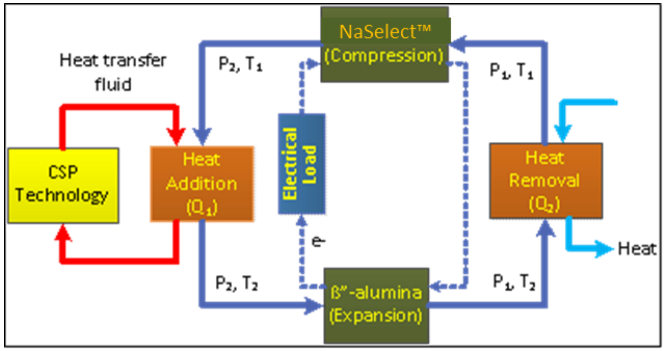
Heat Engines

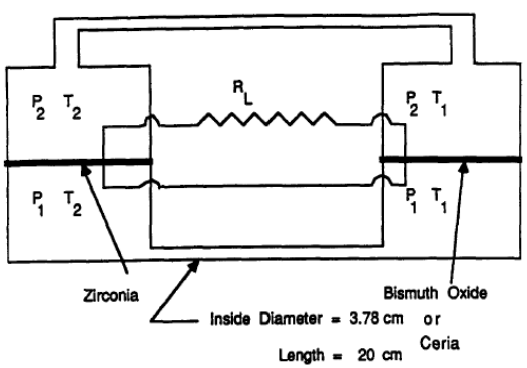
Example 1: Sodium Heat Engine (NHE)



T_1 (K)	+ -	V^{OC} (V)	η
371	$1.65*10^{-5}$	1.36	0.68
421	$8.67*10^{-4}$	1.02	0.63
471	$1.97*10^{-2}$	0.77	0.59
523	$2.69*10^{-1}$	0.57	0.55

Example 2: Oxygen Heat Engines (OHE)-

Thermo chemically Regenerative Electrochemical Systems TRES



- **Unique features**
- Sodium Heat Engines (NHE) uses sodium ions conducting β"-alumina (BASE) and low temperature NaSelect™ solid electrolytes and molten or vapor sodium as working fluid.
- NHE will generate both power and dispatchable heat from bottom cycle.
- Potential improvement to Alkali Metal Thermal to Electric Converters (AMTEC)
- Oxygen heat engine (OHE) used as hybrid solar converters to produce electricity and provide recoverable heat to fuel cell topping cycles
- **Capabilities**
- NHE solid electrolytes can achieve 100-200 mA/cm^2 current density
- An highly conductive NaSelect™ at temperature T_1 provides sufficient vapor pressure for Na mass transfer and large thermal driving force for a large Nernst potential.
- Limits BASE thermal degradation, yet maintains high thermal driving force and high Carnot efficiency
- Oxygen Heat Engines offer 4 – 10 times the power density of conventional photovoltaic cells

Technical Details

- Up to 1 kW
- Weight, Size: TBD
- Efficiency
  - Carnot efficiency(*η) target of* 0.68 for NHE
- Exhaust temperature: 351K
- Inlet temperature: 1153 K
- Durability
  - > 20,000 hours on solid electrolytes
- Cost: TBD
- OHE can reach efficiencies equivalent to Carnot cycle

Membrane Characteristics & Low Cost Manufacturing

Table : Na+ conductivity of NaSelect™ solid electrolytes

Temperature (°K)	Conductivity (mS/cm)
473	128
448	105
423	88
398	53
373	33

Figure 1: NaSelect™ Planar Ceramic membrane on right. Tubular membranes on right–withstands up to 250 psi of differential pressure

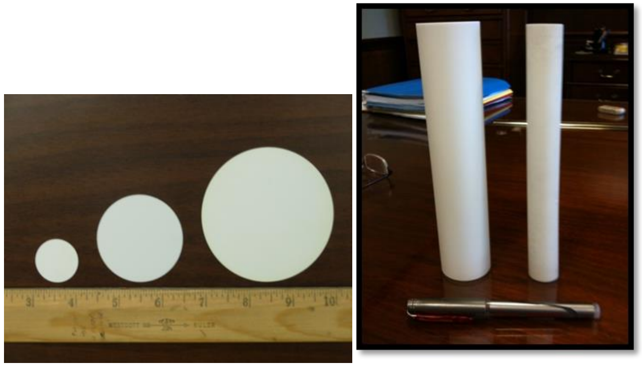
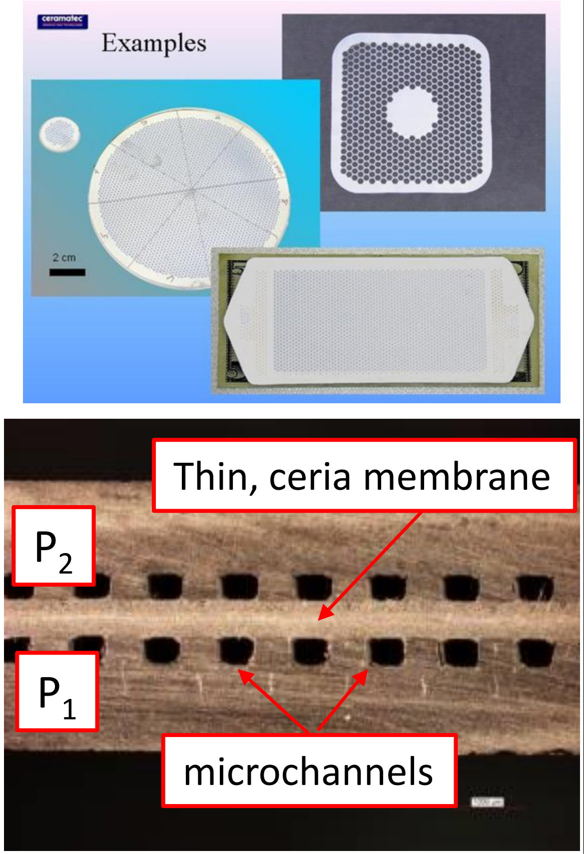


Figure 2: Modular ($0.5m^2$ NaSelect™cell) based on planar ceramic design for sodium methoxide chemical production.

Figure 3: An example of a tube and shell arrangement of $0.5\ m^2$ tubular NaSelect™ unit

Figure 4: Efficient, reliable devices also enabled by micro channel design



Development Needs:

1. Several challenges have to be addressed for the successful development of technology
2. Operation of cells to establish stability of solid electrolytes and demonstrate proof of concept
3. Material for fabricating NHE must be thermally and chemically resistant specifically to molten sodium

Risk	Mitigation Plan
Unknown Environmental Health & Safety (EH&S) issues	○ Preliminary assessment of lifecycle EH&S issues
Insufficient engineering data to develop and demonstrate prototype and commercial designs	○ Fabricate and test: ▪ Single electrolyte test cells ▪ Dual electrolyte test cells ▪ Engineering prototype ○ Develop initial commercial design concept
Undemonstrated operation	○ Assembly and operation of heat engine cell.
Lack of performance data	○ Performance characterization of heat engine cells to determine actual, vs. theoretical, efficiencies as a function of: • Hot and cold chamber temperatures • Pressure gradients • Electrolyte thickness.
Unknown reliability	○ Materials strength characterization at relevant service conditions