DE-FE0032008: Hydrogen Storage for Load-Following and Clean Power: Duct Firing of Hydrogen to Improve the Capacity Factor of NGCC

FY22 FECM Spring R&D Review

May 5, 2022

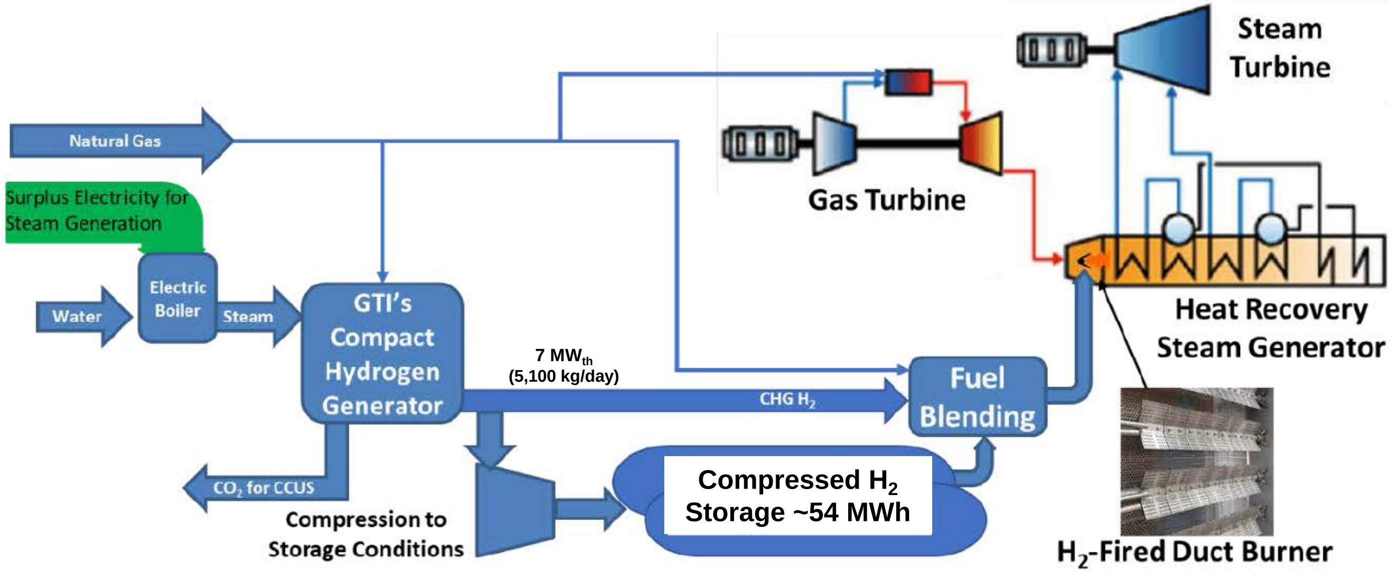
Project Partners

- GTI - Rich history in gas and energy supply, conversion, delivery, and utilization
  - Nearly 80 years of experience in managing energy research projects and has an annual research portfolio of over $150 million
- EPRI - Addresses challenges in the electricity sector including reliability, efficiency, affordability, health, safety, and environment
  - 48 years of experience energy research and has portfolios of programs related to coal & natural gas power generation systems, renewables (including storage), distributed energy, and end use
- Southern Company - Premier energy company with 46,000 MW of generating capacity
  - Nearly 200,000 miles of electric transmission/distribution lines & 80,000 miles of natural gas pipeline
  - One of the very few U.S. utilities with a vertically integrated R&D organization including the National Carbon Capture Center (NCCC)
- PG&E - Gas and Electric Power groups are keen in decarbonizing their fleet
  - Provide utility perspective on hydrogen production and usage markets as it applies, in particular, in seasonal replenishment/makeup of their imported renewable power in their service region
- EPRI and GTI have also developed the Low-Carbon Resources Initiative (LCRI), a five-year, collaborative effort supported by major electric and gas companies
  - Advance technologies needed for decarbonization so they can be deployed in 2030-2050

