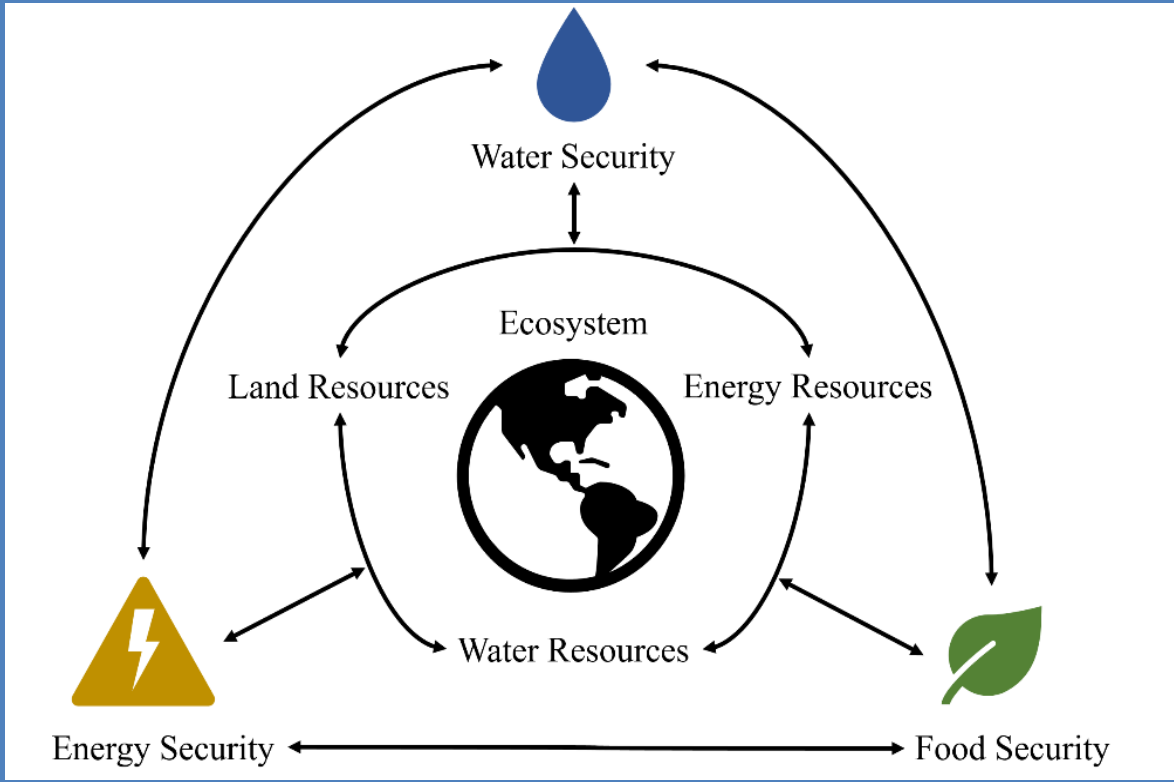
U.S.-China Clean Energy Research Center - Water & Energy Technologies



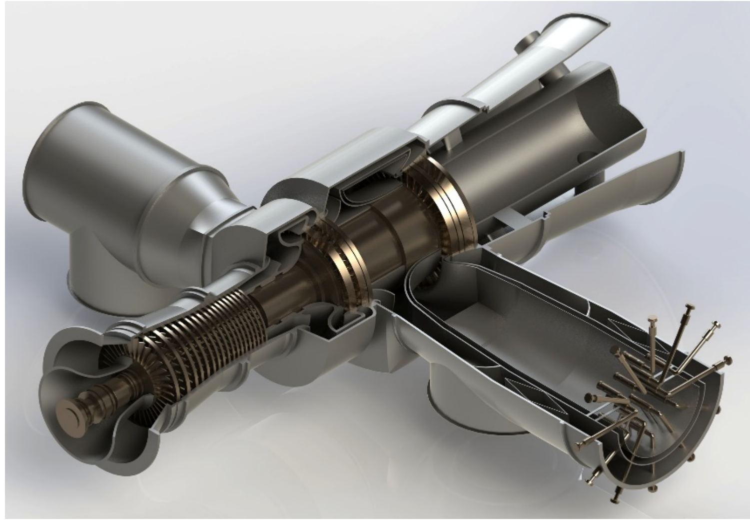
Crosscutting Research, Rare Earth Elements, Gasification Systems, and Transformative Power Generation

Dr. Ashok Rao: Chief Scientist, Power Systems, Advanced Power & Energy Program, UC Irvine

April 11, 2019

Topic Area 1 (Total 5 Subtopics)
Water Use Reduction at Thermoelectric Plants

- **Goal:** Achieve breakthroughs to address electricity needs in regions with water scarcity
- **Challenge:** Conventional approaches to reduce water consumption by thermoelectric plants cause significant reductions in plant efficiency & increase plant CO_2 emissions
- **CERC's Objective:** Pursue breakthroughs in areas of
  - dry cooling
  - non-conventional power conversion technologies
  - dry carbon-capture methods
  - reduced fuel consumption
- **CERC's Capabilities**
  - University/National Lab partnerships
  - Extensive experimental validation capabilities

