Emissions Analysis of Electricity Storage with Hydrogen

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U.S. DEPARTMENT OF ENERGY

Overview

Timeline

- Start: Oct. 2010
- End: Oct. 2011
- % complete: 50%

Budget

- Total project funding from DOE: $200K
- Funding received in FY10: $0K
- Funding for FY11: $200K

Barriers to Address

- Evaluate energy and emission benefits of H_2 storage technologies
- Overcome inconsistent data, assumptions, and guidelines
- Develop models and tools
- Conduct unplanned studies and analyses

Partners (in-kind)

- NREL and other national labs
- Industry stakeholders

Relevance and Objectives

- Conduct life-cycle analysis of
  - Hydrogen as energy storage for integration of large renewable generation sources into the electric grid
  - Alternative energy storage systems
- Support and interact with stakeholders to address energy and environmental benefits of H_2 for energy storage applications

Approach

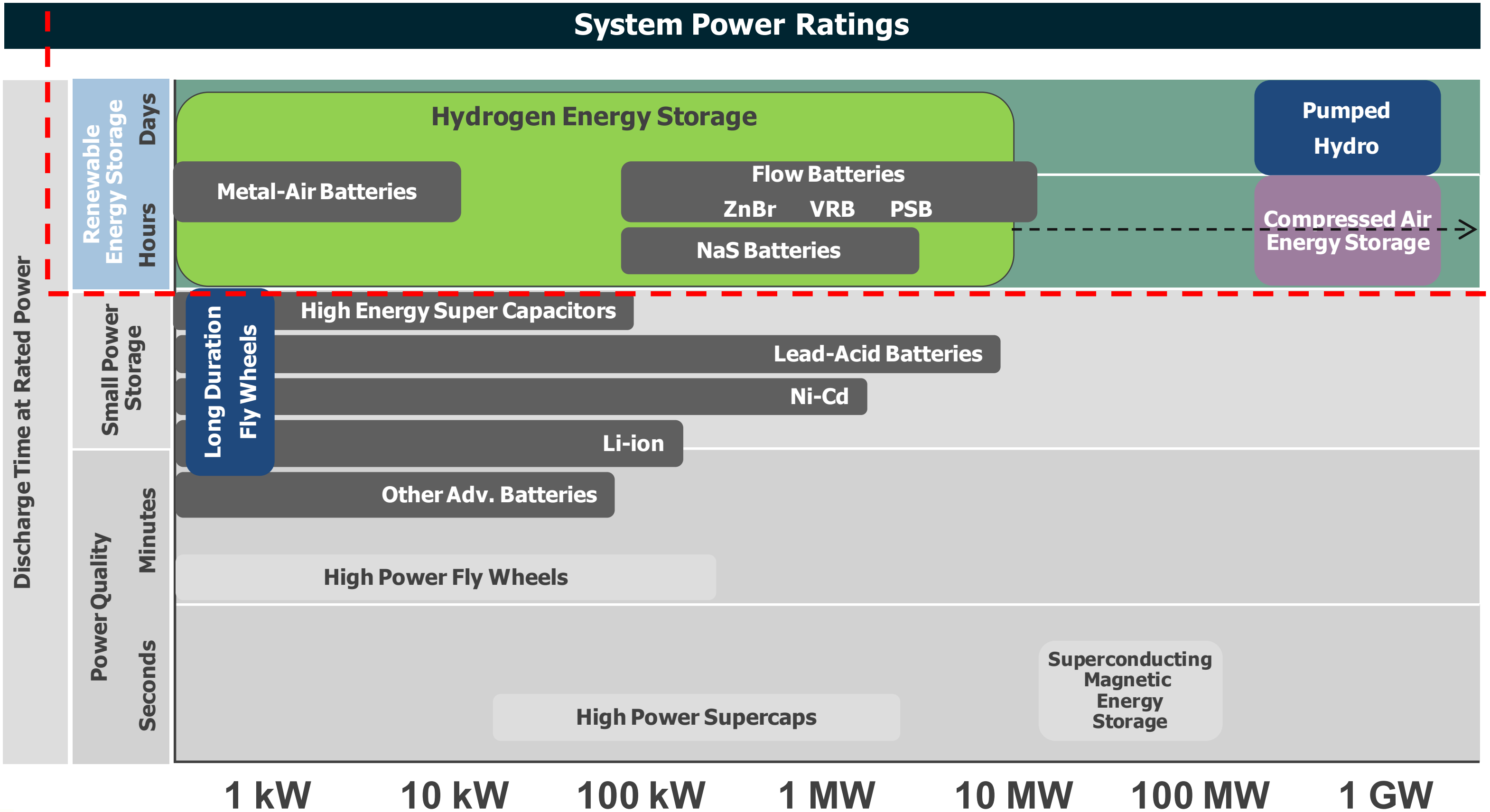
- Identify alternative energy storage systems for grid electricity
- Obtain data for H_2 and alternative energy storage systems
  - Open literature
  - Simulation results from other researchers and studies
  - Existing technologies and projects
  - Demonstration programs
- Conduct LCA
- Document the analysis and results

Key Milestones

1. Conduct fuel cycle analysis for different storage options for various utility regions **(COMPLETED)**
   - Determine the round-trip efficiency for each alternative storage system (AC $kWhe_{out\_of\_storage}$/ $kWhe_{into\_storage}$)
   - Determine generation unit(s) to be displaced by stored electricity
   - Assess the impact of "oxygen" as a co-product of hydrogen production via electrolysis
2. Evaluate the impact of the construction of energy storage facility **(IN PROGRESS)**

