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solutions that transform

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

DOE Fossil Energy and Carbon Management (FECM)

John Vega, Jeff Mays (Principal Investigator)

GTI Energy | April 19th, 2023

Agenda

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- Project Overview/Team members
- Project Objectives
- Proposed System/Benefits
- Phase I Feasibility Study Results
- Phase II Pre-FEED Study Scope/Activities
- Phase II Pre-FEED Study Schedule
- Summary

Hydrogen Storage for Load-Following and Clean Power Project

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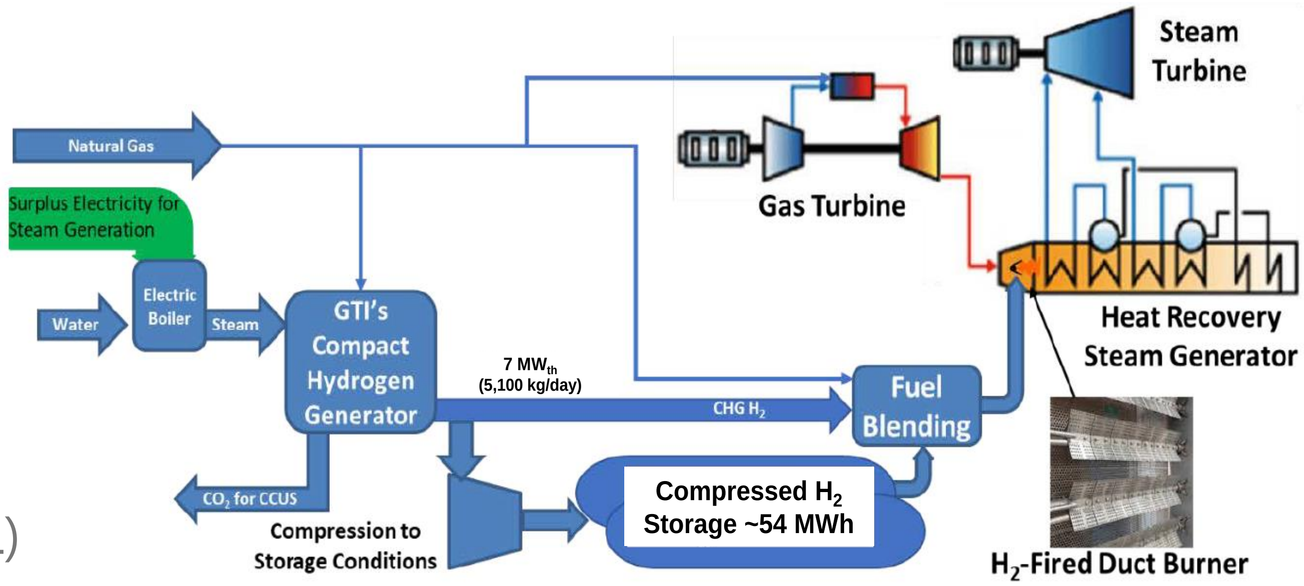
- Scope: Pre-FEED study to advance the concept of asset-integrated production and intermediate duration (~54 MWh) storage of Blue Hydrogen for electric load following
- Team:
  - GTI Energy
  - EPRI
  - Southern Company
  - Pacific Gas & Electric
  - Service & Technology Corp
  - Zeeco
  - Low Carbon Resources Initiative
  - U.S. Department of Energy (DOE NETL)
- Schedule: Phase II through 9/2023
- Funding: Phase II Pre-Feed $800K