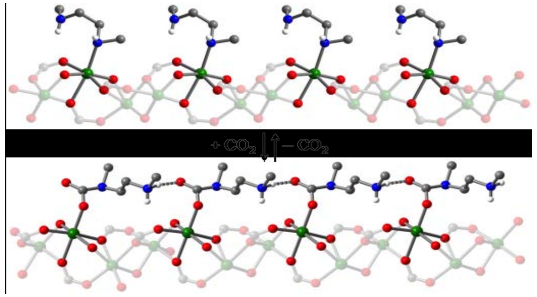


GE 7FB gas turbine modified for external heating via non-fossil sources

Topic Areas 1.1 & 1.2
Goals

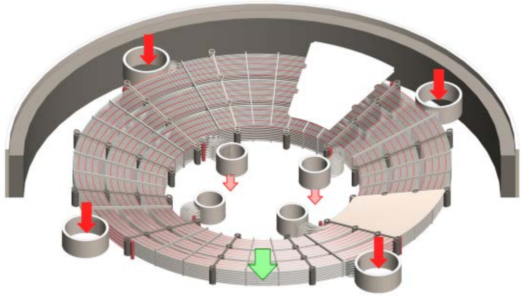
1.1 Dry CO_2 capture based upon nanoscale framework materials
(Rebecca L. Siegelman & Jeffrey Long, UC Berkeley)

- Identify diamine-appended metal-organic framework best suited to minimize energy & water consumption
- Develop strategies & partnerships to advance technology readiness of chosen adsorbent through scale-up, process modeling & slipstream testing



1.2 Reheat air combined cycles (RACC)
(Per Peterson, UC Berkeley)

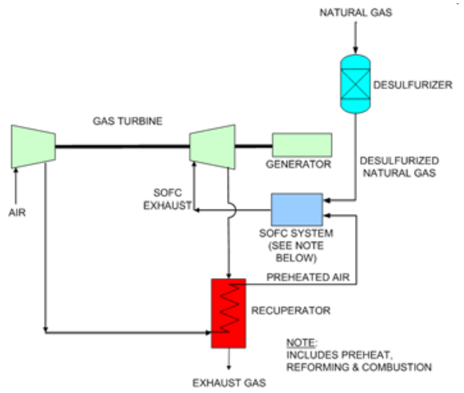
- Evaluate RACC system performance with computer simulation & experiments
- Specialized models for heat exchange, duct & thermal storage systems
- Collaborate with Chinese partners to develop roadmap to achieve major outcomes projected by 2020



Topic Areas 1.3 & 1.6 Goals

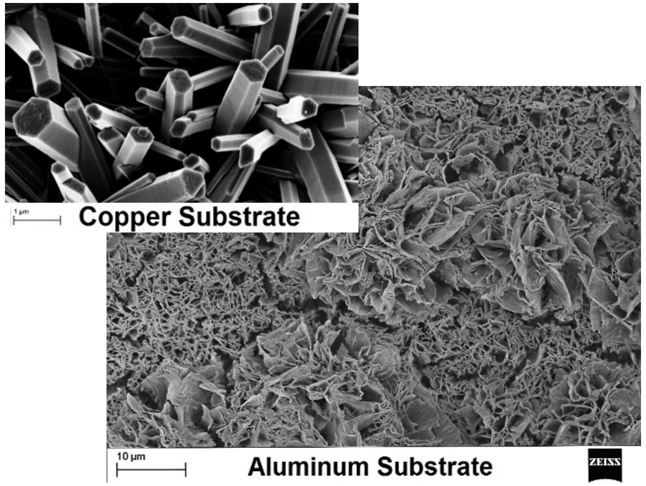
1.3 Fuel cell power plants
(Scott Samuelsen & Ashok Rao, UC Irvine)

- Develop integration schemes to fully realize potential of SOFC/GT hybrids
  - 10 MW scale
  - 50 MW scale
  - 100 MW scale
- Fossil (natural gas & coal) & renewable bio fuels
- Dry cooling
- With & without carbon capture
- With & without water recovery



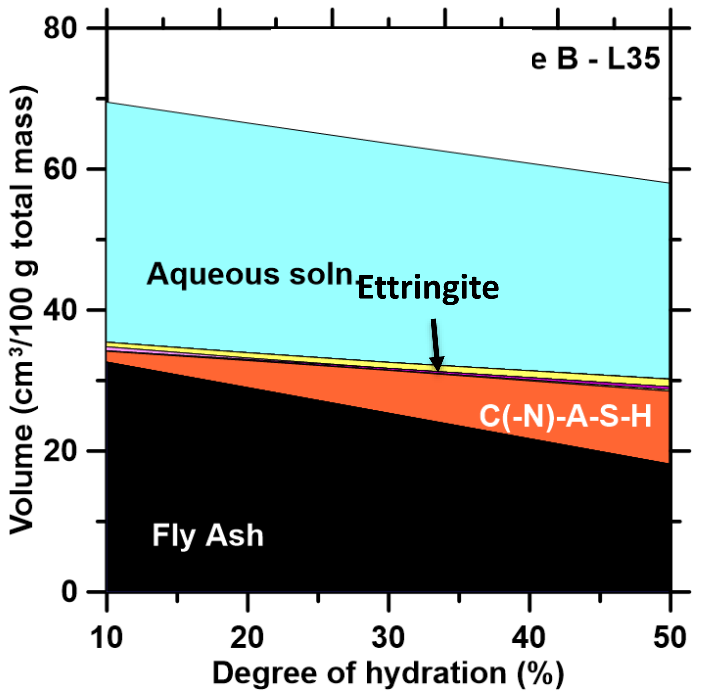
1.6 Nanostructured surface enhancement of spray cooling water vaporization processes
(Van Carey, UC Berkeley)

- Develop scalable methods to create nanostructured superhydrophilic surface coatings on aluminum
- Experimentally assess coating durability & effectiveness to enhance heat transfer
- Reduce water consumption for water spray cooling of power plant air cooled condensers