Power vs. Energy Storage Systems for Grid Electricity

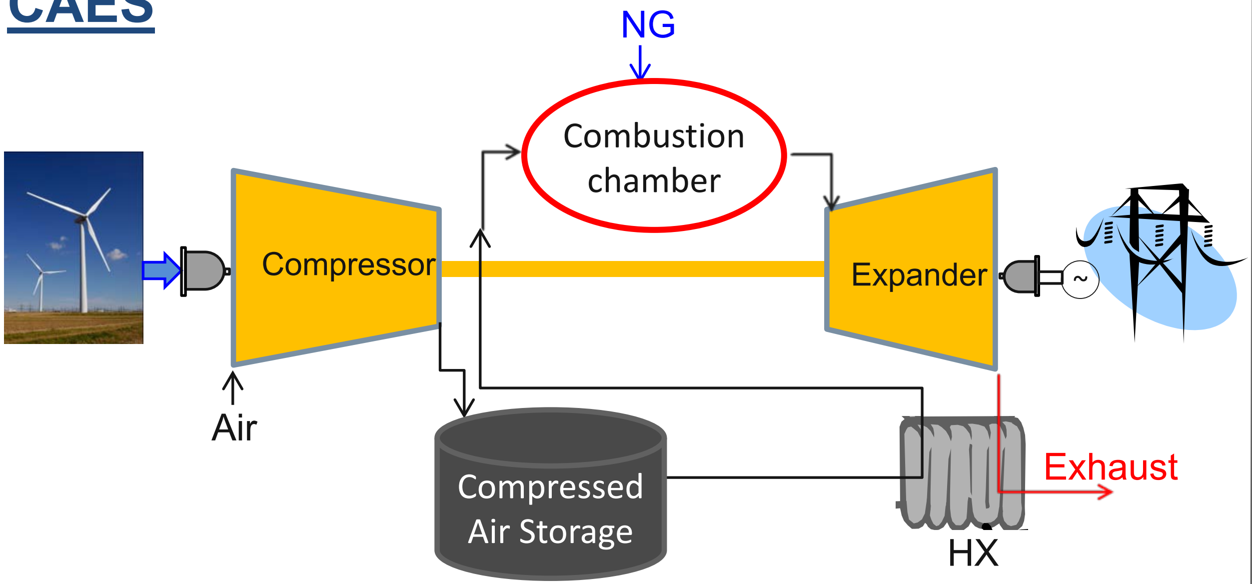
- Power applications require high power output but for short periods of time
- Energy applications are uses of storage requiring relatively large amounts of energy



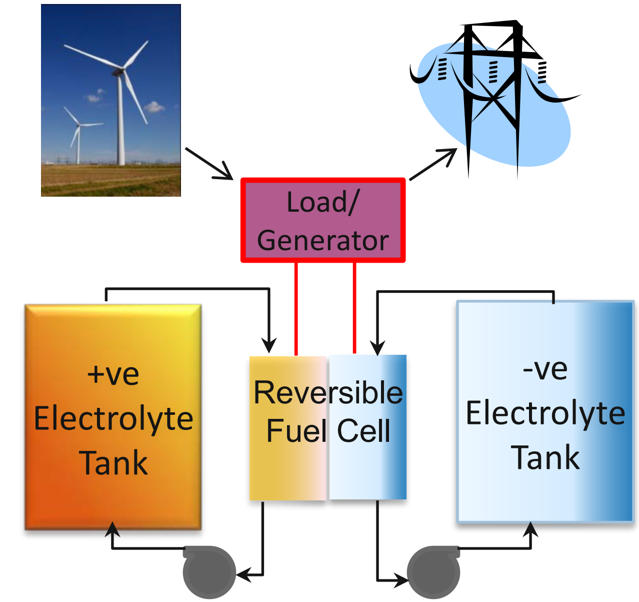
Source: Energy Storage Association)

