Utility Perspectives on the Hydrogen Economy

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SOUTHERN COMPANY

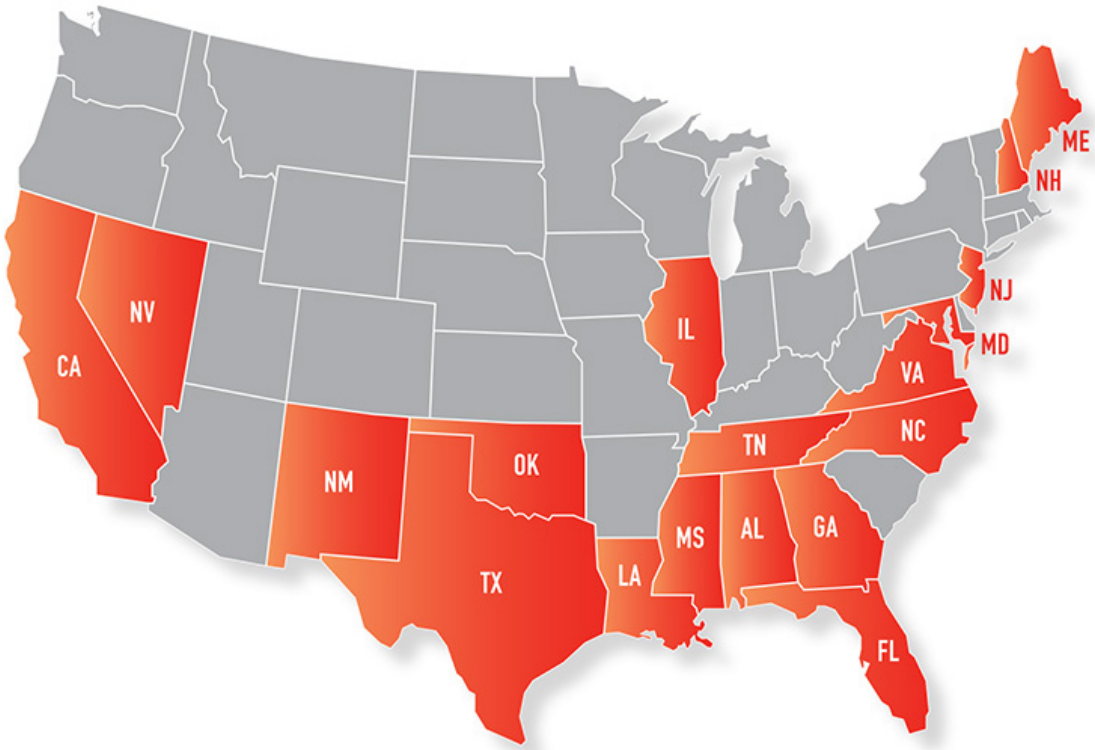
America's Premier Energy Company

Approximately
44,000 MW
of Generating Capacity

Nearly
200,000
Miles of Power lines

More than
80,000
Miles of Natural Gas Pipelines

190 Bcf
of Natural Gas Storage Capacity



Operations in
18 States

11
Electric & Natural Gas Utilities

32,500
Total Employees

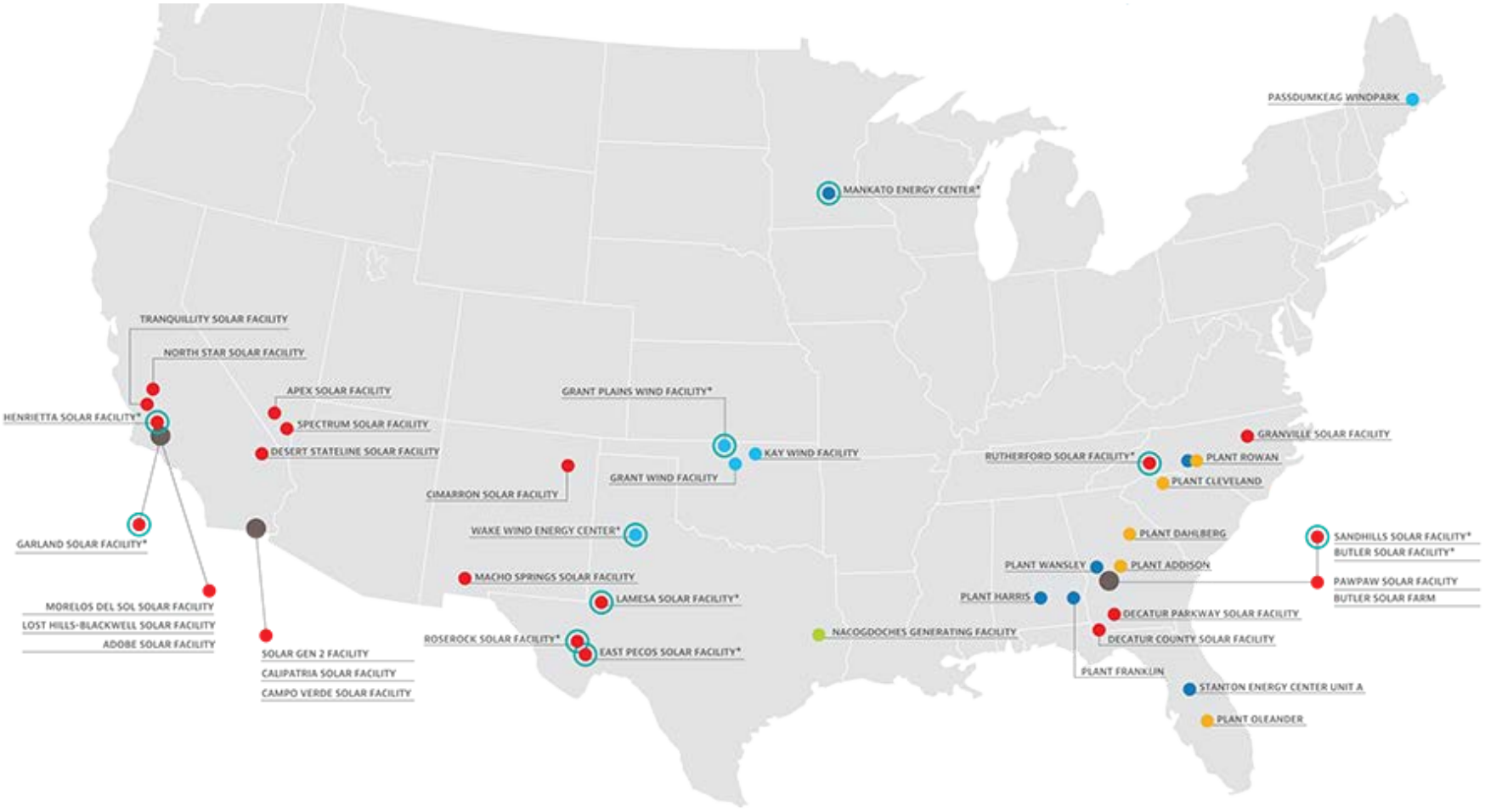
9 Million
Utility Customers

More than
1 Million
Retail Customers

Southern Company Overview

- **Providing clean, safe, reliable and affordable energy for customers and communities**
- **Developing the full portfolio of energy resources**
  - Nuclear
  - 21st century coal
  - Natural gas
  - Renewables (solar, biomass, wind, hydro)
  - Energy efficiency
- **Industry leader in energy innovation**
  - Incubating new products and services at the Energy Innovation Center
  - Engaged in robust, proprietary research and development
  - Company-managed R&D investments totaling approximately $2.1 billion since 1970

Renewables (SPC) Generation



Renewables Development

	2015	2030
Solar	• ~1GW of solar in SE footprint • $2-4/W • 15-18% efficiency • OpCos purchase 90% of their solar energy	• 10+ GW of solar in SE footprint • $1-2/W • 20-25%+ efficiency • OpCos own more than they buy

Wind	• <28% Capacity factor in SO footprint
	• Hub height and rotor diameter limited by logistics
	  • 80-90m hub-height is typical, 100m is highest commonly used
	  • 110m rotors are largest typical
	• All wind is imported
		• 35%+ Capacity factor in SO footprint
		• Advances in manufacturing and construction result in taller tower/longer rotors
		• 140+m hub-height
		• 140+m rotor diameter
		• 3GW of wind in SE

Renewables growth (Oct 31st earnings call; subject to cautionary notes):

2016: **$4.4B investment** by SPC mostly in wind – peak renewables investment

2017+: target **$1B/year wind (650 MW)** and $0.5B other investments

Hydrogen Economy Drivers and Vision

1) Renewables require grid energy storage.
2) Economy-wide decarbonization requires transportation decarbonization.