GTI Hydrogen Generation (CHG) and integrated H2 storage with GTCC

Hydrogen Storage for Load-Following and Clean Power Project Objectives

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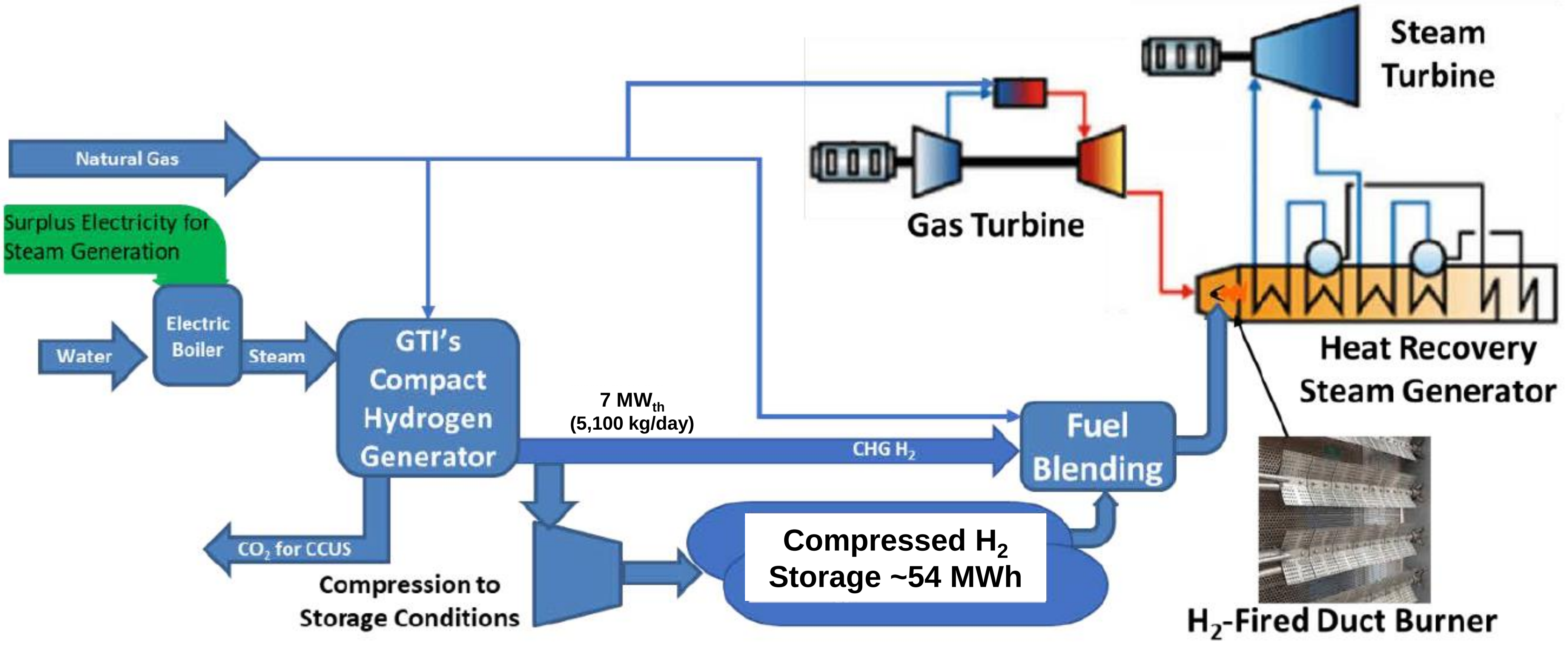
- Pre-FEED study of the concept of using asset-integrated production and intermediate duration (~54 MWh) storage of Blue Hydrogen (i.e., fossil fuel-derived, low-carbon hydrogen) for electric power generation to achieve load following
  - Existing Natural Gas Combined Cycle (NGCC) plant in Southern Company fleet
  - Retrofit with GTI's Compact Hydrogen Generator (CHG) integrated with:
    - CO_2 capture ready
    - Storage of compressed H_2 in roadable storage
  - H_2 duct burner firing within existing heat recovery steam generator (HRSG) section of an NGCC plant
  - Pathfinder for hydrogen power generation while large frame hydrogen-fired gas turbines are matured

Hydrogen Storage for Load-Following and Clean Power Project - Proposed System



- Commercial scale: Baseload = 690 MW_e, Duct-burner Augmentation = 176 MW_e Peak
- Demonstration scale: 84 MW_e, Duct-burner Augmentation = 38 MW_e Peak

GTI Energy Hydrogen Generation (CHG) and Integrated H_2 Storage with GTCC Concept Benefits

