Solar/Nuclear Combined Dynamic Brayton Systems

Christopher Morrison PhD – c.morrison@usnc-space.com
Astro Nuclear Engineer, USNC-Space

About USNC-Space

Ultra Safe Nuclear Co. Terrestrial & Space

www.usnc.com

USNC is Developing the 5 MW_e MMR™ for Remote Terrestrial Locations

For many of the same reason the technology excels in remote location, it also excels in space

MMR™ REACTOR FIRST TO MARKET

2011
Secured FCM™ fuel and MMR™ reactor patents

2016
Established R&D and fabrication laboratories

2017
Initiated FCM™ fuel qualification plan

2018
Completed Concept Design

Received Innovate UK SBRI Advanced Modular Nuclear Reactor grant

Began Basic Design

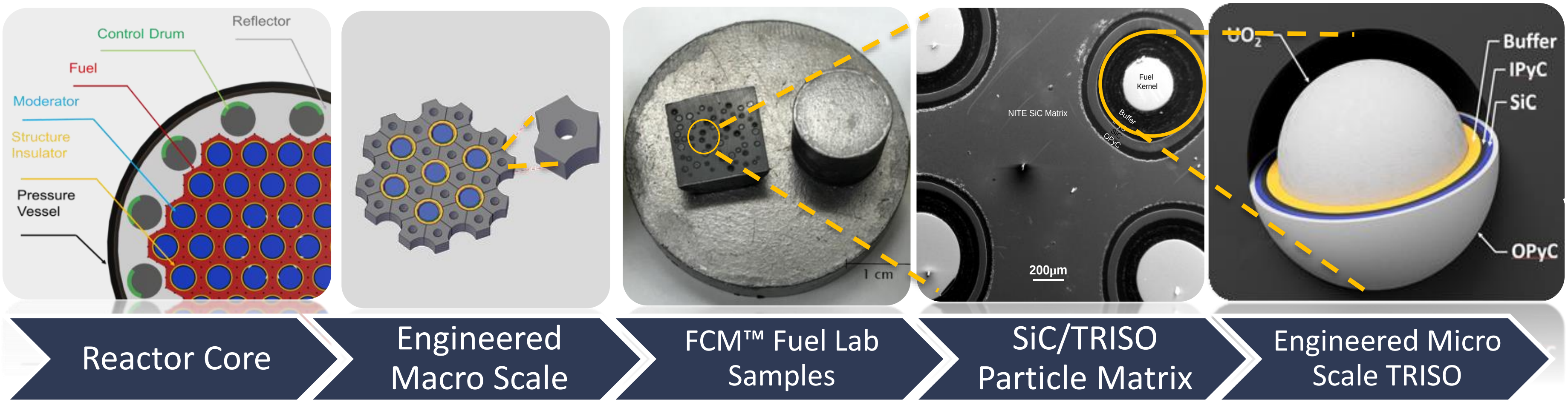
2019
Began Reactor Licensing Vendor Design Review II

Submitted License to Prepare Site for a small modular reactor at Canadian Nuclear Laboratories' (CNL) Chalk River site

About USNC – Key Technology– **FCM™ Nuclear Fuel**

Nuclear Fuel is Foundation of The Nuclear System

Fully-encapsulated Ceramic Matrix **(FCM™)** fuel has over 30 million dollars in R&D from the DoE Accident Tolerant Fuels Program. It is **radiation resistant, chemically non-reactive, fully encapsulates fission products, and capable of extremely high temperatures.** FCM™ is a highly engineered fuel built to ensure no release of radioactive material even under accident scenarios. Current SiC FCM™ is capable of operation at temperatures above 1600 K and is qualified at temperatures of up to 1300 K.

