Southern Company

# Utility Perspectives on the Hydrogen Economy

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DOE Hydrogen and Fuel Cell Technical Advisory Committee (HTAC)
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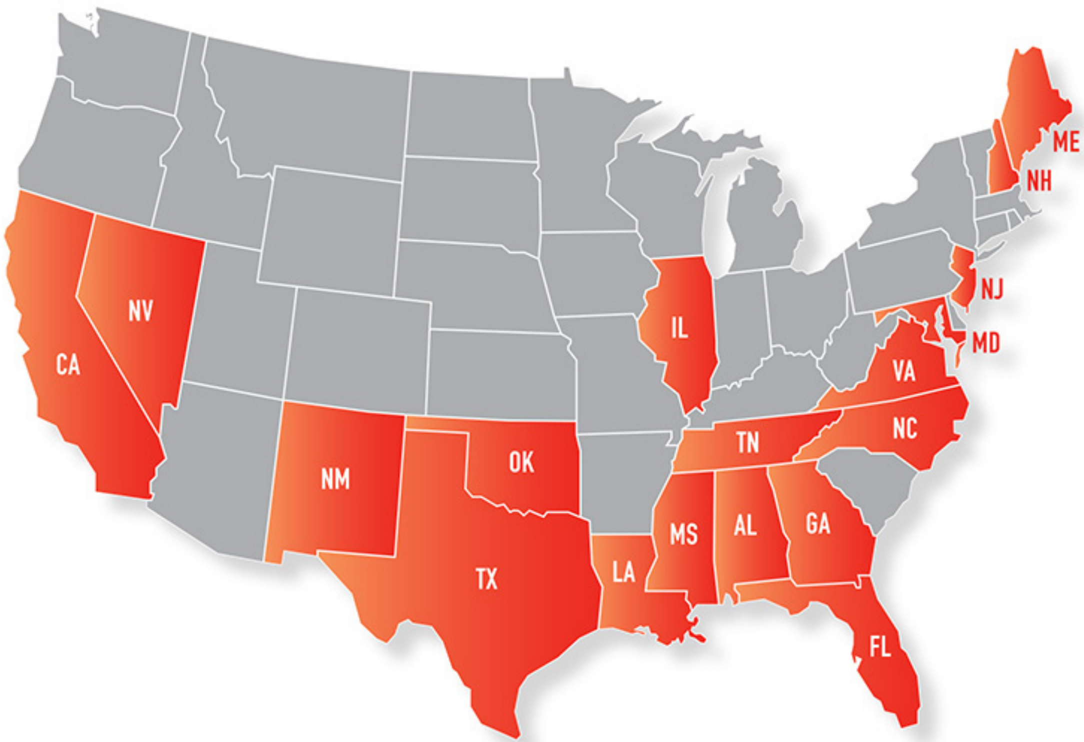
# America's Premier Energy Company