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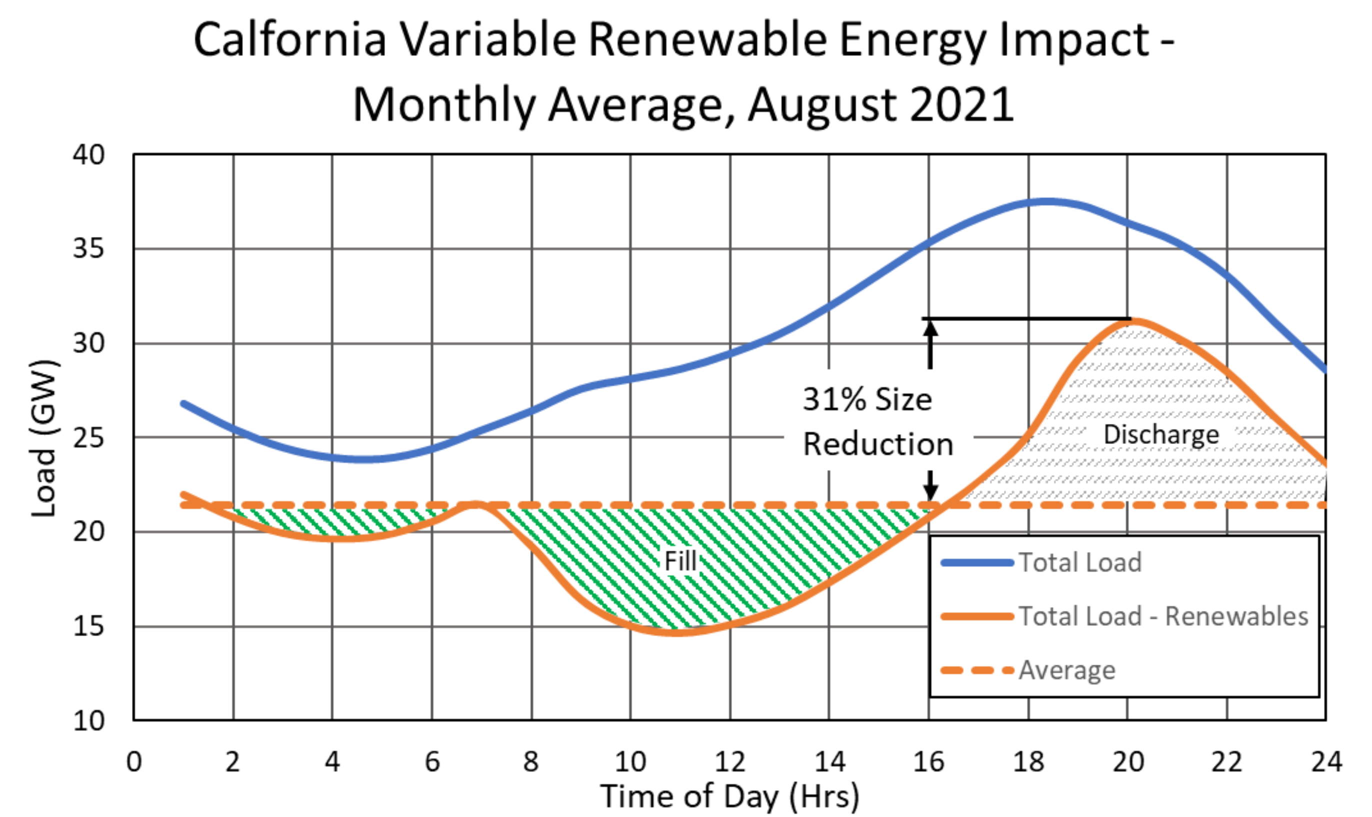
- Low-carbon H_2 produced by the CHG provides dispatchable H_2 production and is significantly cheaper than SMR-based H_2
- Utilization of stored H_2 as the energy carrier enables the system to be dispatchable and support peak energy demands with minimal impact of the fossil asset
  - This offers flexibility in VRE markets
  - Produce faster total plant ramp rates, improving efficiency
- Demonstrates utilization of stored H_2 in an economical and low-carbon manner
  - System is agnostic to the hydrogen source
  - Can provide hydrogen for other uses
- Pathfinder for hydrogen power generation as hydrogen-fired large frame gas turbines are matured

H_2 Storage Concept Benefit

- Hydrogen storage minimizes the size of the hydrogen generation system by adding capacitance to the system.
  - Lowers overall cost (plant size reduction vs. H_2 storage costs[1])
  - Electric utility industry challenge gets worse with increased renewables
- Further benefits of storage concept is the ability to add H_2 from other sources (ex. - 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

GTI's CHG Blue Hydrogen Process Schematic

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Sorption Enhanced Reforming (SER)