Topic Area 1.7 Goals

- **1.7 Waste treatment from coal combustion**
  (Gaurav N. Sant, UCLA)
  - Study methods to simultaneously stabilize (solidify) solid & liquid waste streams from coal combustion
  - Progress towards 'zero liquid discharge' for power plant
  - Creates more durable waste form than simply landfilling fly ash
  - Encapsulate contaminants within permanent, durable engineered materials



Class C FA at variable degree of hydration in contact with a concentrated brine solution

Topic Area 2 (Total 7 Subtopics)
Treatment & Management of Non-Traditional Waters

Challenge

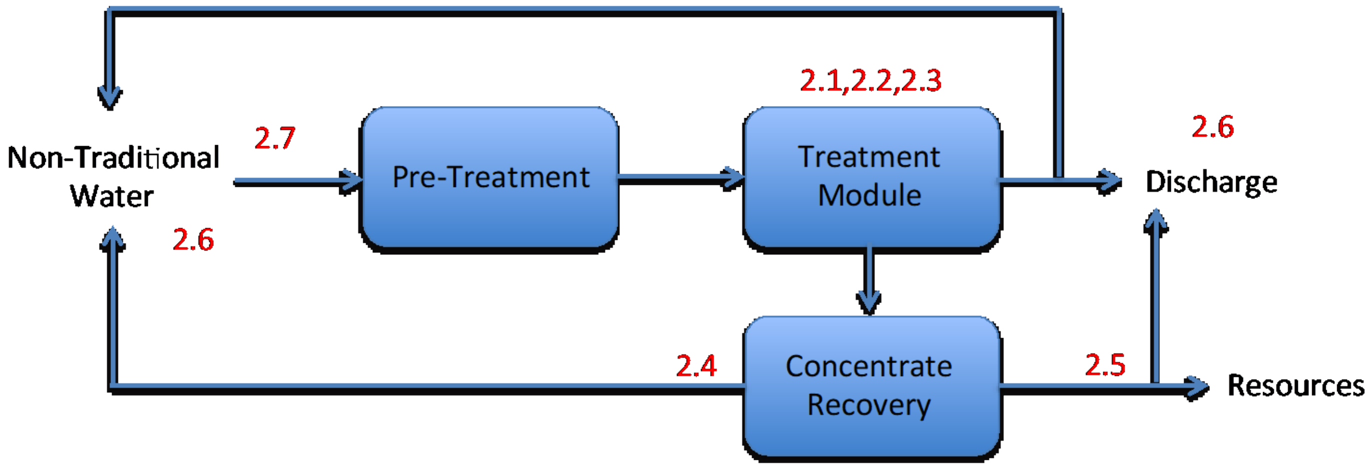
Increasing importance of non-traditional waters requires integrated framework for creating cost-effective treatment trains that protect public health & environment

Opportunity

New technologies allow using non-traditional waters (e.g., municipal wastewater, brackish groundwater, seawater) to address issues related to water scarcity

Approach

- Leverage existing expertise to create new, integrated solutions enabling expanded use of non-traditional waters
- Emphasis on salt management & protection of environment



Topic Areas 2.1 & 2.2 Goals

2.1 Capacitive Deionization of Brackish Waters

(Ashok Gadgil, UC Berkeley & XU Ke Institute of Seawater Desalination & Multipurpose Utilization)

- Demonstrate polymer-embedded electrodes can achieve performance comparable to or better than commercial electrodes
- Optimizing CDI prototype for non-traditional waters

2.2 Selective Removal of Divalent Cations with Graphene Oxide Membranes

(Baoxia Mi, UC Berkeley & WEI Yangyang, Institute of Seawater Desalination & Multipurpose Utilization)

- Optimize graphene oxide charge & structural parameters to minimize partitioning of divalent cations into & slow down their diffusion in graphene oxide membrane
- Assess alternative synthesis approaches for increasing selectivity at least 25% better than conventional polymer membranes over range of conditions representative of non-traditional waters

Topic Areas 2.3 & 2.4
Goals

2.3 Forward Osmosis with Ionic Liquids

(Robert Kostecki, LBNL & Mengshan Duan, Institute of Seawater Desalination & Multipurpose Utilization)

- Assess efficiency of prototype on recovery of water from well-defined solutions using selected ionic liquids as draw solutions with goal of achieving performance comparable to or better than conventional draw solutions
- Design & assemble prototype LCST ionic liquid-based composite membrane suitable for flow reactor operation

2.4 Enhanced Treatment of Desalination Brines

(David Sedlak, Rachel Scholes, Aurora Yueng, UC Berkeley & QIU Jinquan, Institute of Seawater Desalination & Multipurpose Utilization)

- Design/construct open water microcosms using water representative of treatment module exhibiting highest potential for water quality improvement from open water treatment
- Achieve rates of primary productivity comparable to open water cells that receive municipal wastewater effluent

Topic Areas 2.5 & 2.6 Goals

2.5 A Systems-Level Analysis of Non-Traditional Water Management

(Diego Rosso, UC Irvine, JIANG Minzheng, Northeast Petroleum University & JIA Deli, Research Institute of Petroleum Exploration & Development)

- Identify energy saving strategies at multi-plant system level
- Acquisition of high frequency measurements from partnering utilities
- Implementation & testing of novel sensors from partnering manufacturers
- Development of software for validation of model input data

2.6 Geochemical Approaches for Managing of Non-Traditional Waters

(William Stringfellow, Nicholas Spycher & Mary Kay Camarillo, LBNL & ZHANG Yushan Institute of Seawater Desalination & Multipurpose Utilization)