2014 carbon intensity by sector
- transportation 0.31 t/MBTU
- residential 0.05 t/MBTU
- commercial 0.04 t/MBTU
- industrial 0.05 t/MBTU

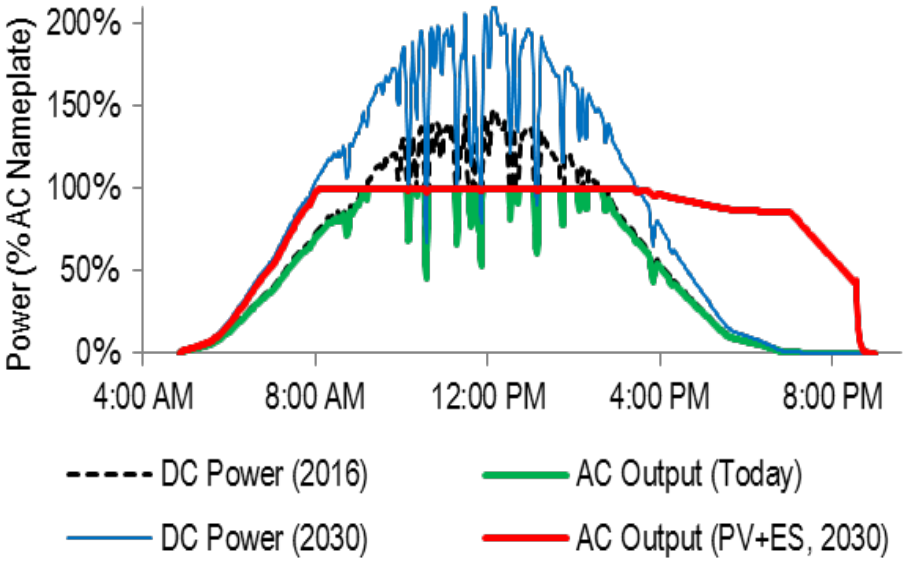
Hydrogen and electrons are preferred energy carriers in a zero-carbon future.

Zero-carbon electrons produced by:
- ***Nuclear***
- ***Renewables***
- ***Fossil with CCS***

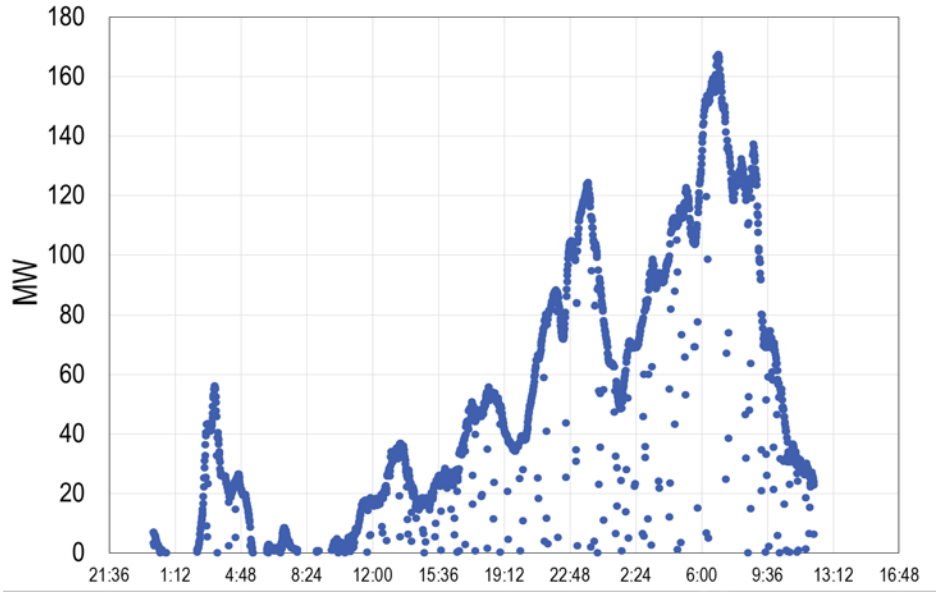
Hydrogen produced by:
- ***Zero-carbon electrons***
- ***Thermochemical water-splitting***
- ***Photochemical water-splitting***
- ***Thermal methane splitting***
- ***Biogas/biomass gasification***
- ***Fossil reforming/gasification with CCS***

