Thermal Devices and Systems For Enhanced Energy Efficiency

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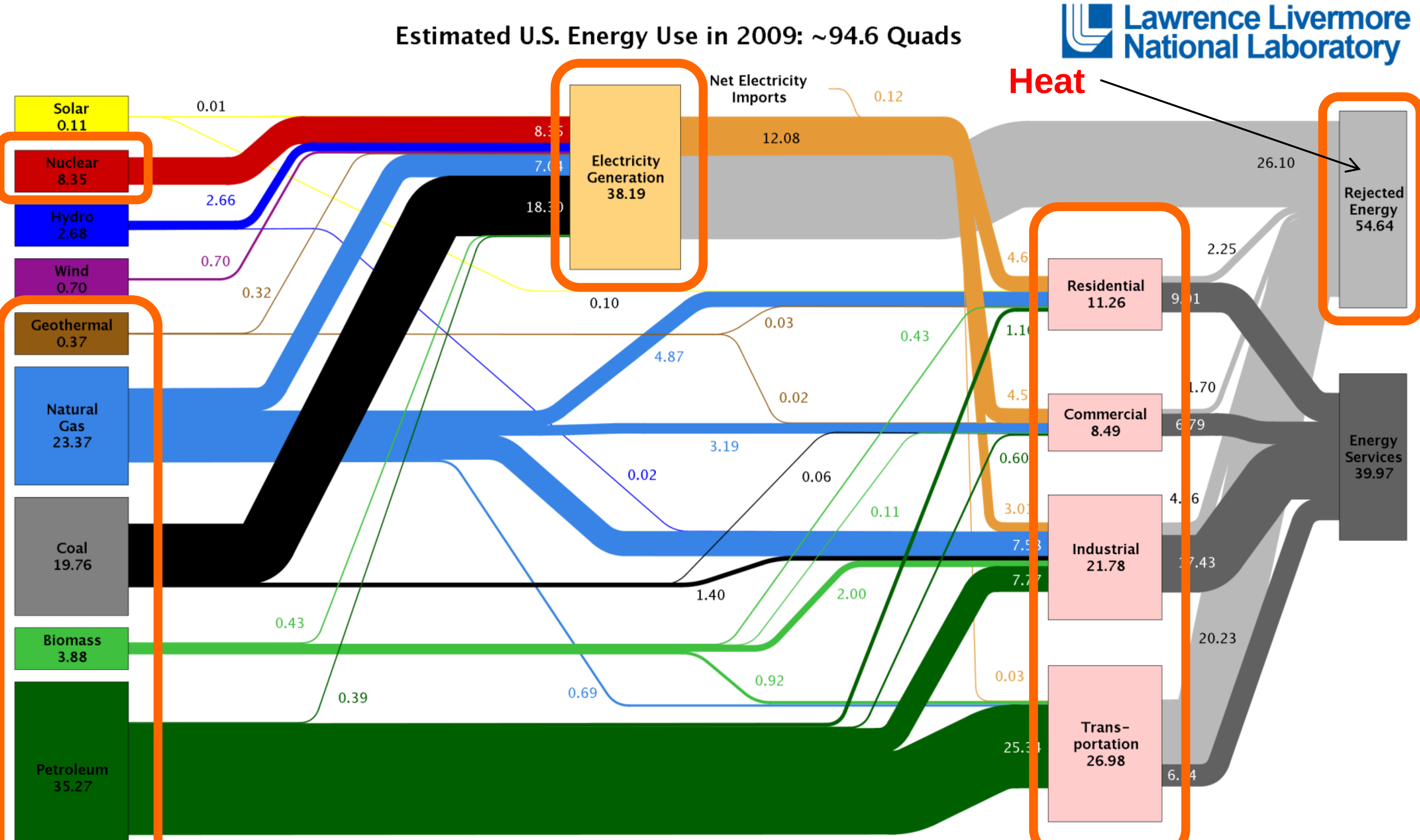
US Energy Diagram

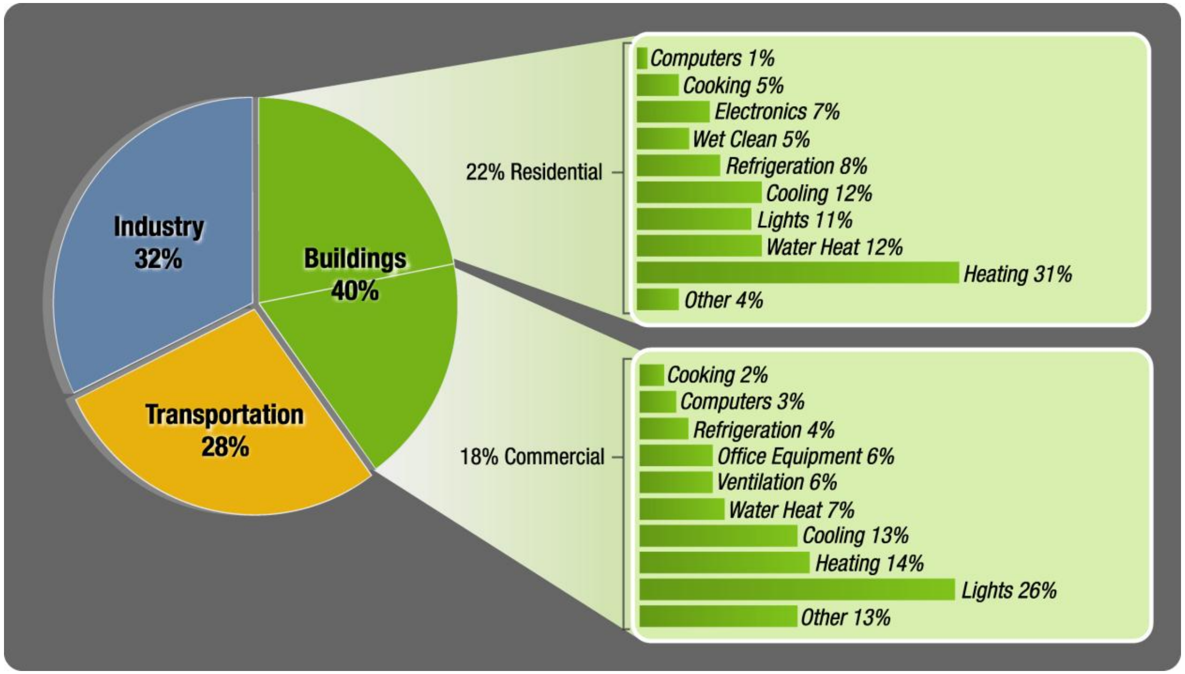


~60% primary energy rejected as heat

Residential and Commercial Buildings Consume 40 Quads of Primary Energy Per Year

Buildings use 72% of the U.S. electricity and 55% of the its natural gas

Heating & cooling is ~50% of energy consumption



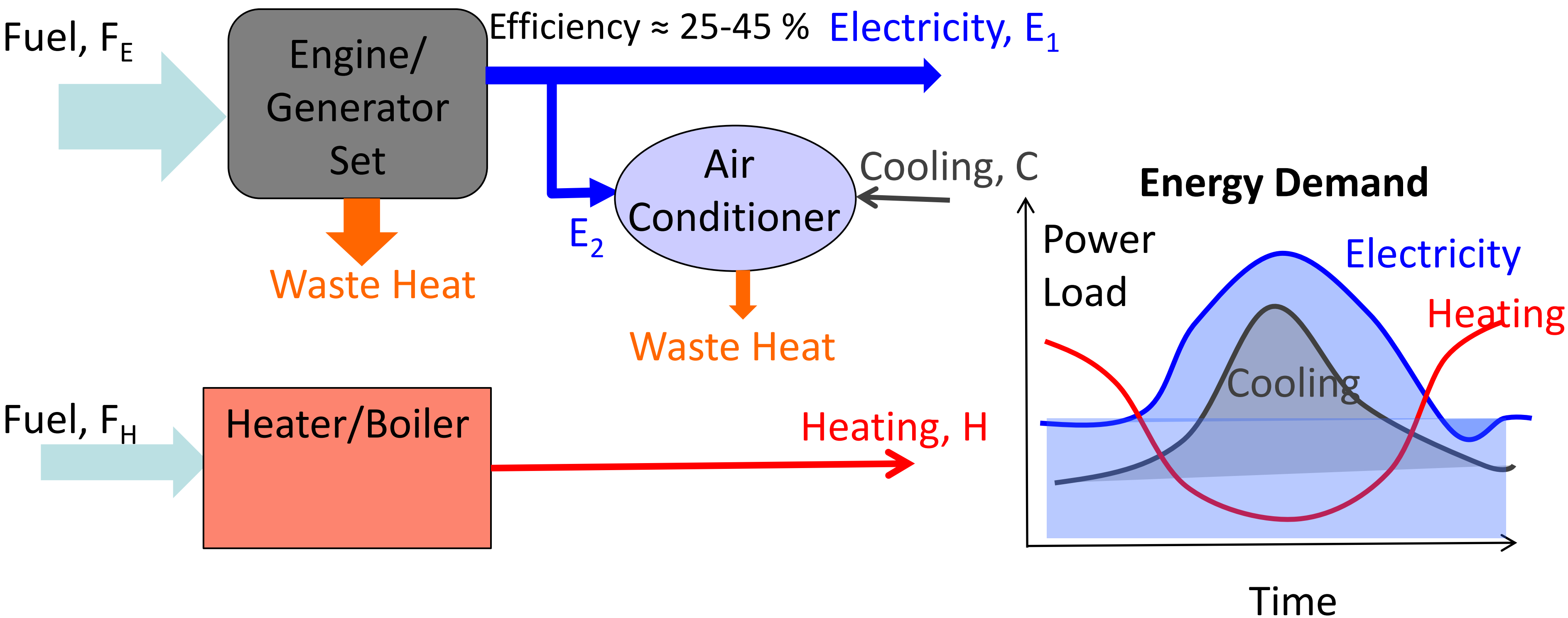
By 2030, Business as usual:

16% growth in electricity demand and additional 200 GW of electricity ($25-50 Billion/yr)

Source: LBNL Environmental Energy Technologies Division, 2009

Energy Supply Systems

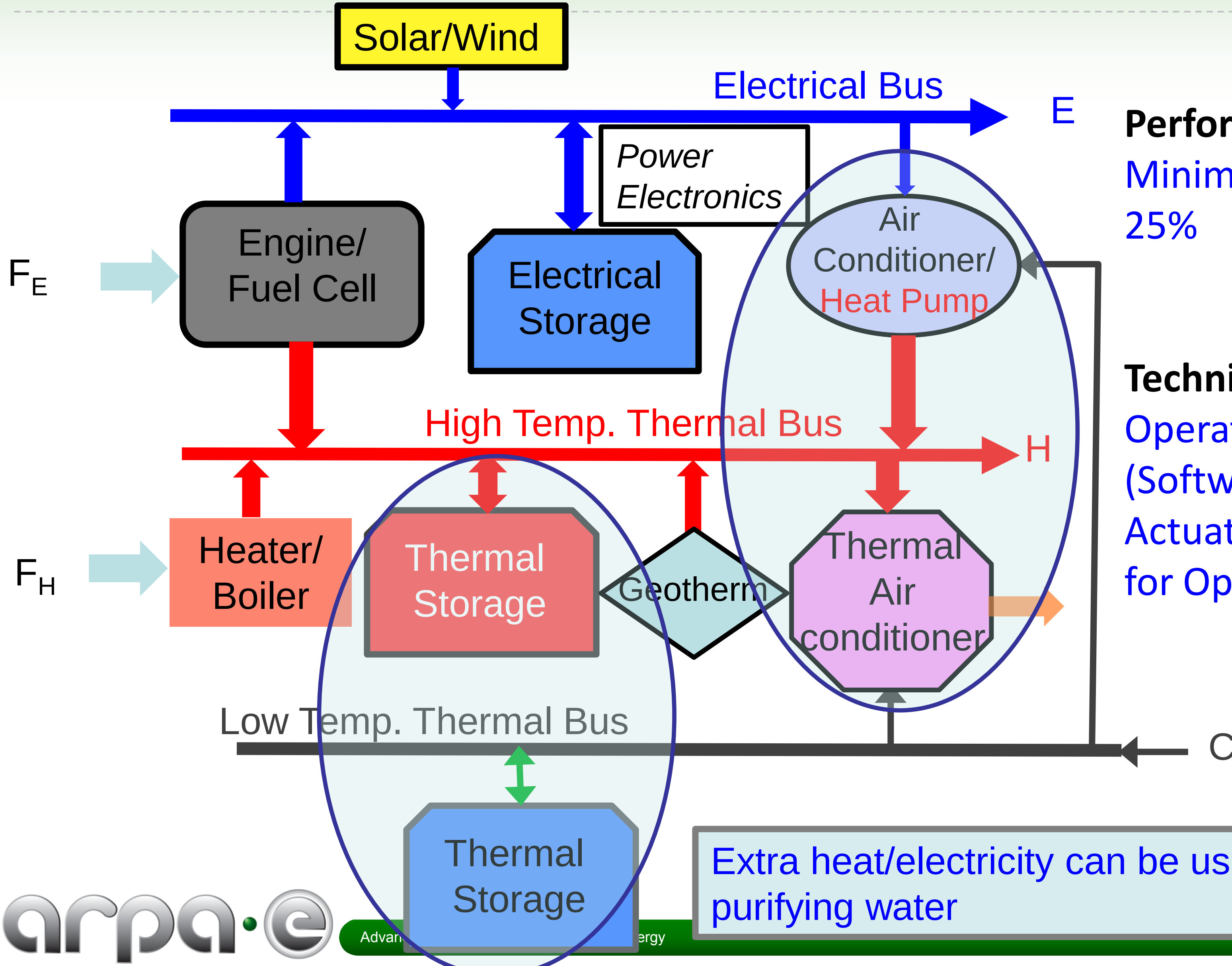
Current System Architecture



Rate of Fuel Use, $F = F_E + F_H$

Integrated Energy Supply Systems:

New Systems Architecture



Performance Goal:

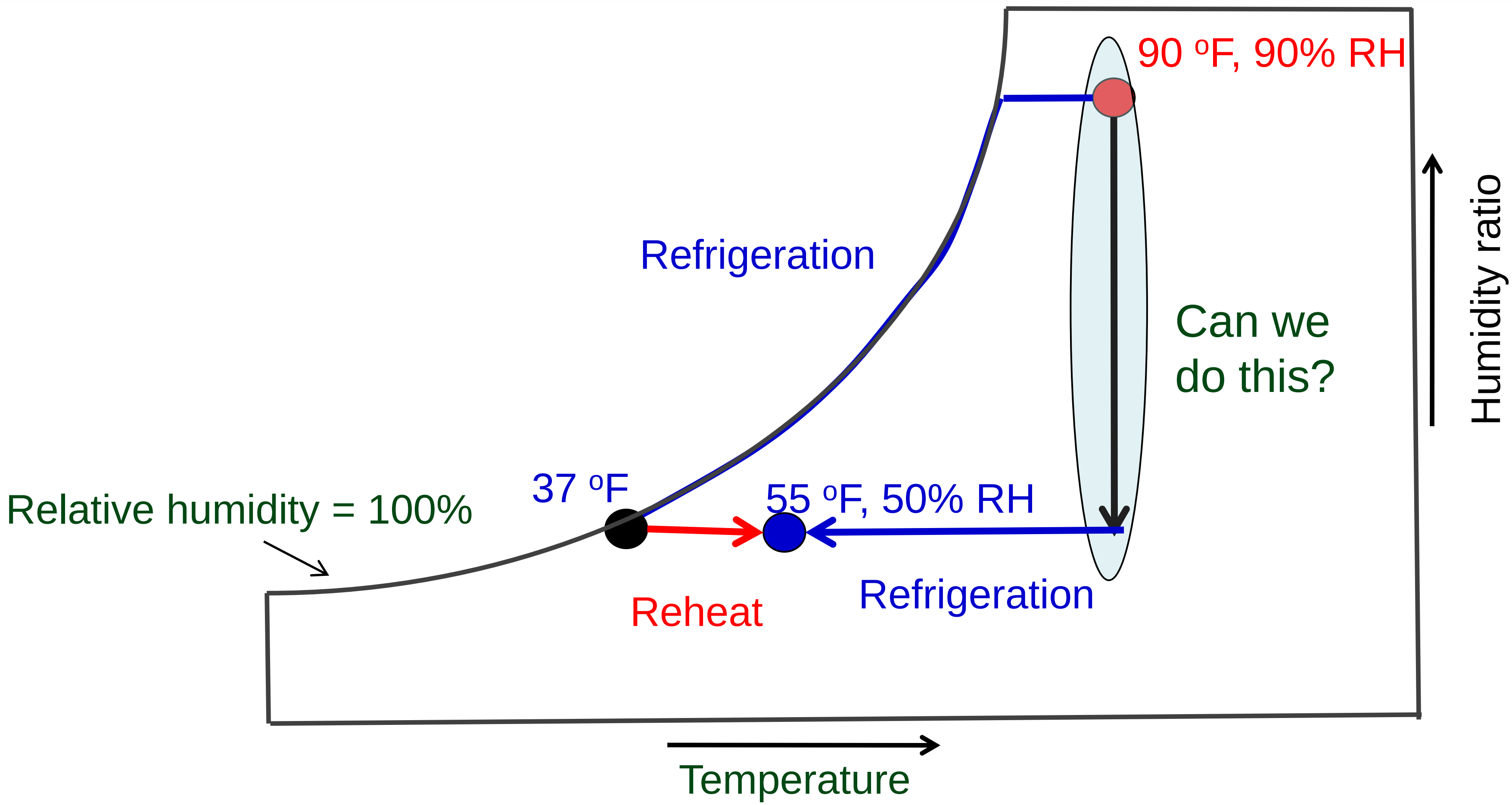
Minimize F by at least 25%

Technical Challenge:

Operating System (Software) & Sensors-Actuators (Hardware) for Optimal Operation

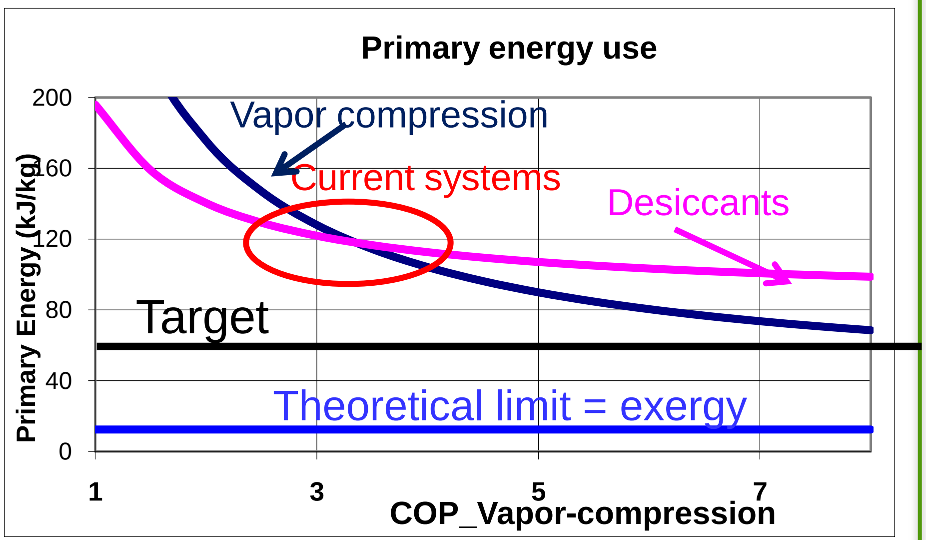
Extra heat/electricity can be used for purifying water

Current Cooling Practice



BEET-IT Target

Building cooling is responsible for ~5% of US energy consumption and CO_2 emissions

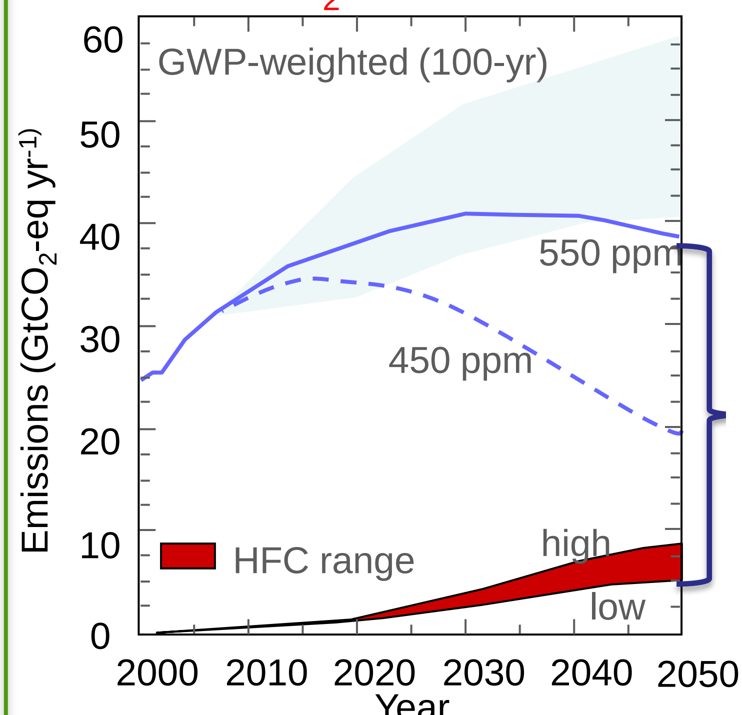


T_{amb} = 90 °F, RH = 0.9
T_{supply} = 55 °F, RH = 0.5

Reduce primary energy consumption by ~ 40 - 50%

- *Current refrigerants have GWP over 1000 x of CO_2*

Global CO_2 and HFC emissions

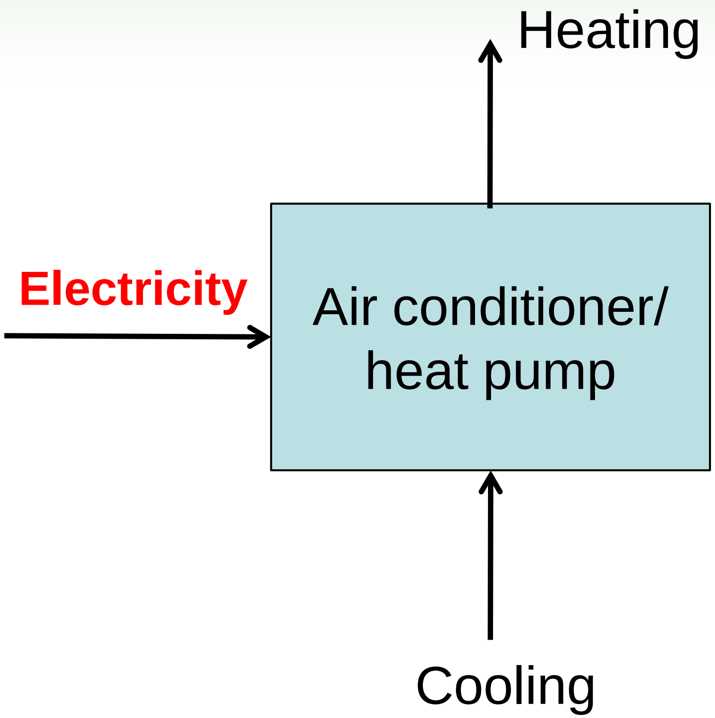


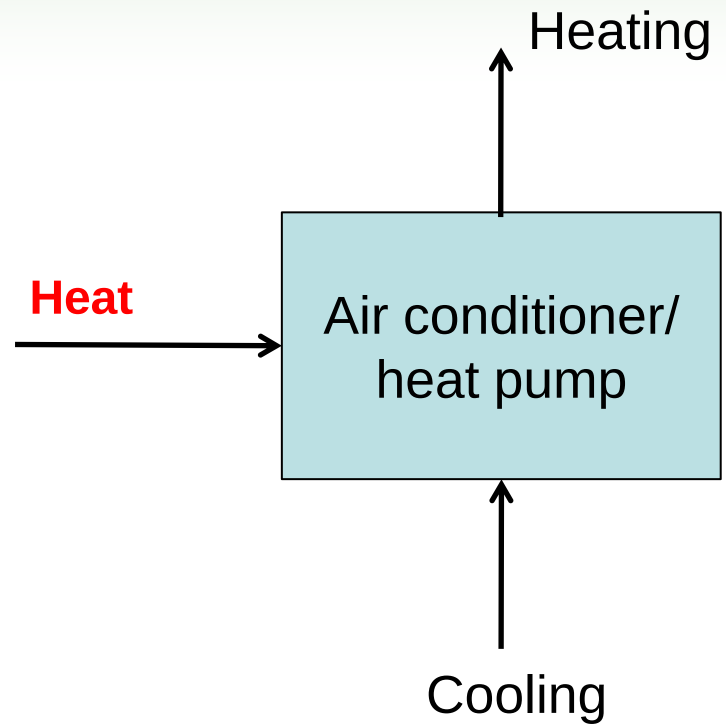
Global hydrofluoro carbon (HFC) refrigerant emissions are projected to account for the equivalent of 9-19% of CO_2 emissions in 2050

