Southern Company

Research & Development

Hydrogen and Energy Storage

Noah D. Meeks, Ph.D.
SCS R&D

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Goals and actions for a low-carbon future

We are setting a long-term goal of low- to no-carbon operations by 2050 on an enterprise-wide basis. On our path to 2050, we have set a goal of 50 percent reduction from 2007 levels in CO_2 emissions by 2030. Achievement of these goals will be dependent on many factors, including natural gas prices and the pace and extent of improvements in energy technology.

Metrics and goals – GHG emissions reductions

Hydrogen mitigates multiple issues in a low-carbon transition.

"A low-carbon future will require developing new and more cost-effective energy conversion, delivery and use technologies. Our R&D strategy seeks at least six revolutionary technological successes:

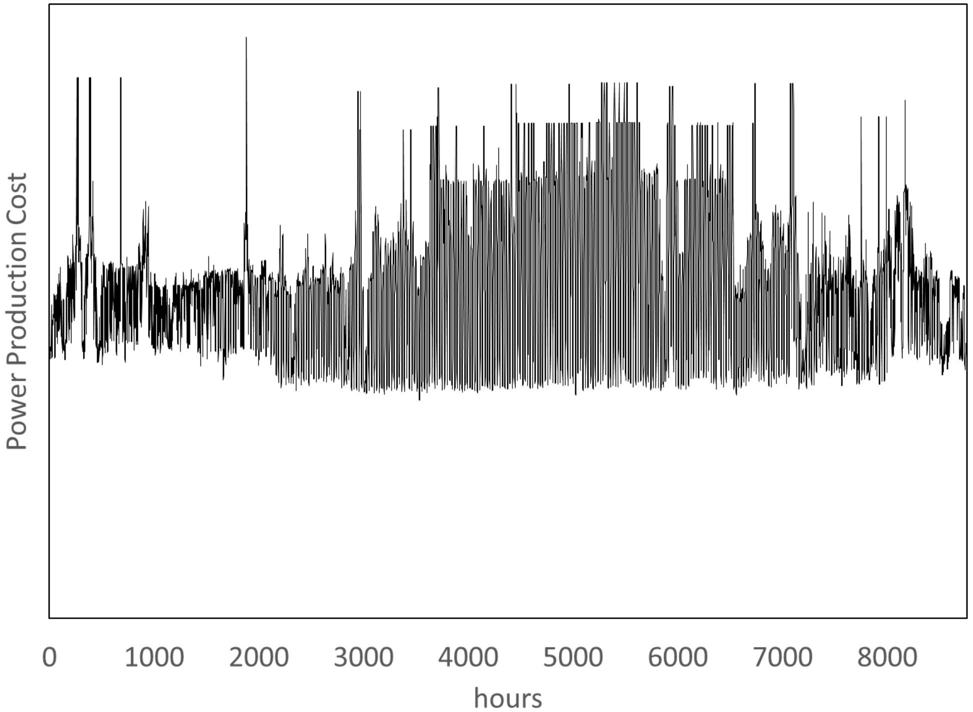
- beneficial electrification
- carbon-free energy resources
- integrated energy delivery grids
- CCUS on natural gas
- ***hydrogen production, delivery and end-use technologies***
- advanced nuclear power generation and polygeneration

Energy Storage	• Enables effective utilization of intermittent generation • Declining capital costs	• High capital cost • Limited storage capacity
Electric Transmission & Distribution	• Increases power transmission capabilities	• Siting and permitting constraints for new infrastructure
Local Natural Gas Distribution	• Abundant supply • Existing infrastructure	• Needs additional infrastructure
Midstream Natural Gas Transmission	• Abundant supply • Opportunity to provide pipeline expansion	• Siting and permitting constraints for new infrastructure