Description of Alternative Energy Storage Systems

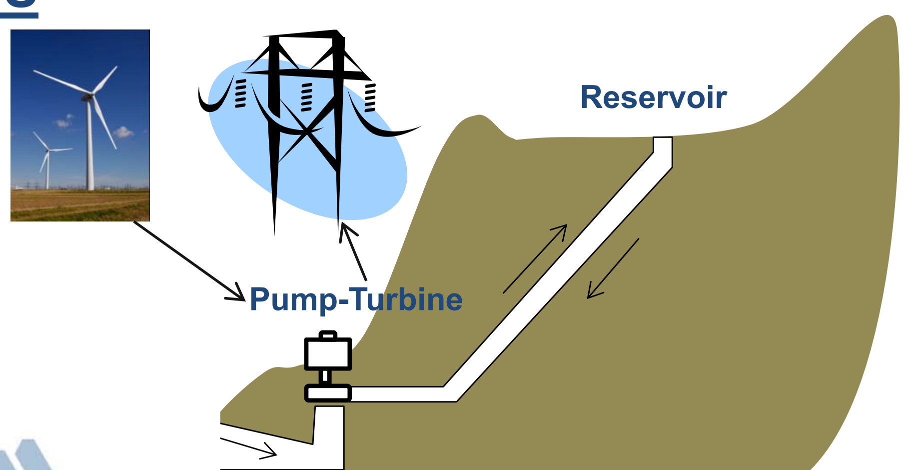
CAES



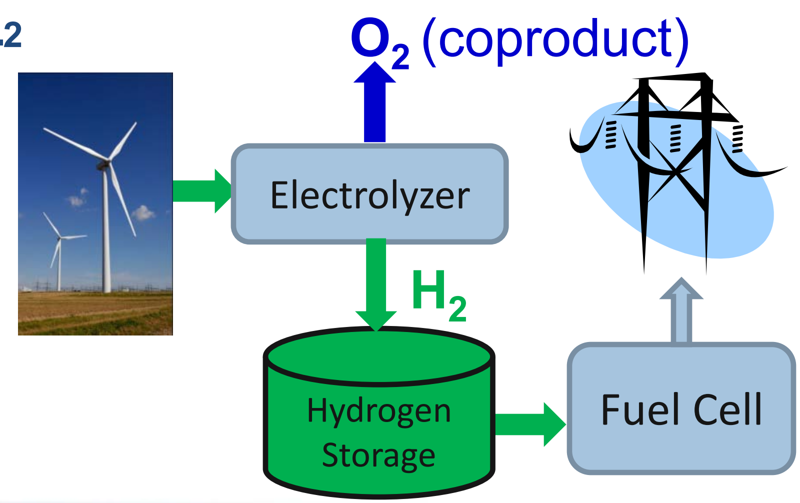
Batteries



PHS



H_2

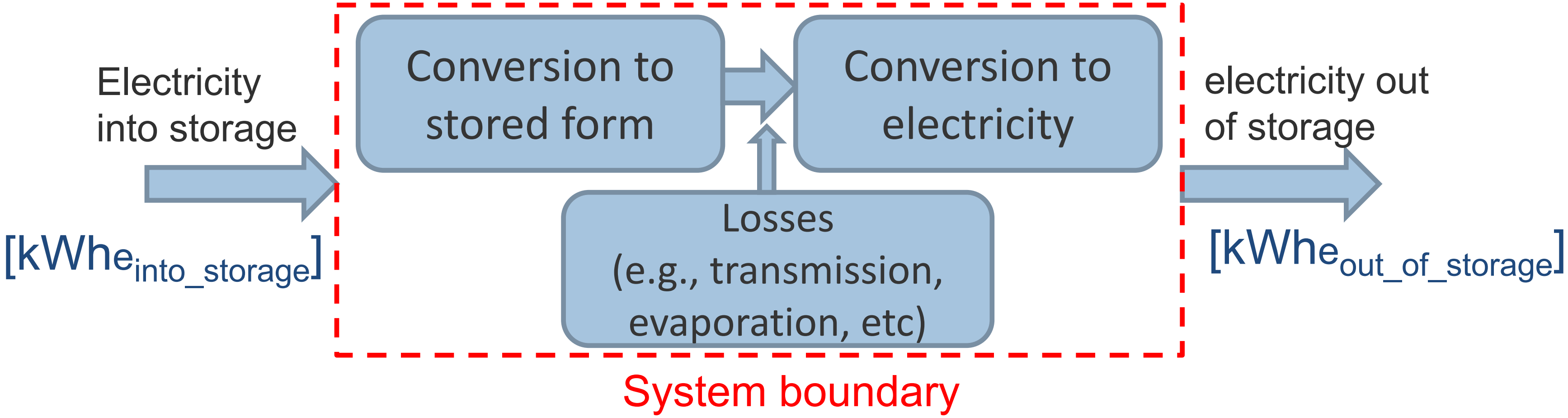


Pros and Cons of Alternative Energy Storage Systems for Grid Electricity

- Compressed air energy storage (CAES)
  - *Pros*: high round-trip efficiency
  - *Cons*: limited to geographically appropriate sites and slow response (~10 min)
- Pumped hydro storage (PHS)
  - *Pros*: high round-trip efficiency , fast response (2-3 min)
  - *Cons*: limited to geographically appropriate sites
- Batteries (electrochemical and flow batteries)
  - *Pros*: high round-trip efficiency, fast response and suitable for any geo. location
  - *Cons*: high cost and limited electrochemical storage discharge duration
- Hydrogen
  - *Pros*: high energy and power density and can be suitable for any geo. location. Also, fast response and unique opportunity with grid congestion
  - *Cons*: low round trip efficiency

Problem Definition and System Boundary

- Electricity recovered from storage will be tracked upstream to its source(s) for energy use and emissions calculations
- Generation displaced by electricity out of storage will be tracked upstream to its source(s) for energy use and emissions calculations
- Net energy and emissions will be calculated

