Integrated Testing of a CPOX Reformer & SOFC

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Remote Alaska electric issues

- Diesel is a preferred fuel because of energy density
  - Diesel has about 17,000 BTU per pound
- Most remote electric is from diesel generator sets
- Cost can be very high in remote villages
  - In Kotzebue, cost is about $.20 per kWh
  - In small villages the cost exceeds $.40 per kWh
  - Transportation of fuel can be a significant cost
- Grid power does not exist in remote areas
- Alternatives that are more efficient and have lower environmental impact are of interest

Remote power generation in Alaska

- Two diesel generators
  - 25 kW
  - 35 kW
- Access by river or aircraft
- Low winds
- Under 400 people – average for Alaska ~450 people
- Environment is a consideration

Aerial View of Lime Village

Technical Issues

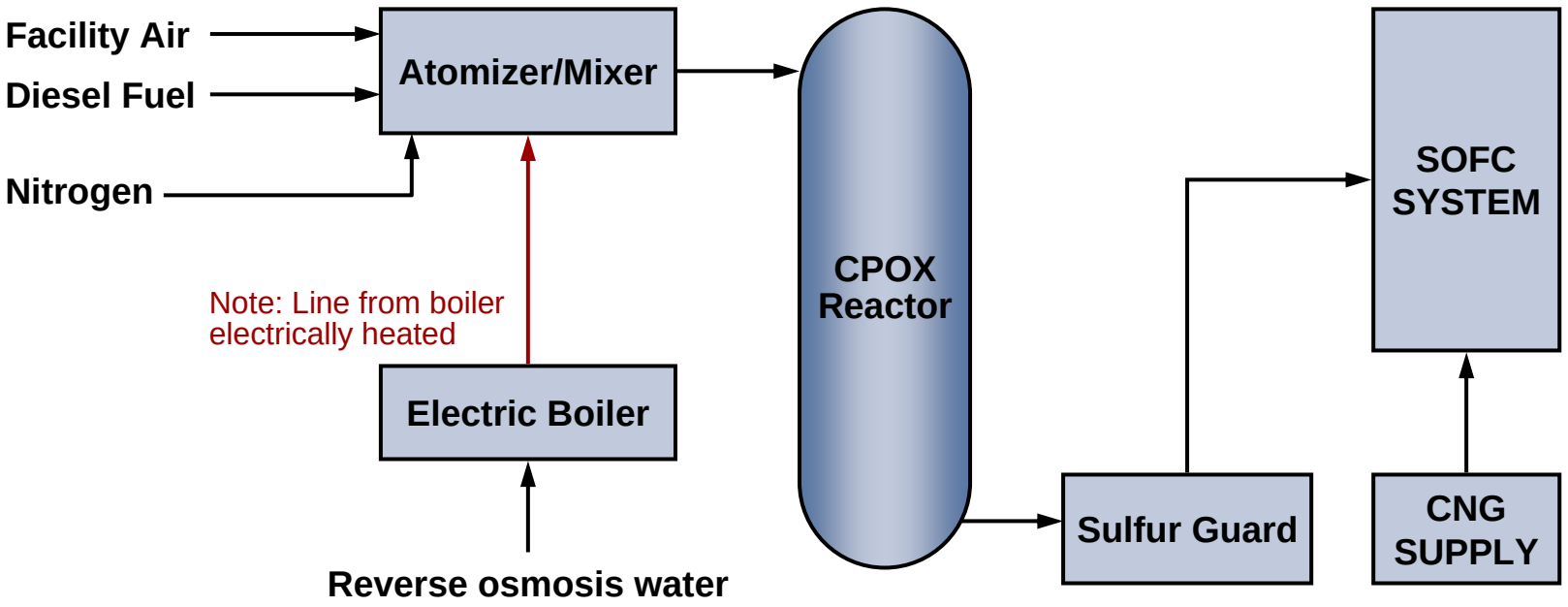
- Fuel cell operation at altitude
  - Lower pressure
    - Higher volumetric flow for the same mass flow
      - Higher pressure drop
      - Lower residence time
    - Lower oxygen content reduces reaction rates