Achieve COP > 4 for GWP ≤ 1

Source: Velders et al, PNAS 106, 10949 (2009)

Two types of Air Conditioners/Heat Pumps

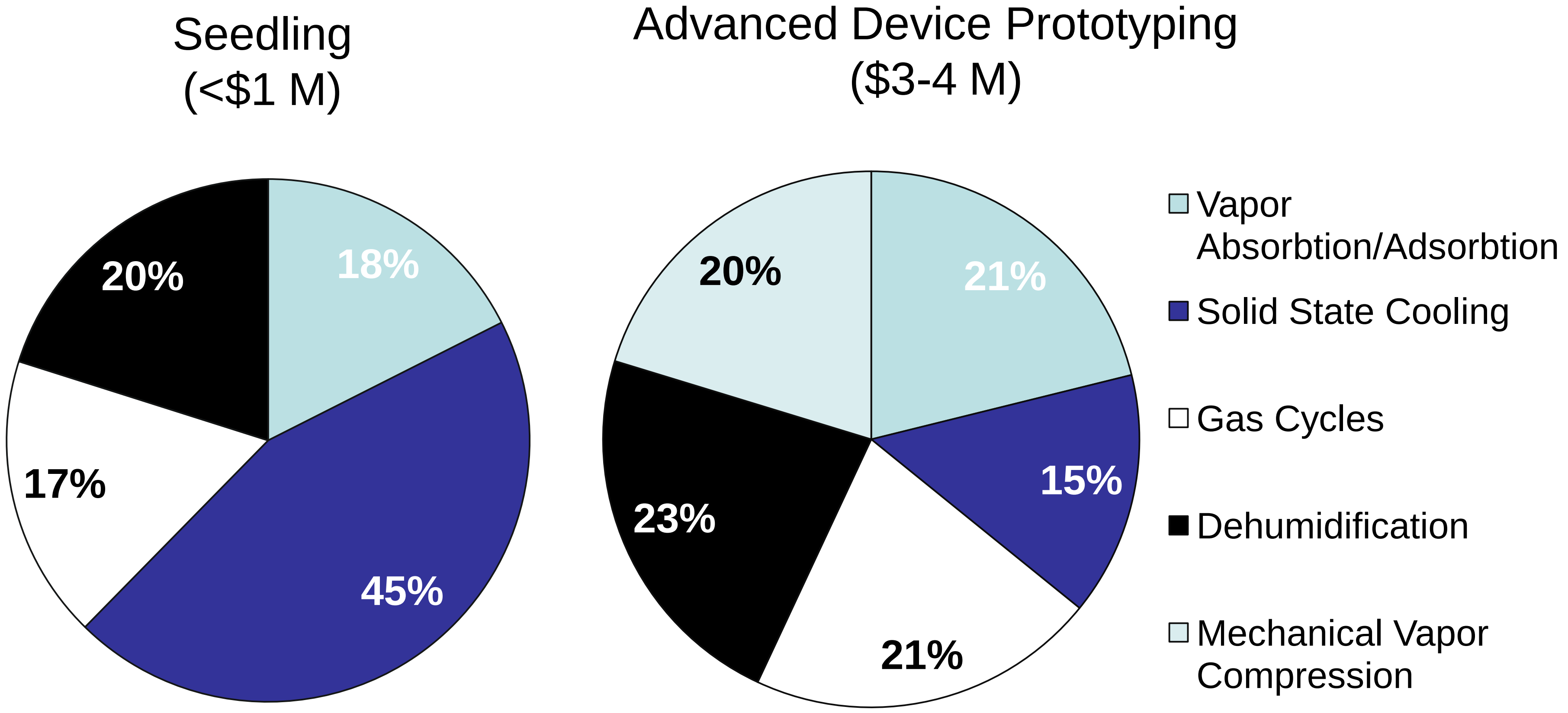




- It can run with any kind of heat source: Waste, Solar, Geothermal
- Very bulky and inefficient

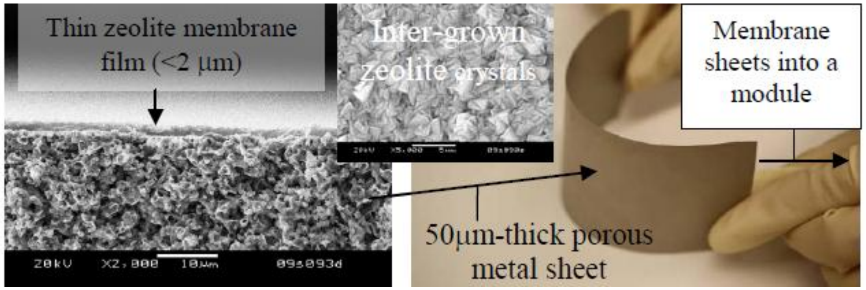
Portfolio of Technologies Funded

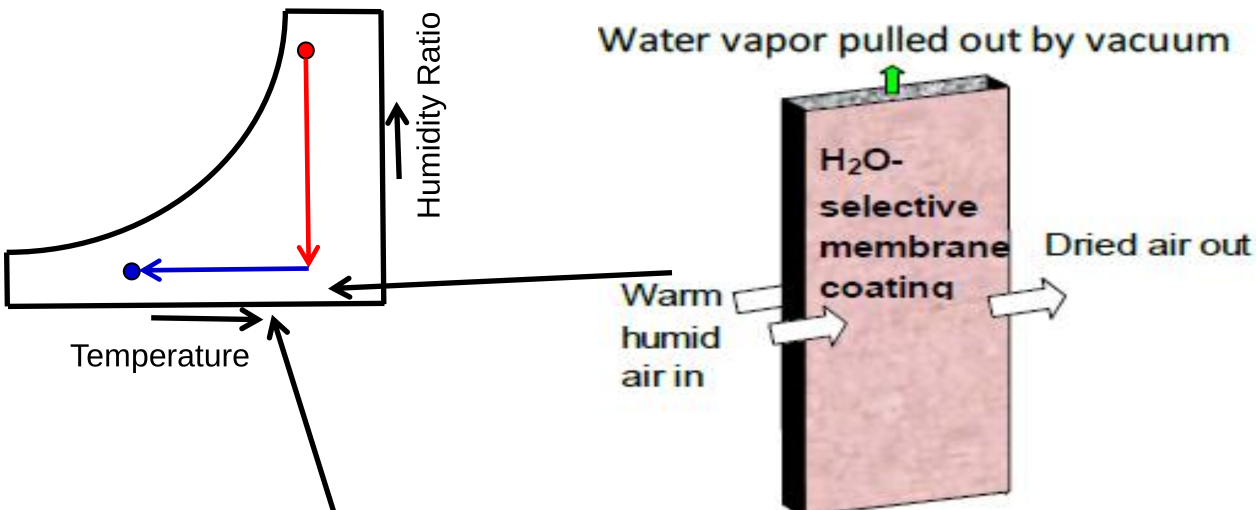
BEETIT: $30.3 M, 3 years, 16 projects



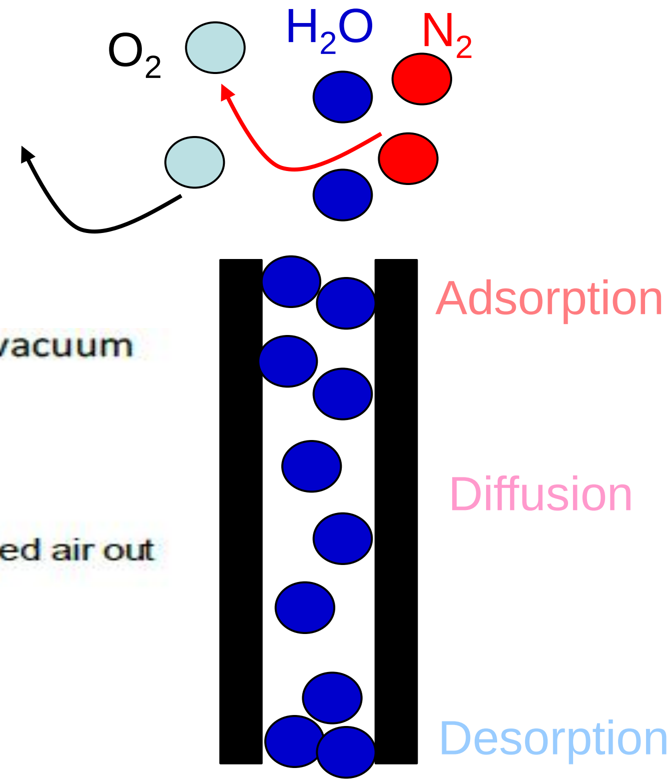
High-Efficiency, on-Line Membrane Air Dehumidifier Enabling Sensible Cooling for Warm and Humid Climates

ADMA Products Inc.