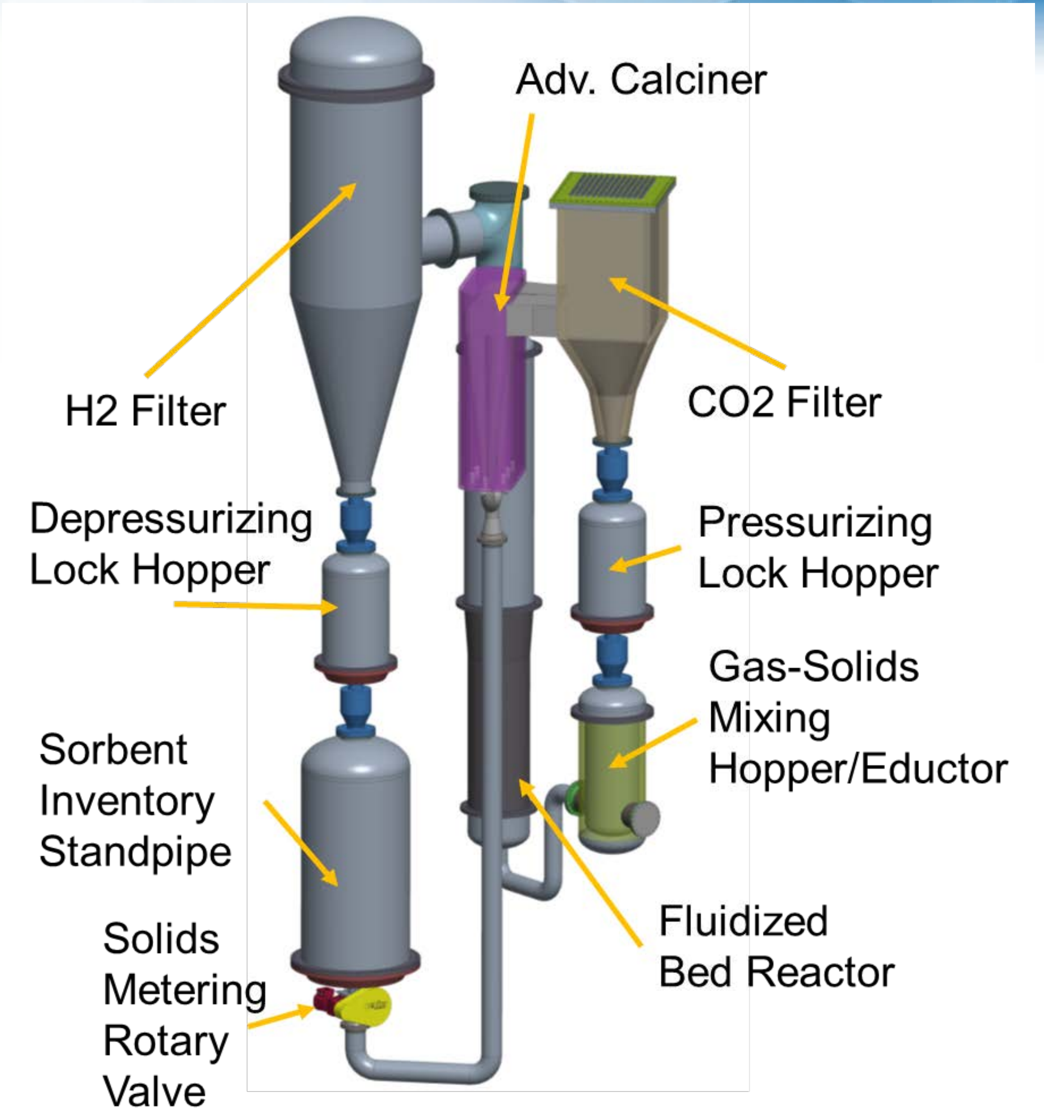
Overview

- GTI lead Pre-FEED (selected for Phase II) for energy stored in the form of hydrogen for load-following at an existing NGCC asset
  - Blue Hydrogen produced from natural gas and Variable Renewable Energy (VRE) with GTI's Compact Hydrogen Generator (CHG)
  - Capable of 54 MWh roadable storage integrated with existing NGCC plant
  - Will sequester CO_2 in commercial application
- Hydrogen combustion in duct burners/HRSG/steam turbine system to accommodate load demands with CO_2 emissions reductions
  - Precursor to hydrogen fired combined cycle power production
- Southern Co. site and Southern Co. will perform as EPC
- EPRI will complete detailed power dispatch modeling
- PG&E and LCRI provide cost share and guidance on system application
- Zeeco – conceptual design dual fuel burner; STC – design & cost for CHG