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

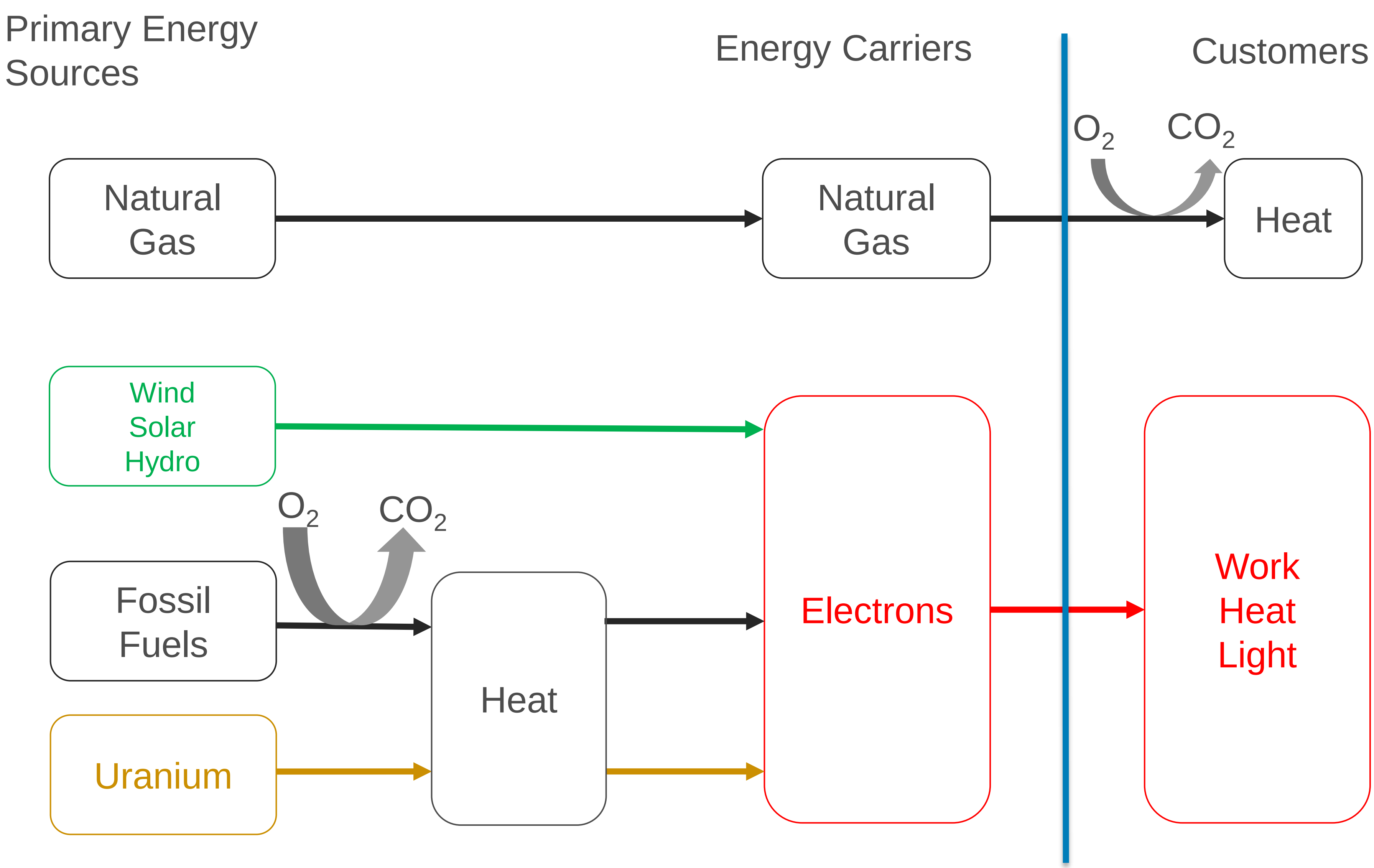
9 Million
Utility Customers

More than
1 Million
Retail Customers

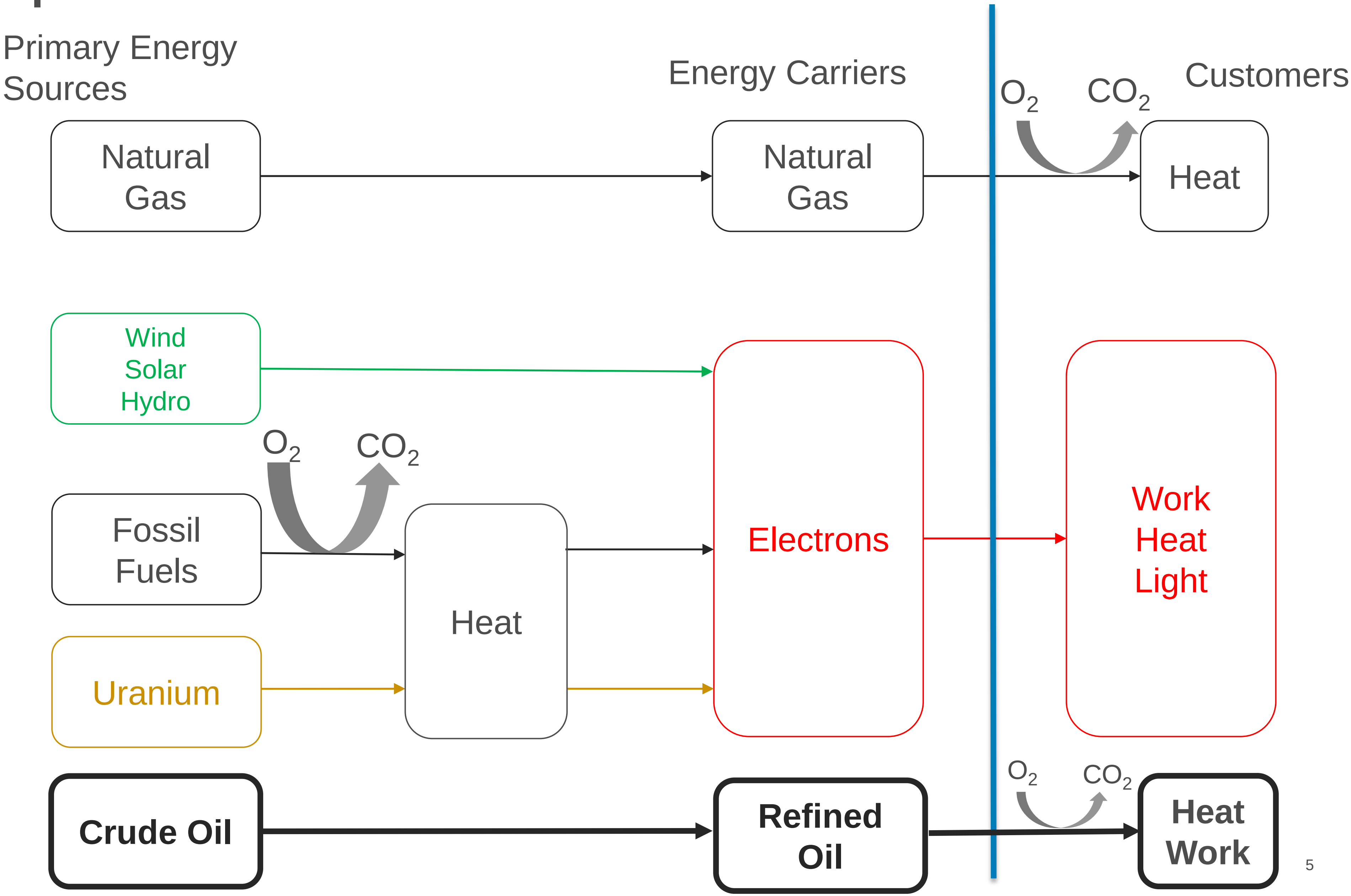
# Southern Company Overview

- **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

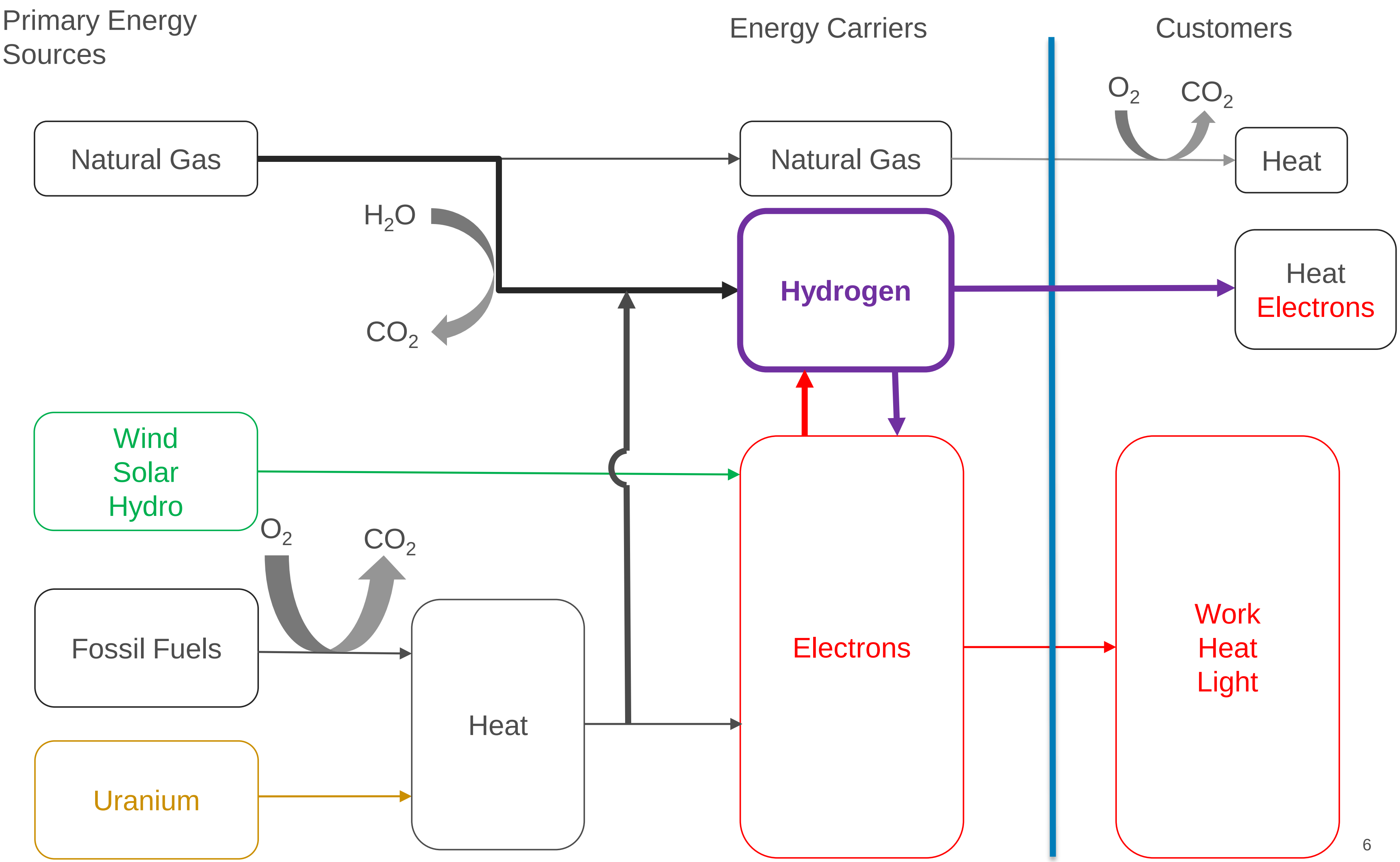
# Today, utilities generate and deliver energy carriers in real time.



