Solid Oxide Fuel Cells for Waste to Materials & Energy

MSW to Materials & Energy Processes Workshop (ARPA-E)
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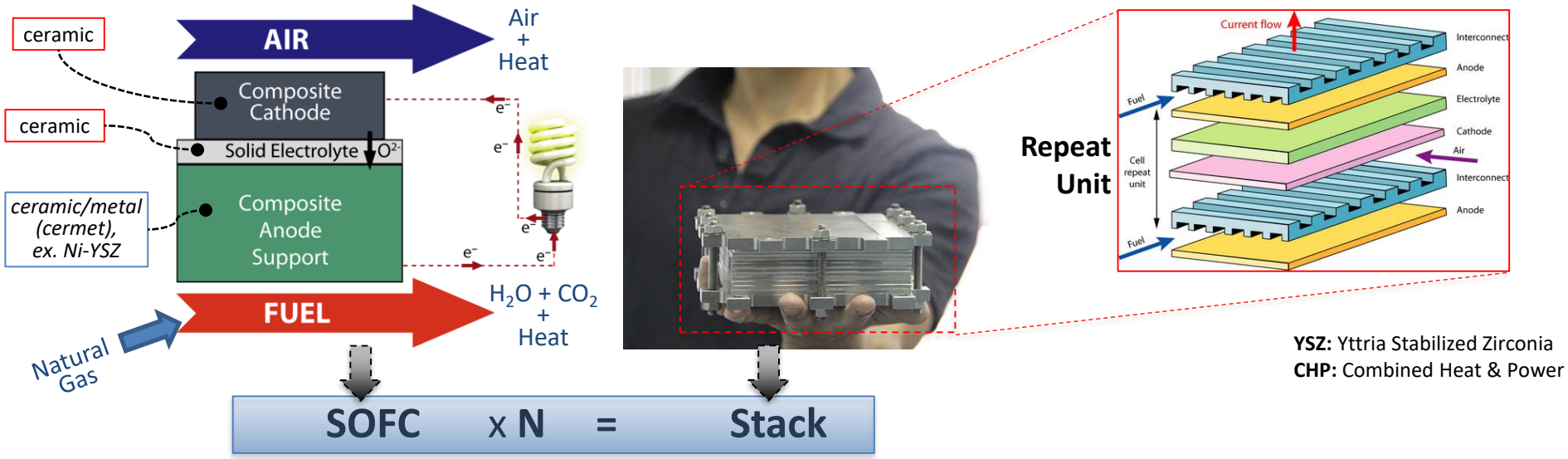
Redox Power Systems

