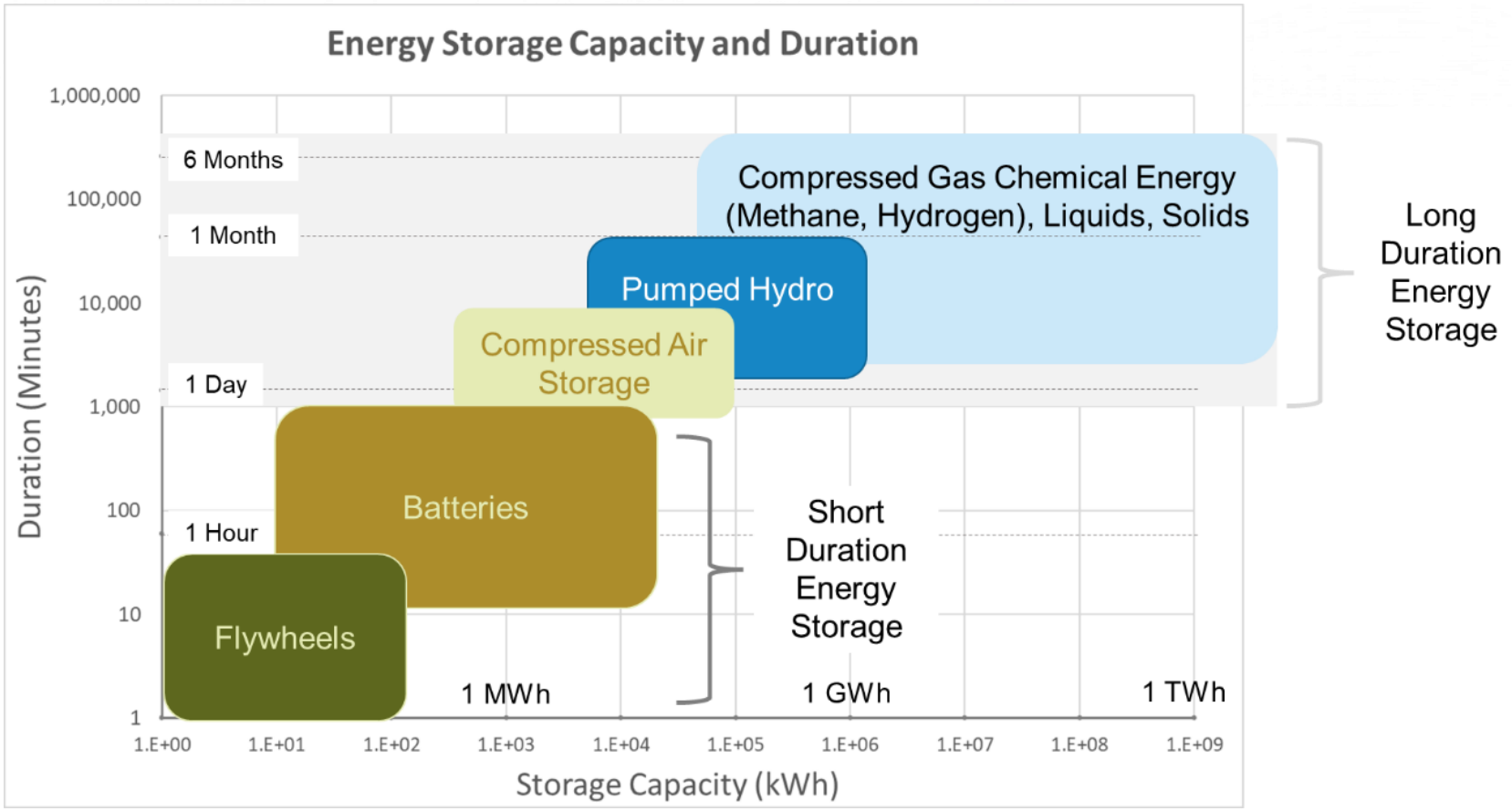
Line Pack provides Instantaneous energy storage



Compressor station 1
Outlet

Compressor station 2
Inlet

Energy Storage Segments: Short and Long-Duration



- Regulated utilities use 3 primary forms of storage for heat and power needs:
  - Pumped hydro
  - Battery energy storage systems
  - Underground natural gas storage
- Main driver is addressing periods of peak demand
  - Short duration: batteries
  - Long duration: pumped hydro, underground gas