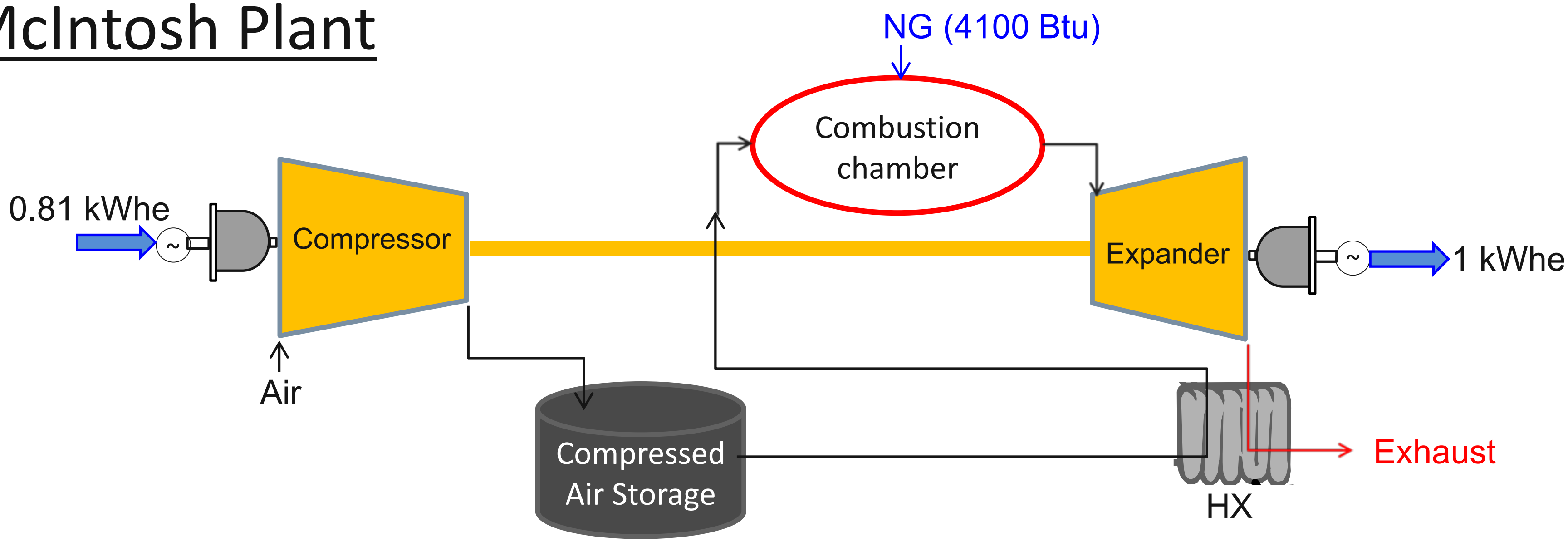


Electricity AC Roundtrip Efficiency (Critical to LCA Results)

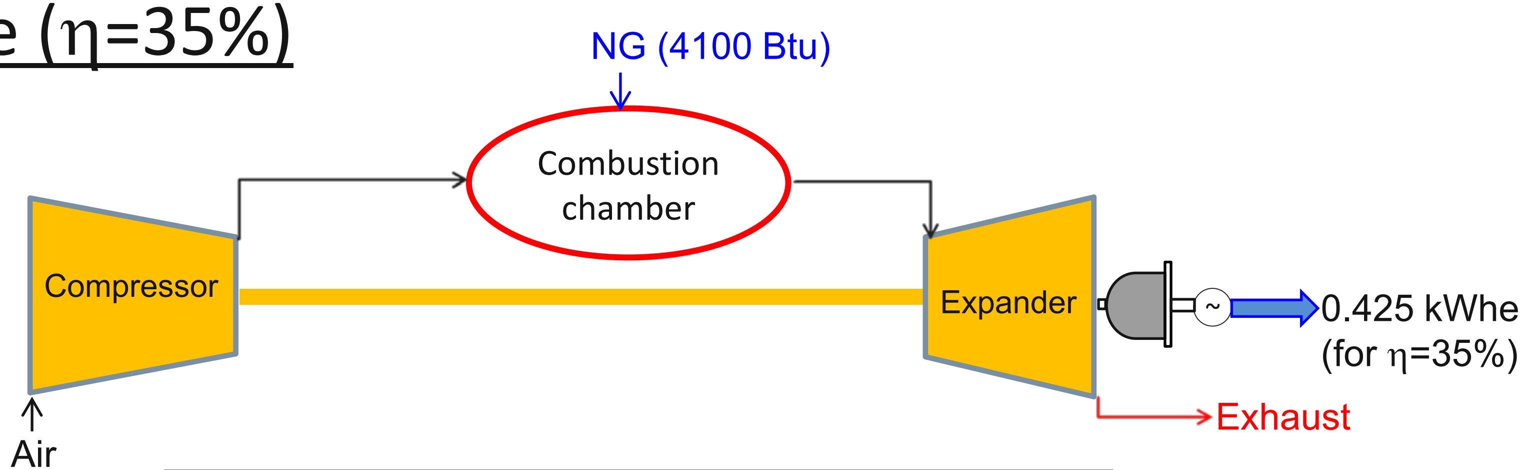
- Compressed air energy storage (CAES) → Not pure energy storage
  - 70-80%
    - ✓ 71%, calculated based on NG cycle with and without CAES
- Pumped hydro storage (PHS)
  - 70-80%
    - ✓ 74% based on data from nine PHS in the U.S.
- Batteries (flow batteries)
  - 70-80% for VRB (vanadium-redox batteries)
    - ✓ 74% based on three independent references
- Hydrogen
  - 30-35%
    - ✓ 34% based on NREL's 2009 report

Roundtrip Efficiency of CAES

McIntosh Plant

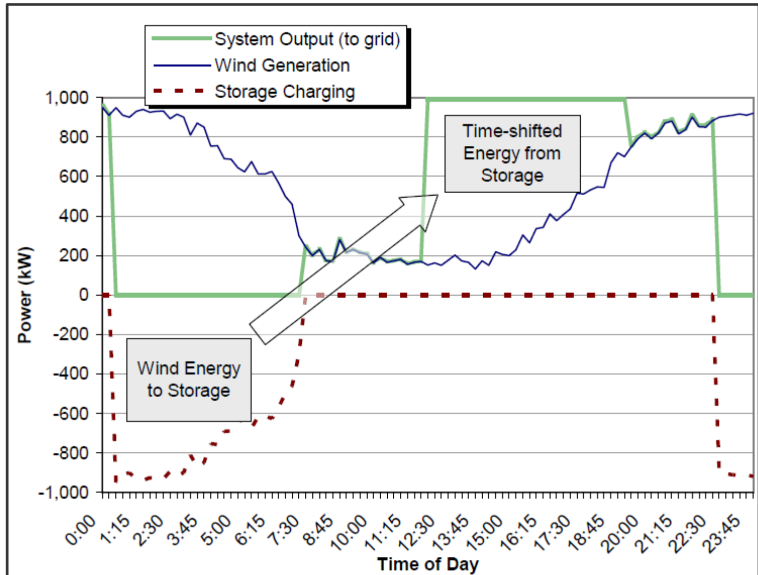


Gas Turbine (η=35%)



CAES RT efficiency = (1-0.425)/0.81 = 71%

What Generation Unit(s) To Be Displaced With Stored Electricity?