- Use of liquid fuels
  - Liquid fuel reformation versus natural gas
    - Results in high volumetric flow rates for the same energy input
    - High pressure drops
  - External reforming affects thermal management
    - Endothermic natural gas versus exothermic reformate
    - Temperature profile changes
    - Additional cooling required in the front part of the cell stack

Test overview

- Use existing infrastructure for fuel (diesel)
- Use a commercially available reformer and SOFC
  - Reformer provided by SOFCO-EFS
  - SOFC provided by Acumentrics
- Test reformer and SOFC at origin
  - Reformer on diesel (low sulfur and synthetic)
  - SOFC on natural gas
- Test each unit independently at INL
- Test the units in integrated operation on diesel
- Gather data for designing a “for purpose” unit

Schematic of CPOX Reformer



Initial tests with methane and diesel

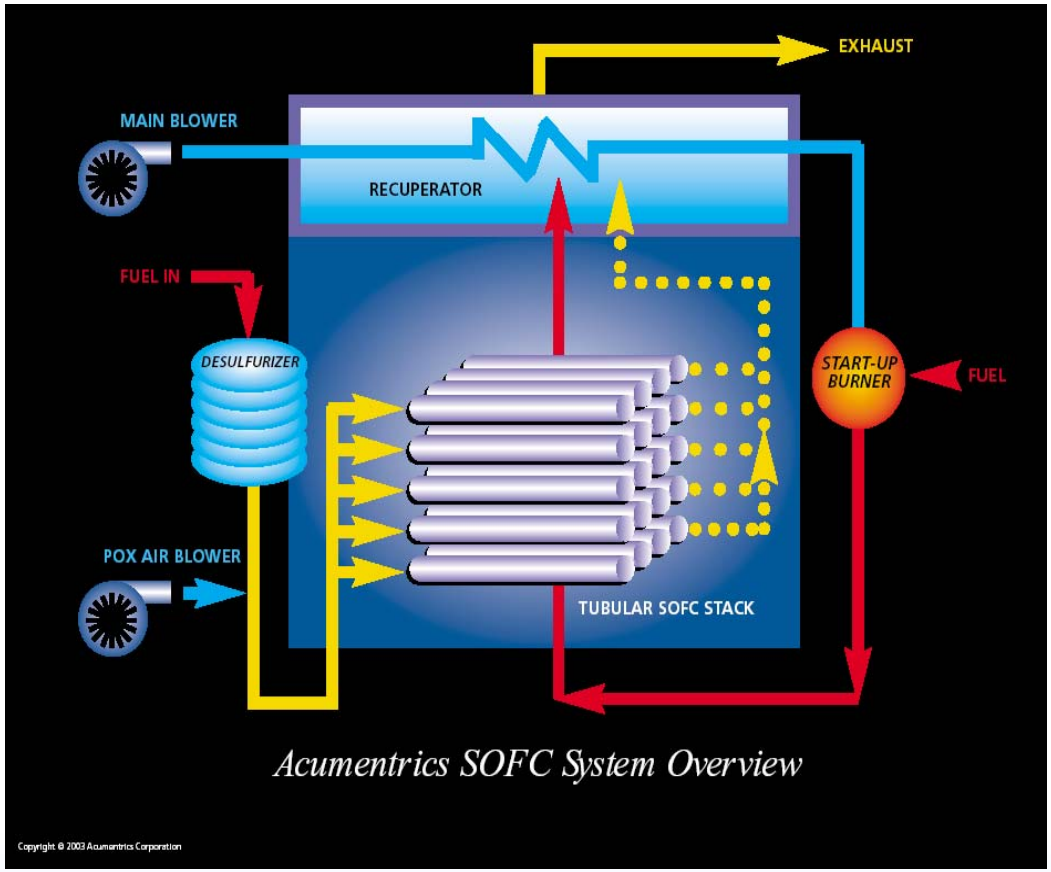
	METHANE	*LOW SULFUR DIESEL*	*SYNTHETIC DIESEL*
Hydrogen %	**31%**	**30%**	**33%**
Carbon Monoxide %	**14.6%**	**12.4%**	**12%**
Fuel type	**Natural gas**	**Phillips**	**Syntroleum**
Hours tested	**2000 +**	**4**	**4**
Conversion of hydrocarbons	**93%**	**99%**	**99%**
Reformer efficiency	**77%**	**82%**	**80%**