$$CH_4 + 2H_2O + Heat(a) \longrightarrow 4H_2 + CO_2$$

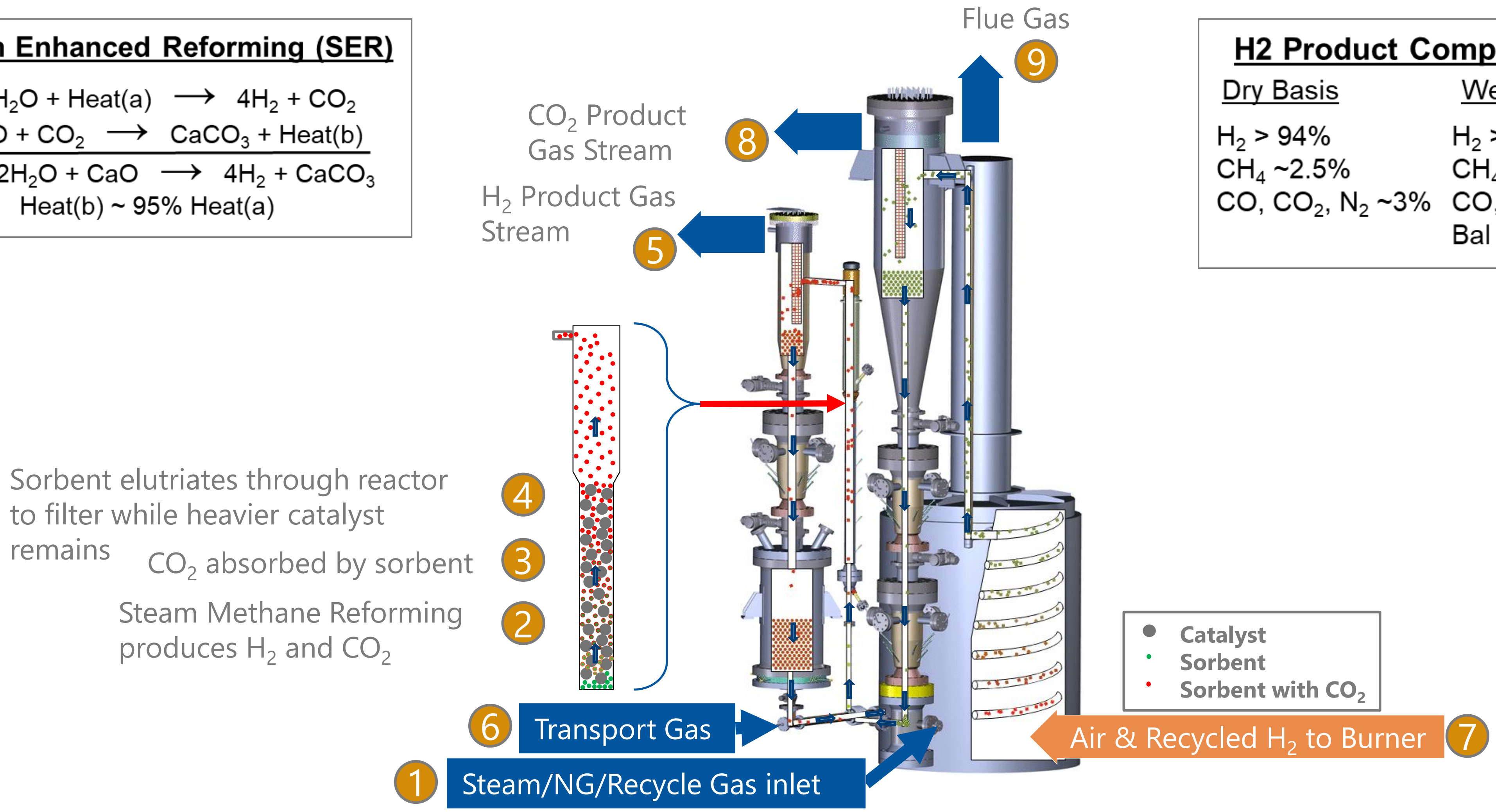
$$CaO + CO_2 \longrightarrow CaCO_3 + Heat(b)$$

$$CH_4 + 2H_2O + CaO \longrightarrow 4H_2 + CaCO_3$$

$$Heat(b) \sim 95\% \; Heat(a)$$

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



GTI's CHG Blue Hydrogen Economic Advantages

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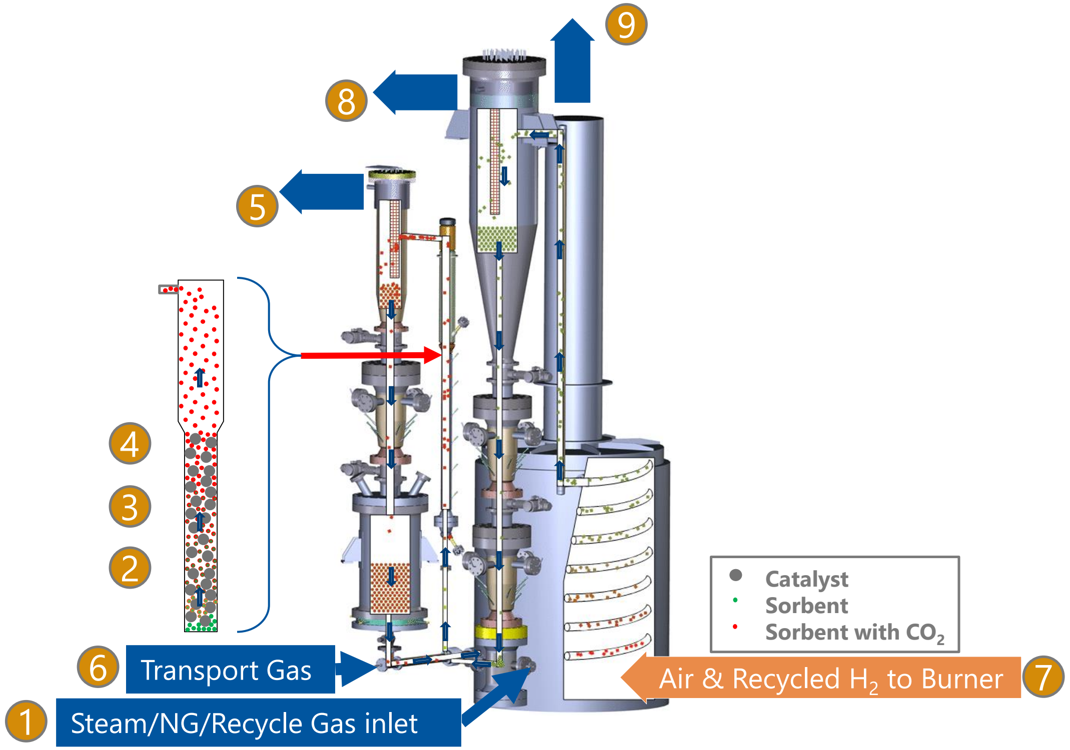