Source: A Study for the DOE Energy Storage Systems Program
By: Jim Eyer and Garth Corey, Sandia National Laboratory (February 2010)

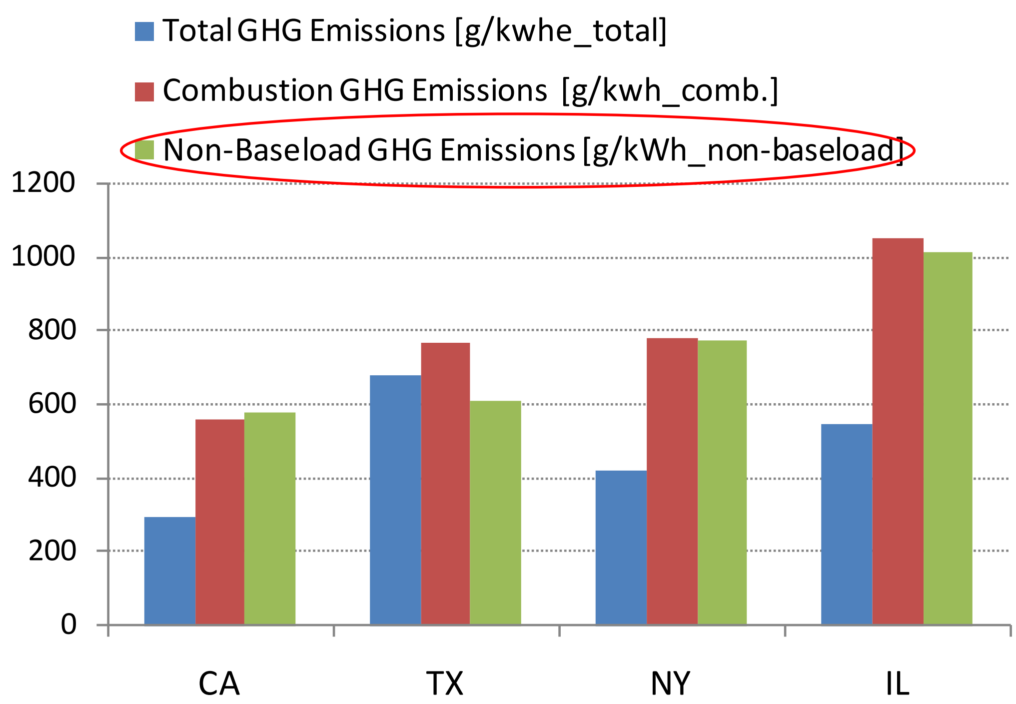
- ❑ Best done through hourly dispatch simulation
  - ➢ Location specific and requires detailed and complex simulations
  - ➢ Beyond the scope of this analysis
- ❑ Average fossil generation mix
  - ➢ Significant part could serve baseload (e.g., coal generation)
  - ➢ May be suitable for very high wind penetration
- ❑ Gas turbine generation (peak generation units)
  - ➢ May be suitable for small scale energy storage
- ❑ Non base-load generation
  - ➢ Available in EPA's eGRID database for different regions
  - ➢ Used for this analysis

Storage Energy Displaces Non Base-Load Generation

- Available in EPA's eGRID database for different regions
- Represents a slice of the total mix with a greater weight given to plants operating coincidently with peak demand
- Capacity factor is used as a surrogate for determining non-baseload mix of generation technologies
  - Combustion plants with capacity factor < 0.8
  - Weighted by capacity factor and generation output
- Provides an improved estimate over fossil fuel generation for emission reduction benefits from clean energy projects

Non Base-Load Generation For CA, TX, NY, and IL

- Represent regions with high renewable energy penetration in their RPS
- Represent regions with distinct mix of generation technologies