Grid must be balanced using reserves or storage

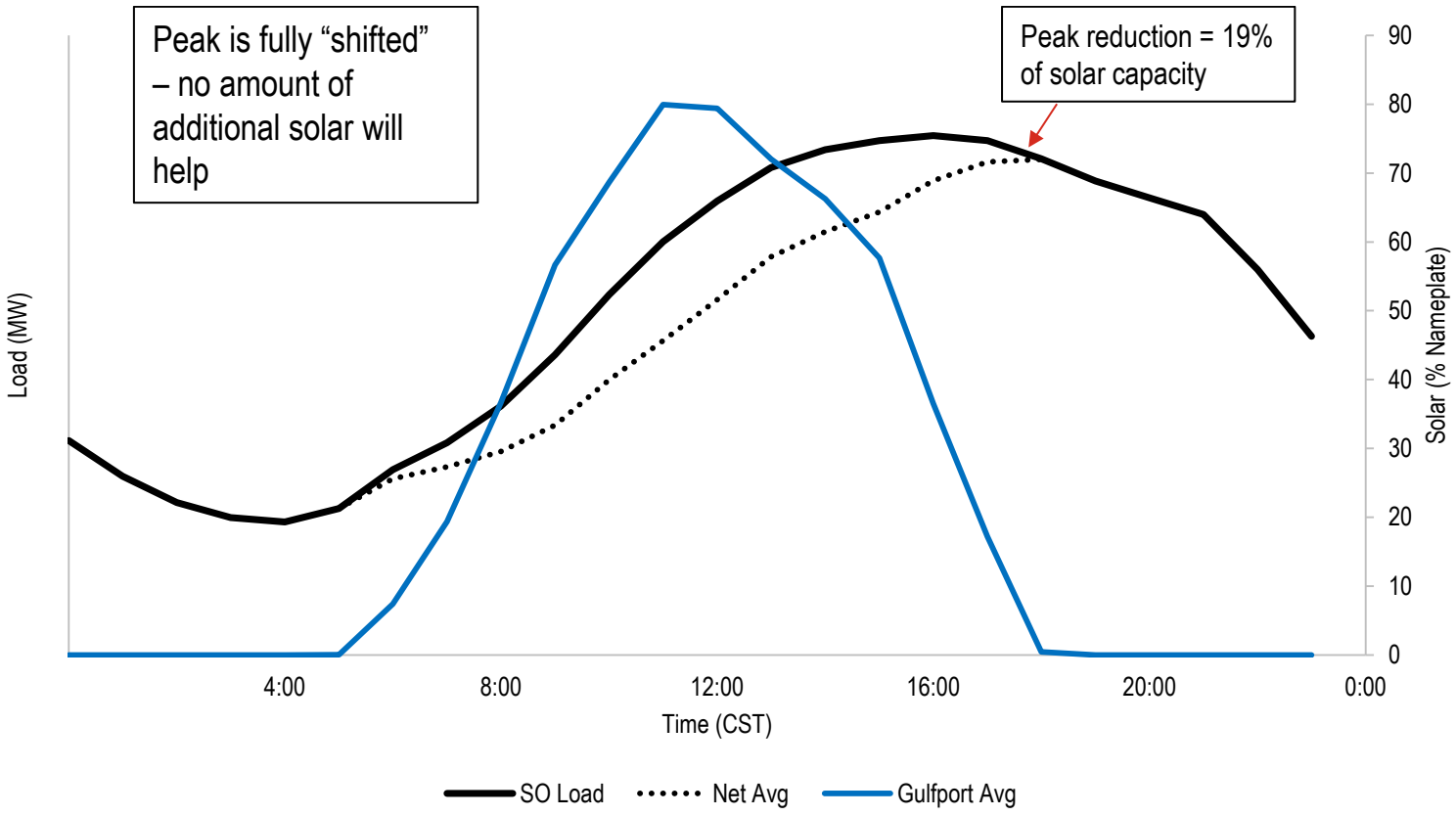
Solar



Wind



Solar has limited value for capacity



Opportunities for Renewables Energy Storage

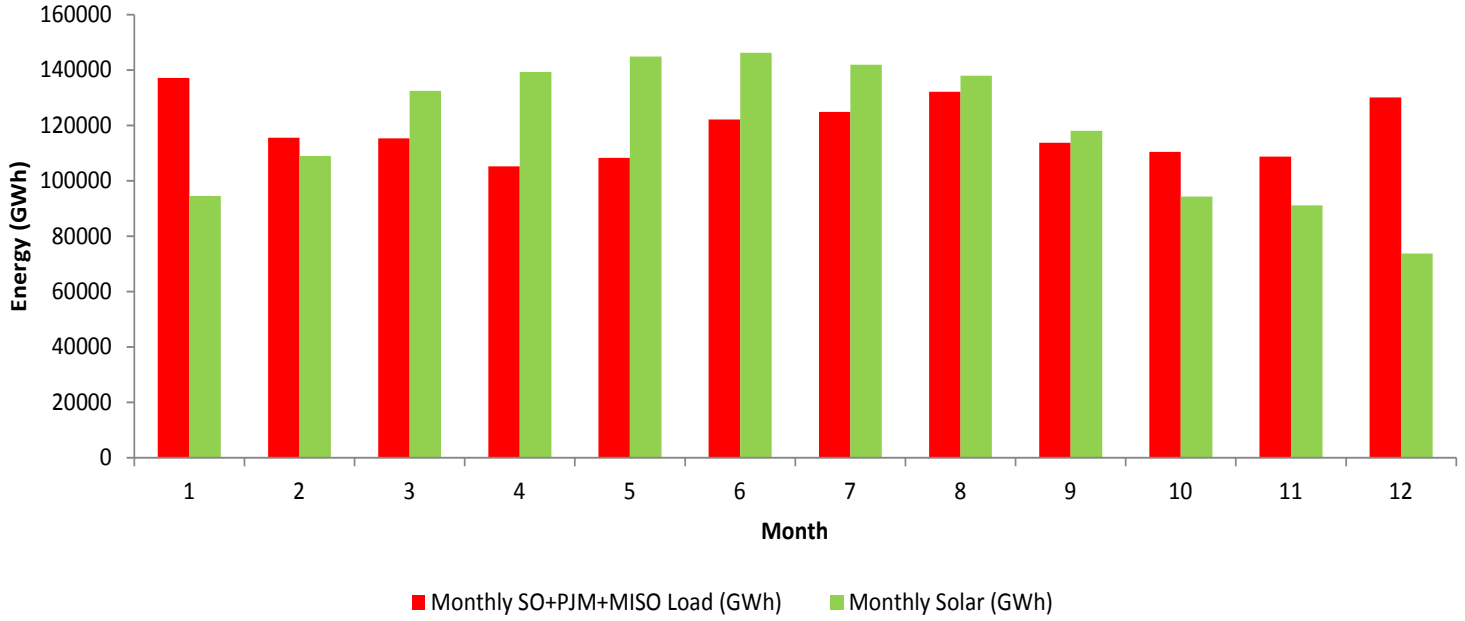
Investment Tax Credits allow excess solar generation