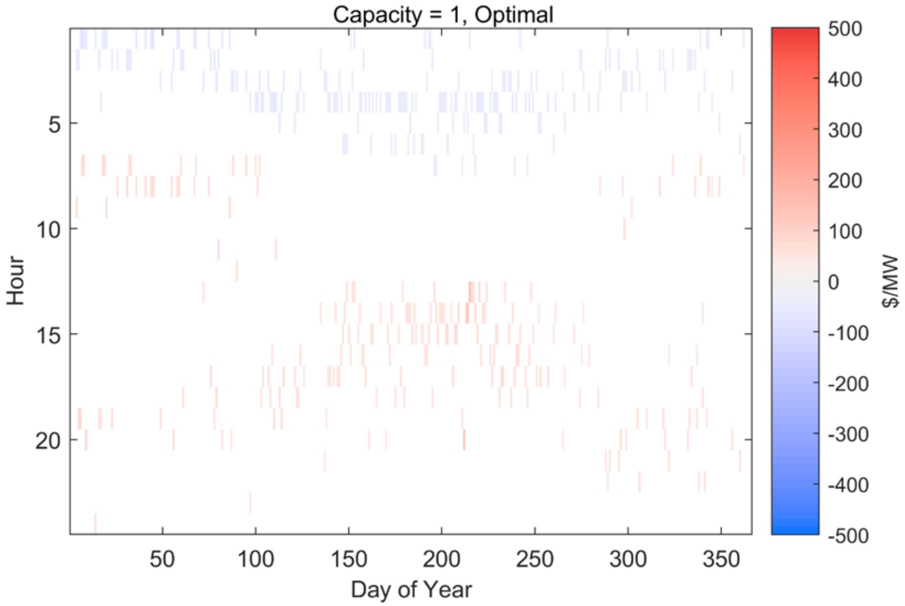
Hydrogen can mitigate these "cons" of battery-based energy storage.

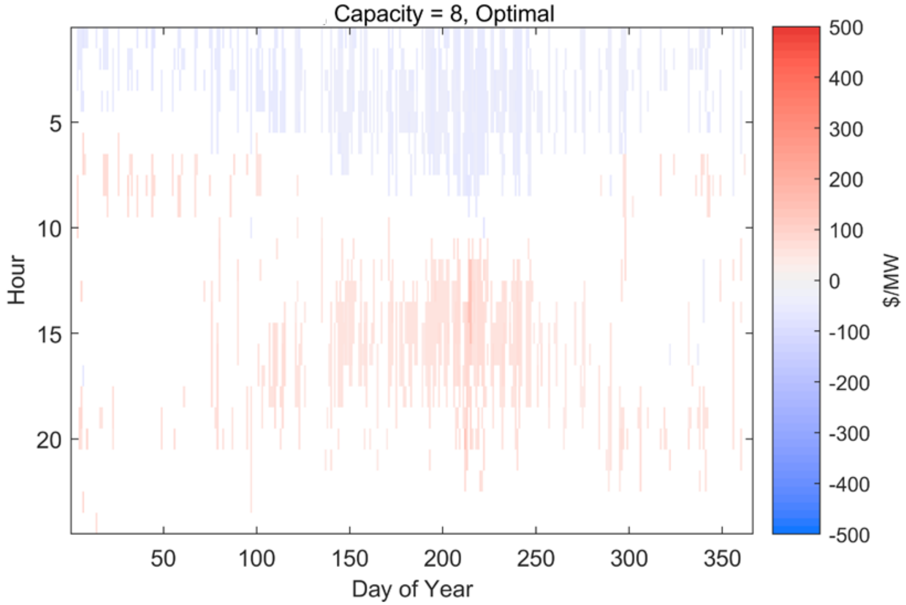
New infrastructure can be built compatible with hydrogen.

Valuation of Hydrogen Energy Storage in High Marginal Cost Scenario



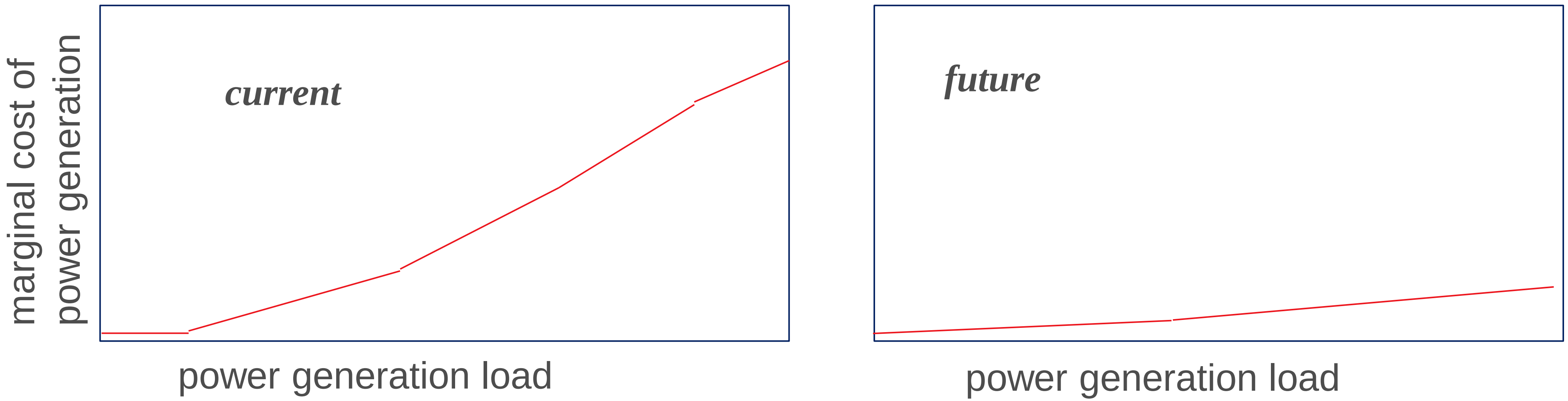
- *Frequent price changes give storage opportunities.*
- *“Real” power prices often more volatile than projected costs.*
  - *Potentially this gives more opportunity than conventional planning process recognizes.*
- *Accurate daily generation forecast required to realize storage opportunities.*
- *High capacity (such as hydrogen energy storage) gives more profit opportunity.*