CPOX unit

- Unit takes about 30 minutes to reach operating temperature
- Steam provided by auxiliary electric boiler
- Fuel controlled at average of 1.134 Kg/hr
- Steam controlled at 1 – 1.5 ratio to carbon
- Temperature of reformate ~800^{O} C
- Cooled for Sulfur guard (~600^{O} C) & SOFC (~50^{O} C)
- Efficiency ~80%

Overview of the Acumentrics system

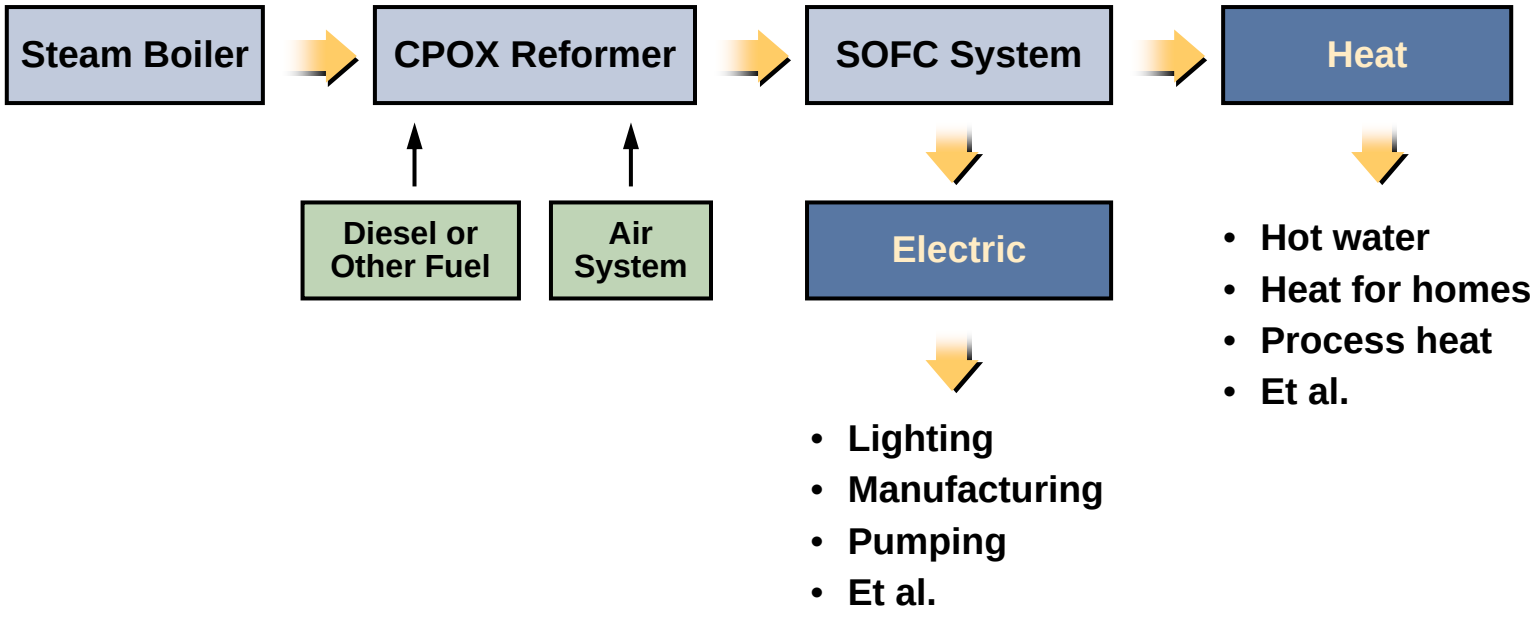
- Schematic of system
- Designed for pipeline natural gas
- Burner provides preheat and adds heat to maintain
- Produces 5 kWe at sea level on natural gas



Fuel Cell system at Acumentrics

- **Successfully operated on natural gas**
- **Consists of four tubular SOFC stacks**
- **No previous tests on diesel fuels**