- Incentivize solar which has limited capacity value
- Solar is least-cost to curtail when energy is not needed

Production Tax Credits demand excess thermal plant generation

- Incentivize energy production
- Shifts least-cost to curtail to thermal plants which have high curtailment costs

Renewables mis-matched with seasonal demand.



Grid Energy Storage

Technology	Round Trip Efficiency	response time	Scalability
Batteries	95%	seconds	linear
Pumped Hydro	75%	minutes	volumetric
Compressed Air	25-70%	minutes	volumetric
Thermal - Physical	40%	mins to hours	volumetric
Thermal - Chemical	40%	mins to hours	volumetric
Hydrogen P2G	27-40%	minutes	volumetric
Hydrogen P2P	33%	hours	volumetric

small applications
geographically limited
may require pre-heating

Options to store, move, or sell

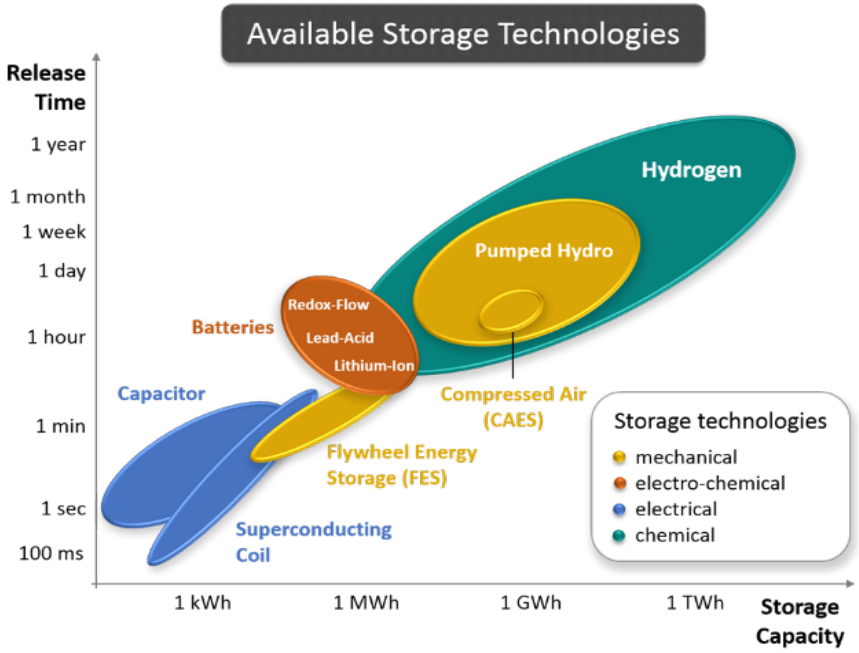


Figure 1: Energy Storage Technologies, Capacity, Timescale, and Applicability (Source: Hydrogenious (www.hydrogenious.com))

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Hydrogen for Transportation (and pipeline energy transmission)

Critical parameter for transportation =
mass energy density (BTU/lb)


Tesla Model S (2013)

Toyota Mirai (2015)