# Today, utilities generally miss a key energy carrier: petroleum.



# What if hydrogen becomes an alternate energy carrier for utilities?



## Natural Gas

- Easily stored and transported
- Abundant infrastructure
- Emits $CO_2$ at point of use

## Electrons

- Difficult to store/transport
- Abundant infrastructure
- No emissions at point of use
- Not suitable for some applications

## Hydrogen

- Easier to store and transport
- Infrastructure needed
- No emissions at point of use
- Versatile applications

## Petroleum

- Easily stored and transported
- Abundant infrastructure
- Emits $CO_2$ at point of use
- High energy density

***Hydrogen is a storable energy carrier which may enable a utility to provide energy with a high capacity factor to existing customers, as well as open up new markets.***

# 5 Ways that Utilities could participate in the Hydrogen Economy

1. Energy storage to achieve high capacity factor and maximize renewables

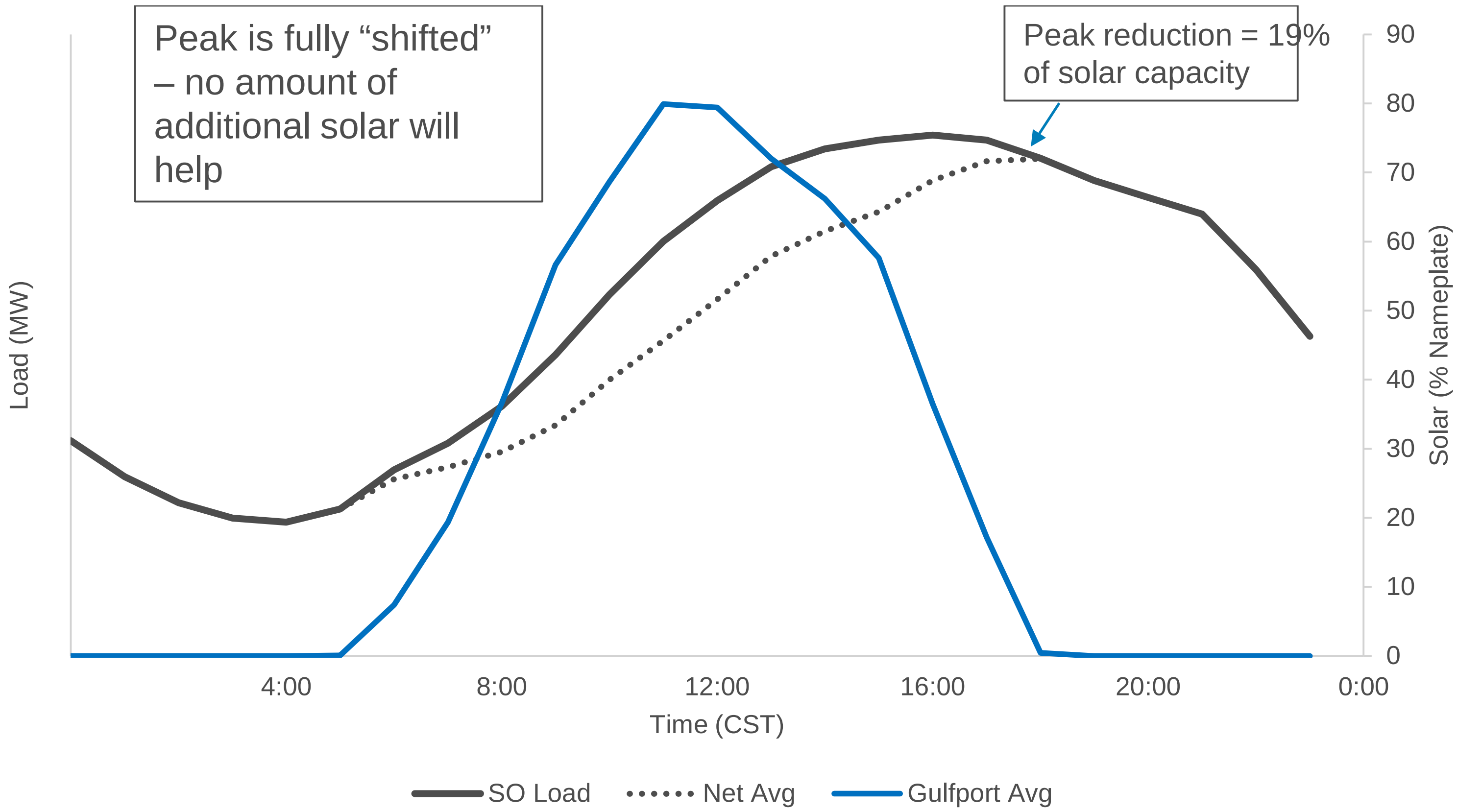
2. Supplement energy transmission with hydrogen

3. Reduce the carbon footprint and maximize heat value for "green" natural gas

4. Provide hydrogen for dispatchable distributed generation

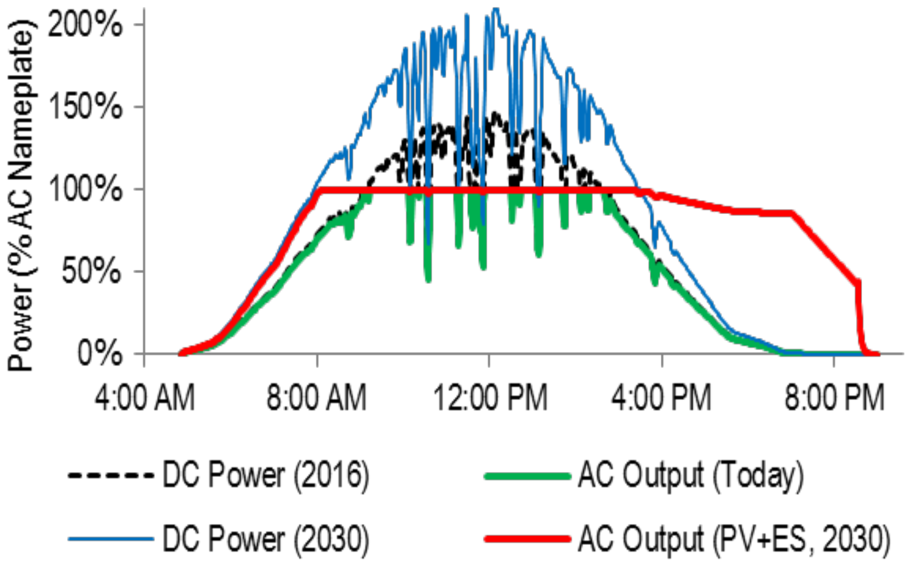
5. Provide the primary energy source for hydrogen for transportation