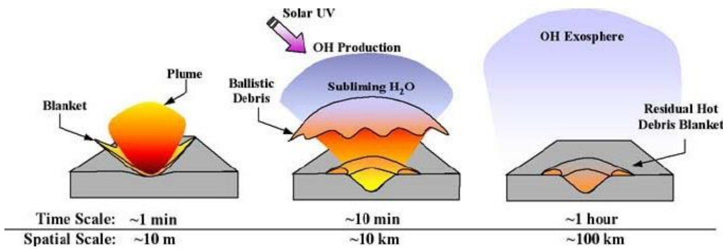


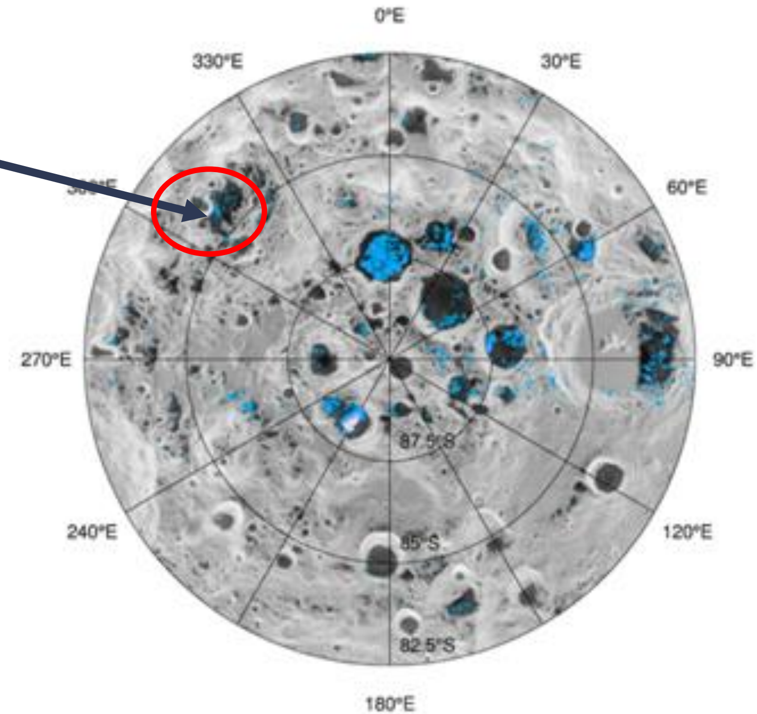
Why Dynamic Power Cycles

The Need for Process Heat

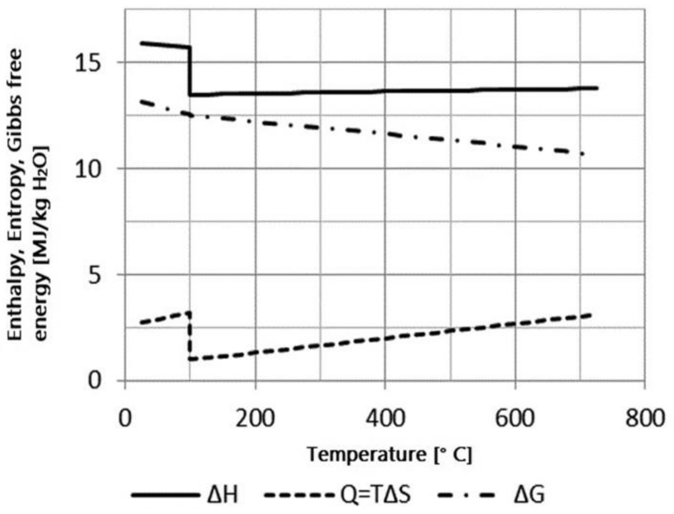
Water on the Moon – LRO and LCROSS

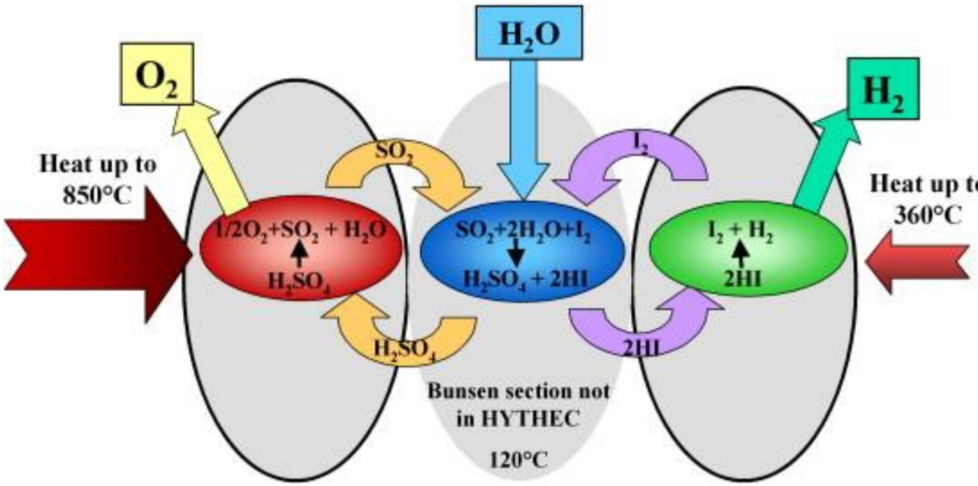
LCROSS suggested that 5.6 percent ± 2.9 water by mass in the Cabeus crater