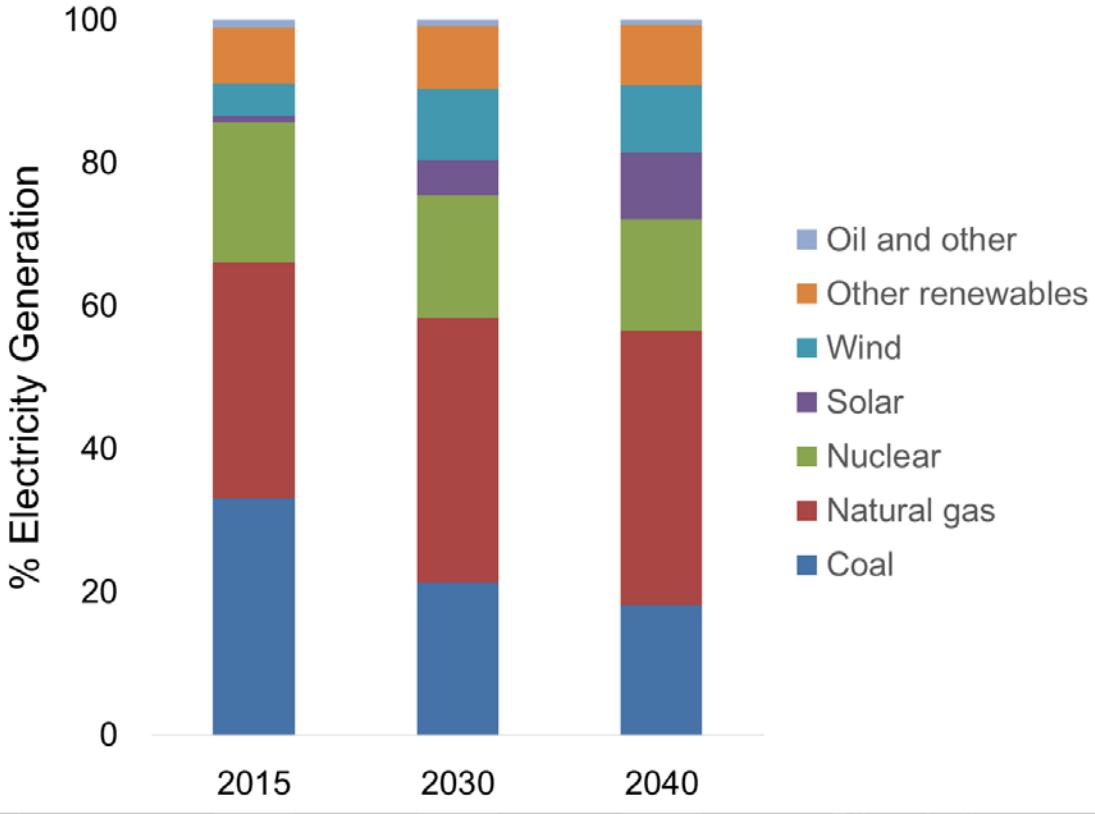
Battery pack:
85 kWh / 1323 lb = **0.064 kWh/lb**
(**219 BTU/lb**)

(Source: Car & Driver)

5 kg H_2 + 87.5 kg H_2 storage + 56 kg stack weight = 327 lb total power plant weight
568,000 BTU in the H_2
1736 BTU/lb thermal ~ **860 BTU/lb electrical**
(Source: InsideEVs.com)

Electrolysis for Hydrogen has Carbon footprint challenges.