Proposed System



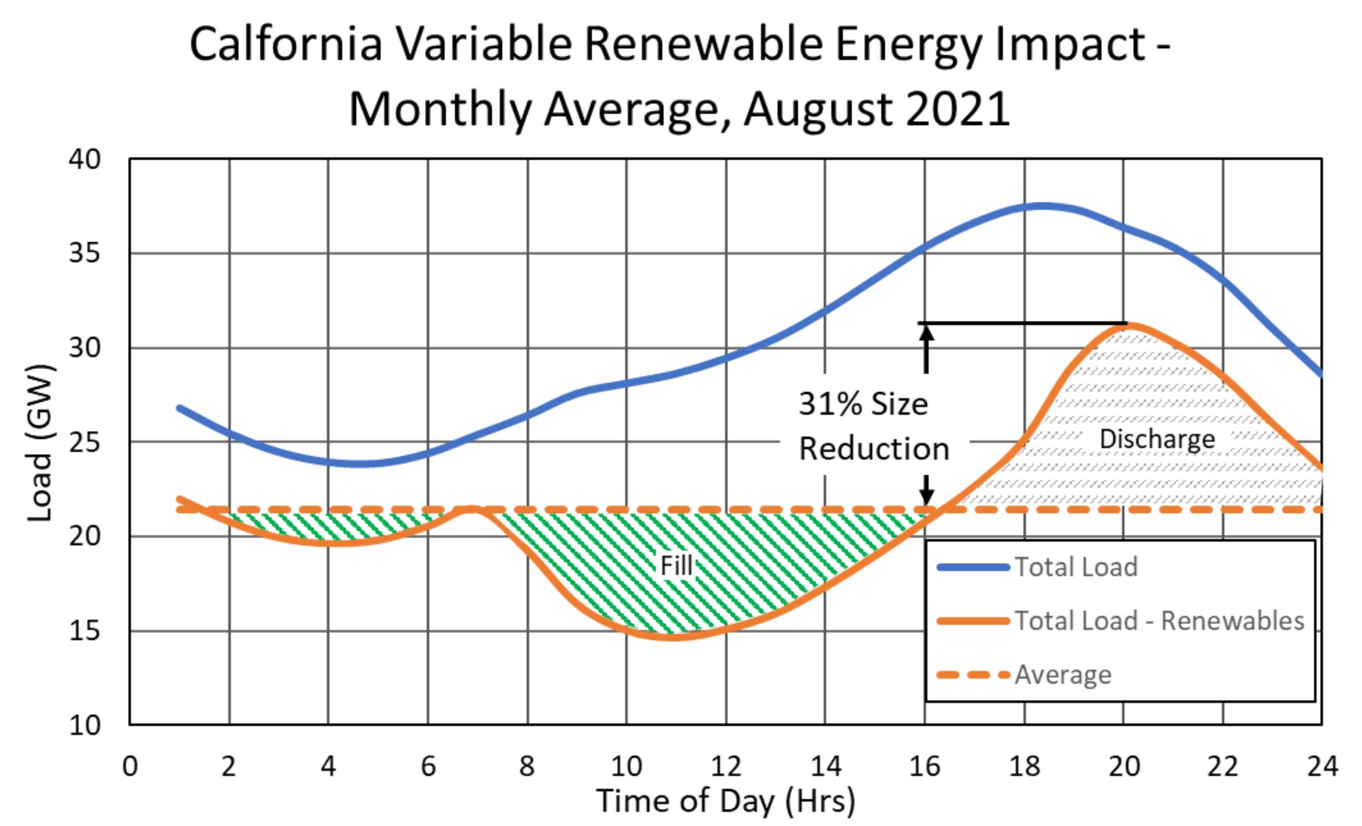
System Schematic



7.6 MWth CHG Subsystem

H_2 Storage Benefit

- Hydrogen storage minimizes the size of the hydrogen generation system by adding capacitance to the system.
  - Potentially lowering overall cost (plant size reduction vs. H_2 storage costs[1])
  - Problem gets worse with increased renewables
- Further benefits of storage are the ability to add H_2 from other sources (produced from curtailed renewable electricity) and provide H_2 to other applications (vehicles, heating, etc.)