Region	Non-baseload GHG Emissions [g/kWh]*
CA	576
TX	611
NY	772
IL	1011

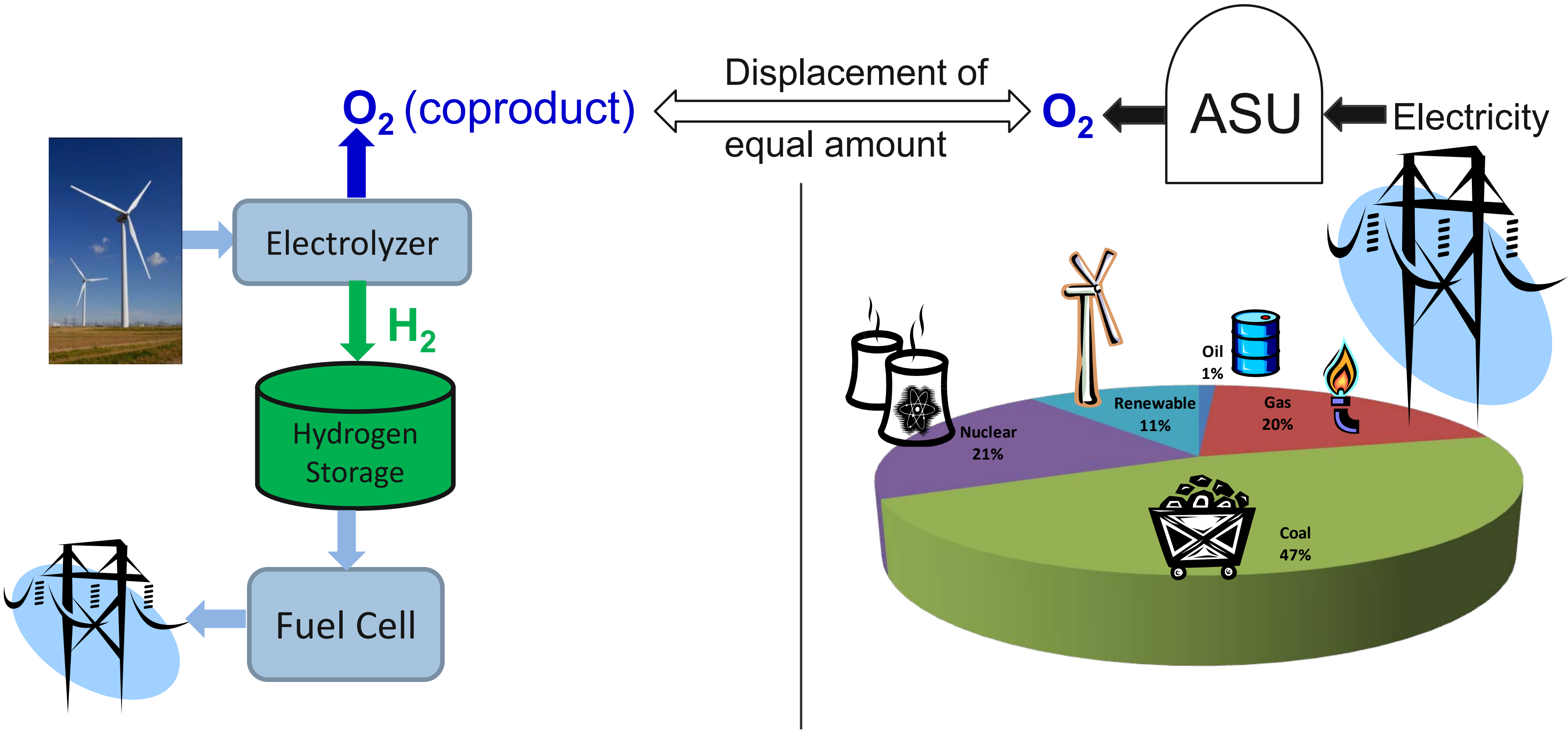
*Calculated based on EPA's eGRID 2007 (including upstream)

Oxygen As A Byproduct of Electrolysis

- Byproduct oxygen is a high value product with high purity
  - Purity > 99%
  - Used in medical facilities, steel production, semiconductor production, wastewater treatment plants, etc.
  - Significant amount is coproduced: 8 kg_{O2} for each kg_{H2}
  - Can displace oxygen conventionally produced in air separation units (ASU)

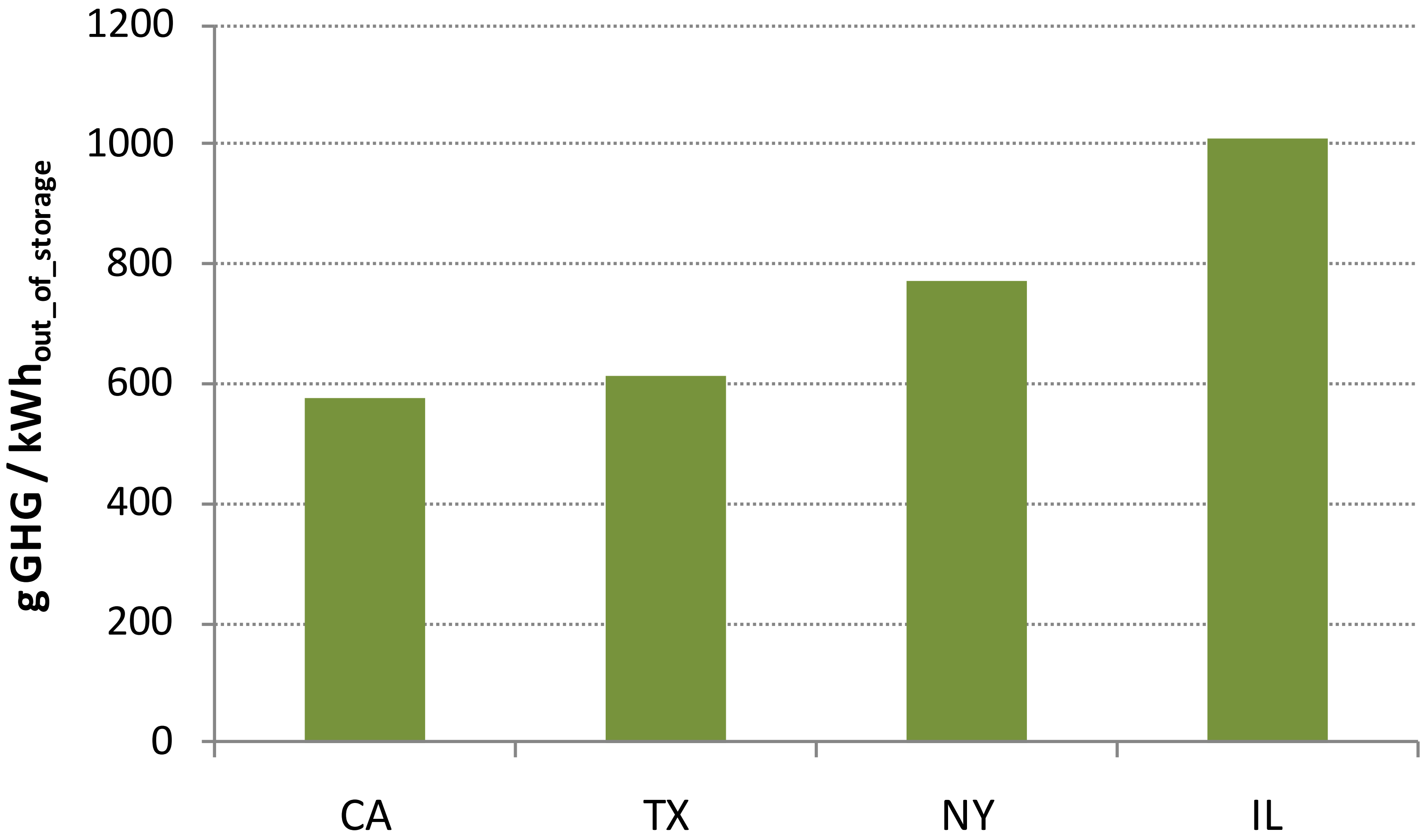
- 0.71 kWh of electricity is used in ASU to produce 1 kg of O_2 (only 0.165 kWh/kg_{O2} is used if allocated by mass with N_2)