Interesting WTE Opportunities with SOFCs

SOFC: *chemical energy → electrical energy*

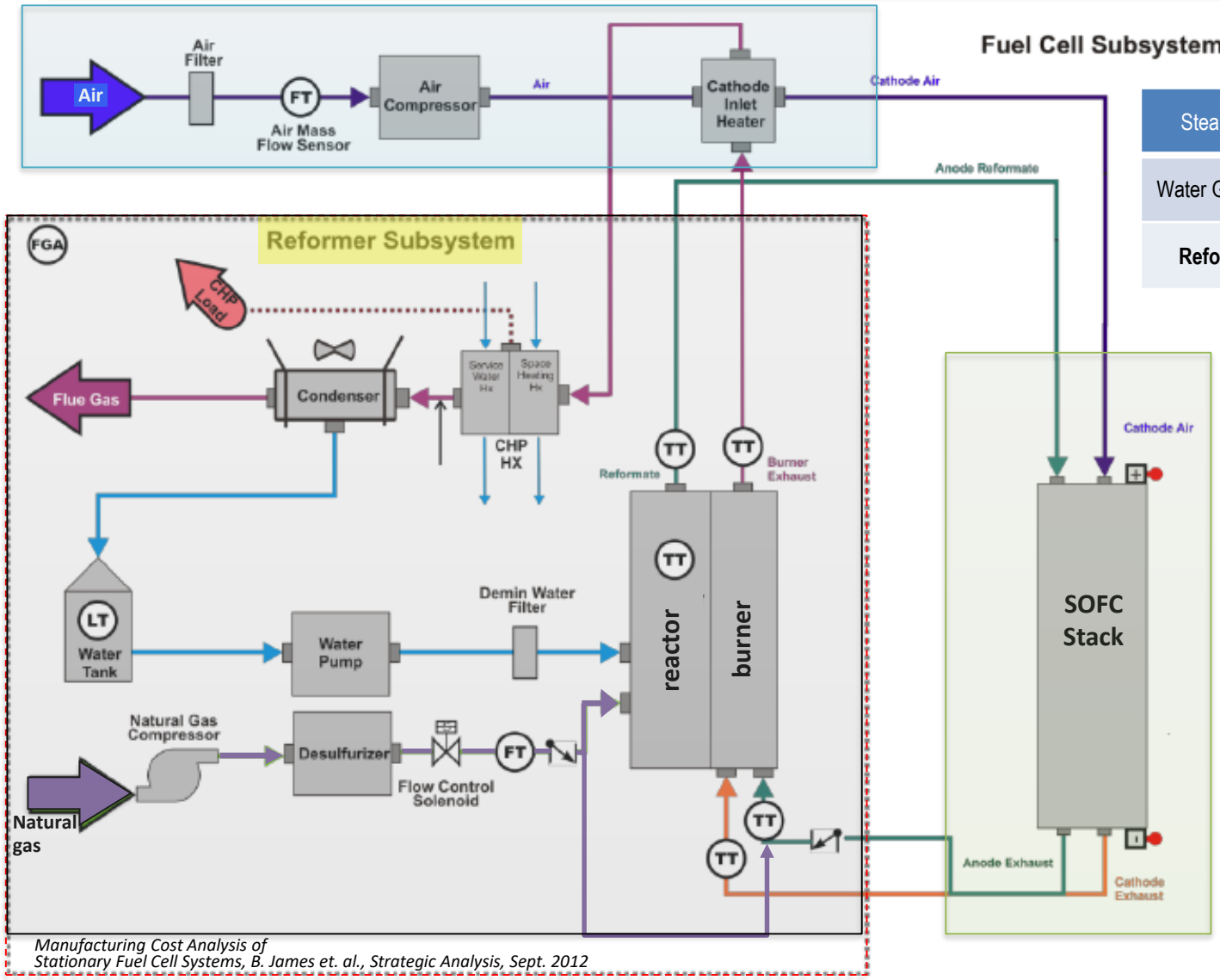


YSZ: Yttria Stabilized Zirconia
CHP: Combined Heat & Power

- 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** + **lower temperatures** = **smaller, lower cost**
    (>1.5 W/cm² vs ~0.3 W/cm²) *(450-650°C * vs 800-900°C)*

*ARPA-E REBELS Program

Typical SOFC Power System



Manufacturing Cost Analysis of Stationary Fuel Cell Systems, B. James et. al., Strategic Analysis, Sept. 2012

Steam Reforming	$CH_4 + H_2O$ (g) <--> $CO + 3H_2$
Water Gas Shift (WGS)	$CO+H_2O$ (g) <--> $CO_2+ H_2$
Reformer Output	CO, CO_2, H_2 (75% dry), H_2O

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, H_2, CH_4, (too lesser degree) lower HCs

Tolerate: H_2O, N_2, CO_2 (diluent)