The Need for Energy - Electrolysis and Pyrolysis



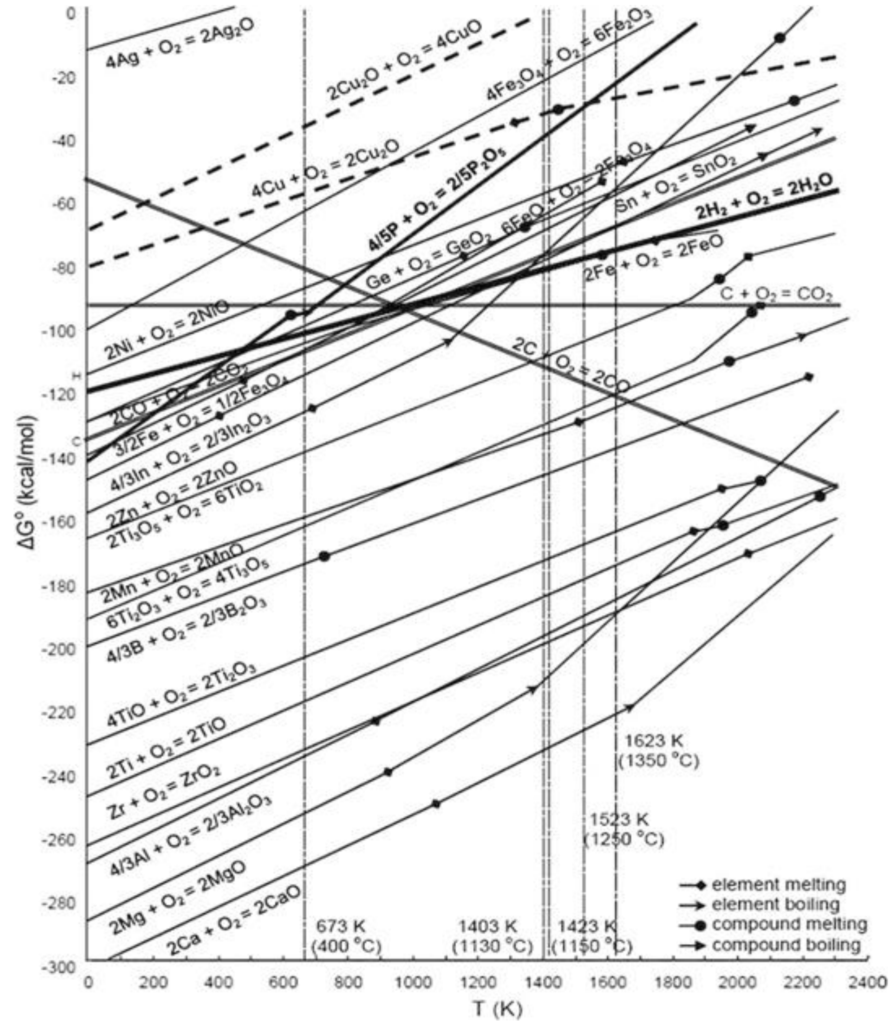


What is on the Moon?

Location	A-11	A-12	A-14	A-15	A-16	A-17	L-16
SiO_2	42.47%	46.17%	48.08%	46.20%	45.09%	39.87%	43.96%
Al_2O_3	13.78%	13.71%	17.41%	10.32%	27.18%	10.97%	15.51%
TiO_2	7.67%	3.07%	1.70%	2.16%	0.56%	9.42%	3.53%
Cr_2O_3	0.30%	0.35%	0.22%	0.53%	0.11%	0.46%	0.29%
FeO	15.76%	15.41%	10.36%	19.75%	5.18%	17.53%	16.41%
MnO	0.21%	0.22%	0.14%	0.25%	0.07%	0.24%	0.21%
MgO	8.17%	9.91%	9.47%	11.29%	5.84%	9.62%	8.79%
CaO	12.12%	10.55%	10.79%	9.74%	15.79%	10.62%	12.07%
Na_2O	0.44%	0.48%	0.70%	0.31%	0.47%	0.35%	0.36%
K_2O	0.15%	0.27%	0.58%	0.10%	0.11%	0.08%	0.10%
P_2O_5	0.12%	0.31%	0.50%	0.11%	0.12%	0.07%	0.11%
S	0.12%	0.10%	0.09%	0.06%	0.06%	0.13%	0.21%
H	51.0ppm	45.0ppm	79.6ppm	63.6ppm	56.0ppm	59.6ppm	-
C	135ppm	104ppm	130ppm	95ppm	106.5ppm	82ppm	-
N	119ppm	84ppm	92ppm	80ppm	89ppm	60ppm	134ppm
He	60ppm	10ppm	8ppm	8ppm	6ppm	36ppm	-