Storage with 50% round-trip efficiency

Value of energy storage in a renewables/nuclear future



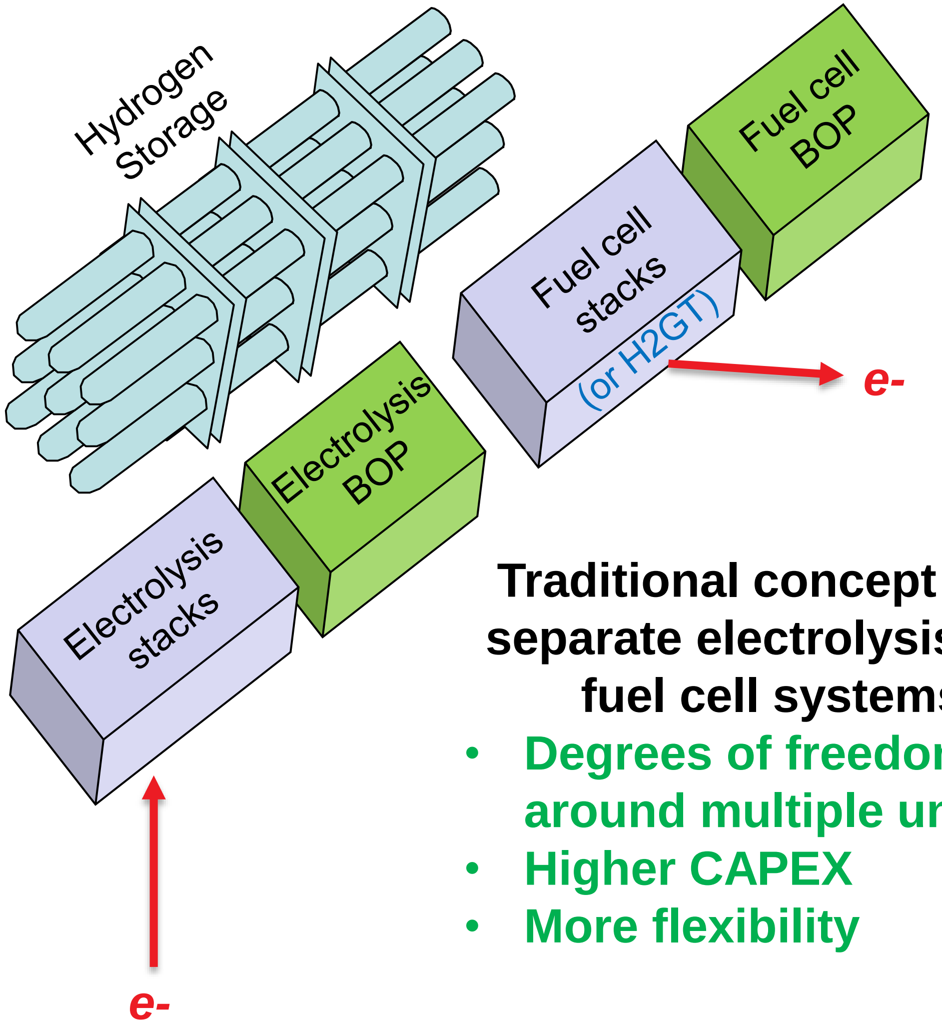
- Renewables and nuclear have low-to-no marginal cost of power

- Available capacity can be deployed but above capacity, demand would be limited.
  - Could be especially challenging in winter mornings and summer afternoon ramps