SOFC System Examples

Bloom Energy

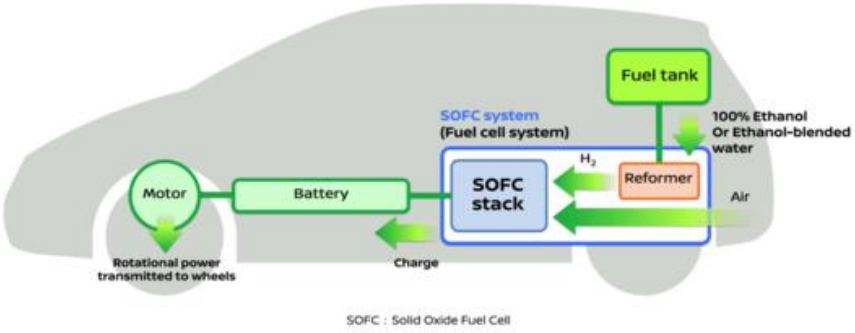
~230 sq ft for 200 kW

Redox Power Systems

~100 sq ft for 200 kW

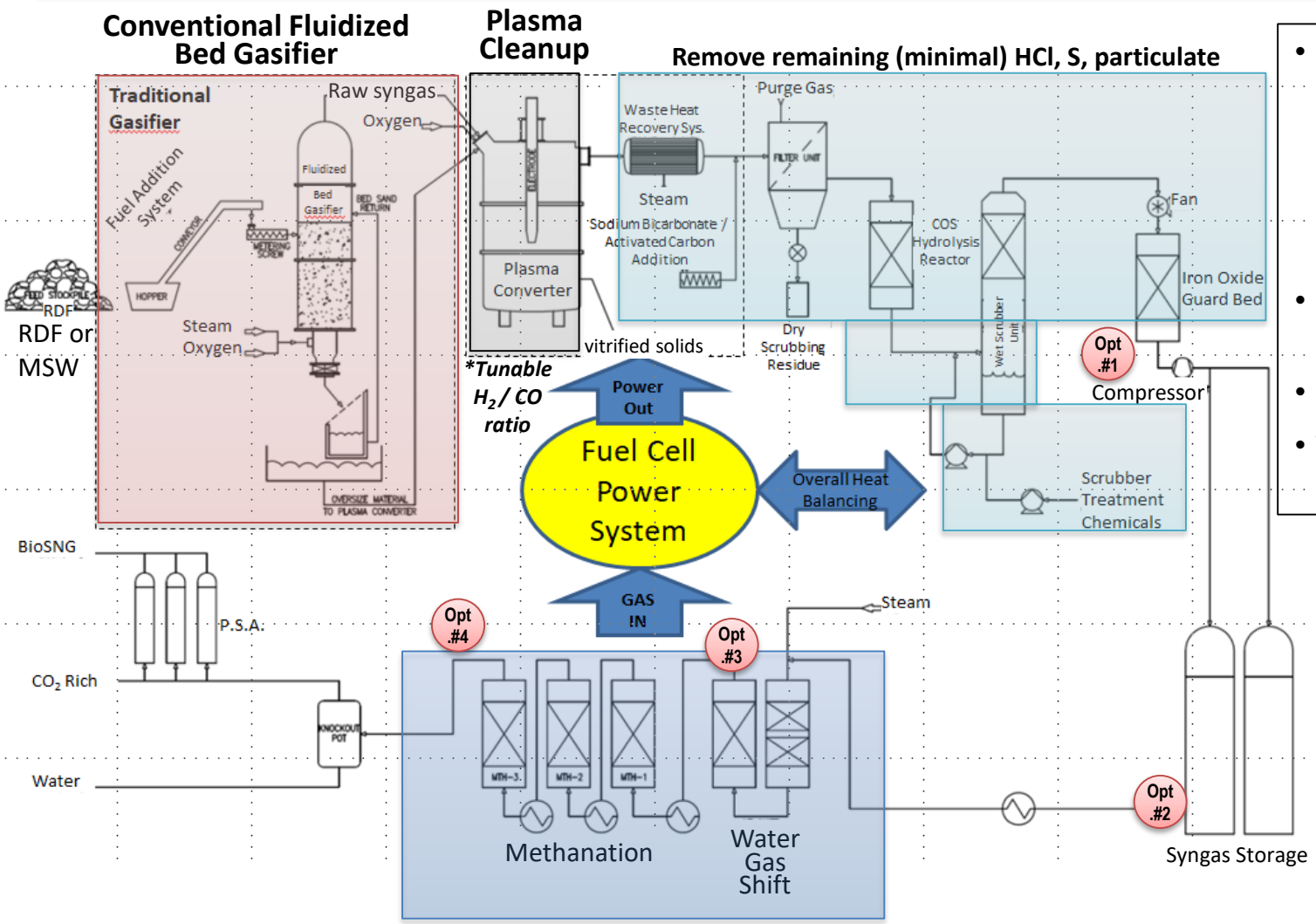
(25 kW to 300 kW building blocks)