# Solar has limited value for capacity

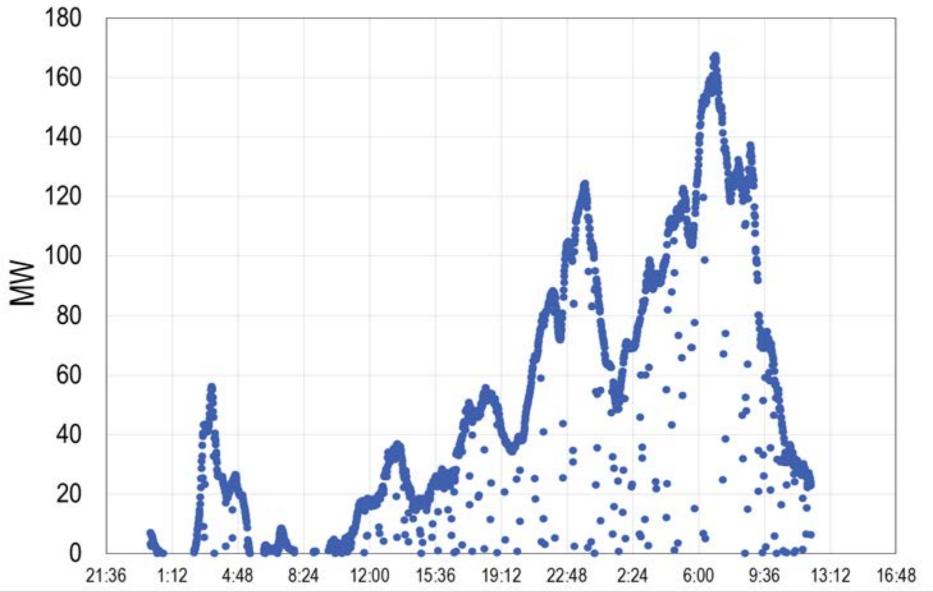


# Solar/wind are highly intermittent.

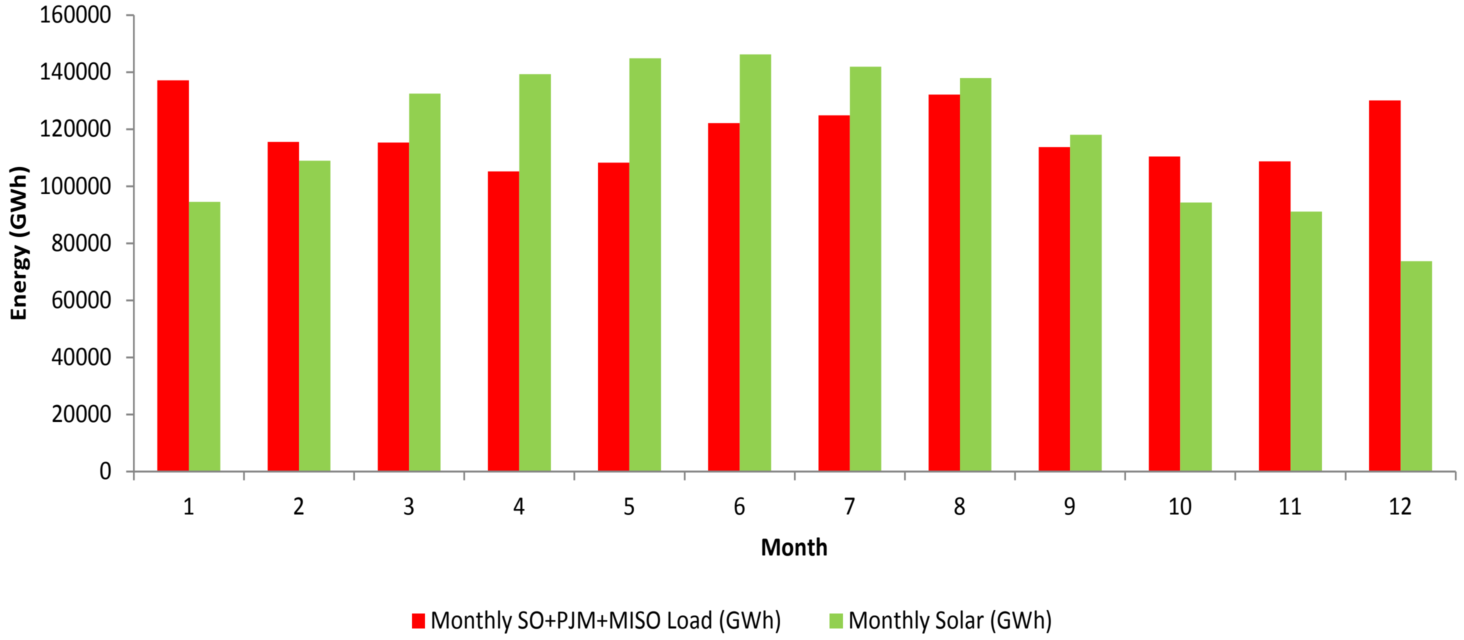
**Solar**



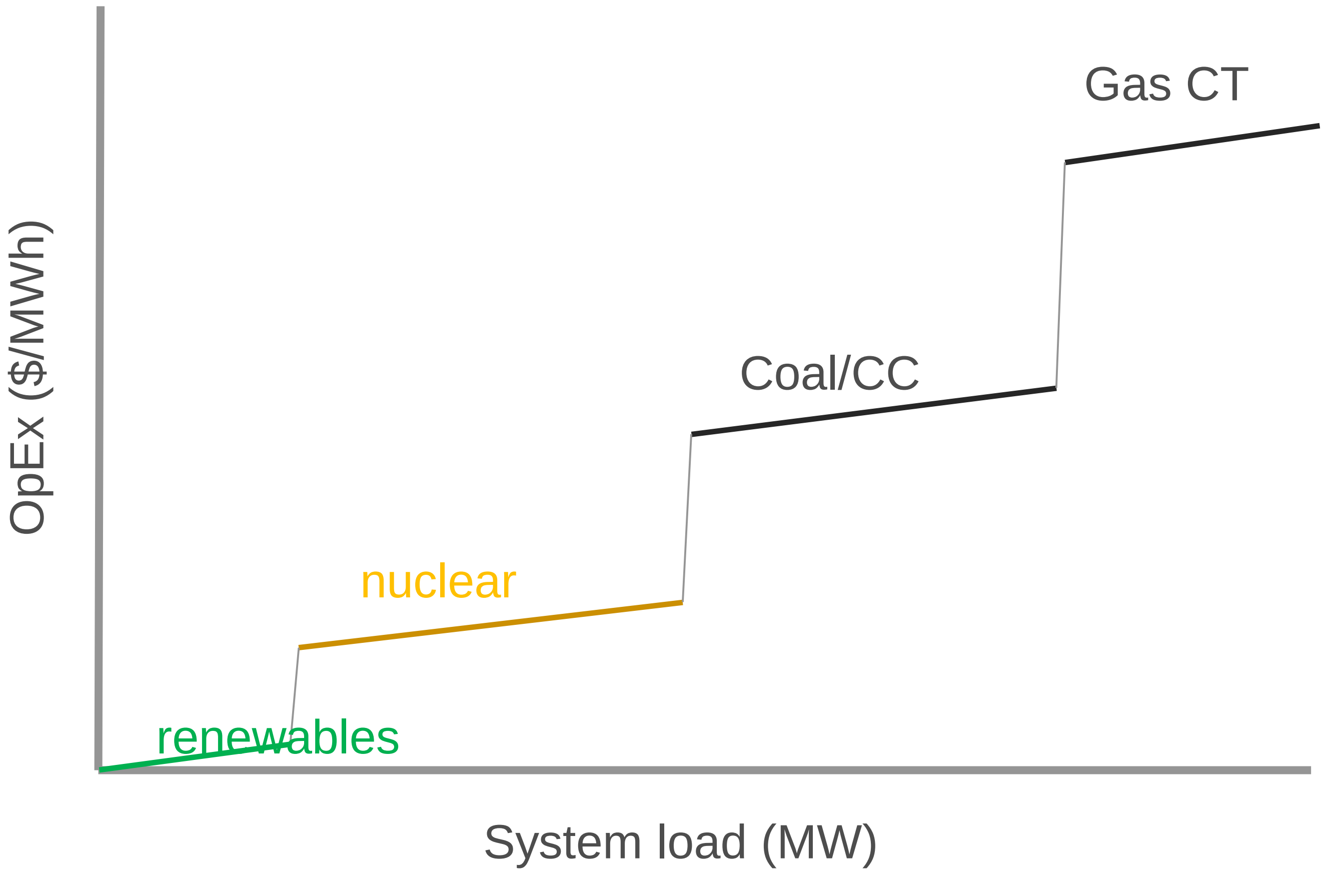

**Wind**



# Renewables mis-matched with seasonal demand

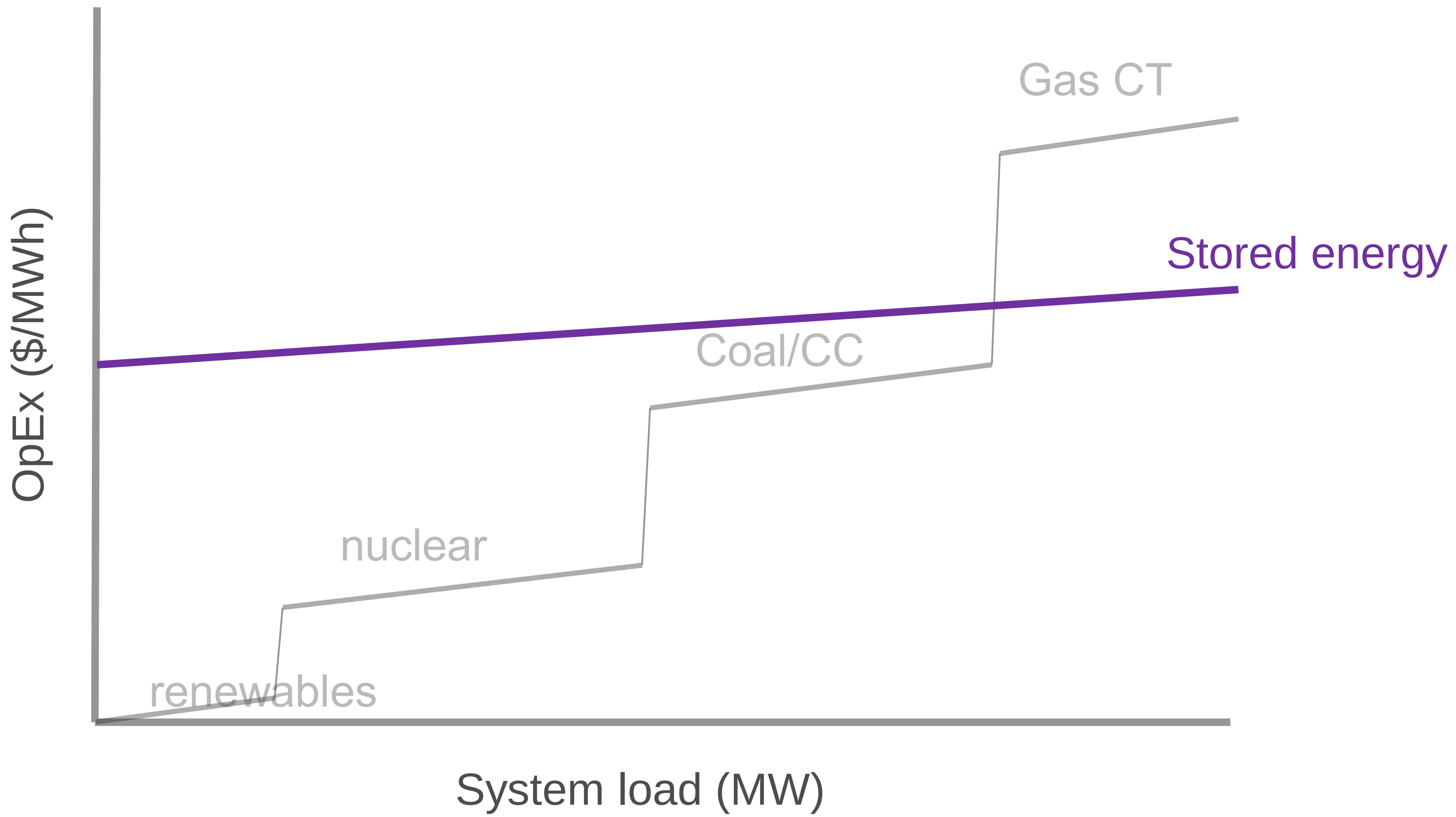


# Electricity is generated according to dispatch curve.




- When renewables are available, they displace generation from coal/CC/CT.
- When renewables are unavailable, coal/CC/CT is dispatched using energy stored at the plant (coal pile).
- “Coal pile storage” is cheap and energy dense but operationally challenging.

# Sufficient grid energy storage can shrink capacity needs and increase capacity factor.




- Units would dispatched to support average energy needs
- Renewables are maximized as intermittency covered
- Capacity factors are increased
- Susceptibility to fuel price volatility diminished

# Grid Energy Storage Options

| Technology | Round Trip Efficiency | response time | Scalability | |
|---|---|---|---|---|
| Batteries | 95% | seconds | linear | *small applications* |
| Pumped Hydro | 75% | minutes | volumetric | *geographically limited* |
| Compressed Air | 25-70% | minutes | volumetric | *may require pre-heating* |
| 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 | |

