Protonic Ceramics for Energy Storage and Electricity Generation with Ammonia
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Project Vision
We are developing regenerative protonic ceramic fuel cell technology for synthesis of carbon neutral ammonia and its subsequent use for electric power generation.

Project Impact
This project will result in a scalable low-cost efficient technology for utilizing renewable energy in production of ammonia and its further use as a fuel source for making electricity.
Innovation and Objectives

Innovation

- Proton-conducting electrochemical cell for hydrogen generation from $\text{H}_2\text{O}$
- Optimized Ruthenium ammonia-synthesis catalyst supported on an electride
- Integration of the catalyst into the electrochemical cell for increasing NH$_3$ production rate

Task outline, technical objectives

- Develop reversible proton-conducting ceramic cells (CSM and FCE)
- Develop and integrate advanced electride catalysts to increase ammonia-production rates by two orders of magnitude (CSM)
- Develop and demonstrate performance and durability of a prototype stack manufactured using commercially relevant processes (FCE)

Tech-to-Market strategy

- Dual market strategies:
  - Scalable ammonia production
  - Electric power generation
- Renewable energy storage potential initial market entry
- Established SOFC manufacturing base
Innovation and Objectives

Project history
- FCE has established pilot scale manufacturing for advanced reversible SOFC power plants, electrolysis and storage applications
- CSM has been developing state-of-the-art protonic ceramic fuel cells (ARPA-E Rebels)
- CSM has verified feasibility of NH$_3$ production from N$_2$ and H$_2$O using protonic ceramic fuel cell (PCFC)

Proposed targets

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<tr>
<th>Metric</th>
<th>State of the Art</th>
<th>Proposed</th>
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<tbody>
<tr>
<td>Ammonia synthesis rate</td>
<td>Highest published solid-state ammonia synthesis rate = $1 \times 10^{-8}$ mol/ (cm$^2$ s)</td>
<td>Target NH$_3$ synthesis rate $\geq 5 \times 10^{-8}$ mol/ (cm$^2$ s)</td>
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<tr>
<td>Proton-Conducting Fuel Cell Performance</td>
<td>Laboratory scale button cell with ammonia fuel at 500 mA/cm$^2$ and 0.75 V</td>
<td>50 W NH$_3$ fueled stack PCFC with: $\leq 0.3%$/khrs degradation, at $\geq 500$ mA/cm$^2$, 0.75V, T$\leq 650^\circ$C, $\leq 20$ bar.</td>
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Anticipated challenges
- Increased activity of the ammonia-synthesis catalyst
- Integration of ammonia-synthesis catalyst into the electrochemical cells
- High-performance steam electrode for efficient water splitting
- Cell and stack fabrication and scale-up

Desirable partnerships
- FCE and CSM team has the sufficient capabilities to proceed with the conduct of the project research and development activities
- The project team is open to the long-term partners involved in the commercial aspects of ammonia production, distribution and use
Technical Details

Ru-C12:A7 catalyst increases ammonia-production by 10x
- C12:A7 catalyst support has unique “cage-like” structure
- Transfers electrons through the cages to react with N₂
- Electrons weaken N₂ triple bond
- 10x improvement in NH₃ formation compared to Haber-Bosch catalyst

Proton-conducting ceramic cells further increase NH₃ production
- Highly reactive protons, rather than gas-phase H₂, are hydrogen source
- Electric potential drives membrane
- Two effects can increase ammonia formation by ten-fold

Ammonia Fueled Protonic Ceramic Fuel Cell (PCFC)
- Focus on cell and stack manufacturing and scale up using well-established ceramic processing techniques
- Develop cost-effective systems for ammonia production and use to generate electricity