Bulk Energy Storage using a Supercritical CO_2 Waste Heat Recovery Power Plant

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Outline: SCO_2 Bulk Energy Storage
One of Many SCO_2 Transformational Power Systems

- List of Transformational SCO_2 Power Systems
- Energy Storage and the Electric Grid
- Pure Bulk Energy Storage SCO_2 Concept (Hermle, ABB)
- Bulk Energy Storage for Power Peaking using WHR Concepts
- Charging Cycle Description
- Discharge Cycle Description
- Energy Storage & Power Peaking Operation
- Economic Benefit
- Summary and Conclusions

Transformational SCO_2 Power Systems

1. Oxy-Combustion Direct Injection + CCS (Eff > 50%)
2. Oxy-Combustion Indirect Heating + CCS (Eff > 43%)
3. Single Cycle High Efficiency Fossil Fuel Combustion (~50%, > ~150 MW_e)
4. Advanced Nuclear Reactor High Efficiency (45% - 50%, TIT > ~600 C)
5. Concentrated Solar Power (>50% with TIT > ~750 C)
6. Integrated Gas Turbines & SCO_2 Power Systems (SCO_2 Bottoming + Others)
   - Distributed Generation (5-20 MWe) :Smartgrid (~48%-50% SCO_2 Combined Cycle)
   - Marine Propulsion, Other Priority Applications
7. Waste Heat Recovery Plants (Eff ~ 25% @ 510 C)
8. USC Pulverized Coal Plant Upgrades (Topping Cycles or Other)
9. Energy Storage and Power Peaking (RT Eff =55-60%, 4 hrs, 50-100 MWe)
10. Combined Cooling, Heat, and Power + CHP, CCP
11. Heat Pump / Refrigeration (Cooling + Heating is favored by CO_2 EOS)

Focus

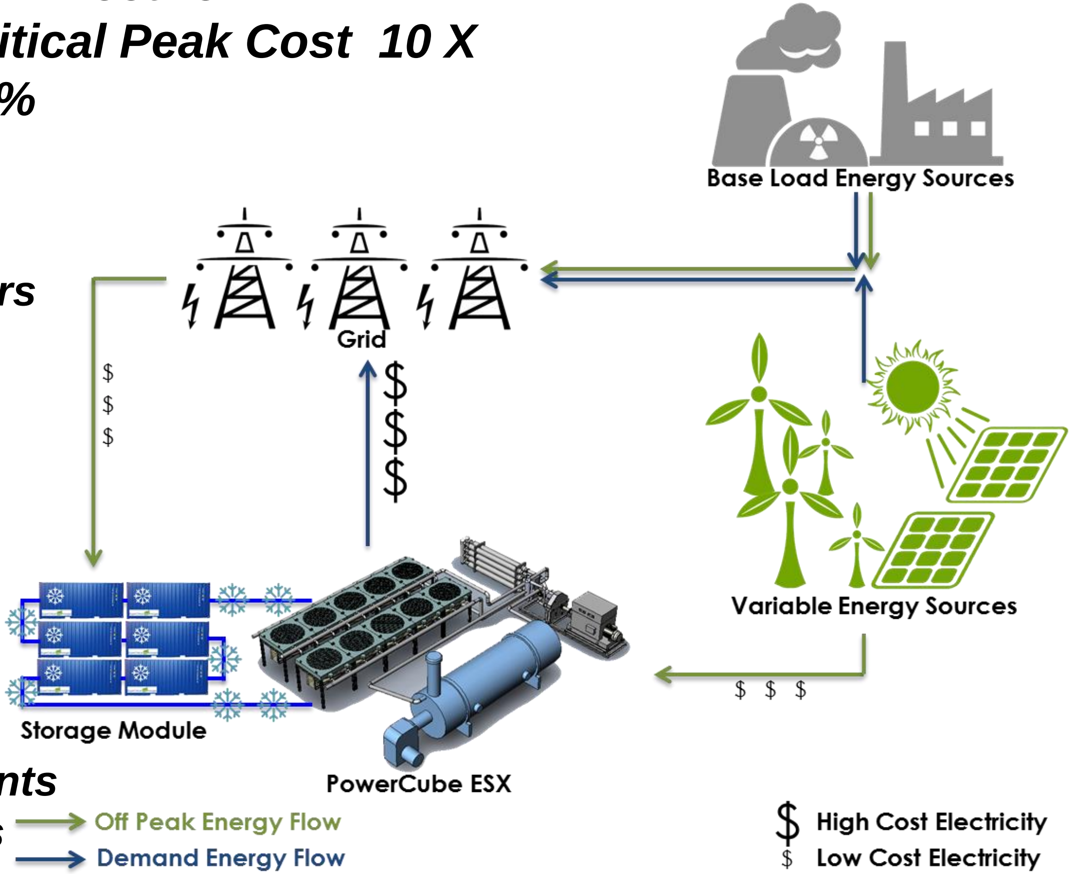
Key to Achieving these Technologies:
Multiple Successful Demonstration SCO_2 Power Systems

