Direct Ammonia SOFC

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Why SOFC and Why Ammonia?

- High efficiency
- Efficient at part load
- Fast response
- Use of many fuels (NH₃)
**SOFC/SOEC Basic Concept**

**SOFC**

- \( \text{H}_2 \) to \( \text{H}_2\text{O} \)
- \( \text{H}_2 + \text{O}^- \rightarrow \text{H}_2\text{O} + 2e^- \)
- \( \frac{1}{2}\text{O}_2 + 2e^- \rightarrow \text{O}^- \)
- \( \frac{1}{2}\text{O}_2 \)

**SOEC**

- \( \text{H}_2\text{O} \) to \( \text{H}_2 \)
- \( \text{H}_2\text{O} + 2e^- \rightarrow \text{H}_2 + \text{O}^- \)
- \( \text{O}^- \rightarrow 2e^- + \frac{1}{2}\text{O}_2 \)
- \( \frac{1}{2}\text{O}_2 \)
Ammonia SOFC/SOEC – Potentially Reversible

NH₃

Air

SOFC

N₂, H₂O

Electric power

Air + Heat

SOEC or Hydrammine

Air
Why Small and Micro-Tubular SOFC?

- The small-scale tubular solid oxide fuel cells (SOFC), have many advantages over larger tubular and planar designs, including:
  - Excellent thermal shock properties giving rapid start-up ability,
  - High mechanical integrity
  - Easy and Cheap to Fabricate
  - Easy design for stacking and manifolding
high efficiency on energy conversion and Selective reactions

**Ceramic reactor**

- **Cube**
  - Thin Electrolyte using ScSZ/CGO etc
  - Porous Cathode Unit
  - Micro-scale Tubular Anode
- **Cell**
  - Stacking
  - Air
  - Fuel
  - High-efficient Ceramic Reactor Module

**Fuel Cells**

**APU for Vehicles**

**SOEC/SOFC Applications**

- **Chemical Syntheses**
  - $\text{NH}_3 \rightarrow \text{CO} + \text{H}_2$
  - $2e \rightarrow \text{O}^2$
  - $\text{O}_2 + \text{N}_2 \rightarrow \text{N}_2$

**Environment Purifying**

- $\text{NO}_x \rightarrow \text{N}_2 + \text{O}_2$

**H₂ Station**

- City gas
  - Water, Electricity
  - Electricity, Water, CO₂

- Daytime
  - Storage, Co-generation
  - H₂ Synthesis

- Night
  - H₂ Synthesis
Overview of SOFC/SOEC Program

- Micro-tubular designed cell
  - high thermal shock proof
  - high productivity
- Intermediate temperature operation (650°C)
  - quick start-up (in a few minutes)
- Modularized design
  - high cubic power density

Micro-tube cells are integrated in a porous cathode cube.
Cell Fabrication Process

Polymer Binder | Anode Powder | Water

Mixing → Vacuuming → Extrusion → Tube Cutting → Pre-firing → Tube Completed (Anode)

Electrolyte Coating → Drying → Sintering

Anode and Electrolyte Completed

Brush Painting → Cathode Firing

Single Cell Completed
Powder Preparation and Mixing
Example of our Extrusion Capability
Fabrication of Micro-tubular Protonic Electrolyte on Anode Support

**Cell Preparation**
- 0.8-1.8 mmΦ support tube

**Electrolyte Application**
- Co-fired at 1450°C

**Application of electrode**
- Sintered at 1000°C for 1 h.

**Support**: Metal oxide-ceramic composite (200µm in thickness)
**Electrolyte**: Perovskite protonic ceramic (10-20µm in thickness)
**Electrode**: Metal oxide-ceramic composite (40µm in thickness)

0.8mm diameter support tube with electrolyte

0.8mm diameter anode tube
Details of the Perovskite Tube

Microstructure

Protonic Perovskite (Sintered Material)
Test Set up for Ammonia in a PCFC and Production in a PCEC
Results from PCFC Testing on Ammonia at 700°C
IV Curves at 700°C
Power Curves at 700°C

- 100% Hydrogen
- 20% Ammonia
- 60% Ammonia
- 100% Ammonia