Refrigeration unit



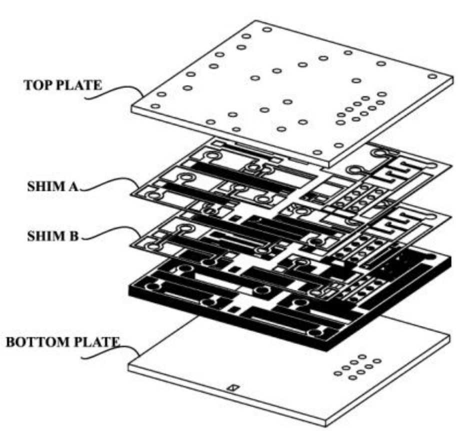
Zeolite pore (0.3 – 0.4 nm)

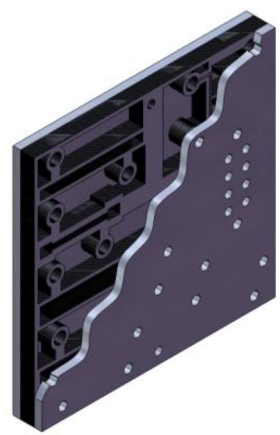
- **Selective absorption of water vapor molecules**
- **Weight one-two orders of magnitude lower**
- **Can potentially beat FOA target by ~50%**

Modular Thermal Hub for Building Cooling, Heating, and Water Heating: Thermal heat pump

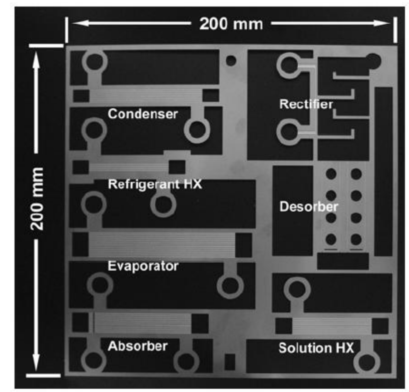
Georgia Technology Research Corporation

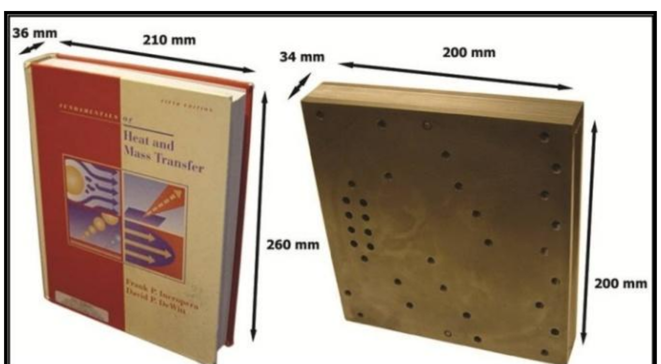
Microscale Monolithic Absorption Heat Pump





SHIM A Components



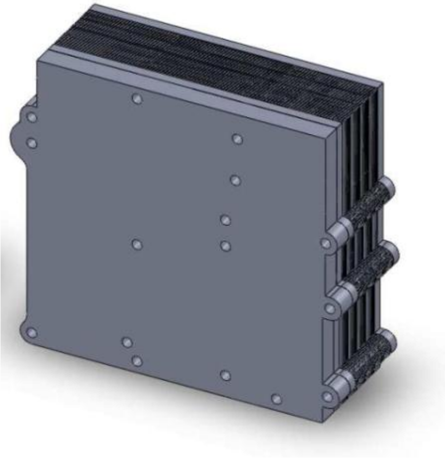


300 W System

Eventual Miniaturization Potential

State of the Art:

- 9-12 ft^3/RT
- 150-210 lb/RT

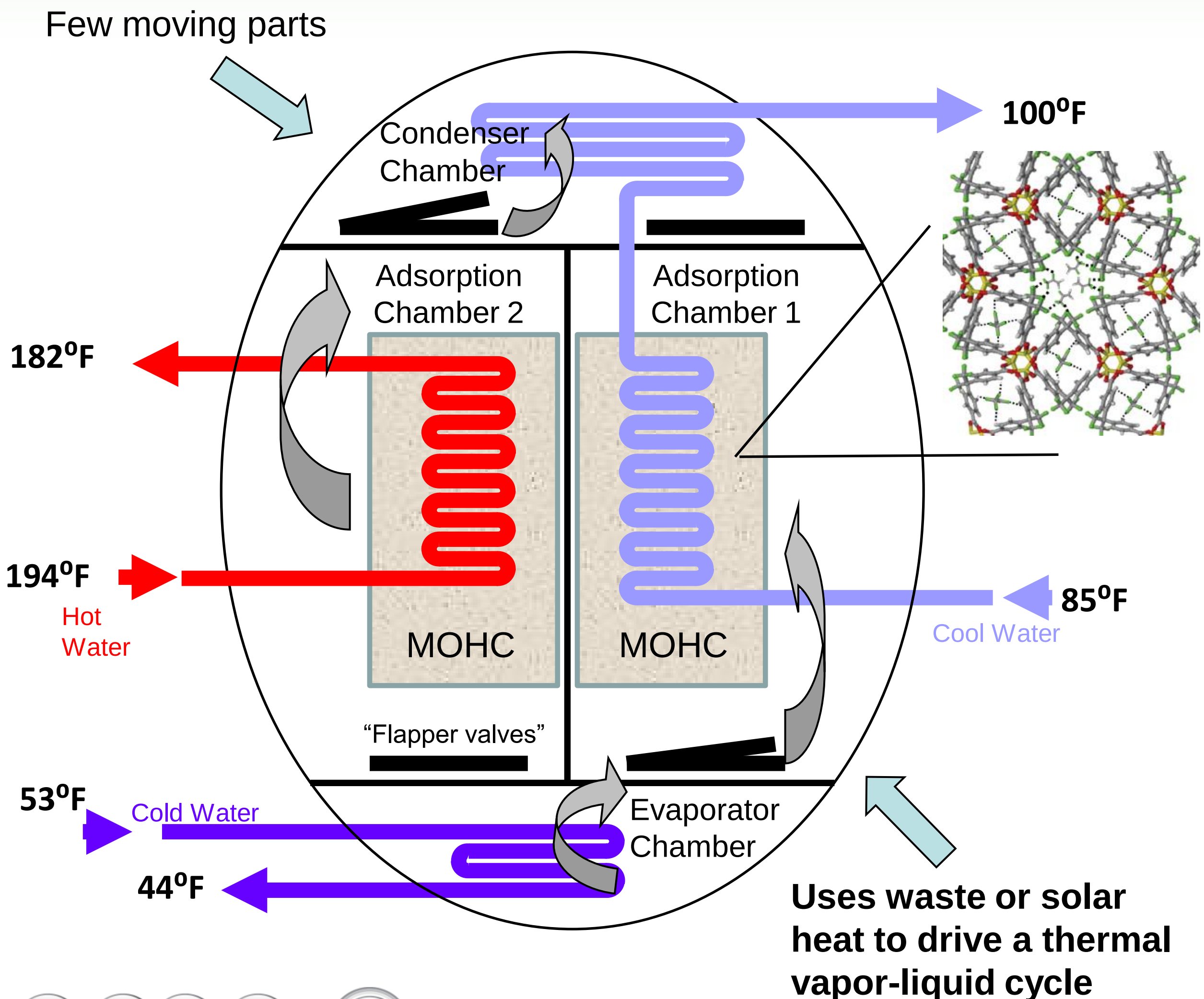


Projected Commercial Units:

- ~ 4 ft^3/RT
- ~ 60 lb/RT
- ~ 2-3x smaller

High-Efficiency Adsorption Chilling Using Novel Metal Organic Heat Carriers: Thermal heat pump