- Sorbent enhanced reforming adds solid sorbent to SMR chemistry
  - Balances heat allowing simple reactor and eliminates WGS reactor = lower cost
  - Inherent CO_2 capture reduces cost

Drives least cost over competing technologies

Configuration	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%

Hydrogen Storage for Load-Following and Clean Power Project - Phase I Feasibility Study Results

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- 12-month Phase I Feasibility study confirmed the system is feasible
  - Hydrogen produced by the CHG/utilized in a duct burner in a HRSG
  - Demonstration will include 54 MWh of hydrogen storage
    - H_2 production is relatively constant by storing H_2
    - CO_2 capture inherent to the CHG process can capture 90% of the CO_2
  - Firing rate of the duct burner is varied for plant response to fluctuations of electrical load
- Proposed system is an improvement over alternate low carbon dispatchable power options - 17.4% lower levelized cost relative to an SMR with an amine system for CO_2 capture
- Revenues are improved by arbitrage between use of low-cost off-peak variable electricity generation or use of stored H_2 under peak demand

Phase II (Pre-FEED) Scope/Activities
Overall Objective - Be Ready to Launch FEED

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- Pre-FEED tasks include:
  - Updating the requirements, Concept of Operations, component modeling and system modeling, performance estimates, emission estimates, fluid/process conditions (PFD), utility usage, and facility sizing/definition
  - TEA
    - Commercial Scale Plant Economics
    - Improved cost estimates from EPC (SCS) and potential CHG OEM (STC)
  - Update Technology Gaps/TMP
  - Develop Environmental Information Volume
  - Conceptual design for the dual fuel burner

Phase II Pre-FEED Status

System Requirements at Battery Limits

Component	Inputs	Outputs		Units	
	Flow	Flow			
Natural Gas	1,618			lb/hr	
HP BFW	5,463			lb/hr	
LP BFW	903			lb/hr	
Sorbent	14,327			lb/hr	
Cooling Water	28,436			lb/hr	
Power	0.521 Peak 0.198 Avg.			MWe	
CO_2 from Calciner		3,918		lb/hr	
Product Gas		609		Lb/hr	
H_2		465.2	96.9%	lb/hr	Mol%
CH_4		87.8	2.3%	lb/hr	Mol%
CO_2		20.9	0.2%	lb/hr	Mol%
CO		14.2	0.2%	lb/hr	Mol%
N_2		15.5	0.2%	lb/hr	Mol%
H_2O		4.33	0.1%	lb/hr	Mol%
Condensate Water		2,037 H_2, 900 CO_2		lb/hr	
Total H_2 Storage (8 hr. fill)		0.7		MMSCF	
Product Gas Heat		7.7 (7.1 H_2)		MWth	

- Requirements updated
- Process model updated
  - PFD updated
  - Performance estimates completed
- Layout completed
- Duct Burner emission estimates completed