- Value of storage would be as a firm capacity resource vs additional generation

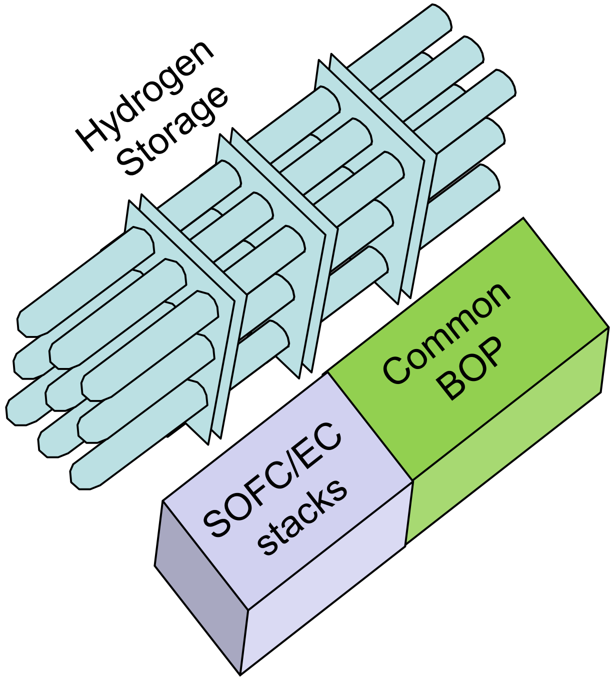
- Results in storage having **low arbitrage value** but **high capacity value**

Hydrogen based energy storage presents multiple degrees of freedom for optimization.



Traditional concept with separate electrolysis and fuel cell systems

- **Degrees of freedom around multiple units**
- **Higher CAPEX**
- **More flexibility**



SOFC/SOEC Concept

- **Lower CAPEX**
- **Simplified operation**
- **Less flexibility**

Storage and Transport of Hydrogen

Concept	Hydrogen Storage Concept	Hydrogen Evolution Concept
Compressed hydrogen	H_2 → H_2 compressed	H_2 compressed → H_2
Liquefaction	H_2 → H_2 (l)	H_2 (l) → H_2
Solid-state storage	H_2 + Metal (M) → M-H	M-H → M + H_2
Liquid carrier	H_2 + Organic → Organic-H	Organic-H → Organic + H_2
Open carrier	H_2 + Gas → Gas-H	Gas-H + O_2 →H_2O + Gas-O
Reactive metal	H_2 + MO → M + H_2O	M + H_2O → MO + H_2

- Need to balance efficiency, safety/materials, and volume/size of installation.
- LOHC and ammonia are known chemicals compatible with some existing infrastructure.
- CO_2 footprint of transport mode should be considered.

	Liquid Carrier Concept	Open Carrier Concept
Advantages	• Endothermic step at point of carrier consumption • Carrier generated from concentrated reactants • Generally non-toxic and non-corrosive	• No regeneration of hydrogen; carrier used directly in application • No return of liquid carrier required
Disadvantages	• Return of liquid carrier is required	• Often based on reaction with dilute atmospheric CO_2 • Endothermic step at point of carrier generation • Generally corrosive and/or toxic carriers

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Large-scale storage of hydrogen needed for utility-scale power generation.

	Clemens Dome	Moss Bluff	Spindletop
Geology	Salt dome	Salt dome	Salt dome
Operator	ConocoPhillips	Praxair	Air Liquide
Year	1983	2007	
Volume (m3)	580,000	566,000	906,000
Mean depth (m)	1,000	1,200	1,340
Pressure range (bar)	1,015-1,986	797-2,204	986-2,929
H2 capacity (GWh)	81	123	274
H2 storage (tonnes)	2,400	3,690	8,230
Days of Storage for 1 GW H2CC (50% eff.)	1.7	2.6	5.8

Southern Company Gas Storage Assets	NG Capacity (BSCF)	NG Max Flowrate (MSCFD)	H2 Capacity (GWh)	Days of Storage for 1 GW H2CC (50% efficient)
Jefferson Island Storage & Hub (Erath, LA)	6.98	698.4	250	5.2
Golden Triangle Storage (Beaumont, TX)	13	600 out (300 in)	465	9.7

Cross-sector coupling of hydrogen demand

- Significant uncertainty in coupling of non-electricity hydrogen demand with electricity demand.
  - Would this minimize renewables curtailment?
  - Would price be set by higher-value hydrogen uses?
    - transportation
    - chemical feedstock

- Stored hydrogen combined with an infrastructure to distribute it, allows a utility to potentially serve all energy demands:
  - electrical through central station and/or distributed power generation
  - thermal
  - chemical
  - transportation
  - Challenge is matching load sizes in co-gen scenarios.