***Options to store, move, or sell***

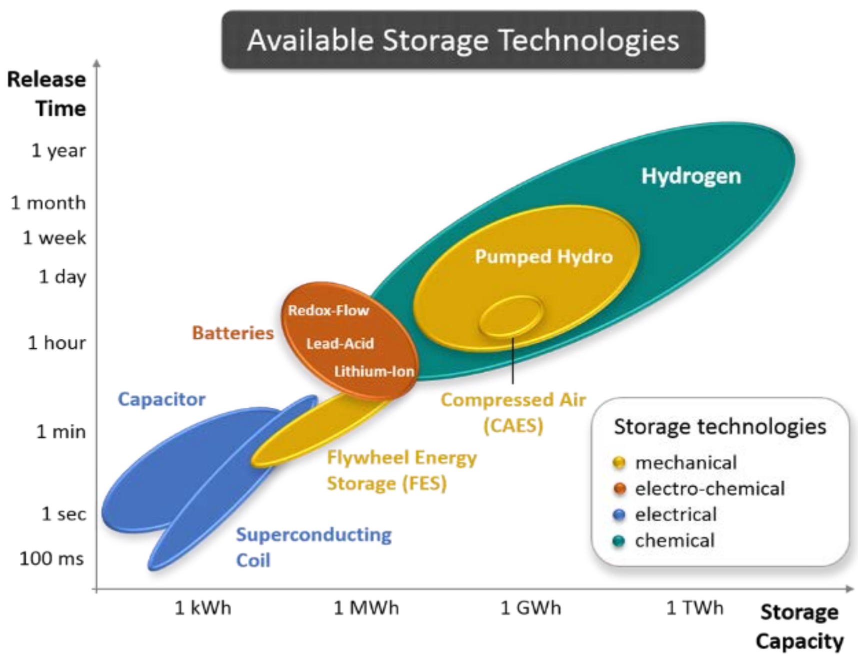
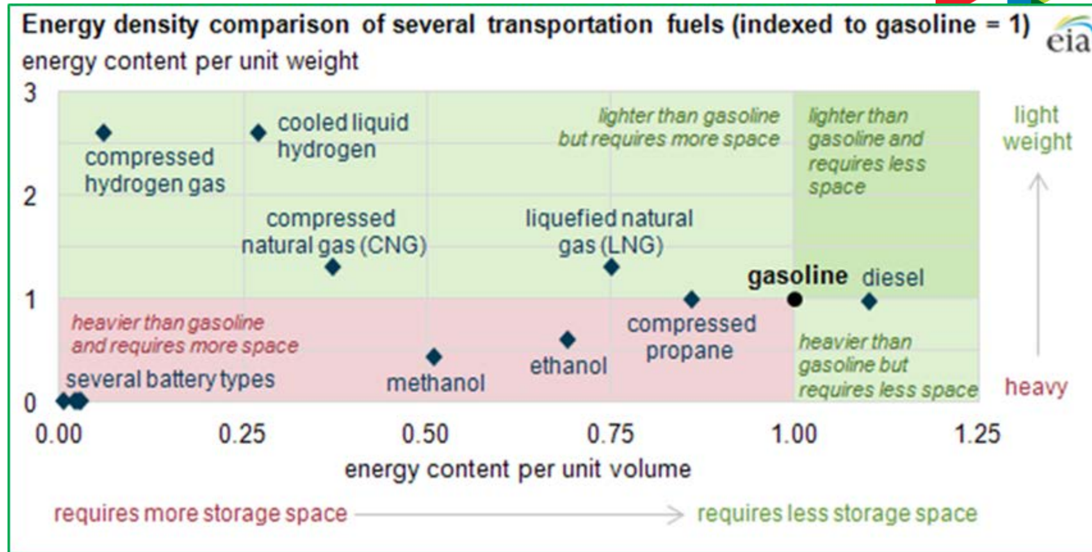



*Figure 1: Energy Storage Technologies, Capacity, Timescale, and Applicability (Source: Hydrogenious (www.hydrogenious.com))*

# 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)

# Even today, hydrogen can decarbonize transportation.

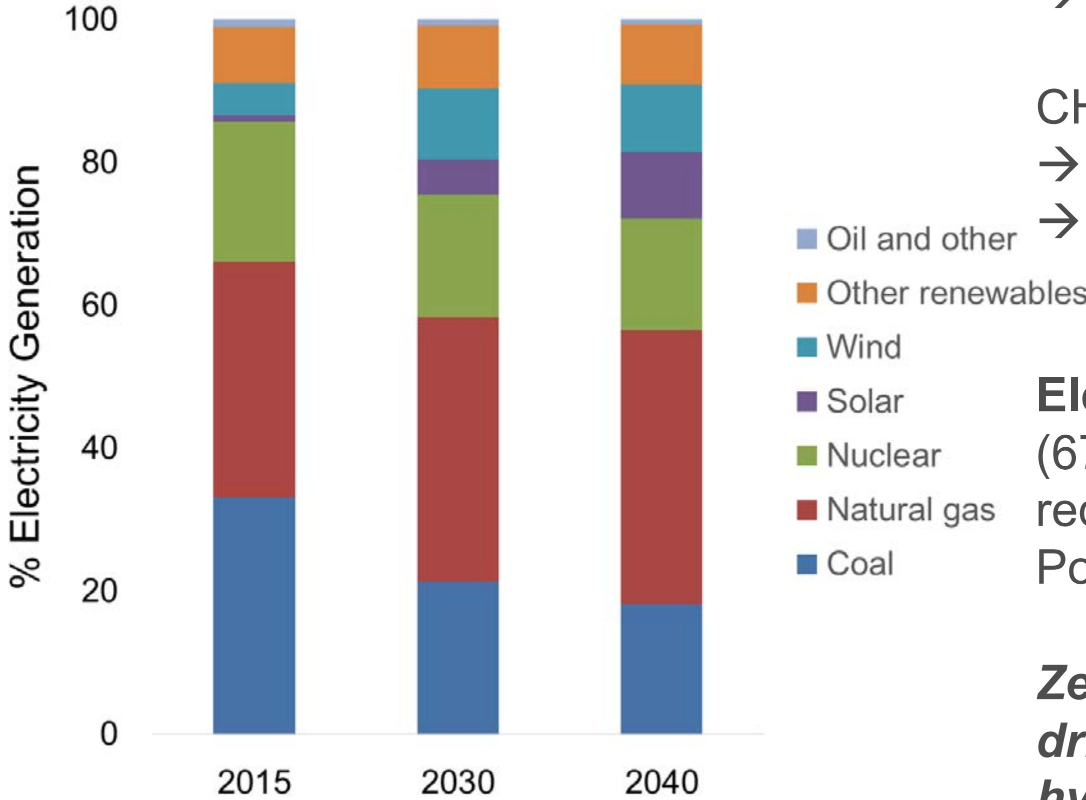
- FCEV may allow for decarbonization of additional vehicles that would not switch from fossil to BEV.
- Hydrogen in the near-term may be produced from steam-methane reforming (SMR).

| Energy Source | Energy Carrier | $CO_2$ emissions ($lb\ CO_2/kWh_e$) |
|---|---|---|
| 100% Coal | Electrons | 2.1 |
| 100% Natural gas | Electrons | 1.22 |
| 33% coal 33% gas 33% non-carbon (EIA 2015) | Electrons | 1.1 |
| 100% natural gas | Hydrogen | 1.33 |

*assume 50% thermal to electrical efficiency for hydrogen fuel cell

# Hydrogen generation 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 $CO_2$
→ 2550 $BTU_e$/lb $CO_2$

$CH_4$ combustion
→ 8500 $BTU_{th}$/lb $CO_2$
→ 4250 $BTU_e$/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 energy is required to drive carbon benefits from hydrogen economy.***

# Zero-carbon energy options

**Renewables**

- Poor energy density
- Intermittent
- EROI varies geographically
- Low OpEx

**Fossil with CCS**

- Good energy density
- Abundant infrastructure
- Dispatchable
- Requires long-term, large-scale $CO_2$ sequestration
- Variable/high OpEx