GTI's 7.7 MW_{th} CHG for Pre-FEED study

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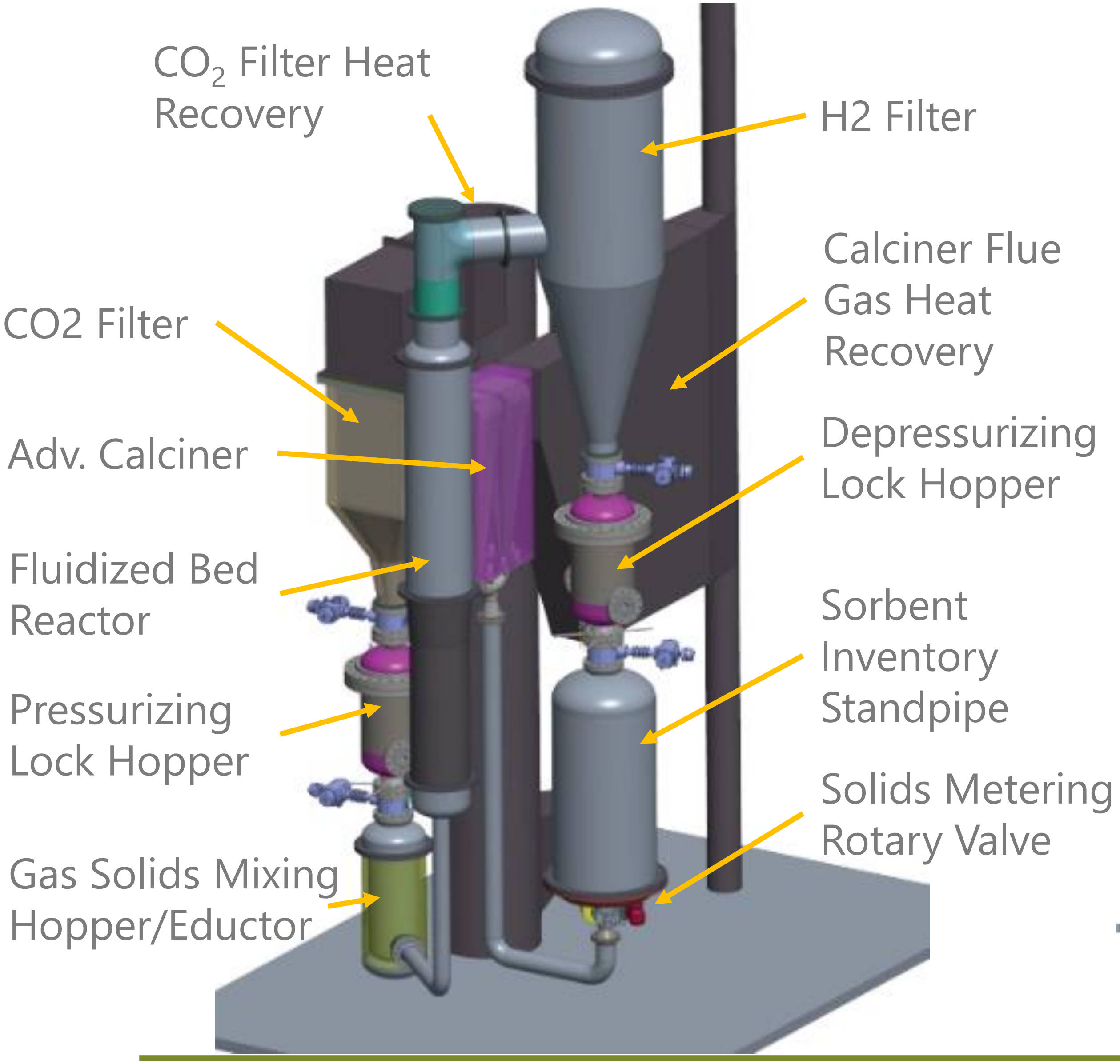