The Power Peaking with Bulk Energy Storage - Addressing the Energy Storage Problem

- ***150 Hours at Peak Usage***
  Costs you ~20% of your Electric Bill
- ***Off-Peak versus On-Peak=Critical Peak Cost 10 X***
- ***2% of Power usage Costs 20%***

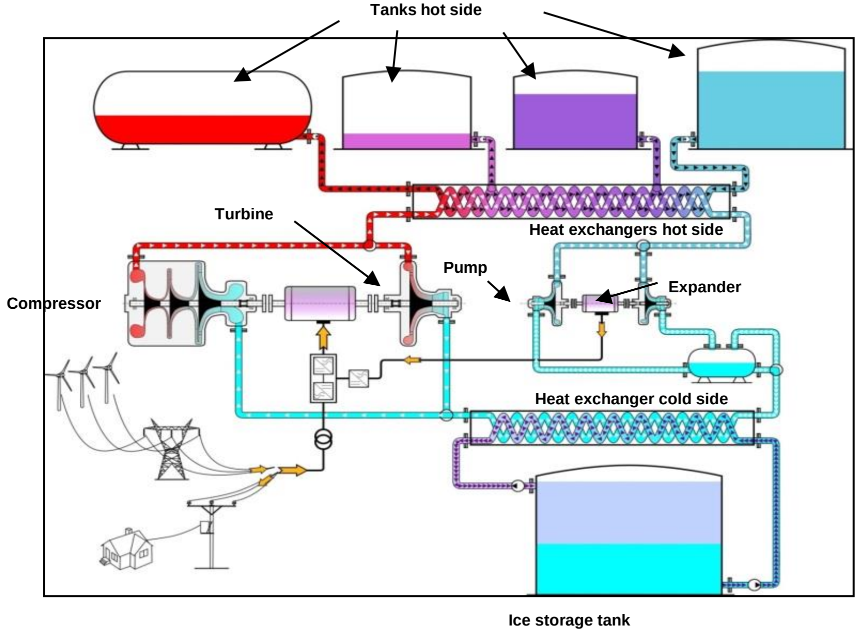
- ***SCO_2 Bulk Energy Storage Offers***
  - ***Site Independent Storage***
  - ***10-100 MWe for 4-5 hours***
  - ***Little Competition***