Pacific Northwest National Lab

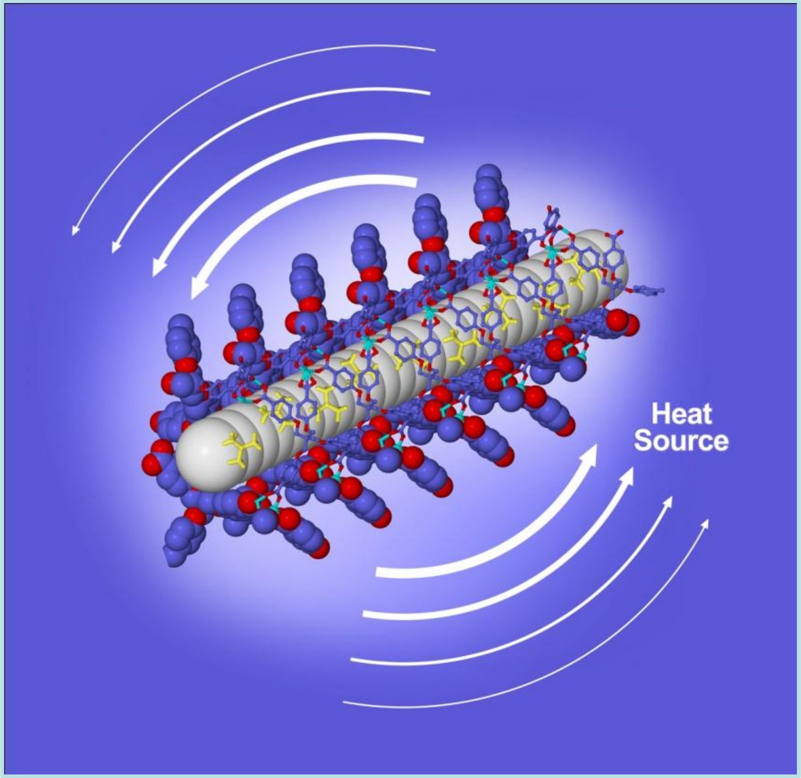


Technology Impact

- Replace silica gel with MOHC sorbents
- Enable operation with more refrigerants
- **2 – 4x reduction in system weight and size**

Metal-organic Heat Carriers

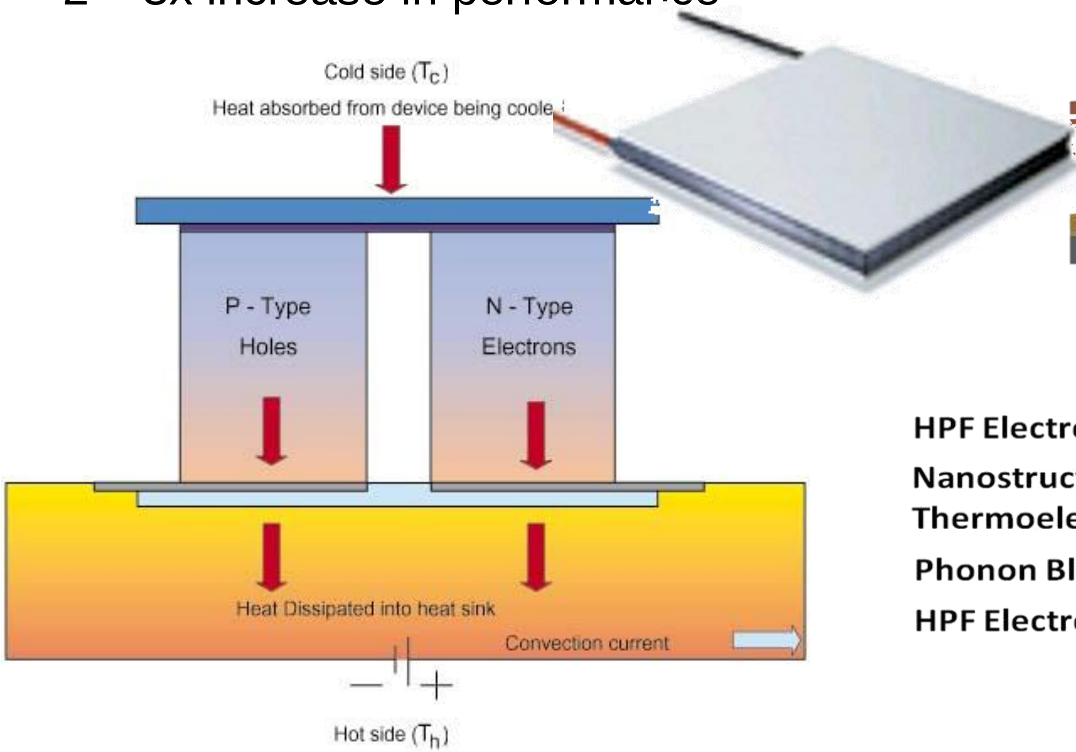
- Crystalline solids or gels formed with self-assembled structural building units
- Continuous porous network with tunable binding energy for gases and liquids
- Synthesis conditions support thin film deposition, nanophase crystals, or bulk powders
- Applications in geothermal power, waste heat recovery, cooling and refrigeration

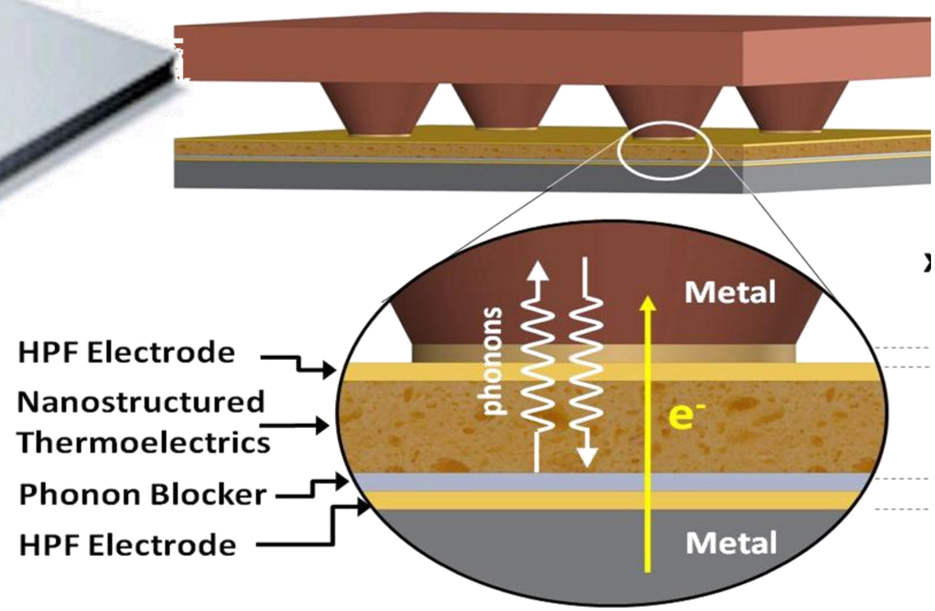


Non-Equilibrium Asymmetric Thermoelectrics (NEAT): Solid State Cooler

Sheetak

- Novel electrodes to reduce interface losses
- Non-equilibrium effects decouple electron and phonon systems
- Atomically-thin phonon-blocking (PB), electron tunneling junctions
- 2 – 3x reduction in cost
- 2 – 3x increase in performance