Courtesy of Callifornia ISO
www.caiso.com/market/Pages/ReportsBulletins/RenewablesReporting.aspx

[1] Reference: Ahluwalia, R. K., et. al., *System Level Analysis of Hydrogen Storage Options*, U.S. DOE Hydrogen and Fuel Cells Program 2019 Annual Merit Review and Peer Evaluation Meeting, Washington D.C. April 29-May1, 2019, Project ID: ST001

Technoeconomic Summary for Commercial Scale Plant

Parameter	Value
Carbon Emission Reduction (% of total plant emissions)	22%
Carbon Captured (MT/yr)	534,616
Incremental Cost of Electricity ($/MW-h)	$69.67
Incremental COE w/$50/MT Tax Credit ($/MW-h)	$38.06
Overall Plant COE	
Baseload Only ($/MW-h)	$42.50
Combined with Incremental COE ($/MW-h)	$45.69
Combined with Incremental COE w/$50//MT Tax Credit ($/MW-h)	$41.98

- Fuel Price = $4.42/MMBTU
- Electricity Hotel Load Cost
  - $27.61 Curtailment
  - $32.79 Non-Curtailment
- Baseload = 726 MWe
- Duct-burner Augmentation
  - Peak = 176 MWe
  - Daily Avg. = 96.5 MWe
- TASC = $169.2 M
- IRR = 7.07% of TASC
- OPEX = 3.3% of TASC

CHG Process Schematic

- Sorbent enhanced reforming adds solid sorbent to SMR chemistry
  - Balances heat allowing simple reactor and eliminates WGS reactor = lower cost
  - Inherent CO2 capture reduces cost

H2 Product Composition

Dry Basis	Wet Basis
H_2 > 94%	H_2 > 75%
CH_4 ~2.5%	CH_4 ~2%
CO, CO_2, N_2 ~3%	CO, CO_2, N_2 ~3%
	Bal = Steam

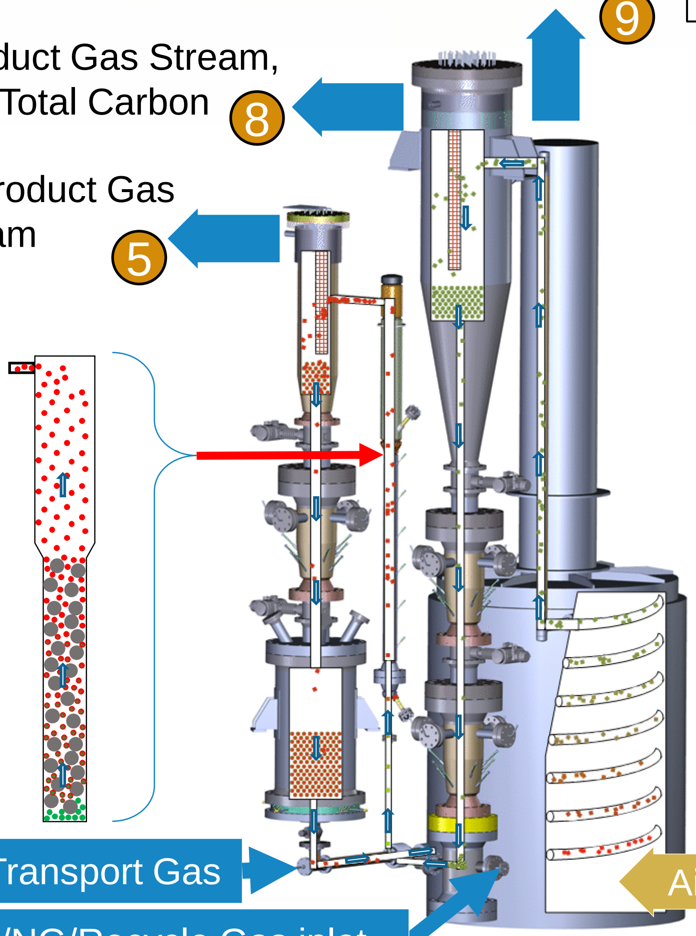
Sorption Enhanced Reforming (SER)

$$CH_4 + 2H_2O + Heat(a) \longrightarrow 4H_2 + CO_2$$
$$CaO + CO_2 \longrightarrow CaCO_3 + Heat(b)$$
$$CH_4 + 2H_2O + CaO \longrightarrow 4H_2 + CaCO_3$$
$$Heat(b) \sim 95\% \; Heat(a)$$

Flue Gas, <2% Carbon Emission (9)

CO_2 Product Gas Stream, >98% of Total Carbon (8)

