SOFC and Gas Separation Membranes

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Published in:
Energy solutions for CO2 emission peak and subsequent decline

Publication date:
2009

Link back to DTU Orbit

Citation (APA):

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Solid Oxide Fuel Cells and Gas Separation Membranes

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Outline

- Background Motivation
  - Combination of Energy Conversion Technologies
    - Solid Oxide Fuel Cells
      - Gas Separation Membranes
    - Summary and Outlook
How can we satisfy our needs for energy – in the right forms and at the right times – with what nature offers?
Background

Biomass

Gasification

Fuel Cells

Membranes

Heat

Electricity
Biomass: Gasification

Gasification of biomass to CO and H₂

- High temperature process
- Use of waste (wood chips, organic waste)
- Efficiency of wood for electricity exceeds 25%
- Potential for increase of electrical efficiency by use of fuel cells and oxygen enriched gasification

! Carbon capture! 

Viking gasifier at Risoe DTU
Combination: Gasification – SOFC-Membrane

• Increase of total efficiency:
  – SOFC convert fuel to electricity with higher efficiency than conventional technologies
  – Oxygen rich gasification gives a gas with lower nitrogen content (less diluted fuel)

• New option: Carbon capture

• Challenges:
  – Changing composition according to used biomass
  – Load fluctuations
  – Impurities, minor components in gasification gas:
    • Sulphur containing, ammonia, higher hydrocarbons, etc.
Solid oxide fuel cells (SOFCs)

- Higher efficiency than conventional power generation systems
- Reduction of emissions and pollution (NO\textsubscript{x}, CO\textsubscript{2}, noise)
- Modular concept (from kW to MW)
SOFC Working Principle and Main Components

**CATHODE**
- Catalytic activity for oxygen reduction
- Gas transport (porosity)
- Electron- (ion-) conducting

**ELECTROLYTE**
- Gas tight
- (Oxygen) ion conducting
- Electronic isolator

**ANODE**
- Catalytic activity for fuel oxidation
- Gas transport (porosity)
- Electron- (ion-) conducting

**GENERAL**
- Chemical inertness
- Thermal compatibility
- Mechanical strength and flexibility

\[
O_2 + 4e^- \rightarrow 2O^{2-}
\]

\[
2H_2 + 2O^{2-} \rightarrow 2H_2O + 4e^-
\]

Gasification gas
• Risoe DTU has developed several SOFC generations based on ceramic materials, which are tailored for different operating conditions
• A pre-pilot manufacture line was established using scale-able and economically competitive processes
Durability of SOFCs – Generation G2

- Good initial performance
- Good durability over thousands of hours in different fuels:
  - Hydrogen, synthesis gas (CO + H₂), methane + steam

![Graph showing power density vs. time under current](image)

- Durability tests on 2G, synthesis gas, 75% fuel utilization
  - 750 °C
  - 850 °C
Tolerance of 2G SOFCs towards H₂S impurities in a fuel mainly containing hydrogen and also hydrocarbons (methane) and steam not sufficient.
Impedance analysis, 750 °C, 20% H₂O

**Cell A (2G)**

- Fit
- Cat I
- Ano I
- Cat II
- Diffusion
- Conversion
- Cell #A

**Cell B**

- Fit
- Cat I
- Ano I
- Cat II
- Diffusion
- Conversion
- Cell #B

Smaller resistance from anode and smaller electrolyte resistance = Better performing cell

16 September 2009
Durability of SOFCs – Generation G2.X with Improved Anode: H₂S Impurities

- Significantly improved tolerance of improved 2G SOFCs towards H₂S impurities in the fuel
From Solid Oxide Fuel Cells – Oxygen Transfer Membranes

CATHODE
• Catalytic activity for oxygen reduction
• Gas transport (porosity)
• Electron-(ion-)conducting

ELECTROLYTE
• Gas tight
• Oxygen ion conducting

ANODE
• Catalytic activity for fuel oxidation
• Gas transport (porosity)
• Electron-(ion-)conducting

GENERAL
• Chemical inertness
• Thermal compatibility
• Mechanical strength and flexibility

O₂ + 4e⁻ → 2O²⁻
Oxygen Transfer Membranes (OTMs)

Oxygen is separated from air, transported through a membrane and supplied to partial oxidation of methane.

Cross section SEM picture of a ceria based membrane.
**OTMs: Performance (Flux)**

**Measurements**
- **Economical feasibility**

**Calculations**
- **Flux** vs. **Temperature (°C)**
  - Flux based on in-situ sensor
  - Flux based on ex-situ sensor

**Membrane thickness**

1. **Hydrogen** 30 µm thick CGO
2. **Air**
3. **0.02 atm O₂**
4. **10 atm air**

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Summary Outlook

Combination of biomass gasification and SOFC:

• Potential electric efficiency of +50% through use of a SOFC
• By using intelligent heat management, high total efficiencies ~ 90% possible
• Well performing and durable SOFCs developed and demonstrated for several fuels, even in presence of H₂S impurities
  – Challenge: Tolerance towards other impurities

Combination of biomass gasification and OTM:

• Increase of overall efficiency due to gasification gas with higher energy density (less diluted)
• Know-how developed for SOFCs can be utilized
• Promising results regarding performance (flux) and economic feasibility
  – Challenge: Increase of flux and durability
Acknowledgements

• We gratefully acknowledge support from our sponsors:

• Topsoe Fuel Cell A/S
• Danish Energy Authority
• Energinet.dk
• EU Framework Programmes
• Danish National Advanced Technology Foundation
• Danish Research Councils
• DONG Energy
• Areva