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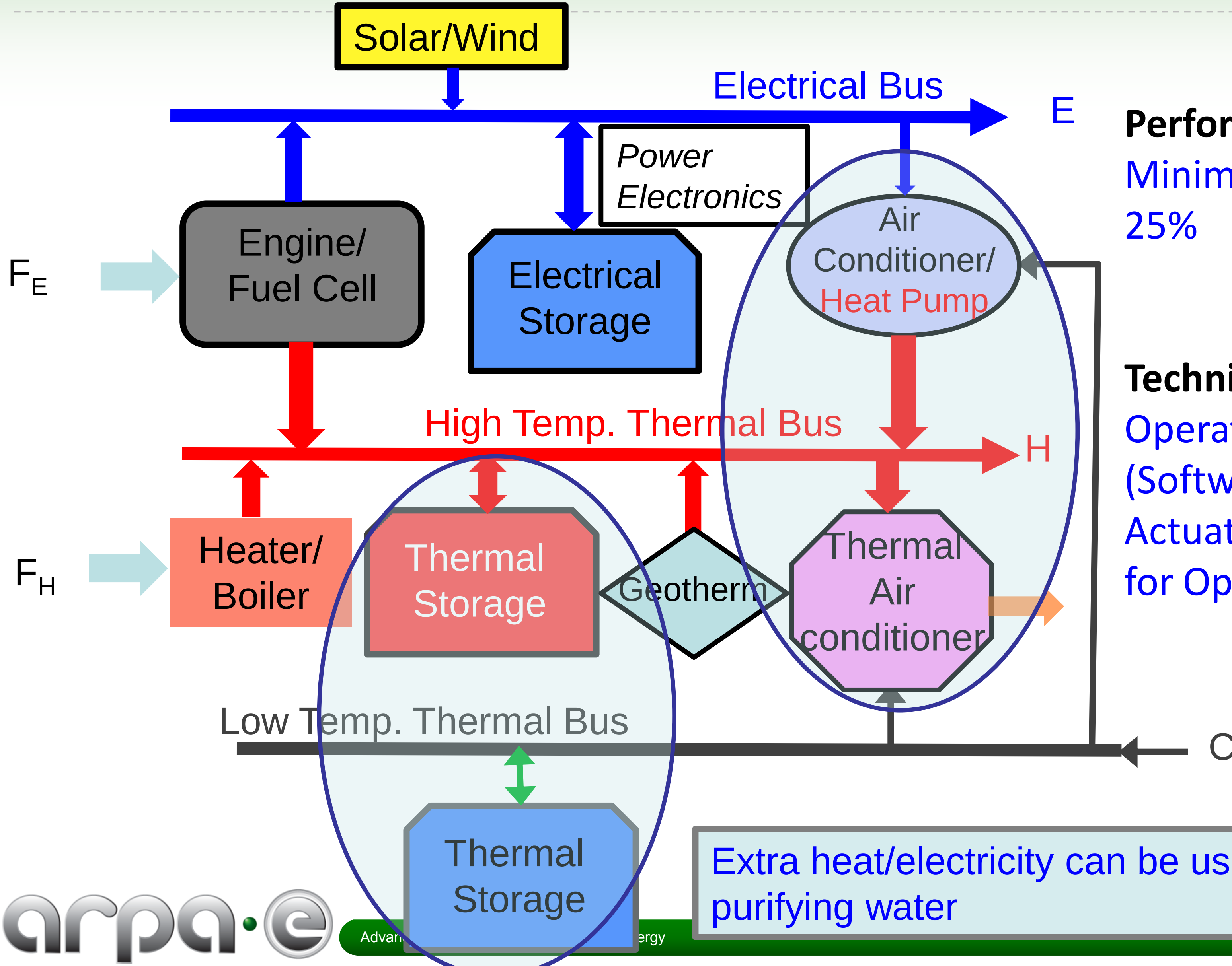

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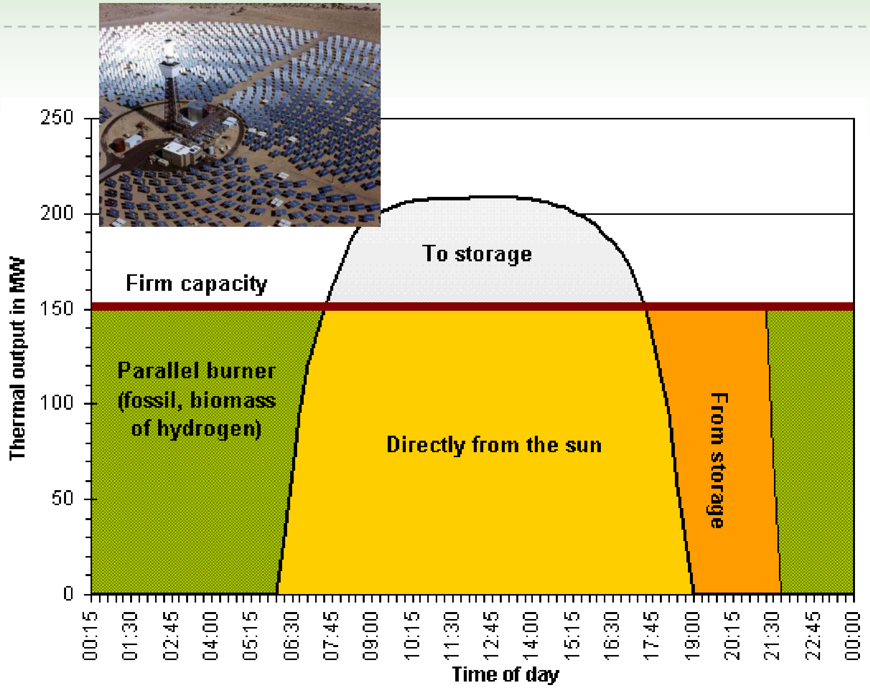
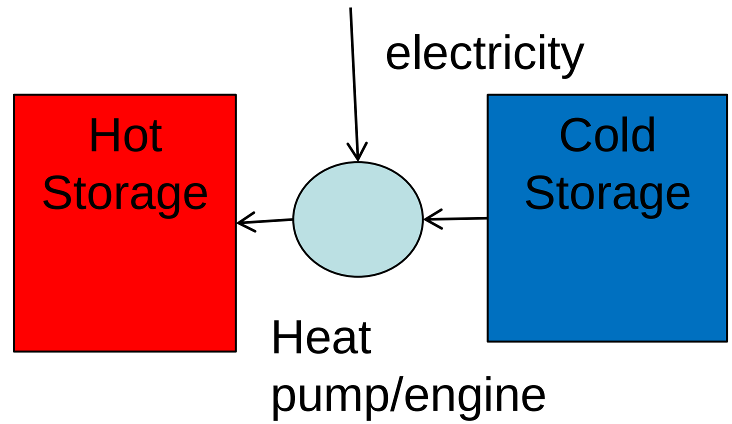
Applications of Thermal Storage



Solar: Convert solar power into base load power using storage

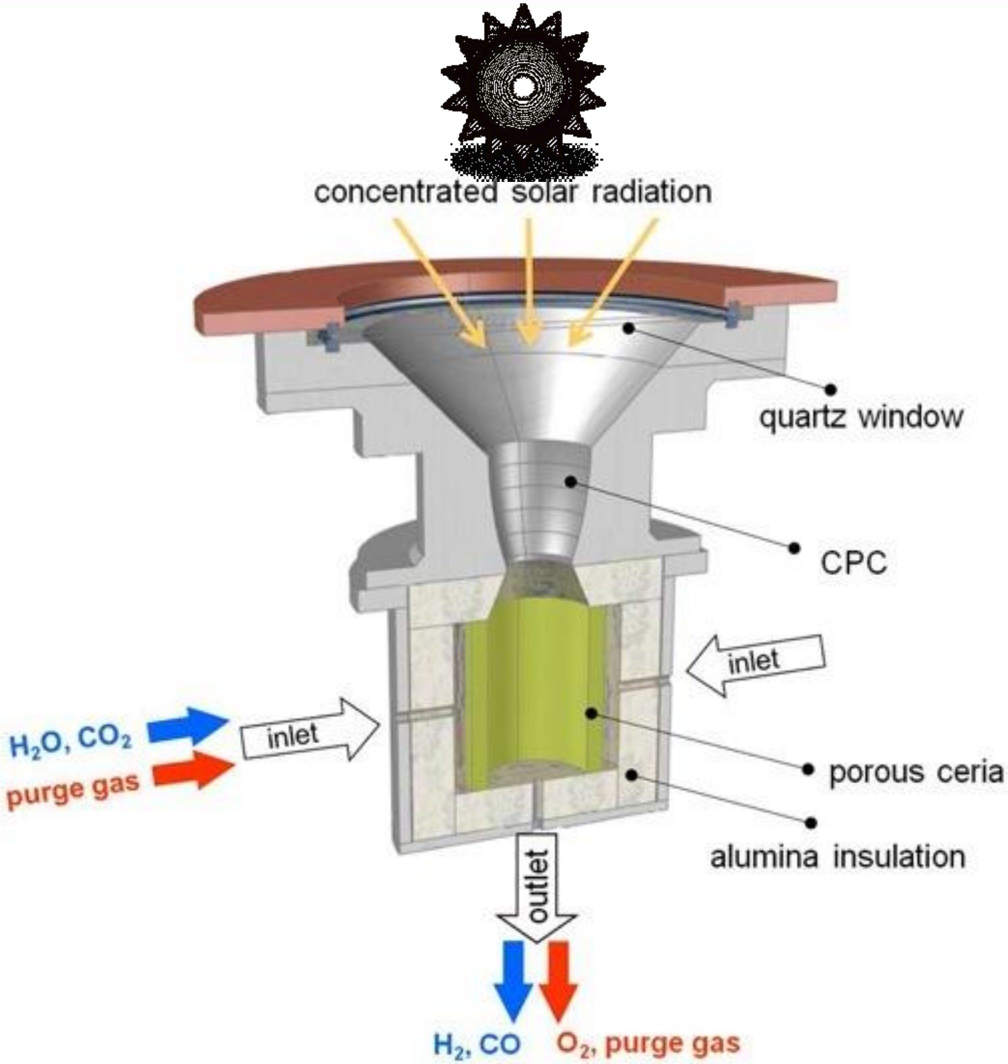
Nuclear: Heat storage for peak power



Grid-level electricity storage: High-temperature thermal storage + subsequent conversion by engines