H_2 Product Gas Stream (5)



(4) Sorbent elutriates through reactor to filter while heavier catalyst remains

(3) CO_2 absorbed by sorbent

(2) Steam Methane Reforming produces H_2 and CO_2

(6) Transport Gas

(1) Steam/NG/Recycle Gas inlet

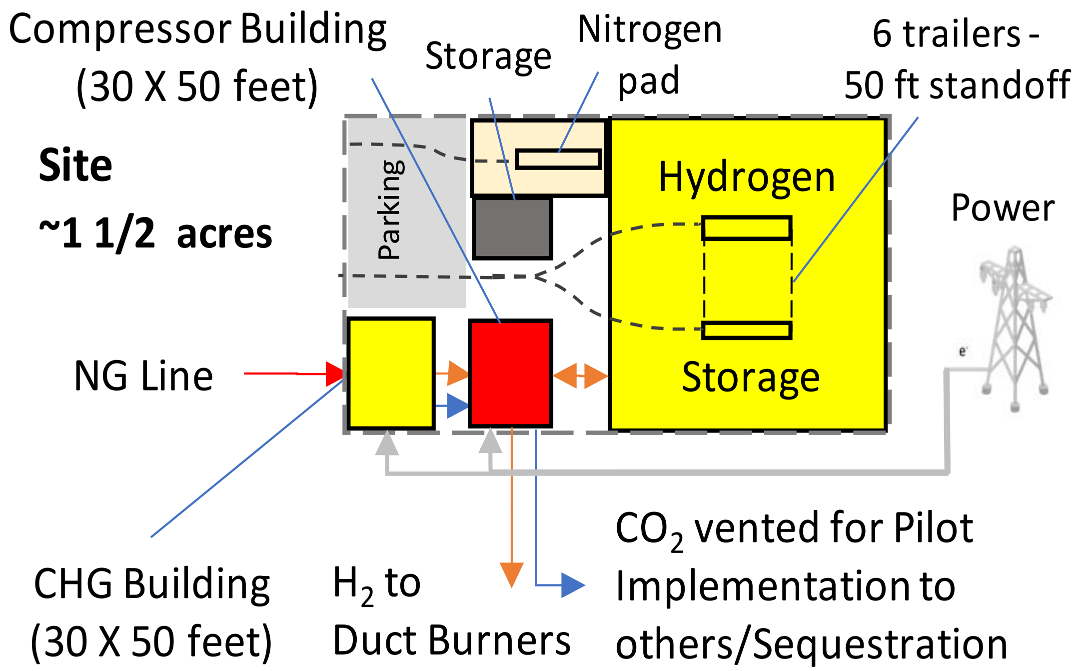
(7) Air & Recycled H_2 to Burner

- Catalyst
- Sorbent
- Sorbent with CO_2

Drives least cost over competing technologies

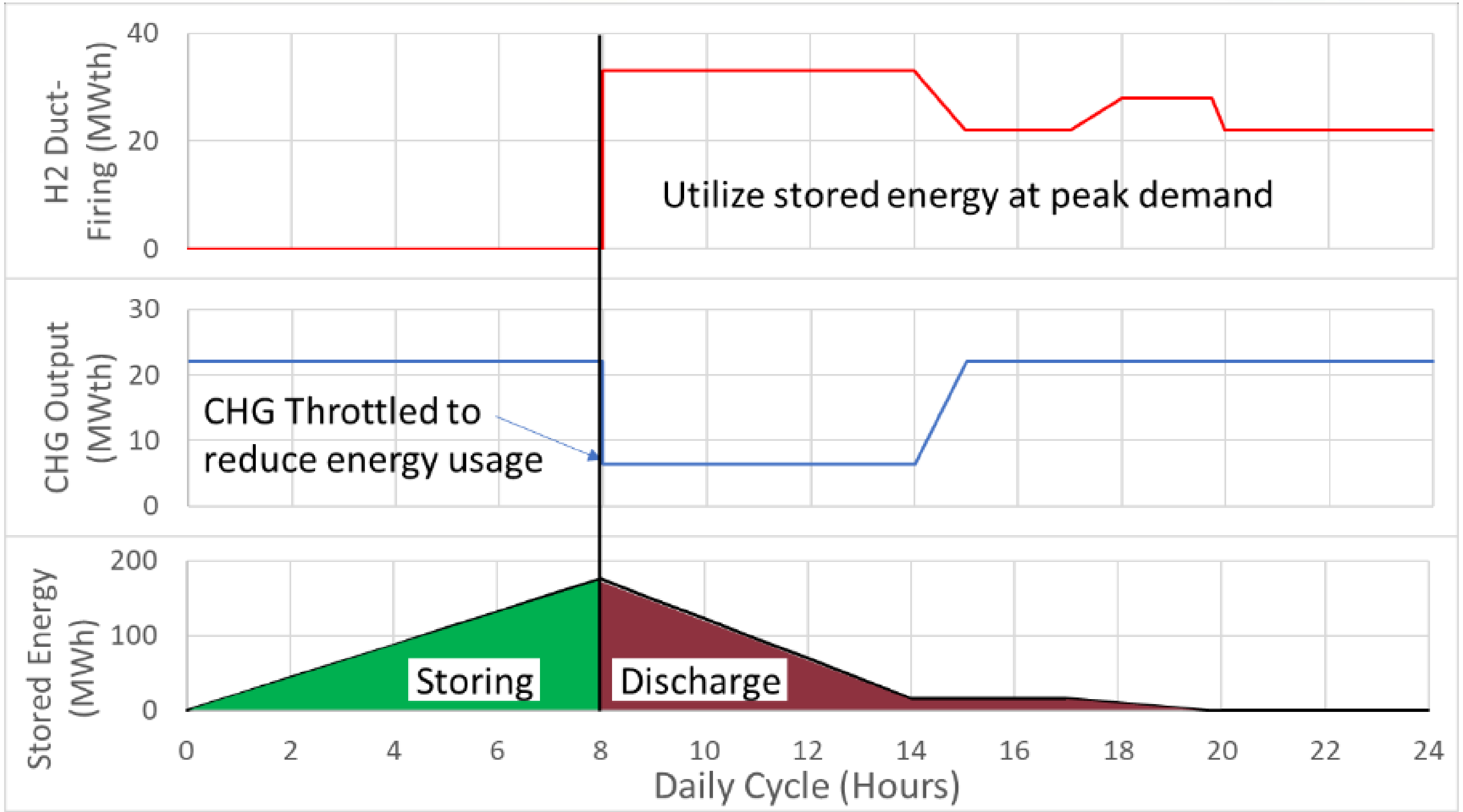
	TPC ($MM)	% of SMR	LCOH ($/kg)	% less than SMR
SMR w/o Capture	277		$1.03	
CHG w/o Capture	159	42.6%	$0.84	19.2%
SMR w/90% Capture	497		$1.68	
CHG w/90% Capture	244	50.9%	$1.21	27.9%

Site Schematic



- Safety standoff for the hydrogen storage (50 feet) requires significant space
- Plan is to use an existing on-site flare for venting combustible gases during startup and upset conditions
  - If not available, a flare will be required that tentatively requires a 150-foot safety standoff (overall ~2 acres)
  - HAZOP to determine in design phase

Operating scenario for H_2-Fired Duct Burner system



Phase I Summary

- 12-month Phase I Feasibility study confirmed the system is feasible
  - Proposed system is an improvement over alternate low carbon dispatchable power options - 17.4% lower cost
- The hydrogen will be produced by the CHG and utilized in a duct burner in a Heat Recovery Steam Generator (HRSG)
- Our demonstration will include 54 MWh of hydrogen storage
  - CO_2 capture inherent to the CHG process can capture 90% of the CO_2 (with upgrades to >98%)
- Firing rate of the duct burner is varied to let the plant respond to fluctuations of electrical load
  - H_2 production is relatively constant by storing H_2
- Revenues are improved by arbitrage between use of low-cost off-peak variable electricity generation or use of stored H_2 under peak demand
- Formulated Commercialization Plan