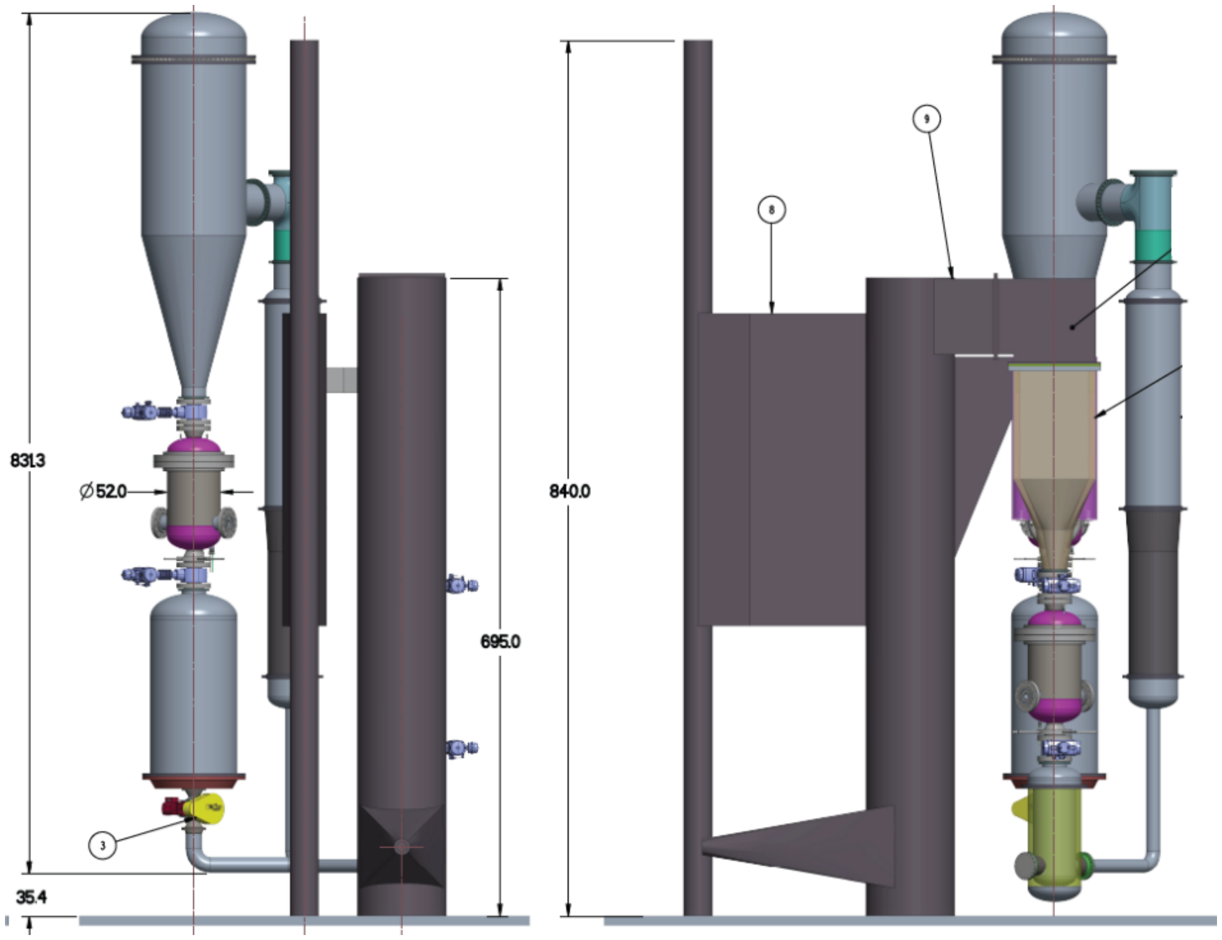

Phase II Pre-FEED Dual Fuel Duct Burner

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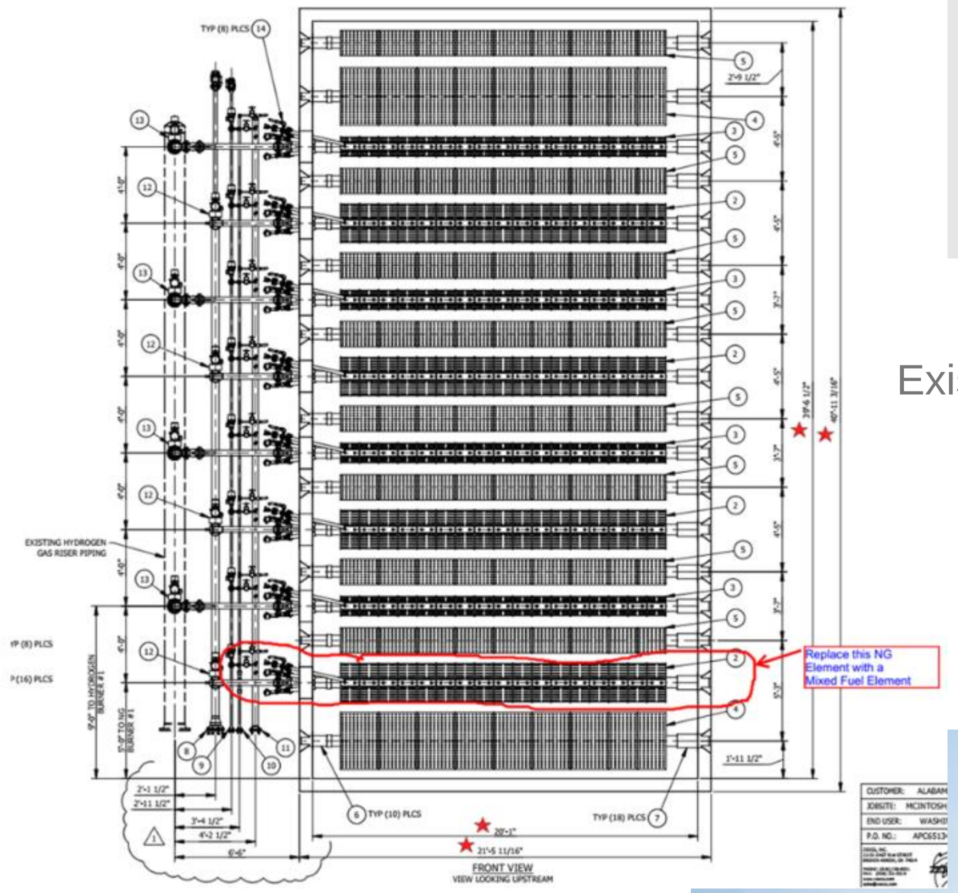

