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

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**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 CO₂ 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
1.1 Dry CO₂ 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
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
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
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
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
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
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
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

<table>
<thead>
<tr>
<th>Task/Subtask/Milestone</th>
<th>Subtask/Milestone Descriptions</th>
<th>Actual or Projected Date for Completion</th>
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<tbody>
<tr>
<td>Task 1.3</td>
<td>Project Kickoff</td>
<td>10/1/2016</td>
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<tr>
<td>Subtask 1.3.1</td>
<td>Identify collaborative researchers and establish plans for coordinating SOFC based systems research efforts.</td>
<td>3/31/2017</td>
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<tr>
<td>Milestone 1.3.1A</td>
<td>Complete and report coordination plans with Chinese researchers</td>
<td>3/31/2017</td>
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<tr>
<td>Subtask 1.3.2</td>
<td>Select design constraints and basis of key equipment such as SOFC, GT, reactors, gasifier, and develop/validate models for integration with Aspen Plus*</td>
<td>9/30/2017</td>
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<tr>
<td>Milestone 1.3.2A</td>
<td>Complete and report basis for selection of equipment design and models</td>
<td>9/30/2017</td>
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<tr>
<td>Subtask 1.3.3</td>
<td>Develop integration schemes and subsystem operating conditions for natural gas and biogas fueled small (~10 MW) systems without CO₂ capture.</td>
<td>3/31/2018</td>
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<tr>
<td>Milestone 1.3.3A</td>
<td>Complete and report promising integration schemes of small SOFC/GT systems</td>
<td>6/30/2018</td>
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<td>Subtask 1.3.4</td>
<td>Evaluate technical and economic feasibility of identified integration schemes for natural gas and biogas fueled small (~10 MW) systems without CO₂ capture.</td>
<td>3/31/2019</td>
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<td>Milestone 1.3.4A</td>
<td>Complete and report results of techno-economics analysis of small SOFC/GT systems</td>
<td>3/31/2019</td>
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<tr>
<td>Subtask 1.3.5</td>
<td>Develop integration schemes and subsystem operating conditions for natural gas fueled medium scale (~50 MW) systems with and without CO₂ capture.</td>
<td>3/31/2019</td>
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<td>Milestone 1.3.5A</td>
<td>Complete and report promising integration schemes of medium size SOFC/GT systems</td>
<td>3/31/2019</td>
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<td>Subtask 1.3.6</td>
<td>Evaluate technical and economic feasibility of identified integration schemes for natural gas fueled medium scale (~50 MW) systems with and without CO₂ capture.</td>
<td>9/30/2019</td>
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<td>Milestone 1.3.6A</td>
<td>Complete and report results of techno-economics analysis of medium size SOFC/GT systems</td>
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<td>Subtask 1.3.7</td>
<td>Develop integration schemes and subsystem operating conditions for natural gas, coal and biomass fueled large (~100 MW) systems with CO₂ capture.</td>
<td>3/31/2020</td>
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<td>Milestone 1.3.7A</td>
<td>Complete and report results of techno-economics analysis of large SOFC/GT systems</td>
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<td>Subtask 1.3.8</td>
<td>Evaluate technical and economic feasibility of identified integration schemes for natural gas, coal and biomass fueled large (~100 MW) systems with CO₂ capture.</td>
<td>9/30/2020</td>
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<td>Milestone 1.3.8A</td>
<td>Complete and report results of techno-economics analysis of large SOFC/GT systems</td>
<td>9/30/2020</td>
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<td>Subtask 1.3.9</td>
<td>Assess technological development needs to bring promising SOFC/GT concepts into market place and perform sensitivity analysis to assess trade-offs between design and performance.</td>
<td>3/31/2021</td>
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<tr>
<td>Milestone 1.3.9A</td>
<td>Issue report documenting assessment of development needs and trade-offs for all SOFC/GT systems developed</td>
<td>3/31/2021</td>
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<td>Subtask 1.3.10</td>
<td>Finalize commercialization plan</td>
<td>9/30/2021</td>
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<td>Milestone 1.3.10A</td>
<td>Issue final report documenting results of techno-economics analysis of all promising SOFC/GT systems developed and commercialization plan</td>
<td>9/30/2021</td>
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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

Thermal Efficiency, % LHV Natural Gas

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<th>Electrical Efficiency in % LHV</th>
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<tr>
<td>None (Reference Case)</td>
<td>67.0</td>
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<tr>
<td>LiBr Absorber</td>
<td>68.0</td>
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<tr>
<td>90% Carbon Capture</td>
<td>69.0</td>
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<tr>
<td>90% Carbon Capture &amp; LiBr Absorber</td>
<td>70.0</td>
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Plant Water Recovery, kg/d in Natural Gas Hybrids

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<th>Plant Water Recovery, kg/d in Natural Gas Hybrids</th>
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<tr>
<td>None (Reference Case)</td>
<td>0</td>
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<tr>
<td>LiBr Absorber</td>
<td>1200</td>
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<tr>
<td>90% Carbon Capture</td>
<td>10000</td>
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<tr>
<td>90% Carbon Capture &amp; LiBr Absorber</td>
<td>12000</td>
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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