ISRU Manufacturing

- Ellingham Diagram – “De-Oxiding”
- Using CO as a catalyst can refine oxides using heat and pressure
- Need high temperatures



Metal Asteroid Refining

1 Ton M-Type Asteroid

200 grams precious metals

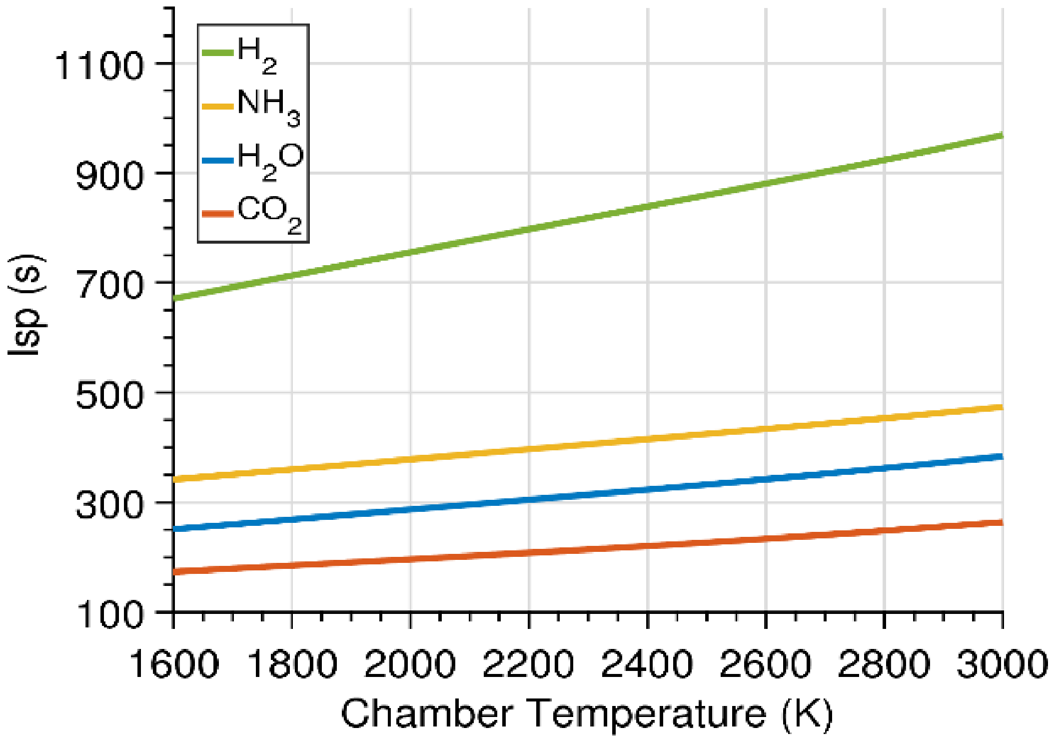
Mond Process

$$\mathrm{NiO(s) + H2(g) \rightarrow Ni(s) + H2O(g)} \quad \mathrm{(500\ K)}$$

$$\mathrm{Ni(s) + 4\ CO(g) \rightarrow Ni(CO)4(g)} \quad \mathrm{(330\ K)}$$

$$\mathrm{Ni(CO)4(g) \rightarrow Ni(s) + 4\ CO(g)} \quad \mathrm{(520\ K)}$$