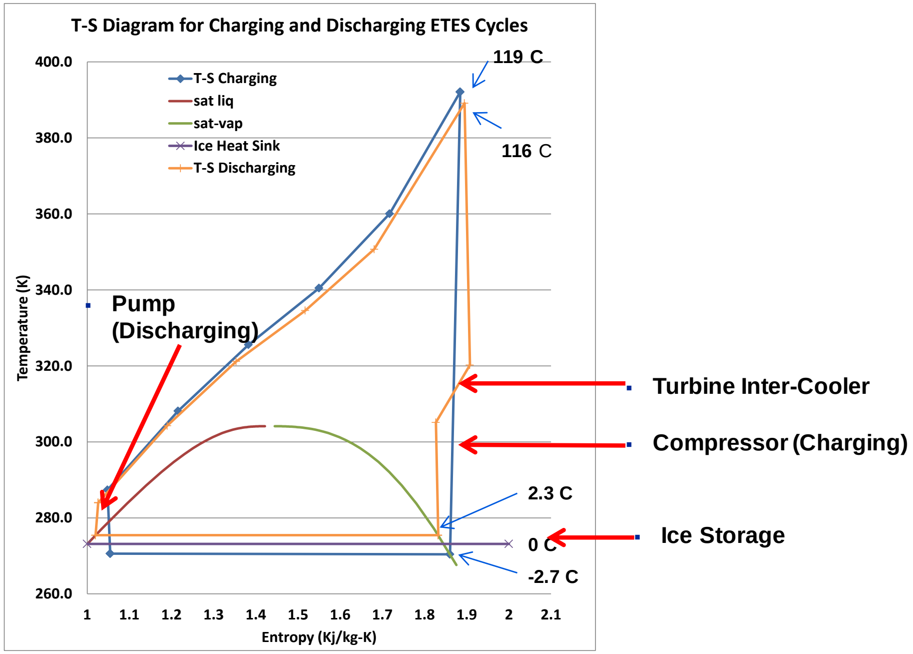
- ***Other Benefits***
  - ***Better Grid Stability***
  - ***Lower Distribution Costs***
  - ***Less Use of Innefficient Plants***
  - ***Better use of Capital Assets***



Bulk Thermal Energy Storage

J. Hermle (ABB), SCO_2 Power Cycle Symposium 2011, Boulder Co.





Key Performance Parameters	Value
Coefficient of Performance in Charging Cycle	**4.51**
Efficiency in Discharge	**13.35%**
Heat Added/Removed to/from Water HX	179895 kWh
Heat Removed/Added from/to the Ice	139989 kWh
Round Trip Efficiency (no additional losses)	**60.2%**
Round Trip Efficiency with 3% losses	**56.7%**
Maximum CO2 Temp Charging	119C
Maximum CO2 Temp Discharging	116C
Minimum CO2 Temp Charging	-2.7C