Credit for Oxygen As a Byproduct of Electrolysis

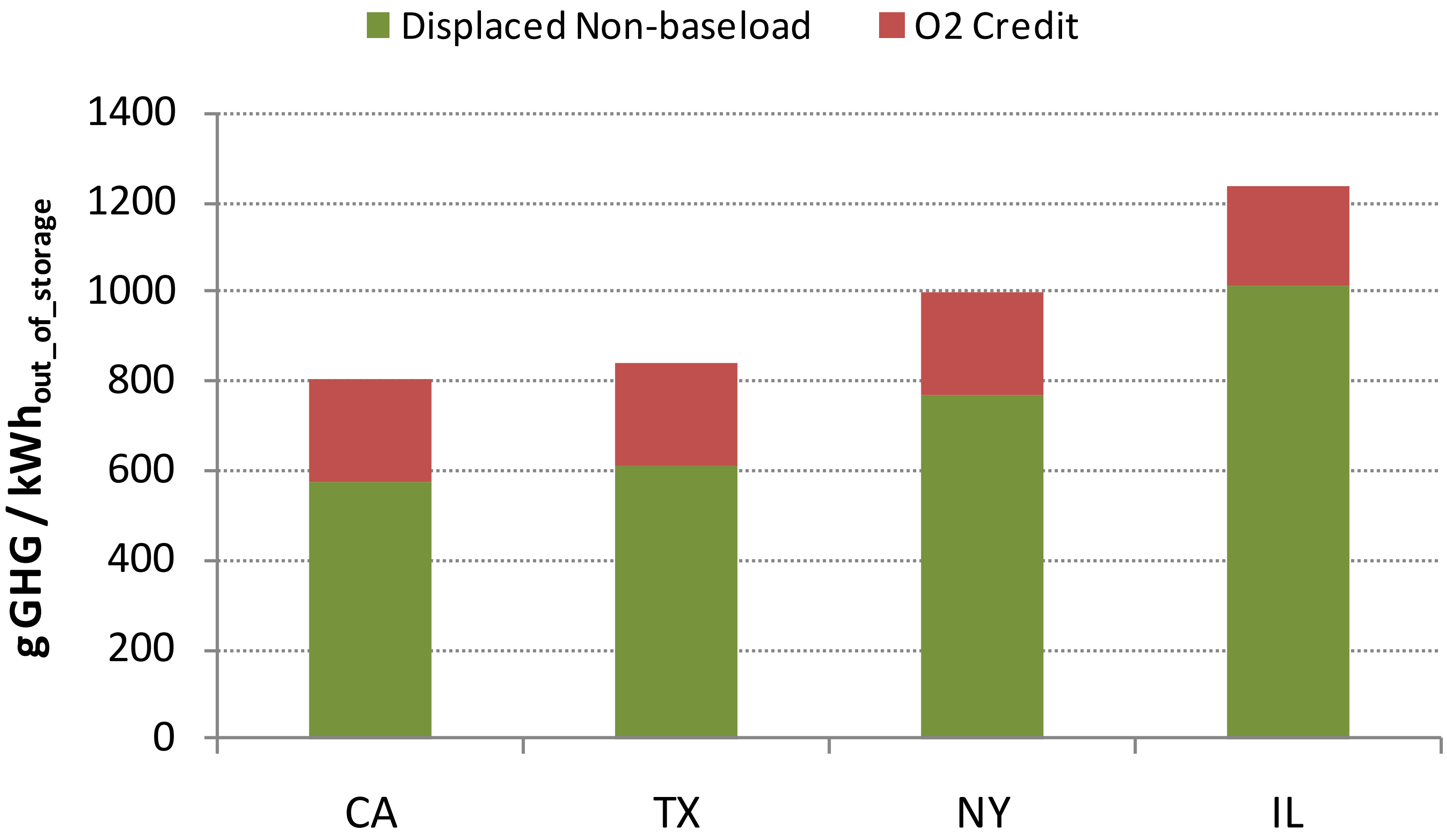


0.34 kWh (or 0.08 kWh if allocated) of electricity could be displaced by each kWh of electricity out of H2 storage