Nissan: *SOFCs for Automotive*



Microsoft: *SOFCs for Data Centers*

SOFCs/WTE: FB Gasifier + plasma clean-up

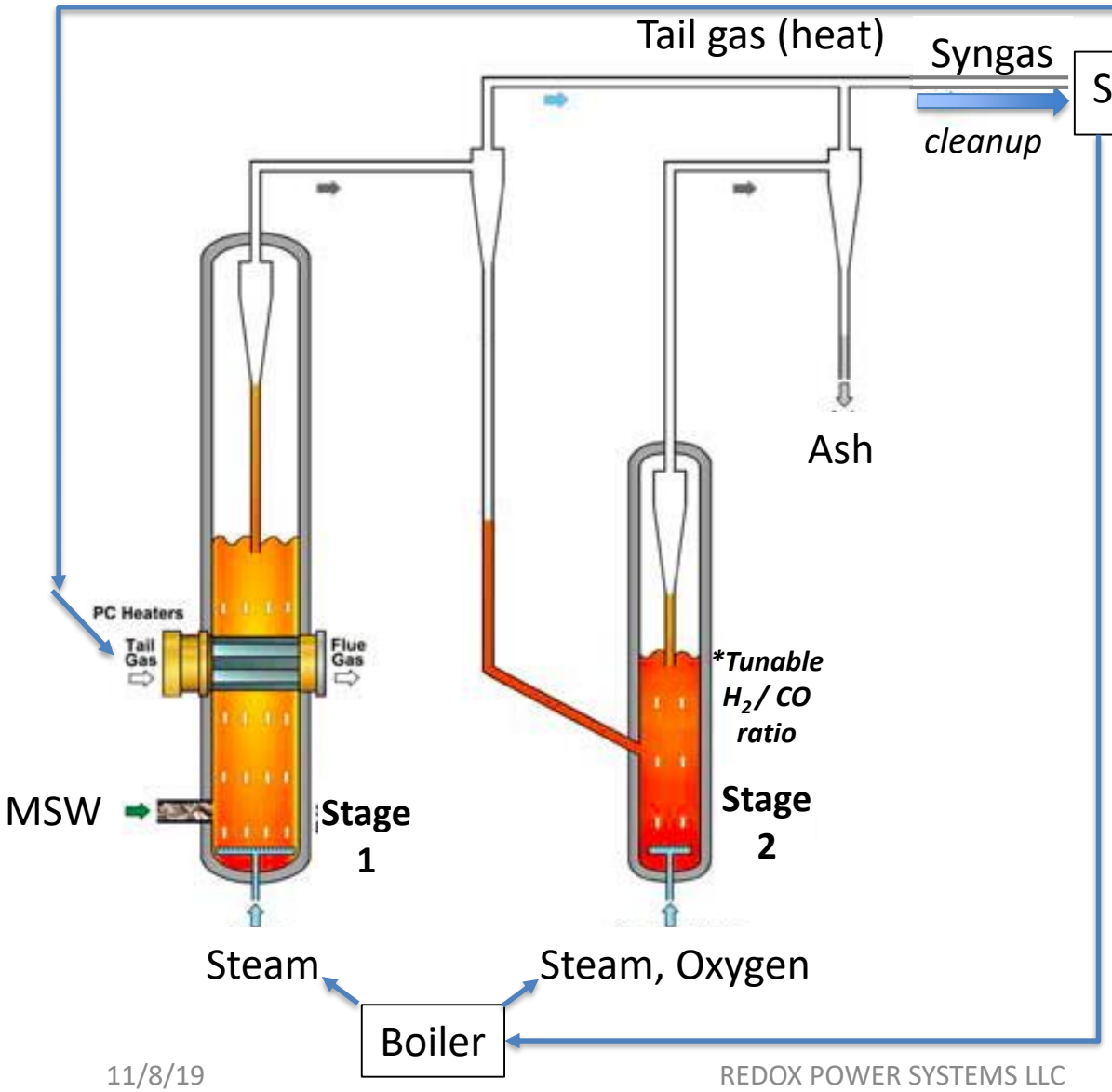


- Different options for SOFC fuel feed
  1. Clean syngas
  2. Compressed syngas
  3. H_2-rich syngas
  4. Bio-methane
- Native DC electricity (SOFC) feeds DC plasma
- Cold gas efficiency >75%
- Vitrified solids pozzolanic for cement