**Nuclear***

- High energy density
- Dispatchable
- Waste recycle/storage required
- Low OpEx

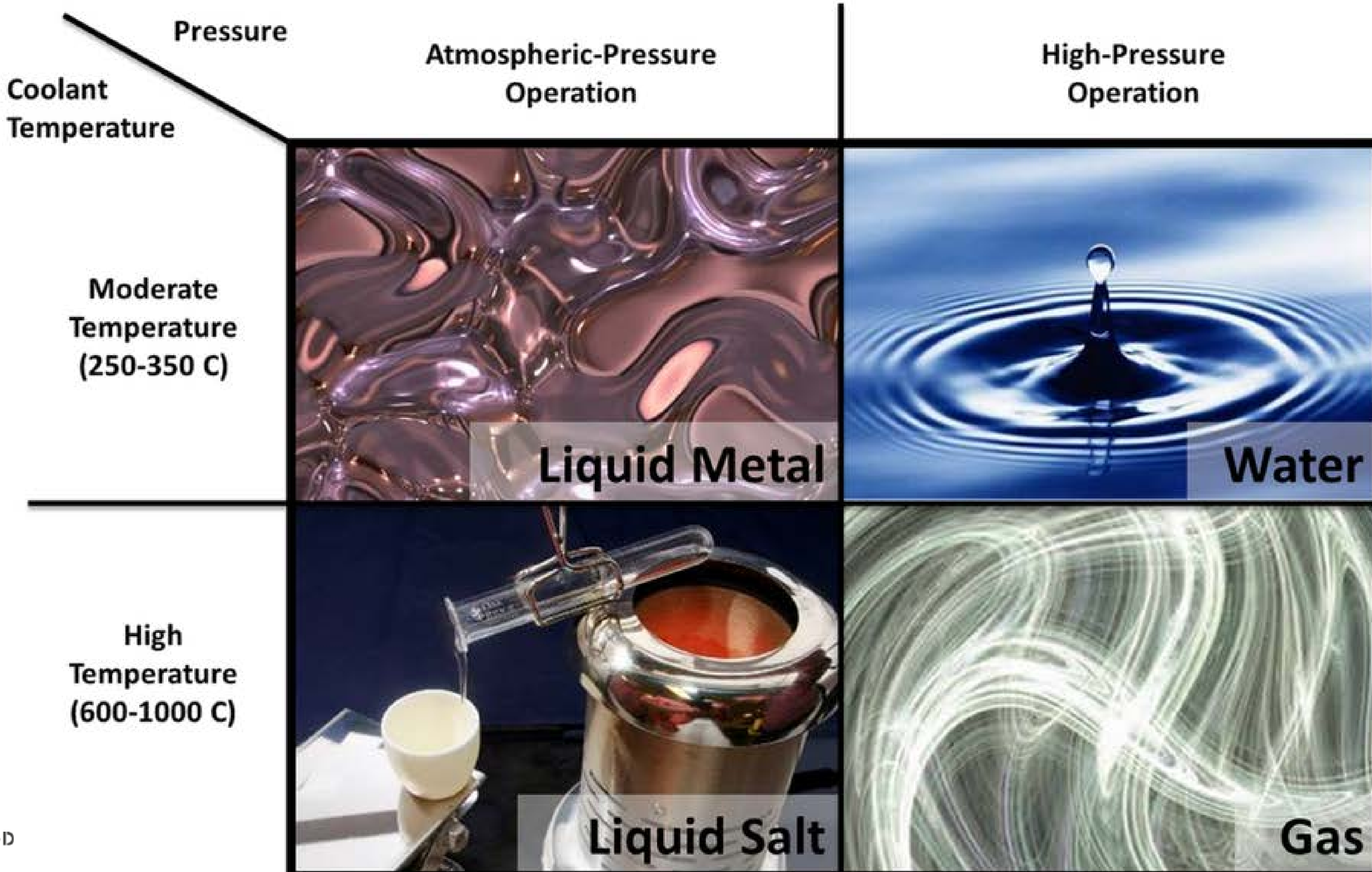
## Nuclear Reactor Design →

| | | |
|---|---|---|
| Fast | | Thermal |
| Breeder | vs | Burner |
| Liquid Fuel | | Solid Fuel |
| Thorium | | Uranium |

COOLANT CHOICE

Salt, Water, Gas, Metal

# COOLANT CHOICE



# Advanced Reactor Features

| | High temperature | Low pressure | Online refueling | Sustainable fuel cycle | High power density | Cooled with natural convection | Complete walkaway safety | Ever been built before |
|---|---|---|---|---|---|---|---|---|
| LWR | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ |
| HTGR | ✓ | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ |
| SFR | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| MCFR | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |

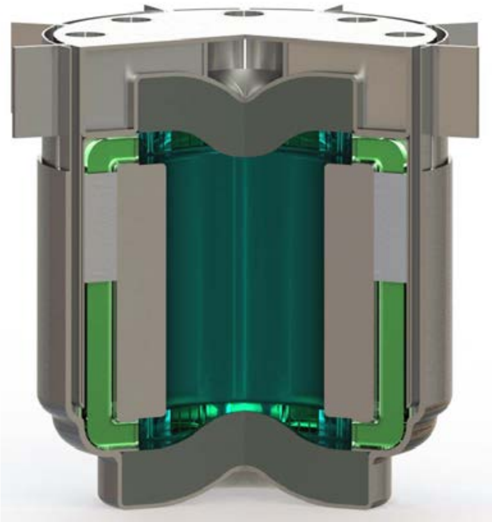
R+D

# Advanced Nuclear Research

- SCS Selected for $40M DOE Award - Molten Chloride Fast Reactor (MCFR)

- Project will answer key technical questions related to the development of MCFR
  - Demonstrate the relevant phenomena and operations (electrically heated ~2MW)
  - Prepare license application ~30MW Test Reactor

- MCFR meets Southern's goals of Clean, Safe, Reliable, and Affordable energy for the foreseeable future