$$\eta_{Round-Trip} = COP_{Heat\ Pump} \times \eta_{Thermal} = 100\%_{(Ideal)}$$

Site Independent Bulk Energy Storage

Footprint = City Block

50-100 MW_e for ~4 hours

Unlimited Cycles, Target RT_{eff}=60%

Reference: *Round Trip Efficiency*

Batteries: = 70%, 600 cycles

Pumped Hydro = 70%

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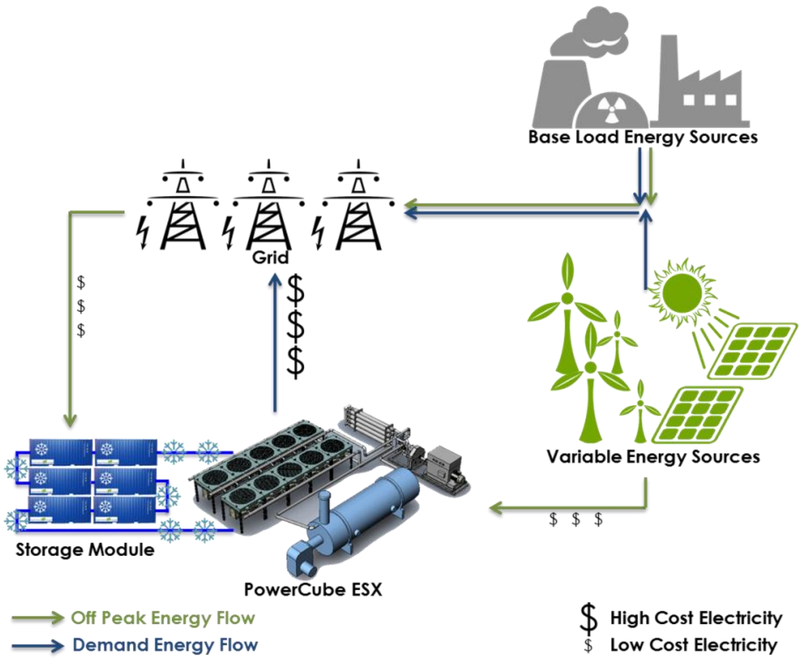
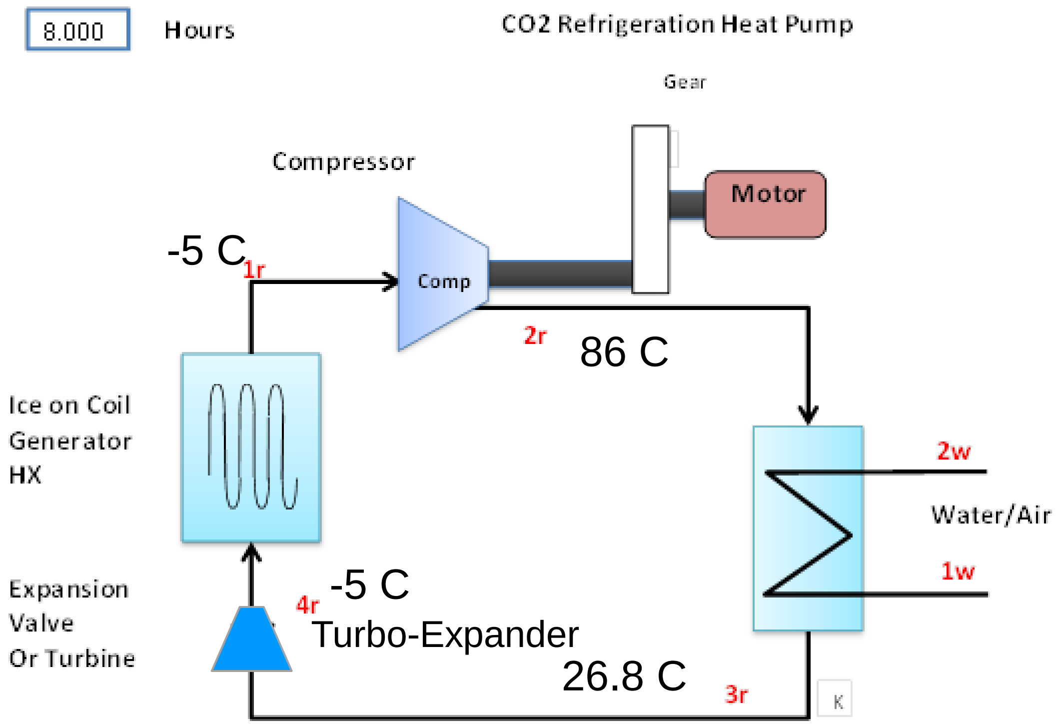
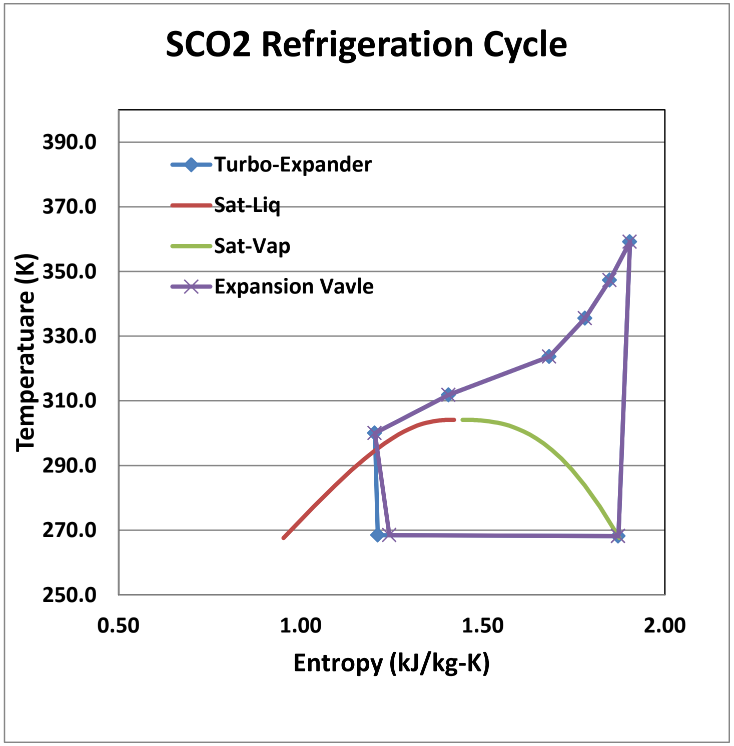
Ice Energy Storage for SCO_2 Power Peaking