- Use geochemical modeling approach to tailor treatment systems for unconventional waters to meet specific beneficial reuse objectives
- Use combined biological-physical-chemical treatment for unconventional waters to reduce mineral scaling & biofouling in downstream processes
  - reverse osmosis
  - other membrane treatment systems

Topic Areas 2.7 & 2.9 Goals

2.7 High Water Recovery Desalination of Non Traditional Waters

(Eric Hoek, Richard Kaner, UCLA & ZHANG Yushan, Institute of Seawater Desalination & Multipurpose Utilization)

- Effectiveness of Nano-Structured Membranes in Mitigating Fouling in California market
- Assess integration of concentrate treatment/minimization strategies

2.9 Affordable, Effective Arsenic Remediation of Ash Pond Water from Coal-Fired Power Plants

(Ashok Gadgil, UC Berkeley)

- Test effectiveness of previously established arsenic remediation technology (ECAR) with samples of interstitial ash pond water
- Design & build with high throughput in small laboratory prototype with synthetic pond water
- Demonstrate successful remediation of arsenic in samples of ash-pond water with ECAR
- Operate high throughput set up in laboratory under different parametric conditions & explore its effectiveness for use in industrial settings

Topic Area 1.3 Natural Gas & Integrated Gasification Hybrid Fuel Cell Plants

Professor Scott Samuelsen & Dr. Ashok Rao, UC Irvine
Graduate Student Researchers: Fabian Rosner, Daniel Jaimes, Amber Fong

Challenge

- Water use reduction at thermo-electric plants (10, 50 & 100 MW)
- Greenhouse gas emissions reduction
  - CO_2 capture & sequestration for larger scale plants (50 & 100 MW)
- High thermal efficiency (even at 10 MW scale)

Industry Partners & Research Organizations

- U.S.
  - Southern California Edison (SCE)
  - Southern California Gas Co (SoCalGas)
  - Southern California Air Quality Management District (AQMD)
- Chinese (Project 1.4)
  - Chinese Academy of Sciences (CAS)

Planned Achievements by End of CERC-WET

- SOFC/GT hybrid configurations that meet challenges
  - Minimize water usage
  - Minimize GHG emissions
  - Maximize efficiency
- Technological development needs & commercialization plan to bring promising concepts into market place

Completed & Remaining Work

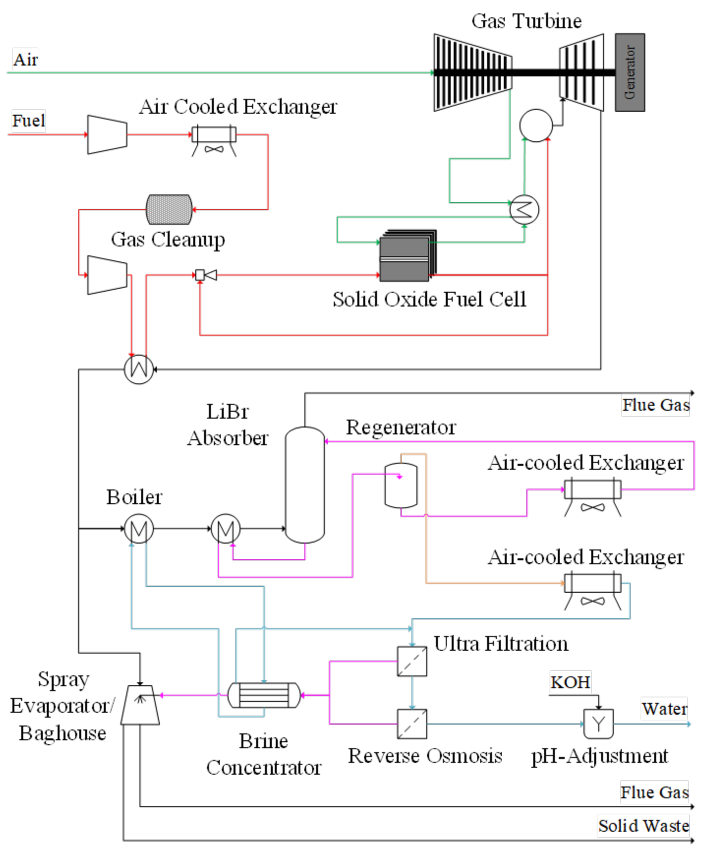
Plant Types (with ZLwD*)

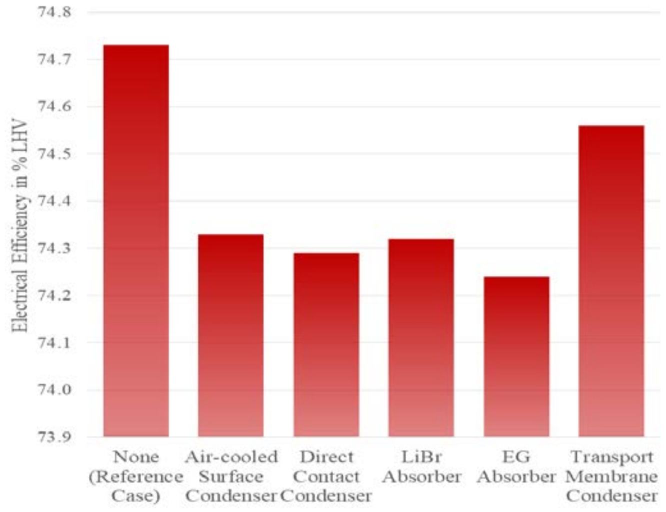
- 10 MW Natural Gas w/o Carbon Capture
- 10 MW Digester Gas w/o Carbon Capture
- 50 MW Natural Gas with & w/o Carbon Capture
- 100 MW Natural Gas with Carbon Capture
- 100 MW Coal with Carbon Capture
- 100 MW Biomass with Carbon Capture