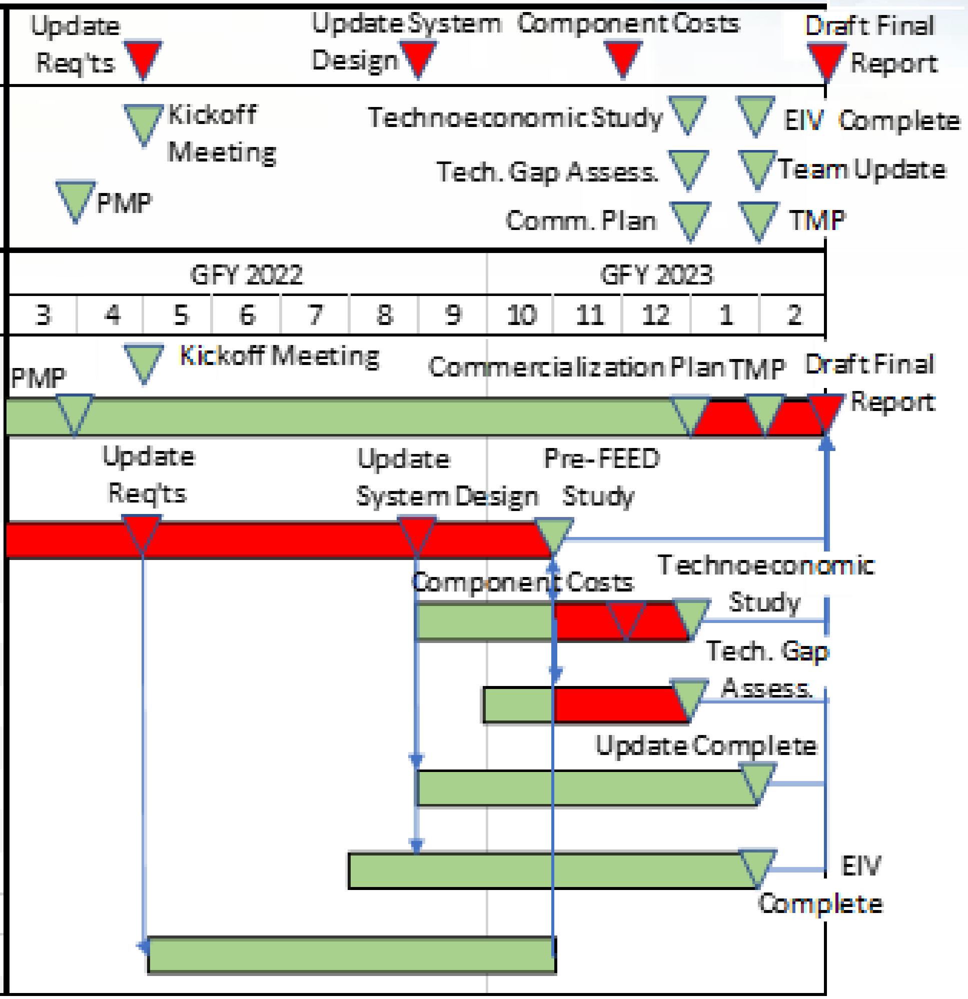
Phase II Plan

Task	Title	Start Date	Stop Date
1	Program Management	3/22	2/23
2	Pre-FEED Study	3/22	10/22
3	Technoeconomic Study	9/22	12/22
4	Technology Gap Assessment	10/22	12/22
5	Update Project Team	9/22	1/23
6	Environmental Review	8/22	1/23
7	Dual Fuel Duct Burner	5/22	10/22