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

See: Tetronics/APP

SOFCs in WTE: Combustion Steam Reforming

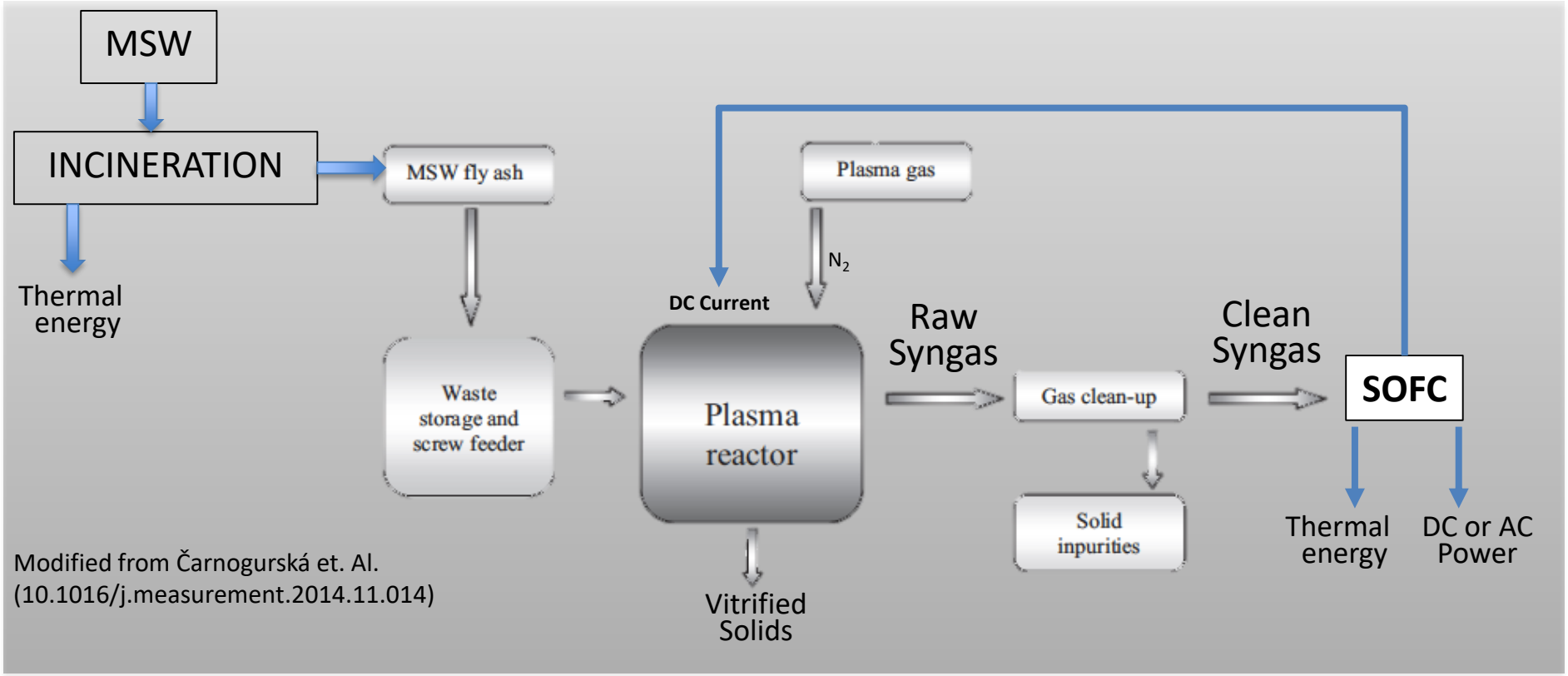


Pulsed combustion steam reforming (gasification)

- **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 H_2/CO)