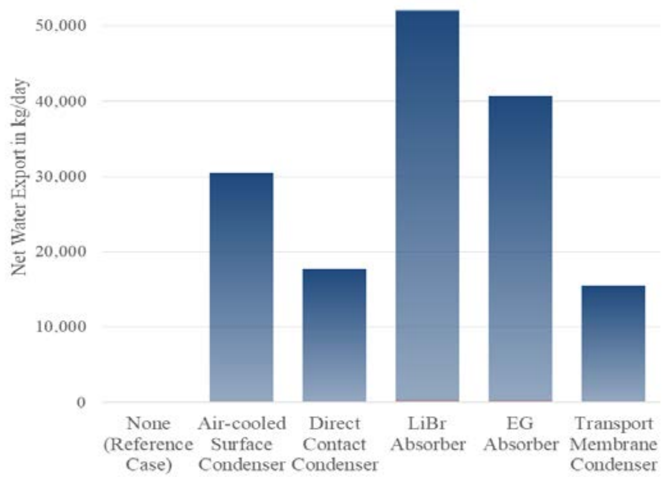
* In digester gas cases, recovered raw water supplied back to sewage treatment facility

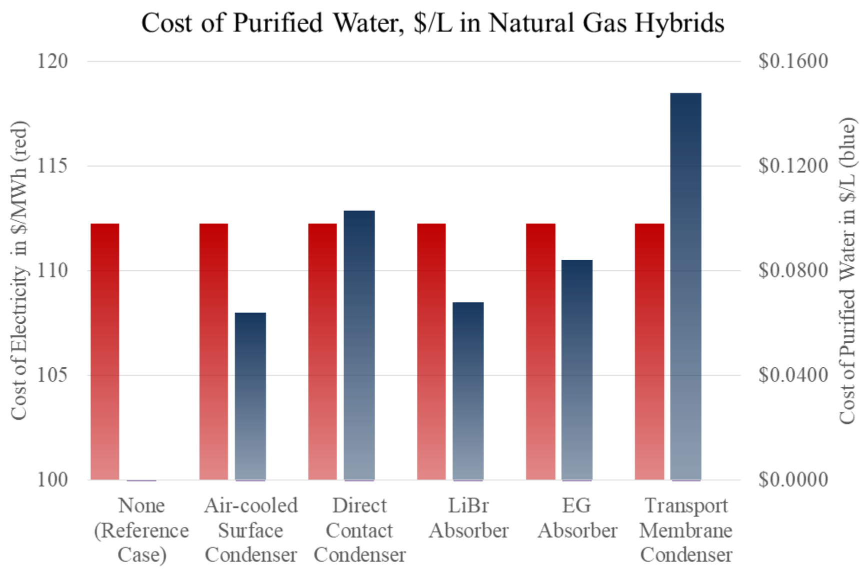
Task/Subtask/Milestone	Subtask/Milestone Descriptions	Actual or Projected Date for Completion
Task 1.3	**Project Kickoff**	10/1/2016
Subtask 1.3.1	***Project planning and coordination with Chinese collaborators***	
	Identify Chinese collaborating researchers and establish plans for coordinating SOFC based systems research efforts.	3/31/2017
Milestone 1.3.1.A	Complete and report coordination plans with Chinese researchers	3/31/2017
Subtask 1.3.2	***Key equipment design basis and models***	
	Select design constraints and basis of key equipment such as SOFC, GT, reactors, gasifier, and develop/validate models for integration with Aspen Plus®.	9/30/2017
Milestone 1.3.2.A	Complete and report basis for selection of equipment design and models	9/30/2017
Subtask 1.3.3	***Integration schemes and modeling of small SOFC/GT systems***	
	Develop integration schemes and subsystem operating conditions for natural gas and biogas fueled small (~10 MW) systems without CO_2 capture.	3/31/2018
Milestone 1.3.3.A	Complete and report promising integration schemes of small SOFC/GT systems	6/30/2018
Subtask 1.3.4	***Techno-economics analysis of small SOFC/GT systems***	
	Evaluate technical and economic feasibility of identified integration schemes for natural gas and biogas fueled small (~10 MW) systems without CO_2 capture.	3/31/2019
Milestone 1.3.4.A	Complete and report results of techno-economics analysis of small SOFC/GT systems	3/31/2019
Subtask 1.3.5	***Integration schemes and modeling of medium size SOFC/GT systems***	
	Develop integration schemes and subsystem operating conditions for natural gas fueled medium scale (~50 MW) systems with and without CO_2 capture.	3/31/2019
Milestone 1.3.5.A	Complete and report promising integration schemes of medium size SOFC/GT systems	3/31/2019
Subtask 1.3.6	***Techno-economics analysis of medium size SOFC/GT systems***	
	Evaluate technical and economic feasibility of identified integration schemes for natural gas fueled medium scale (~50 MW) systems with and without CO_2 capture.	9/30/2019
Milestone 1.3.6.A	Complete and report results of techno-economics analysis of medium size SOFC/GT systems	9/30/2019
Subtask 1.3.7	***Integration schemes and modeling of large SOFC/GT systems***	
	Develop integration schemes and subsystem operating conditions for natural gas, coal and biomass fueled large (~100 MW) systems with CO_2 capture.	3/31/2020
Milestone 1.3.7.A	Complete and report results of techno-economics analysis of large SOFC/GT systems	3/31/2020
Subtask 1.3.8	***Model large SOFC/GT systems***	
	Evaluate technical and economic feasibility of identified integration schemes for natural gas, coal and biomass fueled large (~100 MW) systems with CO_2 capture.	9/30/2020
Milestone 1.3.8.A	Complete and report results of techno-economics analysis of large SOFC/GT systems	9/30/2020
Subtask 1.3.9	***Assess development needs and trade-offs***	
	Assess technological development needs to bring promising SOFC/GT concepts into market place and perform sensitivity analysis to asses trade-offs between design and performance.	3/31/2021
Milestone 1.3.9.A	Issue report documenting assessment of development needs and trade-offs for all SOFC/GT systems developed	3/31/2021
Subtask 1.3.10	***Finalize commercialization plan***	
	Develop commercialization plan to bring promising SOFC/GT concepts into market place.	9/30/2021
Milestone 1.3.10.A	Issue final report documenting results of techno-economics analysis of all promising SOFC/GT systems developed and commercialization plan	9/30/2021