Milestones

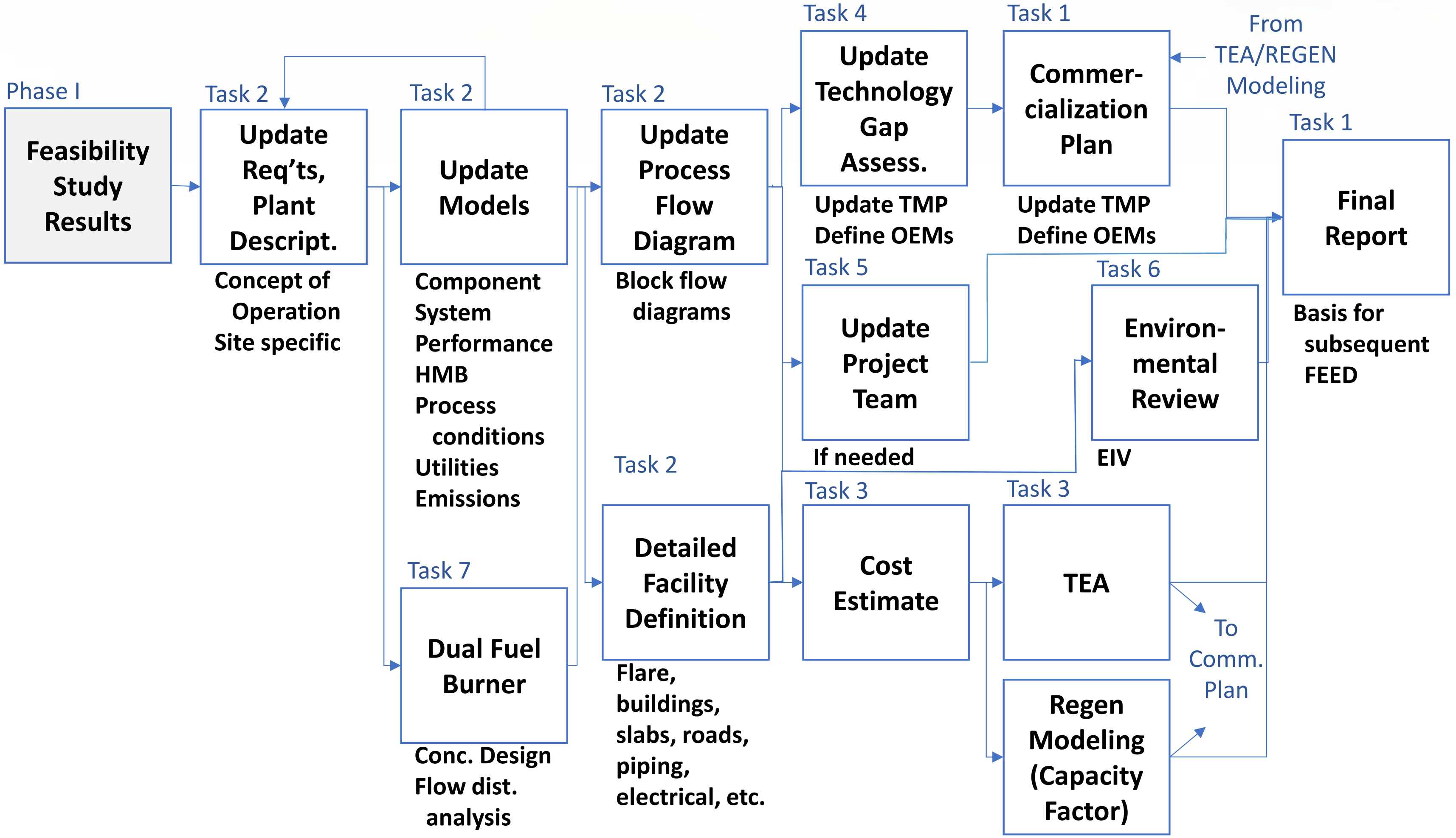
Deliverables/Key Meetings
(also Quarterly Reports, Financial and Other Reporting per the checklist - not shown)

Fiscal Year / Calendar Month



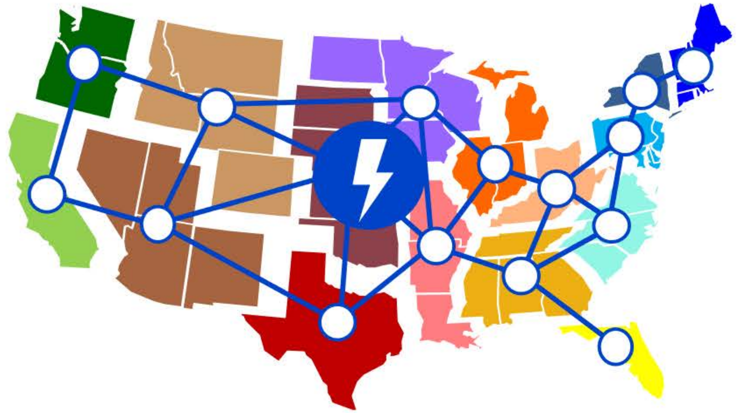
Task connections — Deliverables — Tasks/Subtasks — Critical Path — Milestones

Phase II Logical Progression of Tasks



US REGEN model Synchronizes Electricity Generation and Use

Electric Generation



Detailed representation of:

- Energy and capacity requirements
- Renewable integration, transmission, storage
- State-level policies and constraints

Synchronized

↔

Hourly Load, Renewables, and Prices

Model Outputs:

Economic equilibrium for generation, capacity, and end-use mix

Emissions, air quality, and water

Energy Use

Detailed representation of:

- Customer heterogeneity across end-use sectors
- End-use technology trade-offs
- Electrification and efficiency opportunities