Thermal Propulsion - OMS



Key Points

1. For ISRU, process heat is just as useful as electricity (especially at high temperatures).

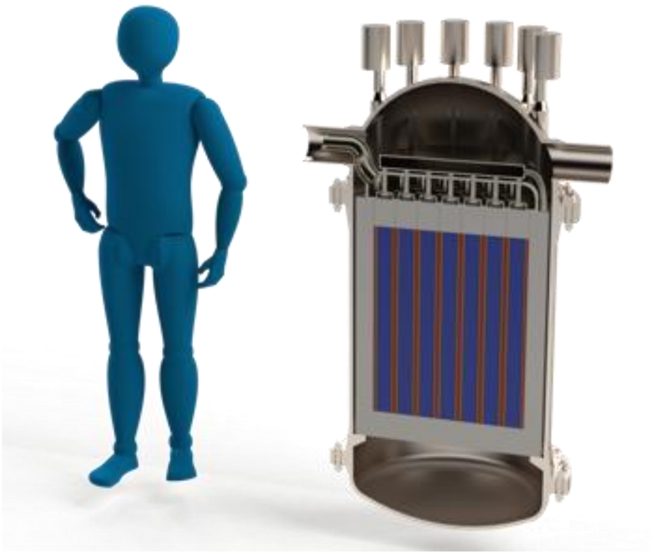
2. Dynamic power conversion cycles are not as vulnerable to environmental conditions as PV.

Brayton Cycle 101

Heat Source ~~Agnostic~~ Polytheistic

Brayton Cycle – Heat Source Agnostic

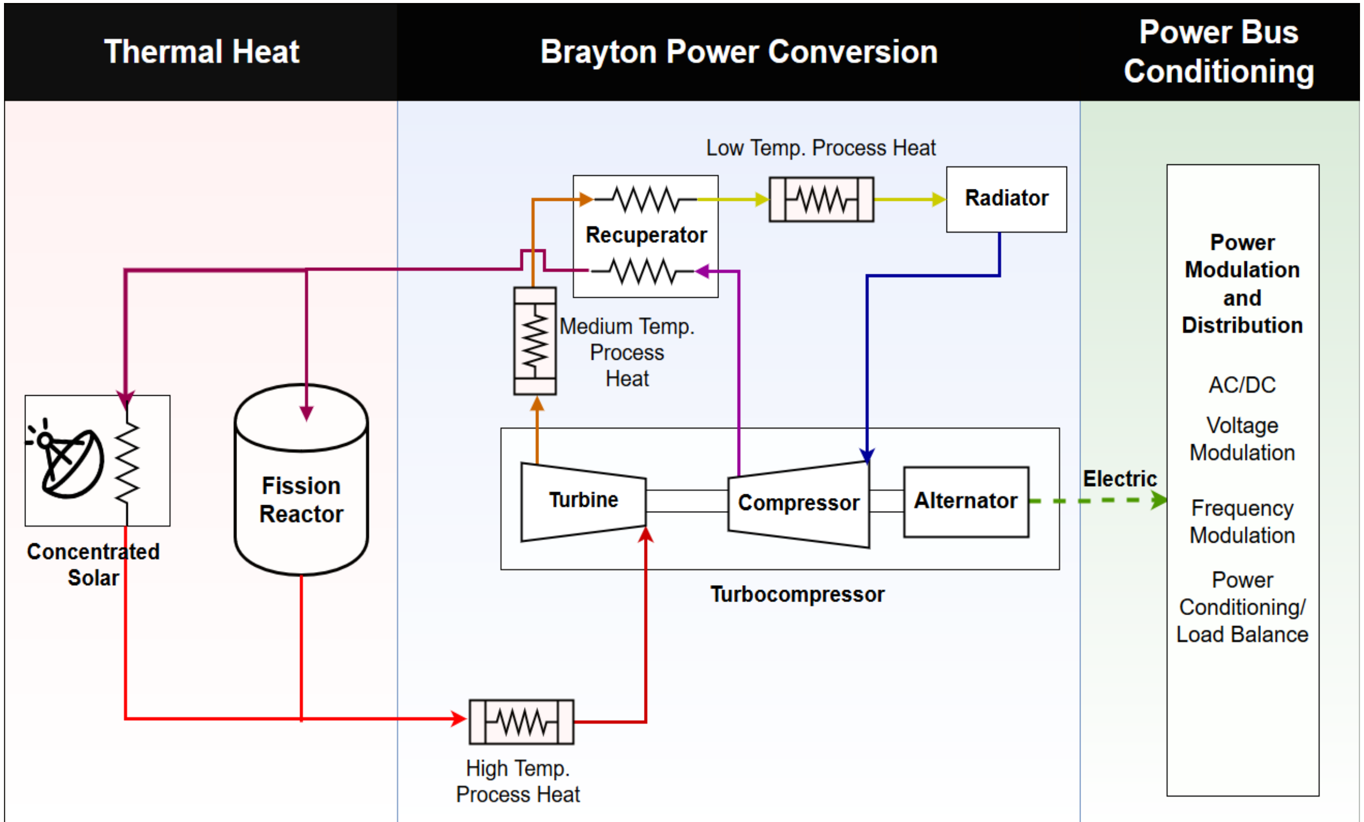
USNC-Space Pylon - 1 MW_{th} Nuclear Heat Source