- Goal: More Efficient use of Capital Assets (SCO_2 Hardware) than Orig. Concept
  - Orig Concept Operates 4 hrs/day
  - This Concept Operates 24 / 7 / 365
- Avoids Flow Direction Reversal
- Avoids Flow Rate Doubling
- Uses larger dT in HXs
- Provides Bulk Energy Storage as Ice
- Uses Waste Heat from Gas Turbine
  - No Hot Water Storage Tanks
- Maintain: Site Independence
  - No Dams or Caves
  - Foot Print: ~City Block for 50-100 MW_e
- Maximize Dispatchable Power (profit)
- SCT Patented Process



Charging Cycle, SCO_2 Heat Pump





T_{evap} = -5 C , T max = 86 C

P_{evap}= 30.5 bar , P max =91.3 bar

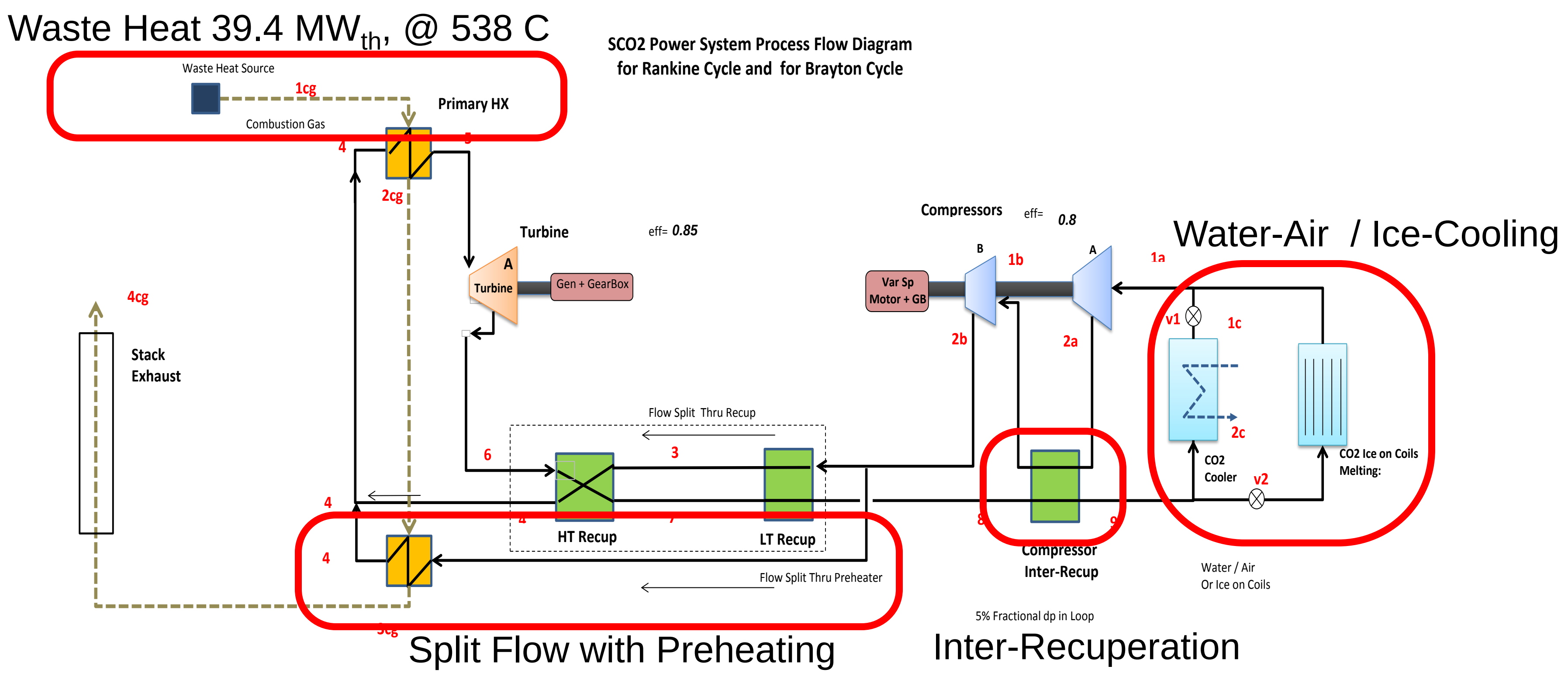
Net COP_{Refr} = 2.69 exp-valve / COP = 3.34 turbo-exp