Integrated Reformer and Fuel Cell System



5kW Diesel Fueled Acumentrics SOFC

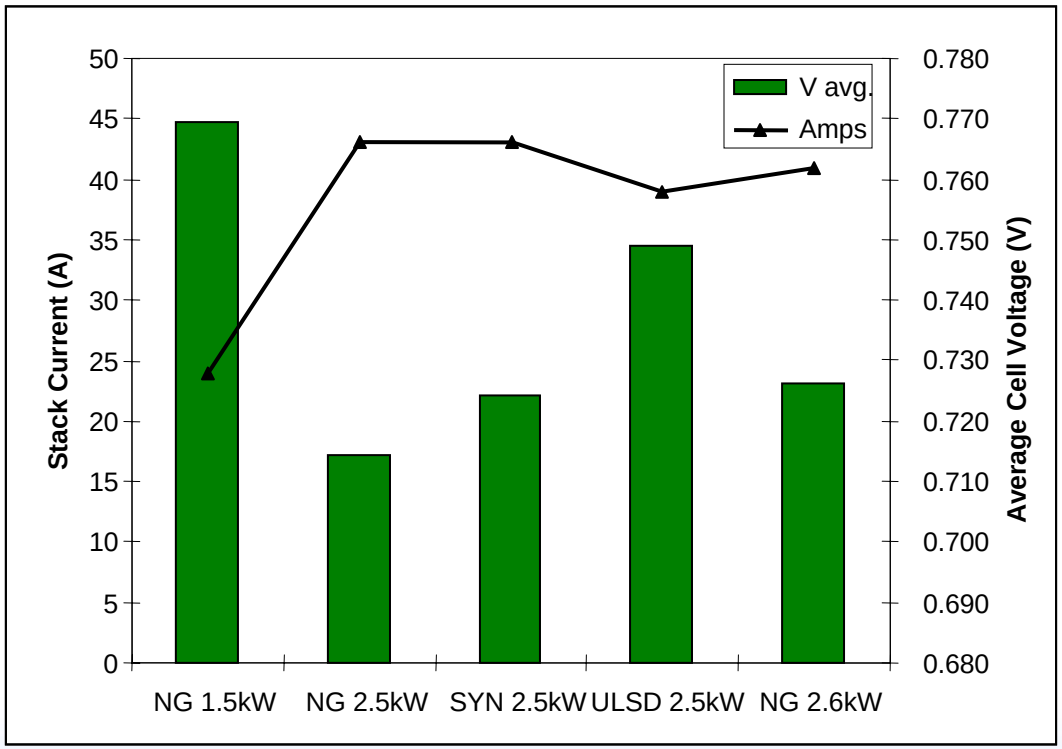
Preliminary results on system

Fuel Type	*Hydrogen*	*Carbon Monoxide*	*CH_4 – C_3H_8 ppmv*	*Load*
Synthetic Diesel	**20%**	**18%**	**987**	**2.5 kW**
Low Sulfur Diesel	**16%**	**15%**	**657**	**2.5 kW**

Notes:

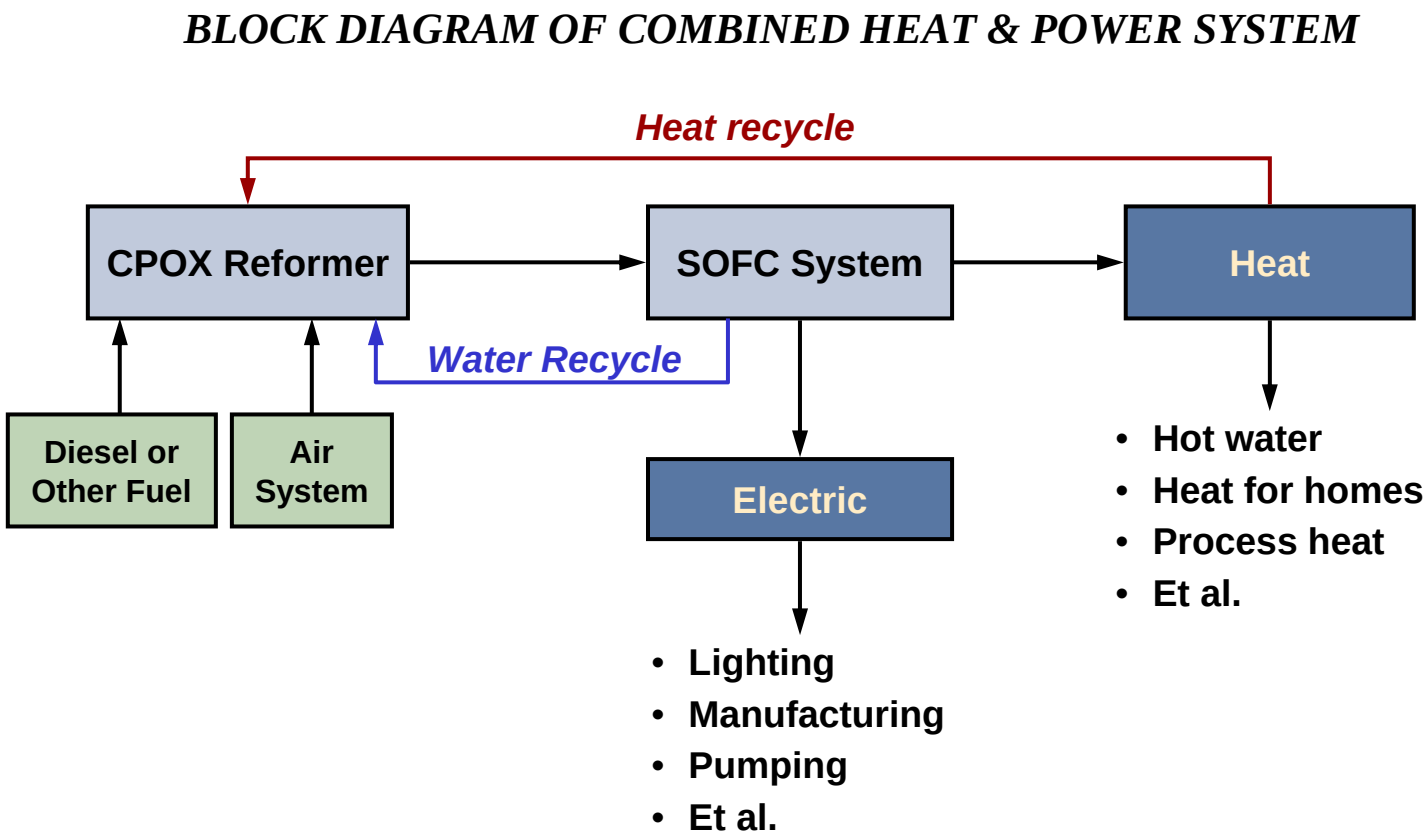
1. *Amounts shown are on a dry basis*
2. *Samples were drawn and had oxygen contamination, amounts are corrected*
3. *Some drift on steam flow between samples that may have affected numbers*
4. *Carbon monoxide was in the expected range but hydrogen was low*
5. *System efficiencies about as expected for non-optimized system*
6. *Synthetic diesel ~120 BTU/SCF; Low Sulfur ~108 BTU/SCF*

Diesel Fueled SOFC Performance



Graph courtesy of Acumentrics

Preliminary “for purpose” System



Preliminary observations

- CPOX reformer system
  - Can successfully reform low sulfur diesel and synthetic diesel
  - More stable operation on synthetic diesel
    - Less drift in mass flow
    - Temperature has narrower range
- SOFC system
  - Can successfully operate at altitude (~5000 feet)
  - Adjustments to air flow needed for diesel reformate
  - Performance is slightly better on synthetic diesel

Comparison of fuel costs

SYSTEM TYPE	*EFFICIENCY*	*FUEL USED*	*COST / YEAR*
DIESEL	**25%**	**~49,000 GAL**	**$194,000**
SOFC	**50%**	**~24,000 GAL**	**$97,000**

Notes:
1. **Costs are for one year of operation**
2. **Fuel cost delivered of ~$4/gallon**
3. **Three (3) 35 kW generators as basis**
4. **No adjustment for transportation, storage, maintenance, etc**

- Potential exists for other savings from combined heat and power units