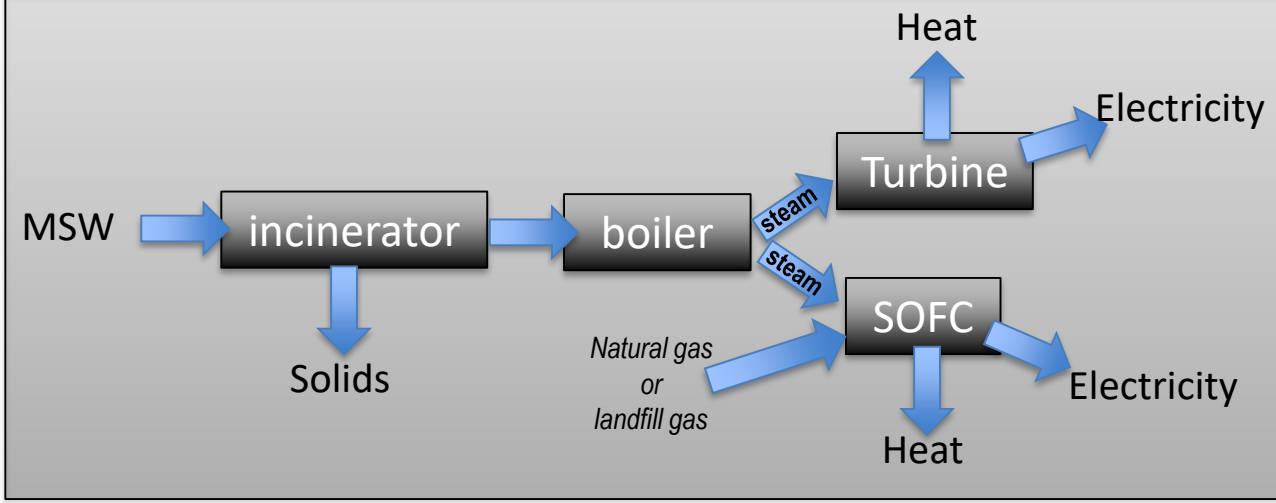
See: Thermochem Recovery International

Syngas from Traditional WTE (incineration)?



- Create syngas from incinerator ash
  - Assumes some remaining carbon (e.g., perhaps to reduce NO_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

Syngas or H_2 from Traditional WTE (incineration)?

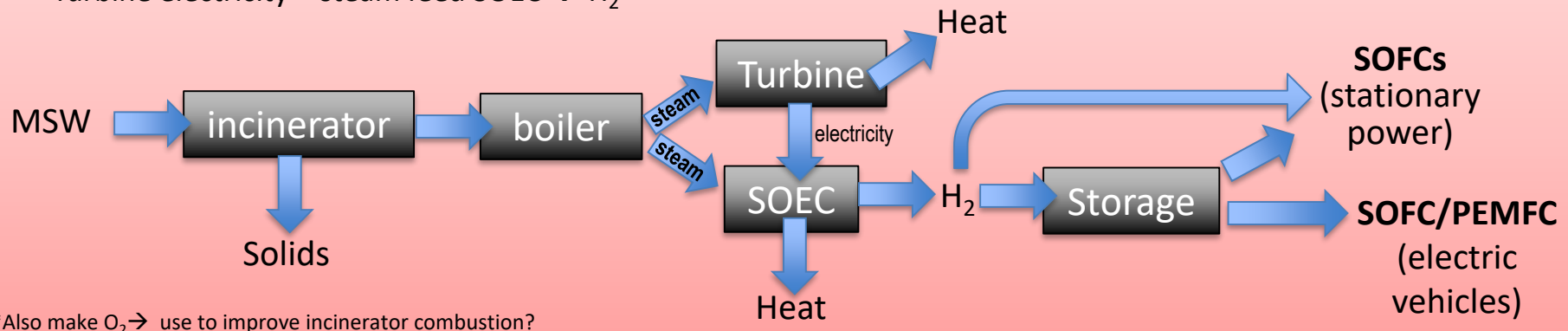


Solid Oxide Fuel Cell

- 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 → H_2 *

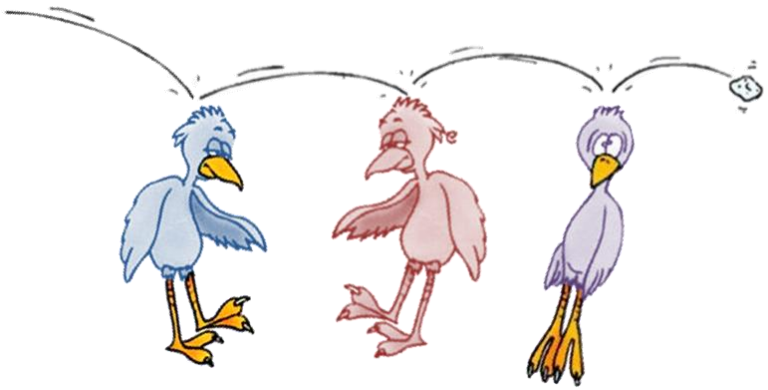


*Also make O_2→ use to improve incinerator combustion?

SOFC-Related WTE Challenges

- Impurities can poison SOFC
  - *Potential minor impact:* Hg, Si, Zn, NH_3, Cd, Se
    (e.g., some evidence, tolerate Hg < 10ppm)
  - *Potential major impact:* Cl, As, Sb, H_2S, 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



Waste/Landfill Problem ☑

Cleaner Electricity Product ☑

Cleaner Solid product ☑

- 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

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/H_2 production/compression)