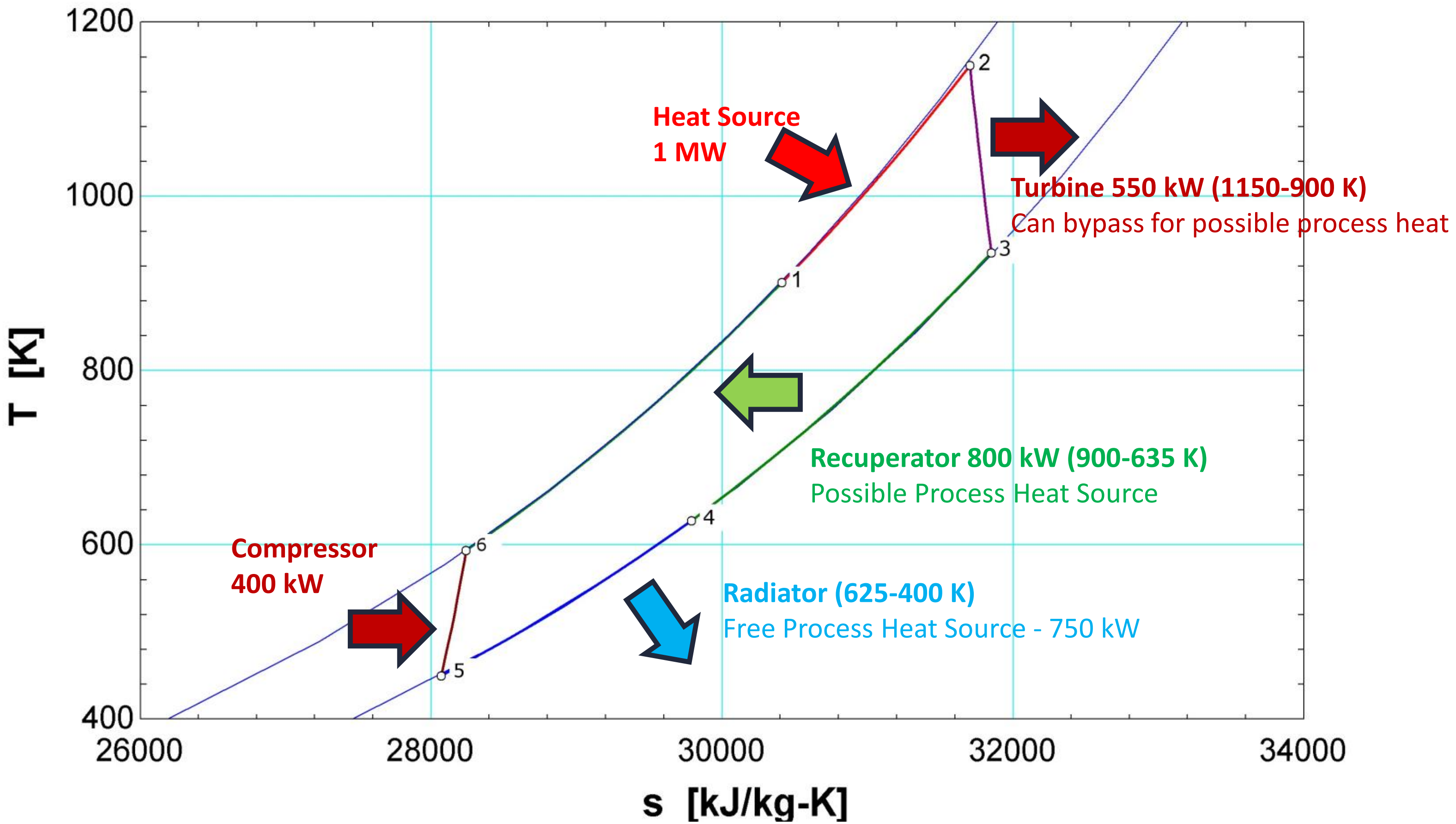
or

Your 1 MW_{th} Solar Collector

Brayton Cycles – Heat Source ~~Agnostic~~ Polytheistic



Brayton Cycle T-S Diagram



Why Nuclear?