EIA U.S. electricity grid projections



SMR H_2 production: 10 lb CO_2/lb H_2 → 5100 BTU_{th}/lb CO_2

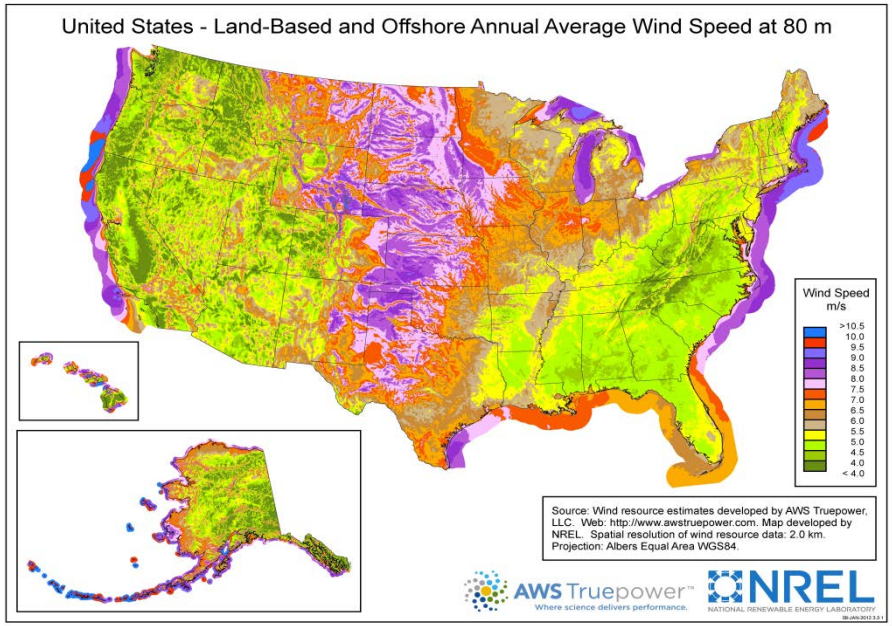
CH_4 combustion → 8500 BTU_{th}/lb CO_2

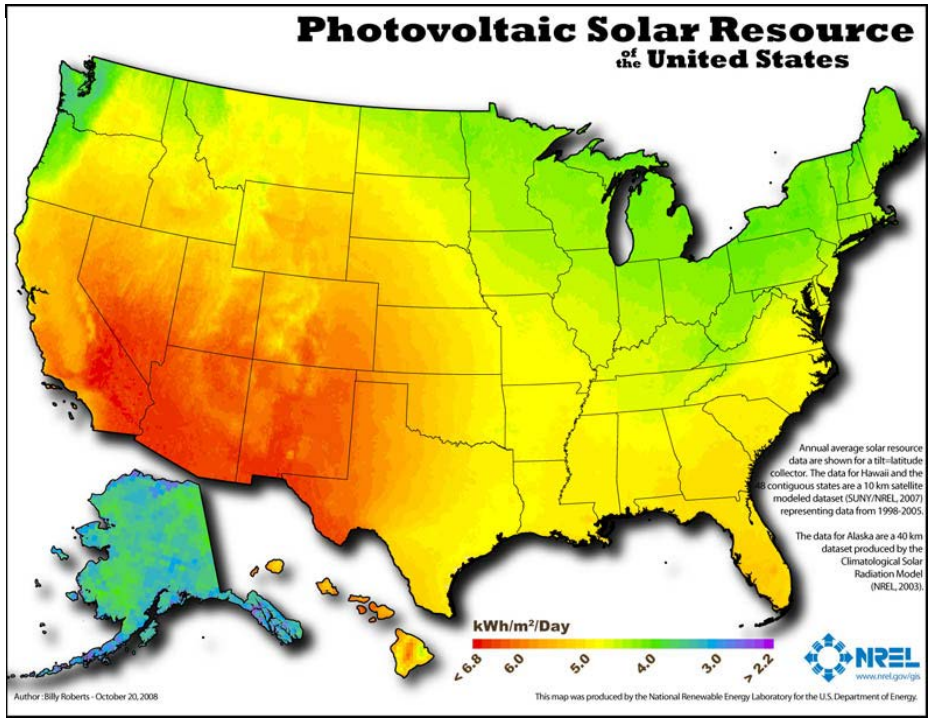
Electrolytic H_2 → 19.5 lb CO_2/lb H_2 (67% efficient; 50 kWh/kg H2 required; EIA case: assuming Clean Power Plan is implemented)

Zero-carbon electricity generation required to drive carbon benefits from electrolysis.

Roles for Nuclear in Hydrogen Economy

- Nuclear provides zero-carbon electricity at scale today with low O&M (price certainty).
- Nuclear plants may be challenged in some ISO due to wind PTC.
- Southeast has less renewable resource
- Nuclear power EROI is stronger.





High temperature Nuclear Reactors

High Temperature Gas Reactor (HTGR)

- Cooled with high pressure helium
- 850 °C

Molten Salt Reactor

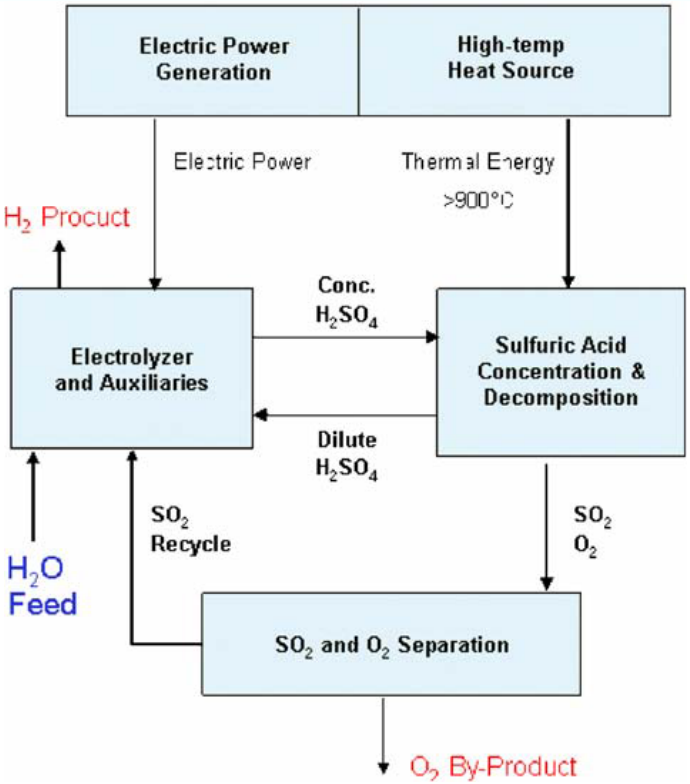
- Fast reactor → high fuel utilization → security
- Low pressure and molten salt → safety
- High temperatures → efficiency