Mass Flow Rate = 50 kg/s-valve /48 kg/s-turbo-exp

Q_{Refrig} = 8445 kW = 2401 Refr.-Ton

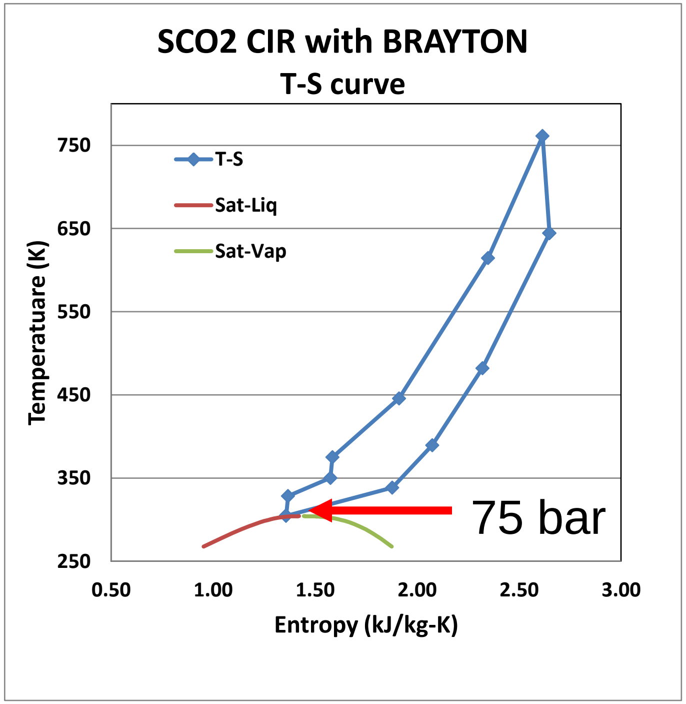
SCO_2 with Waste Heat Recovery

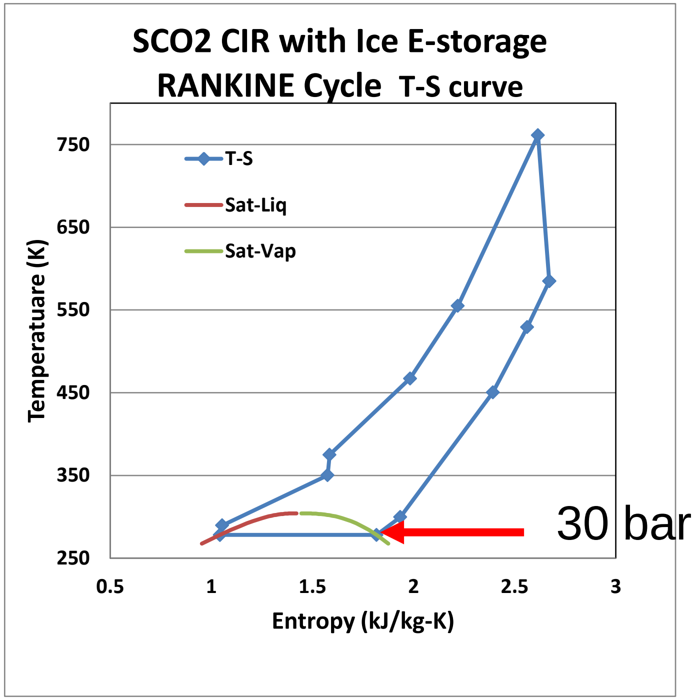
Normal Operating WHR Cycle : Water-Air Cooling (20 hrs)
Discharge Cycle: Ice Cooling (4 hrs)



1. Waste Heat 39.4 MW_{th}, @ 538 C
2. Split Flow with Preheating, Typical Cycle for Waste Heat Recovery (ORCs)
3. Compressor Inter-recuperation (SCT Patented)
4. Water-Air Cooling versus Ice-Cooling^{+}

WHR Brayton Cycle and the Ice-Rankine Cycle





- Lower Heat Rejection Temperature due to Ice Melting
  - Increases Cycle Efficiency 31.7% – 34.5%
  - Increases Combustion Efficiency 44.7% – 68%
  - Lower Turbine Back Pressure Increases Pwr+ 5.58 MW_e – 9.25 MW_e + 66%