Summary of Results – 10 MW Nat Gas



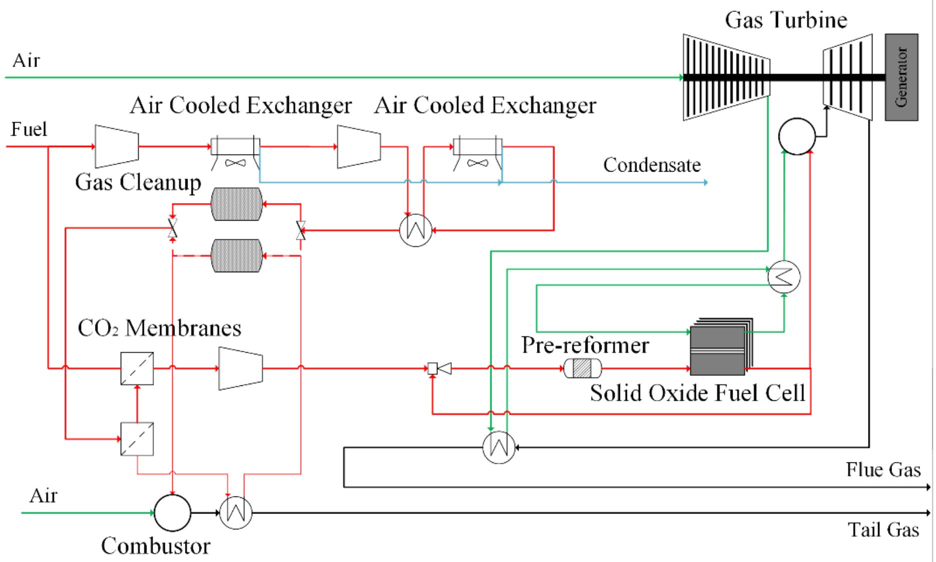


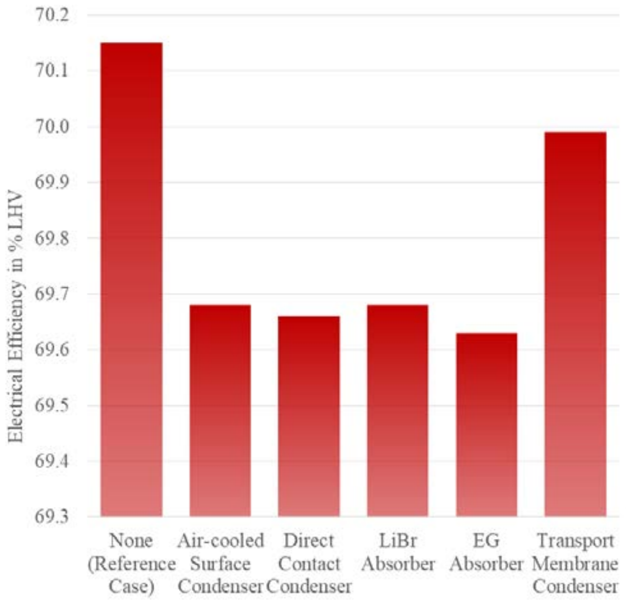


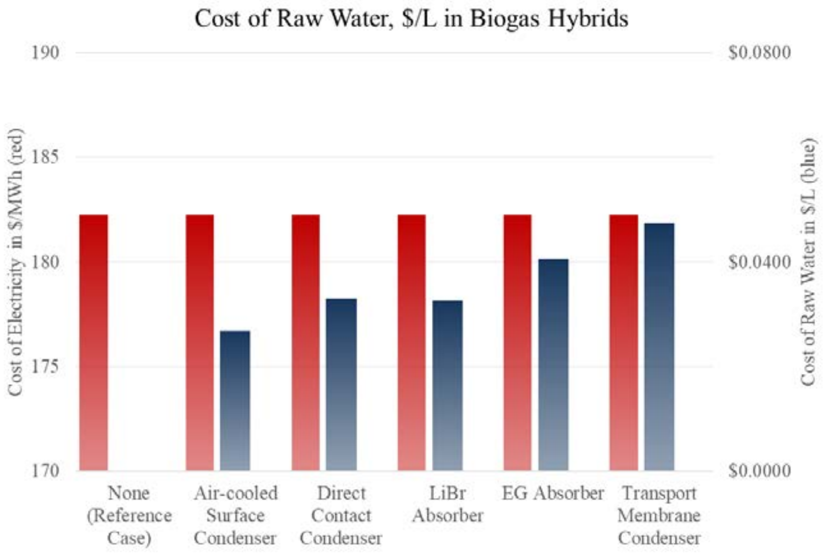


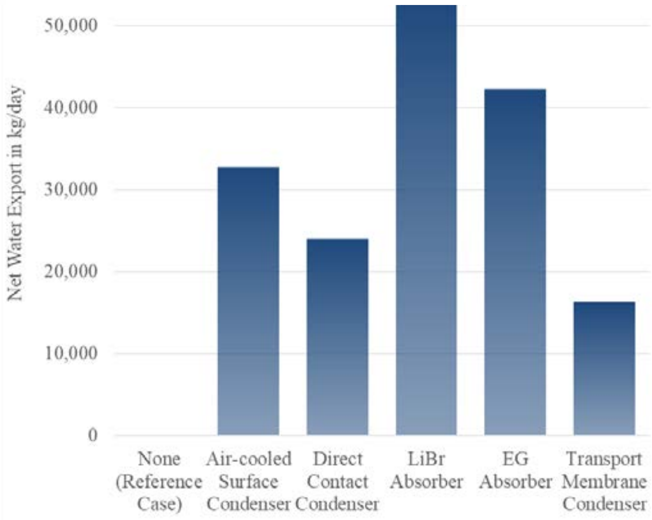
- Lowest water cost with air-cooled condenser & LiBr absorption
- But significantly higher GT back pressure with air-cooled condenser
- While significantly higher water recovery with LiBr absorption
- Zero water usage in reference case