Applications of Thermal Storage

Thermochemical production of fuel from sunlight using heat



Photons

↓

Phonons

↓

Energy in chemical bonds

William C. Chueh, *et al.*
Science **330**, 1797 (2010)

Applications of Thermal Storage

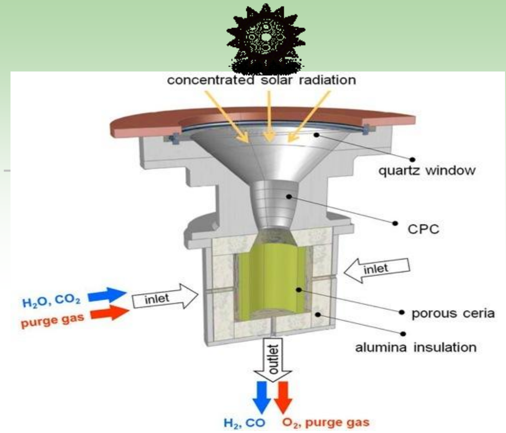
PHEV/EV: Thermal battery for thermal management and cabin conditioning

Storing and redeploying heat or cold to match building loads

Industrial waste heat capture and storage

Refrigerated trucks and LNG Transport

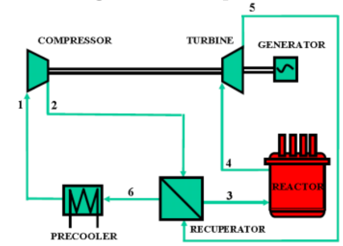
HEATS Focus Areas



Thermochemical Fuel Production from Sunlight

Conversion efficiency > 10%

Synergy between Solar and High-Temp Nuclear



Efficiency > 50%

Grid level storage using heat pumps

Increase EV range by ~ 40%

Scale

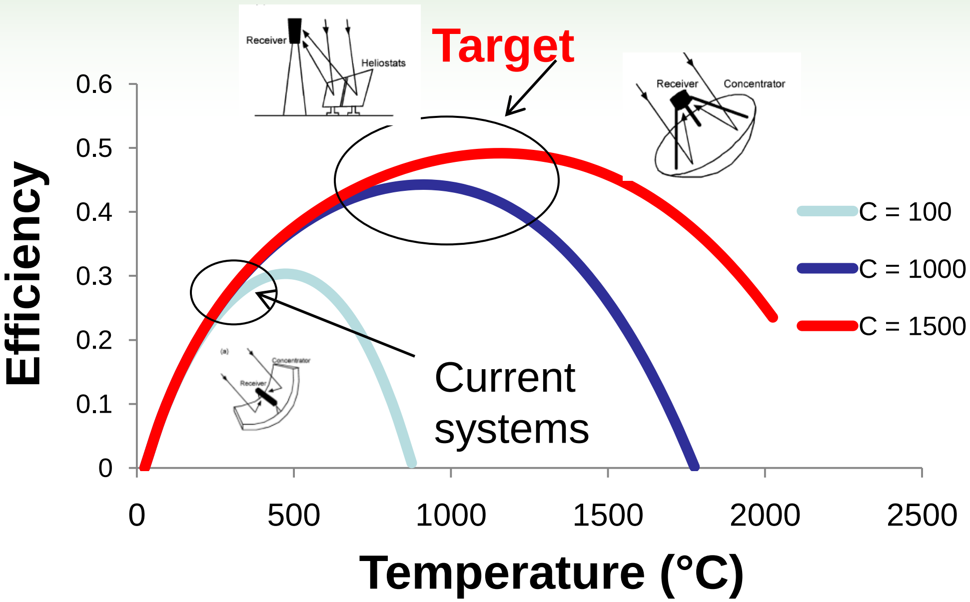
<100 ^oC

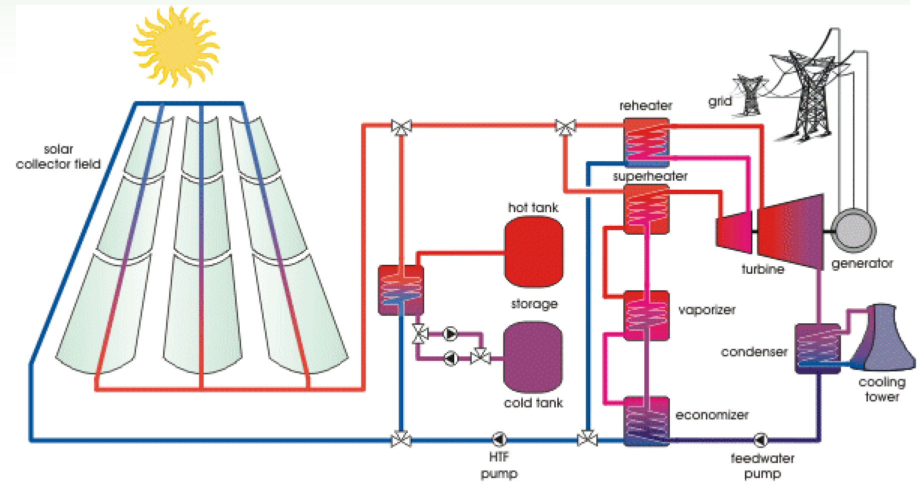
>600 ^oC

800-1500 ^oC

Temperature

High-Temperature Applications: CSP



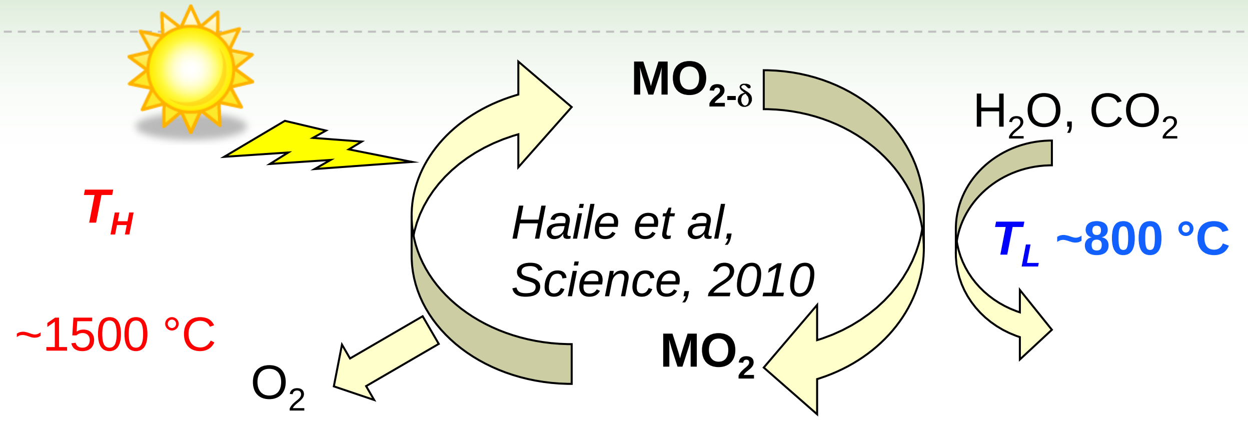


	Storage Cost ($/kWh$_t$)
SOA	80-120
Target	**15**

SOA:

- **3 fluids: Oil, Molten salt, Steam**
- **Molten salt**
- **Sensible storage**
- **ΔT = 100 ºC (290 – 390 ºC)**

Thermochemical Production of Fuel (Thermofuel)



Direct thermolysis of water = 4000 °C

- **Theoretical efficiency can be greater than 30%**
- **Best demonstrated ~ 1 %**
- **Temperature > 1500 °C**

	efficiency
SOA	~1%
Target	>10%

Significant potential of heat recycling and harvesting

Low temperature: Effect of Climate Control on PHEV and EV

- Best example of combined heat and power: heating of cabin of IC engine vehicle (**heating is free**)
- Fully electrified light duty fleet will require > 1 Quad for heating
- Power consumption in EV ~ 6 KW @ 40 miles/hr and 13 KW @ 60 miles/hr (Source: Tesla)

Mode	Peak load (kW)	Steady state load (kW)
A/C	3.9	2.1
Heat	6.0	2.0

Barnitt et al., NREL, 2010

Heating and cooling can reduce the range of EVs by 5 -40%