+Additional Turbomachinery stages may be required for larger P_{ratio}

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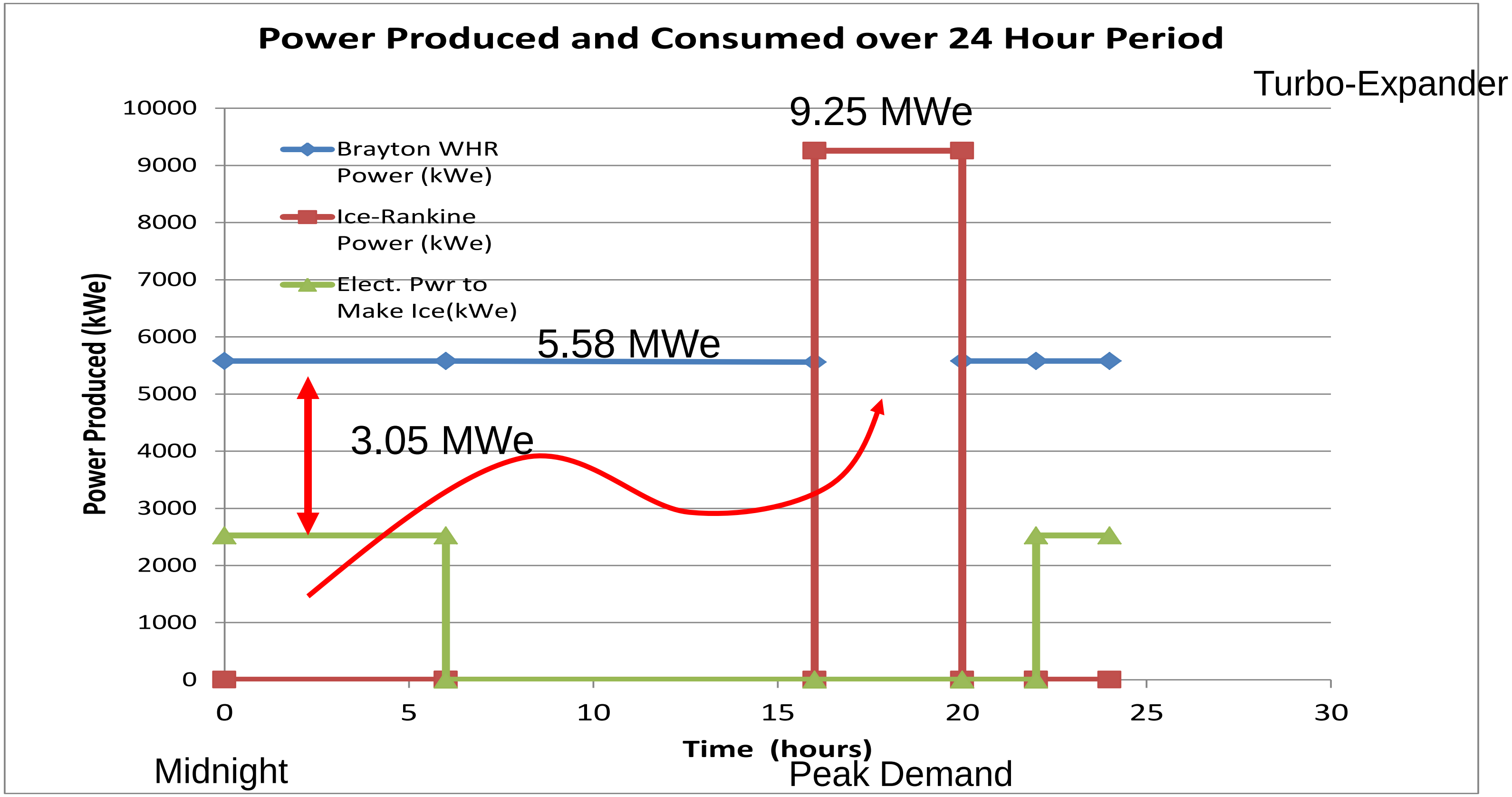
Power Peaking Operation



Dispatchable Power Round Trip Efficiency 148%-183%

Excess Dispatchable Power Round Trip Efficiency 58.6% – 73%

9.25 MWe for 4 Hours using 2.5 MWe for Ice Generation over 8 hrs

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Economics

- Addressed in a Companion Paper
  - Presented in the Poster Session (William Scammel)
- Major Results
  - Primary benefit is from the conversion of Waste Heat to Electricity
  - ROI for WHR ~3 years
  - Given the assumed pricing structure (Peak Cost at 2-4 X Off-Peak)
    - Additional Benefit is due to Ice-Energy Storage (~8% / year)
- Other Benefits not studied
  - Demand Peak Reductions
  - Spinning Reserve Benefit
  - Grid Stability improvements
  - Need to Work with a Utility to fully understand the Peaking Benefit
    - Will vary by location throughout the country

Summary and Conclusions

- SCO_2 Power Systems Promise Transformational Power Systems
- SCO_2 Offer Methods for Bulk Energy Storage
- Power Peaking with Ice-Energy Storage Plant was Described using Waste Heat Recovery
- System Proposed was designed to make maximum use of capital assets 24 hours per day
- System
  - Produces Ice using a SCO_2 Heat Pump during off-peak, (8 hrs, 2.5 MWe)
  - SCO_2 Power Cycle using water or air cooling: off-peak (20 hrs, 5.5 MWe)
  - Power Cycle is switched to Ice Melting for Peak Power (4 hrs, 9.2 MWe)
- Excess Round Trip Efficiency **58.6% – 73%**
- Dispatchable Round Trip Efficiency **148%-183%**
- **Improved Economics due to (ROI < 3 yrs)**
  - **Waste Heat Recovery** (primary economic benefit)
  - **Ice-Energy Storage** (secondary economic benefit)