Why Concentrated Solar?

The Moon

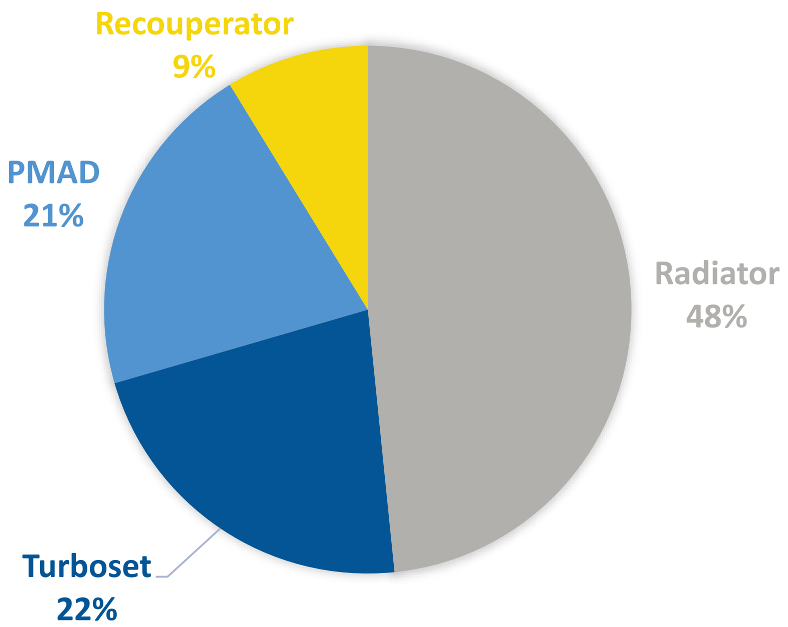
Why Combined Cycle
Dynamic Power
Conversion?

Maximum Flexibility and
Reliability

50 K
384 Hour Night

400 K
384 Hour Day

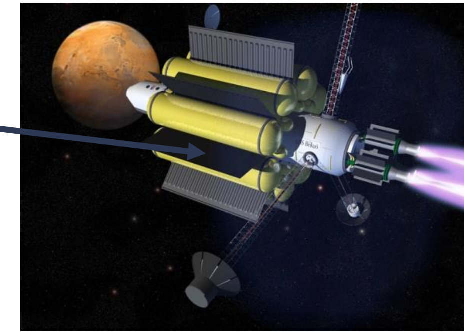
Recuperated Brayton Cycle (No Heat Source)



System Property	Description
Power Output	150 kW_e/850 kW_{th}
System Efficiency	15%
Pressure Ratio	1.7
High Pressure	2 MPa
Hot Fluid Temperature	1150 K
Cold Fluid Temperature	450 K
Fluid	Noble Gas Mix
Mass	~1600 kg