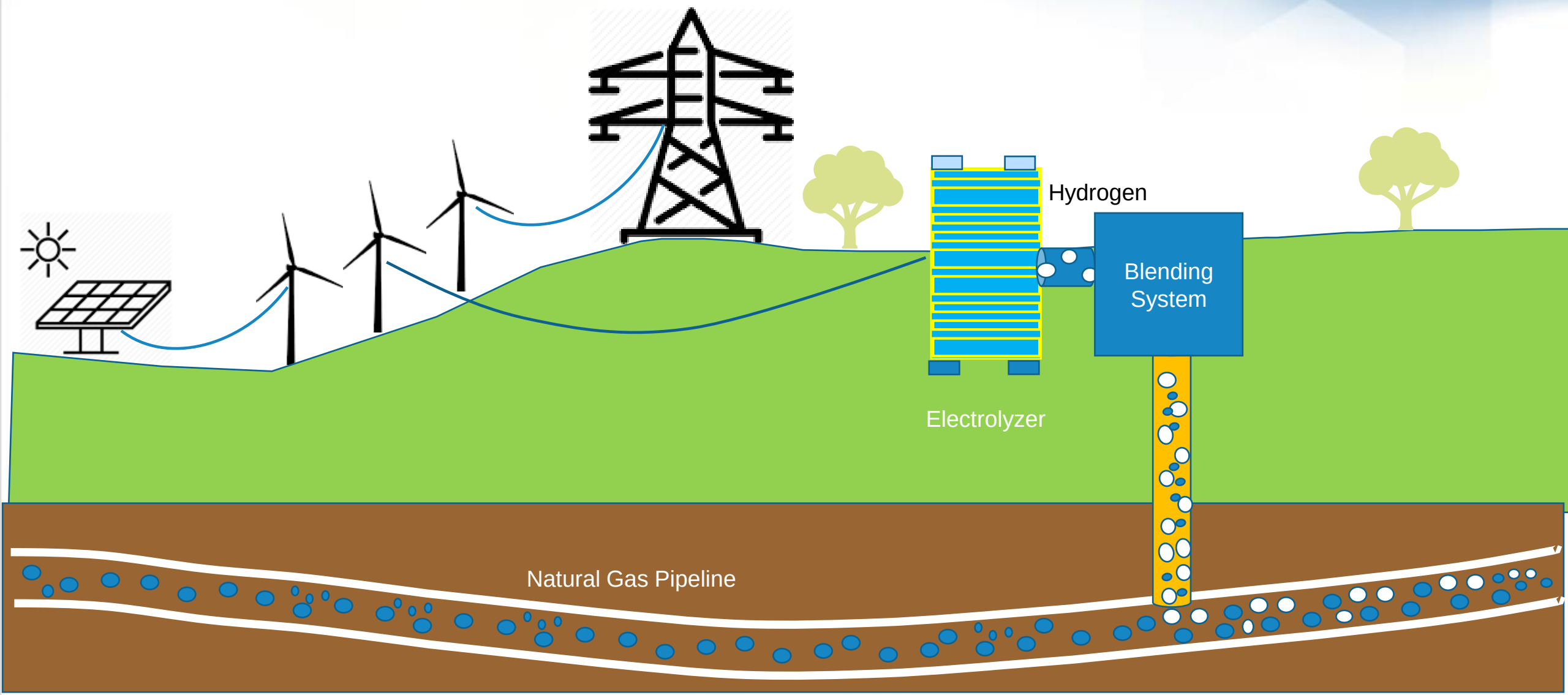
Source: DOE-EIA

Possible Technology Solutions for Grid Renewable Energy Storage

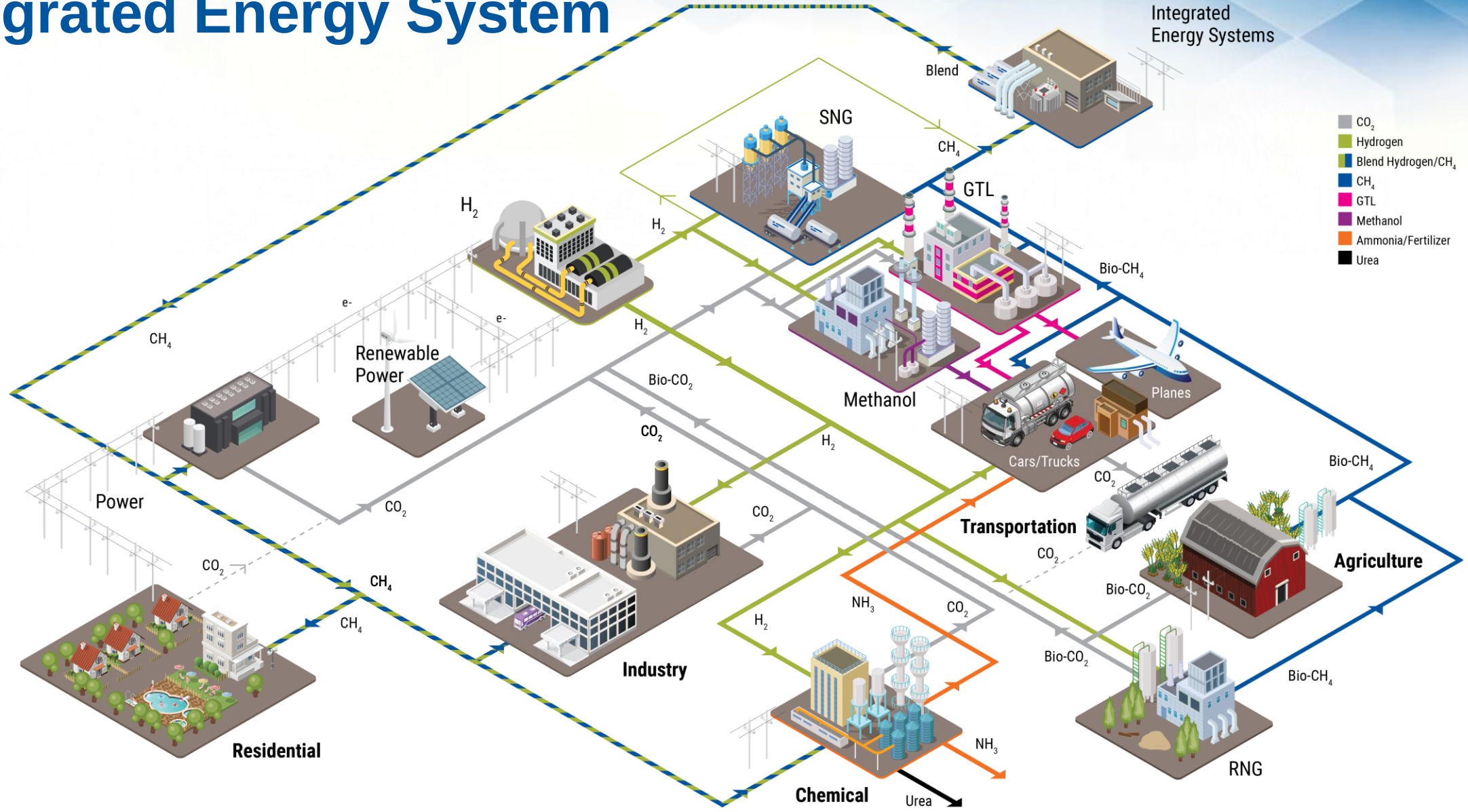
	How it Works	Ratio of MWh out to MWh in	Storage Duration	Today's Installation Cost	Key Advantages (+) Disadvantages (-)
Lithium Ion Batteries	Power absorbed by the battery and stored for later use on the grid	0.85	1-4 hours	$1137/kw	(+) Commercial equipment from many reputable suppliers (-) Storage adequate for <10% of oversupply events
Compressed Air Energy Storage (CAES)	Off-peak electricity is used to operate an air compressor which stores pressurized air and later used to run a turbine generator	Adiabatic - 0.7 Approx. Diabatic - .25 - .30	+48 hours	$1295/kw@ 48 hours	(+) Commercial equipment available (+) Solution works for >50% of oversupply events (-) Solution not zero-emission. It requires natural gas to heat air prior to injection in turbine generator
Power to Gas (includes CoGen to Green H2, Excess renewables, CAES to Green H2)	Electrolysis uses off-peak power to separate water into hydrogen and oxygen. The hydrogen is stored and used later in a hydrogen-capable turbine for power generation or in a fuel cell.	.33 - .63	Multi-day / seasonal	No estimate	(+) Unlimited storage time (+) very large capacity – can potentially accommodate all oversupply events (+) Can reduce CO2 from must-run Cogen facilities (-) Technology gaps in pipeline blending and hydrogen storage (-) Costs and LCA work to be done

Source: University of Houston / Center for Houston's Future

“Green Hydrogen”, a.k.a. Power-to-Gas



Integrated Energy System



Expand, Modify, Repurpose, Leverage Existing Infrastructure

Summary

- *In order to meet decarbonization policy goals, trajectory shifts must be made in energy production and consumption*
- *Grid-scale energy storage is a necessary component to support continued growth of renewables*
- *Chemical energy carriers (gases and liquids) are highly efficient at transporting and storing energy*
- *An Integrated Energy System will help achieve carbon goals by leveraging infrastructure to lower the cost of decarbonization.*
- *Markets are likely to form in hubs with significant and stable H_2 demand*