Existing HRSG and Burners

HRSG from significantly larger power plant

- Current Heat Recovery Steam Generator (HRSG) Duct Burners
  - Four (4) Hydrogen Duct Burner Elements (see item 3)
  - Four (4) Natural Gas Duct Burner Elements (see item 2)
- Bottom Natural Gas Element clouded in red will be replaced with a Dual Fuel Burner

Phase II Pre-FEED Schedule

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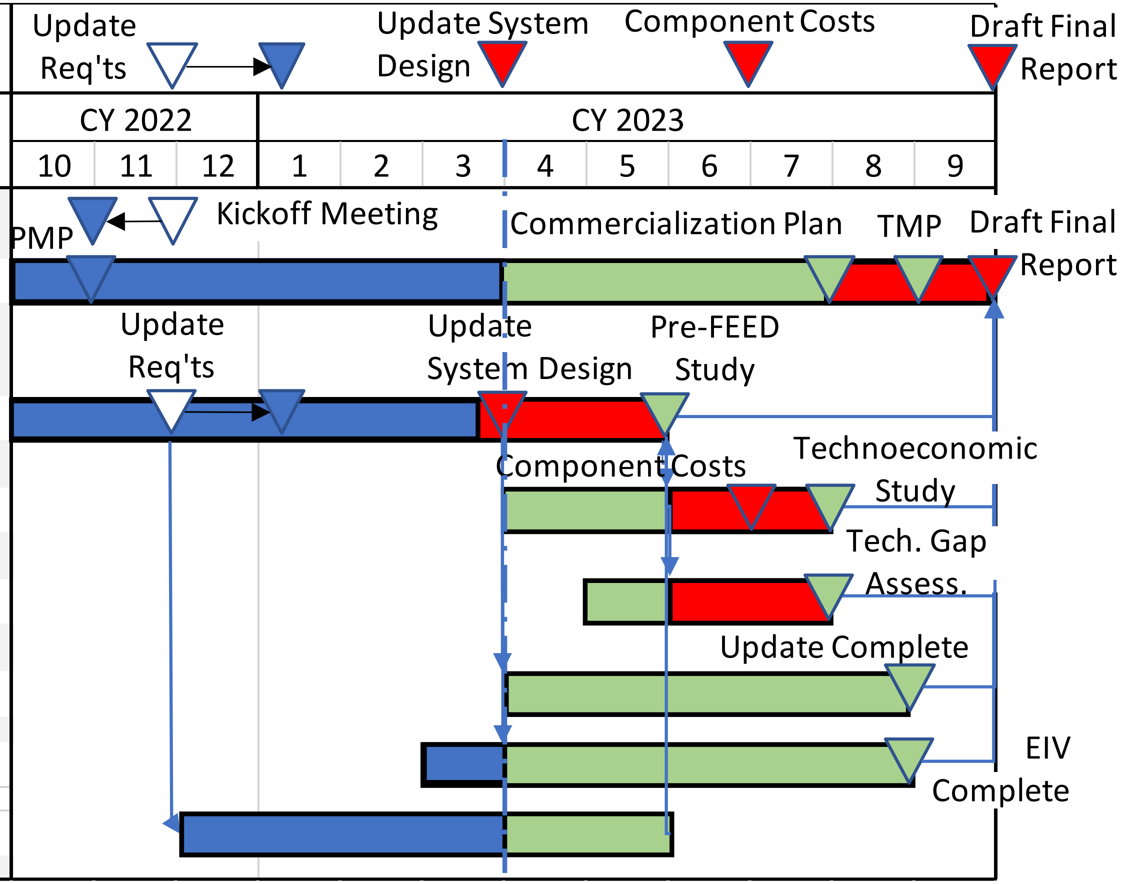
Milestones

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



Task connections | Deliverables/Key Activities | Tasks/Subtasks | Critical Path | Milestones

Hydrogen Storage for Load-Following and Clean Power Project Summary

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- 12-month Phase I Feasibility study confirmed the system is feasible
  - 17.4% lower cost than alternate low carbon dispatchable power option
- 12-month Phase II Pre-FEED is ongoing:
  - Requirements definition, process modeling, performance, emissions, PFD, utility usage, and facility sizing/definition are now complete or ongoing for specific site
  - Gathering detailed costs for the TEA
  - Conceptual design for the dual fuel burner ongoing
- Team is pursuing multiple paths for the demonstration (FEED is the next step)

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Team thanks Heather Hunter (DOE PM) and DOE for the support to the project

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