TerraPower

EPRI

Oak Ridge National Laboratory

Vanderbilt University

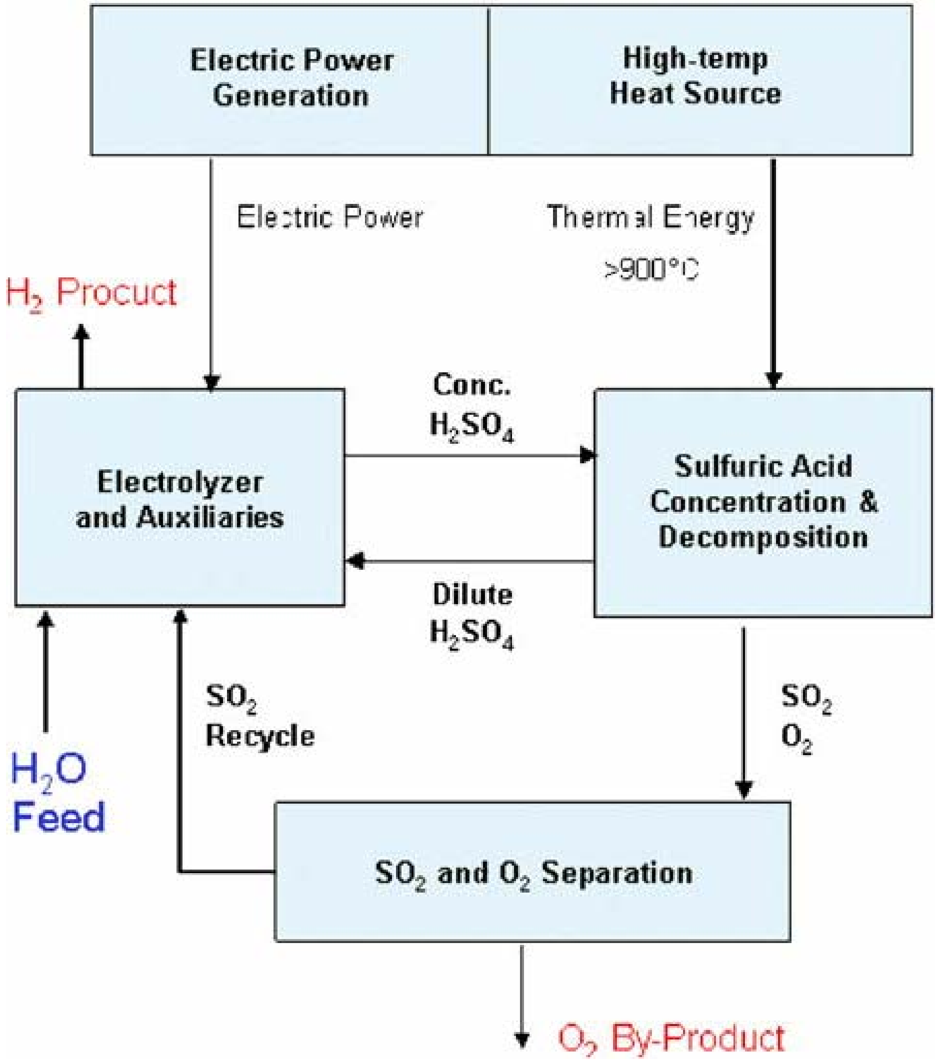
# Thermochemical Water Splitting

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

mediated by thermochemical cycle

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

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

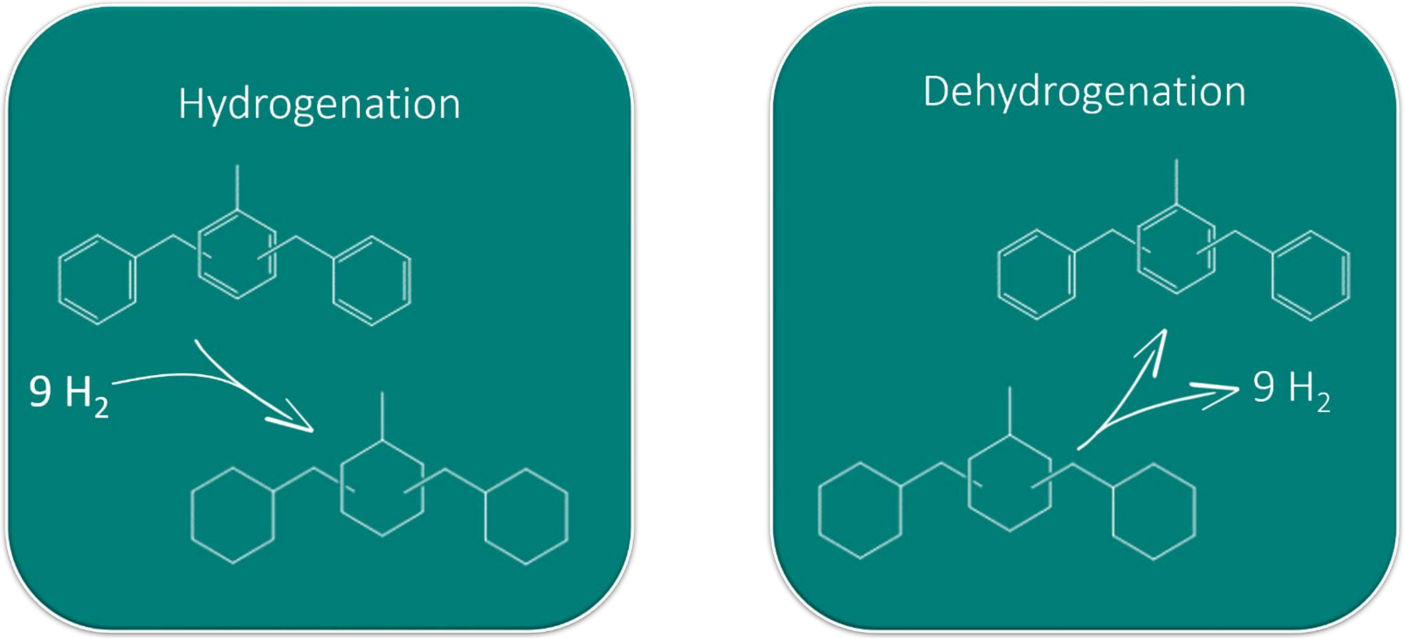


# Liquid Hydrogen Carriers

| | 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 |

- Increased volumetric energy density using carrier molecule
- More amenable to existing infrastructure
- Heat integration to improve efficiency

# Hydrogenious (LOHC) Process




- No molecular hydrogen stored
- High storage capacity of 6.23 wt% (630 $Nm^3$ $H_2$ /$m^3$ LOHC)
- Storage medium is dibenzyltoluene – liquid organic hydrocarbon
- Low flammability and non-explosive – even when loaded with hydrogen
- Fully reversible loading and unloading of LOHC material possible
- Storage and transport in commercially available diesel-tanks possible

# Hydrogen Research Efforts

- CRADA with Savannah River NL on Hybrid-sulfur process
- Developing framework around thermochemical cycles paired with MSR (URS/AECOM)
- Dehydrogenation of liquid organic hydrogen carrier (LOHC) demonstration
- Ongoing discussions:
  - Mitigating California duck curve with electrolysis
  - Southeast-based electrolyzer demonstration
  - DOE roadmapping for thermochemical hydrogen
  - Methanolysis demonstration
  - EPRI-led hydrogen utility demonstration
- Ongoing in-house work:
  - Valuation of hydrogen based on drivers
  - Technology assessments
- Key Collaborators: DOE FCTO, DOE NE, DOE ARPA-E, NREL, SRNL, EPRI, UC-Irvine NFCRC, IEA HIA, electrolysis companies (Proton), fuel cell companies (Versa Power), Auto OEMs

# Conclusions

- Hydrogen is flexible energy storage medium with the opportunity to maximize renewable penetration
- Nuclear is an important zero-carbon energy source
- Advanced nuclear has additional advantages including high-temperature heat for thermochemical water splitting
- Hydrogen or liquid $H_2$ carriers allow for high density energy transmission
- Hydrogen can decarbonize transportation and couple transportation energy to primary energy sources handled by utility
- SCS is leading industry with studies and pursuing industry-led demonstrations

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