Solid Oxide Fuel Cells for Waste to Materials & Energy

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Bryan Blackburn, Ph.D.
Redox Power Systems
Interesting WTE Opportunities with SOFCs

**SOFC:** *chemical energy → electrical energy*

- SOFCs: 50-60% (LHV) electric conversion efficiency (>80% in CHP)
  - steam turbine @ 18-25%; large gas turbine (single cycle) @ ~35-40%
  - high efficiency even @ partial loads (unlike, e.g., gas turbines)
  - MSW: variable energy content (1.2-2.5 MWh/ton) → syngas compression/storage for certain tech

- Typical fuel is natural gas (*other:* liquid fuel & bio-fuel)

- Redox’s SOFC technology
  - higher power densities (>1.5 W/cm² vs ~0.3 W/cm²)
  - lower temperatures (450-650°C * vs 800-900°C)
  = smaller, lower cost

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*ARPA-E REBELS Program*
Typical SOFC Power System

**System Cost Breakdown**

- **Reformer**: ~25%
- **SOFC**: ~50%
- **Other**: ~25%

**WTE can replace reformer, reduce cost!**

**SYNGAS Requirements**
- **Don’t want**: Halides, particulates, chlorides, sulfur, tars
- **Want**: CO, H₂, CH₄ (too lesser degree) lower HCs
- **Tolerate**: H₂O, N₂, CO₂ (diluent)

SOFC System Examples

Bloom Energy

~230 sq ft for 200 kW

Redox Power Systems

~100 sq ft for 200 kW
(25 kW to 300 kW building blocks)

Microsoft: SOFCs for Data Centers

Nissan: SOFCs for Automotive
SOFCs/WTE: FB Gasifier + plasma clean-up

Possible outputs: fuel production (e.g., bio-methane) and efficient electricity

See: Tetronics/APP
SOFCs in WTE: Combustion Steam Reforming

Pulsed combustion steam reforming (gasification)

- **Primary Stage**: Indirect heating of MSW in medium temperature, low pressure (indirect bubbling) fluidized bed gasifier/steam reformer

- **2nd Stage**: higher temperature, low-pressure fluidized bed gasifier → partial oxidation of stage 1 char (tune H₂/CO)

See: Thermochem Recovery International
Syngas from Traditional WTE (incineration)?

- Create syngas from incinerator ash
  - Assumes some remaining carbon (e.g., perhaps to reduce NO\textsubscript{x} without SCR)
  - Divert toxic material from landfill → clean, efficient electricity (SOFC)
  - Mass and volume reduction
  - Pozzolanic material to use in, e.g., cement production

- Plasma/Ash + SOFC → add to incineration power

Modified from Čarnogurská et. Al. (10.1016/j.measurement.2014.11.014)
Syngas or $\text{H}_2$ from Traditional WTE (incineration)?

**Solid Oxide Fuel Cell**
- Incineration heats boiler → steam drives (NG or landfill gas) steam reforming → syngas to SOFC
- Combined cycle with SOFC & steam turbine producing electricity for higher efficiency?

**Solid Oxide Electrolyzer Cell (SOEC) + Fuel Cells**
- SOEC is like SOFC running in reverse (electrolytic operating mode)
- Use heat from incineration to make steam for turbine and SOEC
- Turbine electricity + steam feed SOEC → $\text{H}_2$ *

*Also make $\text{O}_2$ → use to improve incinerator combustion?
SOFC-Related WTE Challenges

• Impurities can poison SOFC
  – Potential minor impact: Hg, Si, Zn, NH₃, Cd, Se
    (e.g., some evidence, tolerate Hg < 10ppm)
  – Potential major impact: Cl, As, Sb, H₂S, P
    (react with Ni in anode)
  – Potential tar tolerance: Napthalene < 100 ppm; Benzene < 150 ppm

• Possible Solutions
  – WTE Process
    • Front-end recycling (most Cl-based plastics)
    • Syngas cleanup, may be cost & efficiency sensitive
  – SOFC: use non-Ni catalysts at anode
Triple Play Increases the Odds of Success

- Find ways to further optimize waste-to-energy
  - Better recycling (plastics)
  - Minimize final waste stream (quantity)
  - Expand uses for solids, improve economics with complete cycle

- Find synergistic technologies to maximize benefit
  - Advanced energy conversion technology (e.g., SOFC / SOEC)
  - Syngas: gasification or pyrolysis tech
  - Novel integrations of SOFC/SOEC into incineration while simultaneously improving solids
  - Boost energy efficiency, coupling electrical/thermal

Waste/Landfill Problem ✔
Cleaner Electricity Product ✔
Cleaner Solid product ✔
Challenges, Risks, Strategies

- **Overcome “New Technology” barrier**
  - Unavoidable, unless solutions can fit into status quo (at least at early stages of implementation)
  - Find early adopters (e.g., USVI: ~$0.50/kWh)

- **Cost**
  - Find ways to boost economic output on multiple fronts (e.g., syngas for SOFC while simultaneously improving solids for sale, or vice versa)

- **Scalability**
  - Modular approach for WTE that can match SOFC modularity
  - Find ways to fit SOFC/SOEC, gasification into incineration at smaller scale for real world experience with less financial risk

- **Flexibility**
  - Integrations that allow for flexibility in revenue stream
  - Use technology that is less sensitive to changes in variable ”fuel” content (e.g., SOFC)
  - Designs that allow for variable MSW (e.g., syngas/H₂ production/compression)