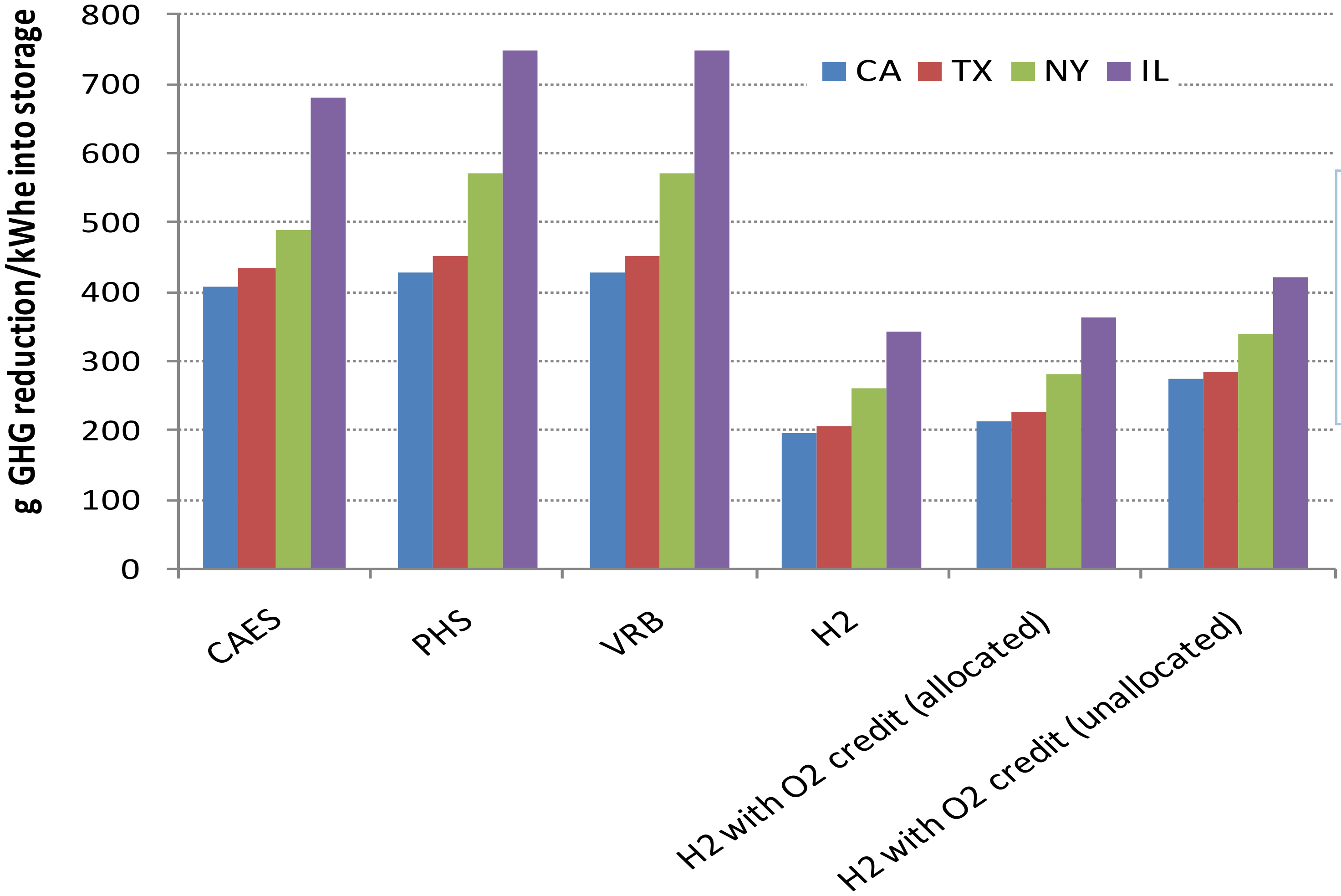
Potential GHG Emissions Reduction Using Any Storage System -By Region (per $kWh_{out\_of\_storage}$)



Potential GHG Emissions Reduction Using H_2 Storage -By Region (per $kWh_{out\_of\_storage}$)



Potential GHG Emissions Reduction By Region and Energy Storage Type (per $kWh_{into\_storage}$)



Not including energy storage construction emissions

Construction of Energy Storage Facility

- Total construction-related emissions divided by lifetime output of storage plant
  - PHS: reservoirs, dams (earth or rock-filled , concrete)
  - CAES: Land clearing and mine development, air compressors, heat exchangers
  - Batteries: Stack, power converter, cooling system, electrolyte tanks, housing structure
  - Hydrogen: Electrolyzer, compressor, storage, fuel cell

- ✓ Currently in progress
- ✓ Batteries are expected to produce greater GHG emissions
- ✓ Construction contribution is expected to be relatively small but not insignificant

Summary of Results

- Round-trip (RT) efficiency is crucial for LCA of energy storage systems
  - More GHG emissions reduction with increased RT efficiency
- Energy storage systems benefits are regional
  - Achieve greater GHG emissions reduction when displacing more carbon intensive generation
- O_2 byproduct credit associated with hydrogen storage system improves its competitiveness with alternative storage systems
  - Does not entirely close the gap with alternative storage systems
- LCA highlights the emissions benefits of alternative energy storage types
  - Emissions benefits should be viewed in conjunction with other economical and technological aspects unique to each technology option

Future Work

- Evaluate the impact of the construction of energy storage facility on LCA GHG emissions
- Documentation of analysis and results