Thermochemical Water Splitting

$2\ H_2O \rightarrow 2\ H_2 + O_2$

mediated by thermochemical cycle

- Metal – metal oxide
- Copper – copper chloride
- Sulfur iodine
- Hybrid sulfur (electricity and heat used)
- 300+ other cycles



- *Utilization of both heat and electrons*
- *2 steps – 3 unit operations*
- *All fluid phases*

Liquid Hydrogen Carriers

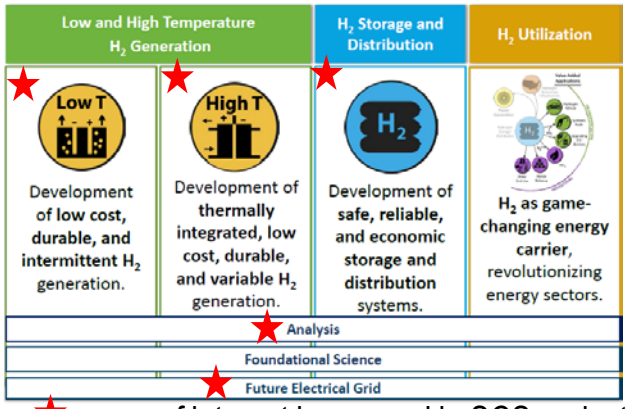
	Wt% H2	Energy density kWh/L
Liquid Organic	**16**	**9.7**
Biodiesel	**14**	**9.2**
Methanol	12.6	**4.67**
Ethanol	12	**6.3**
Formic acid (88%)	3.4	2.1
Ammonia	**17.8**	**4.32**
Liquid Hydrogen	100	2.54

Electrolysis Demonstration in the Southeast

Electrolysis Test Bed
- PEM
- High Temp
- High Pressure
- Solid oxide EC
- Adv. Electrolysis and electrochemistry

Storage & Handling
- Hydrogen
- Liquid Organic
- Metal

Usage & Fuel Cell
- Phosphoric acid
- Solid Oxide
- PEM
- Fleet trucks



★ =area of interest is covered in SCS project

Partners:
- *DOE*
- *Southern Company*
- *EPRI*
- *Southern Research*
- *National Lab / NREL*
- *City of Birmingham*
- *Electrolysis and Fuel cell makers*

Hybrid Sulfur Thermochemical Demonstration

Sulfuric Acid Decomposer Work

Molten Salt Nuclear Integration design

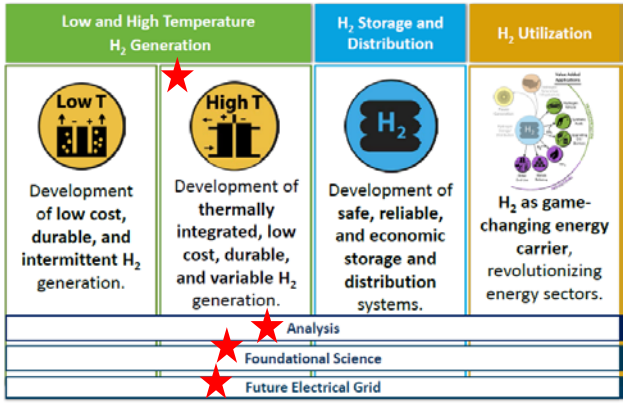
→

Integrated Electrically Heated Demonstration in Lab

→

Commercialization Path development

Scale-up and Field Demonstration



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- *Southern Company*
- *EPRI*
- *National Lab / SRNL*
- *Technology Commercializers*

Conclusions

- Hydrogen may meet energy storage need and present opportunity for renewables
- Efficiency and energy density of nuclear drives it as a dominant zero-carbon electricity generation
- Advanced nuclear includes option for hydrogen from heat
- Hydrogen or liquid H_2 carriers allow for high density energy transmission
- Hydrogen has energy density required for transportation
- SCS pursuing industry-led demonstrations

Questions?

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