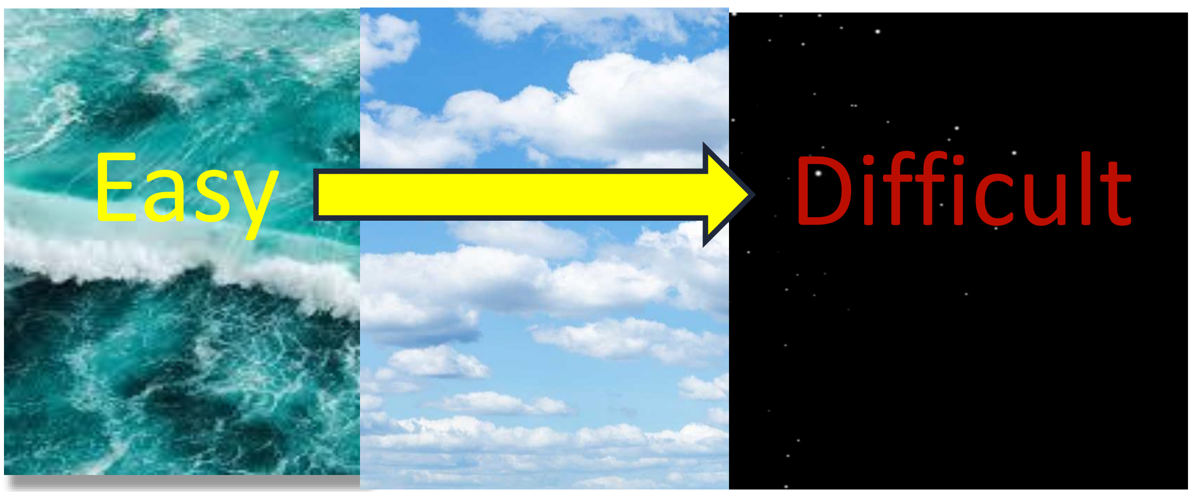
The Importance of High Temperature

Compact High Temperature Radiators

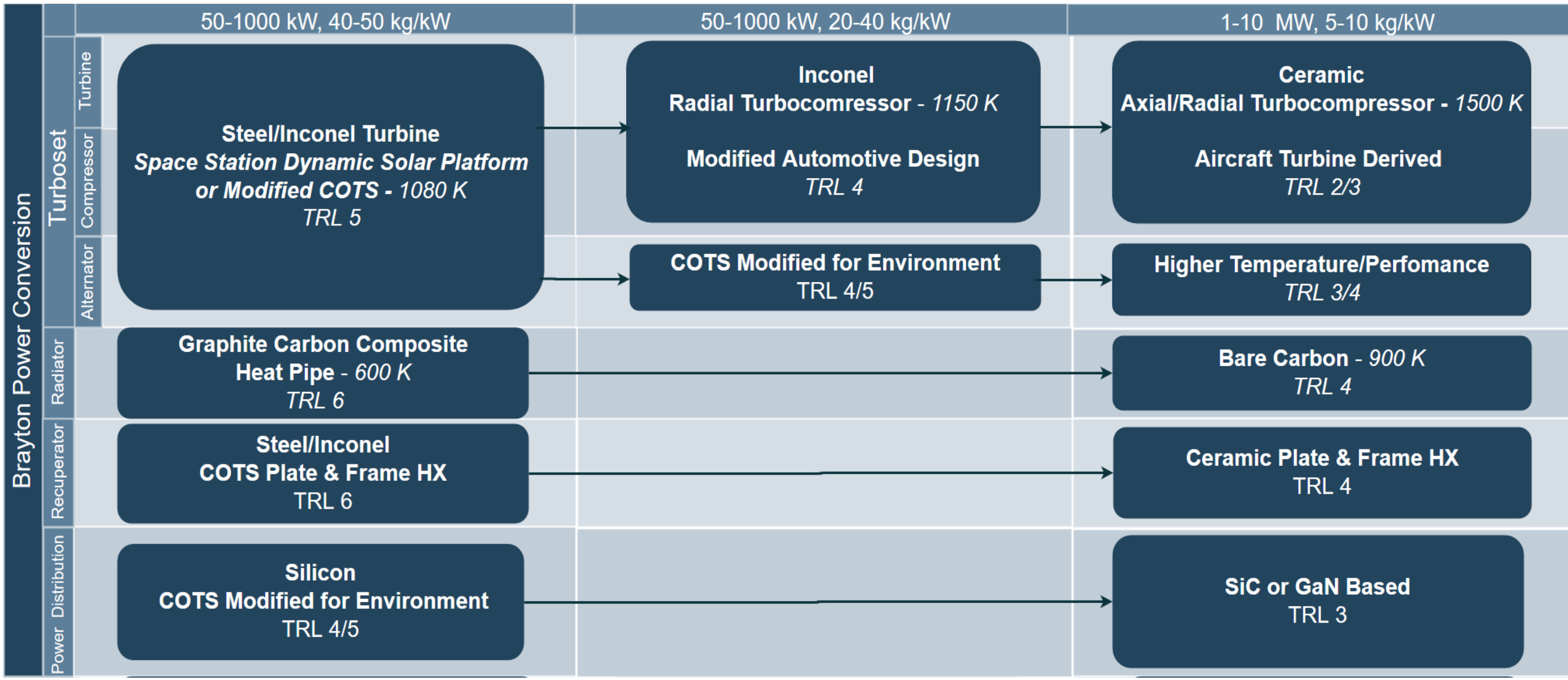


Large Low Temperature Radiators

Heat Rejection



Brayton Development Roadmap



Final Thoughts

1. Co-gen Brayton systems can utilize the strengths of both nuclear and solar for maximum reliability/flexibility.

2. Brayton systems are simple, compact, and utilize components similar to the automotive/aircraft industry

3. USNC-Space wants to work with solar dynamic partners to develop Lunar, Martian, and space systems.