Summary of Results – 10 MW Digester Gas





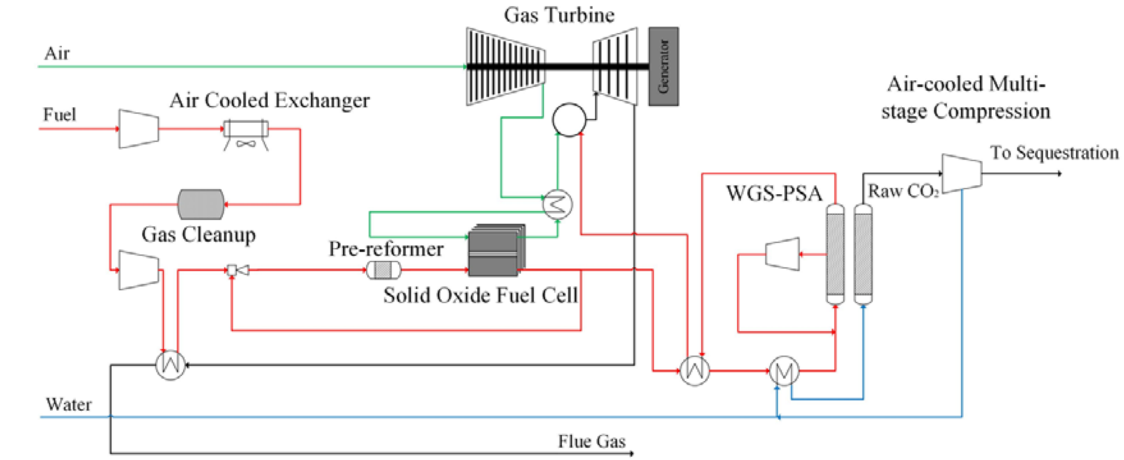


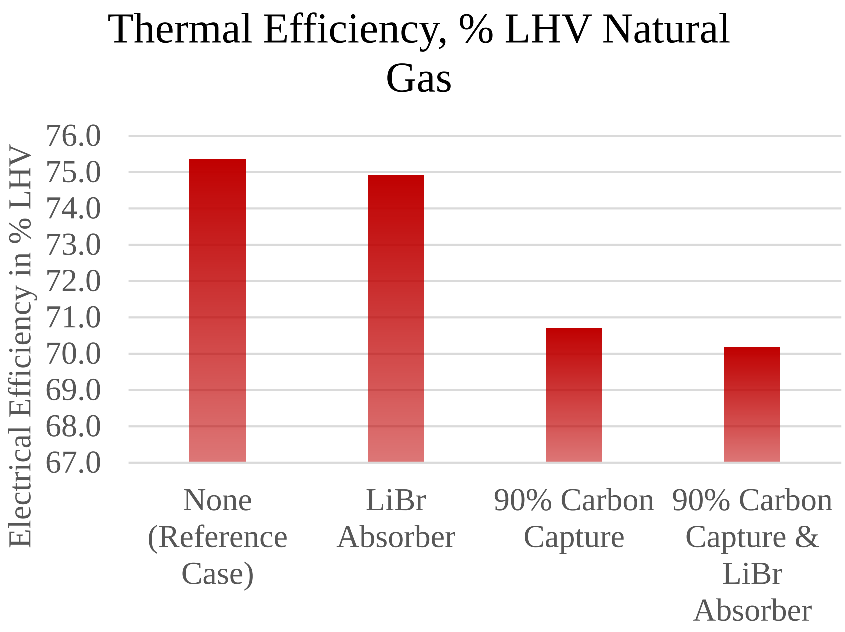


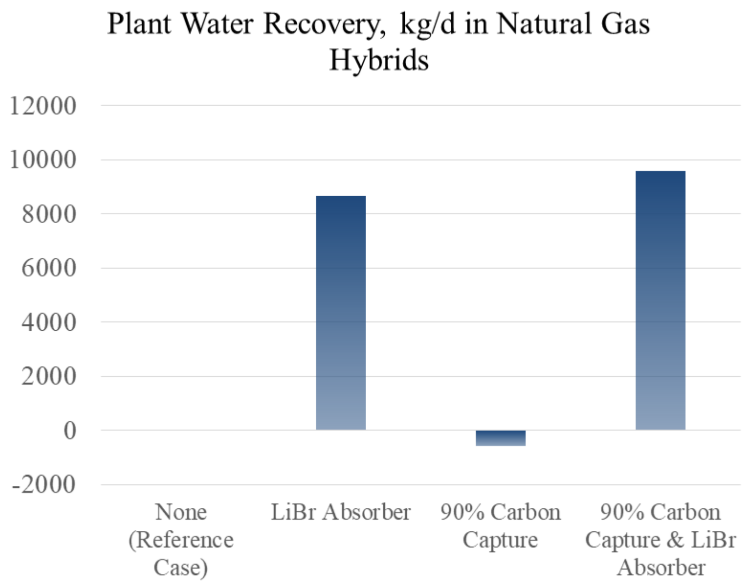
- Lowest water cost with air-cooled condenser & LiBr absorption
- But significantly higher GT back pressure with air-cooled condenser
- While significantly higher water recovery with LiBr absorption
- Zero water usage in reference case

Summary of Results – 50 MW Nat Gas

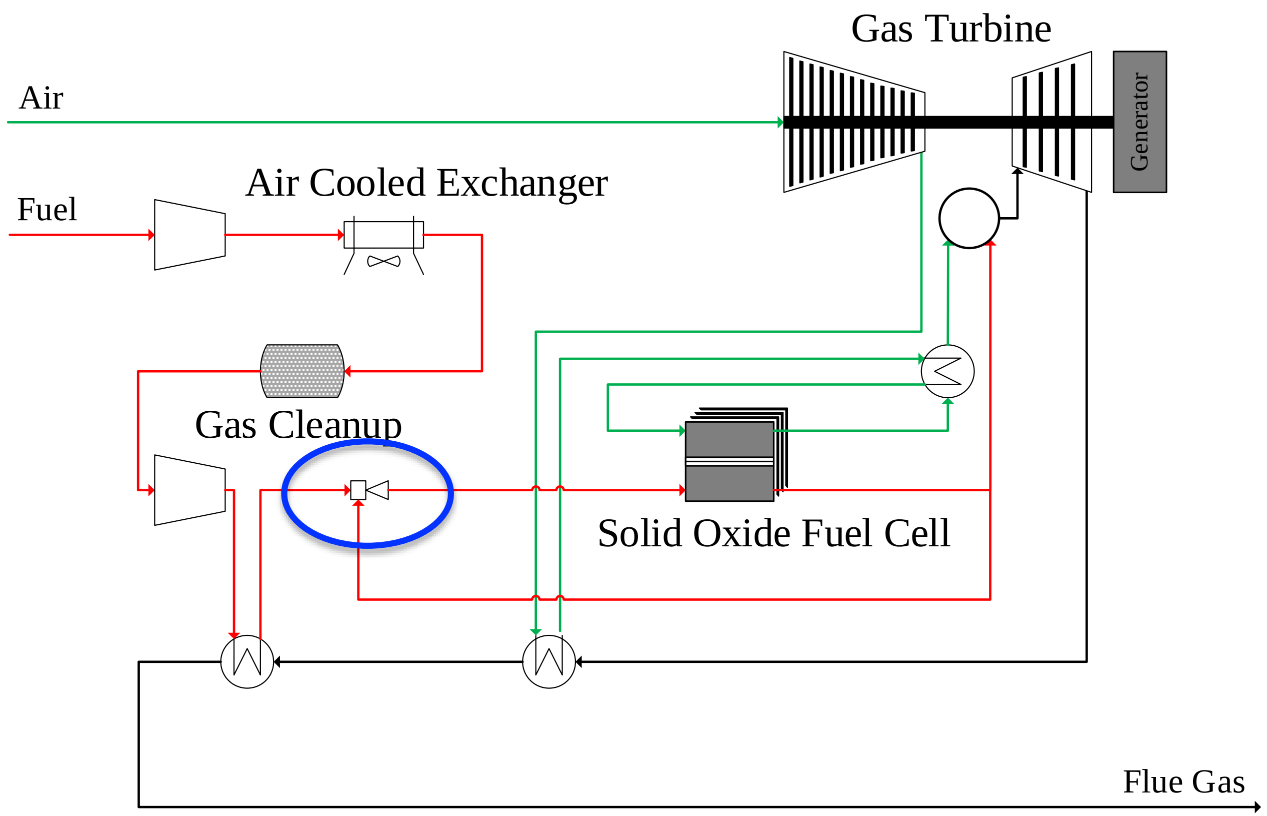
- Costs/economics under development
  - w/o water recovery, w/o CCS
  - w/o flue gas water recovery, with CCS
  - with flue gas water recovery, with CCS







Summary of Results – Eductor



- CFD model under development
  - Extent of fuel deoxidation
  - Soot formation being accounted for
- Test rig also being set up

Potential Barriers – Recovered Water Cost

- Cost of recovered water high
  - ~50% of cost due to purification & ZLD systems
  - Collaboration with water treatment vendor to optimize above systems
  - Identify new desiccant systems & optimize regeneration
  - Experimental validation of identified absorption system(s)

Next Steps in Systems Analysis

- **50 MW Plants**
  - **Techno-economics assessment**

- **100 MW Plants**
  - **Plant simulations & performance**
  - **Develop capital, O&M costs**
  - **Techno-economics assessment**