Design and Modeling of an Electrochemical Device Producing Methane, Oxygen and Polyethylene from In-Situ Resources on Mars

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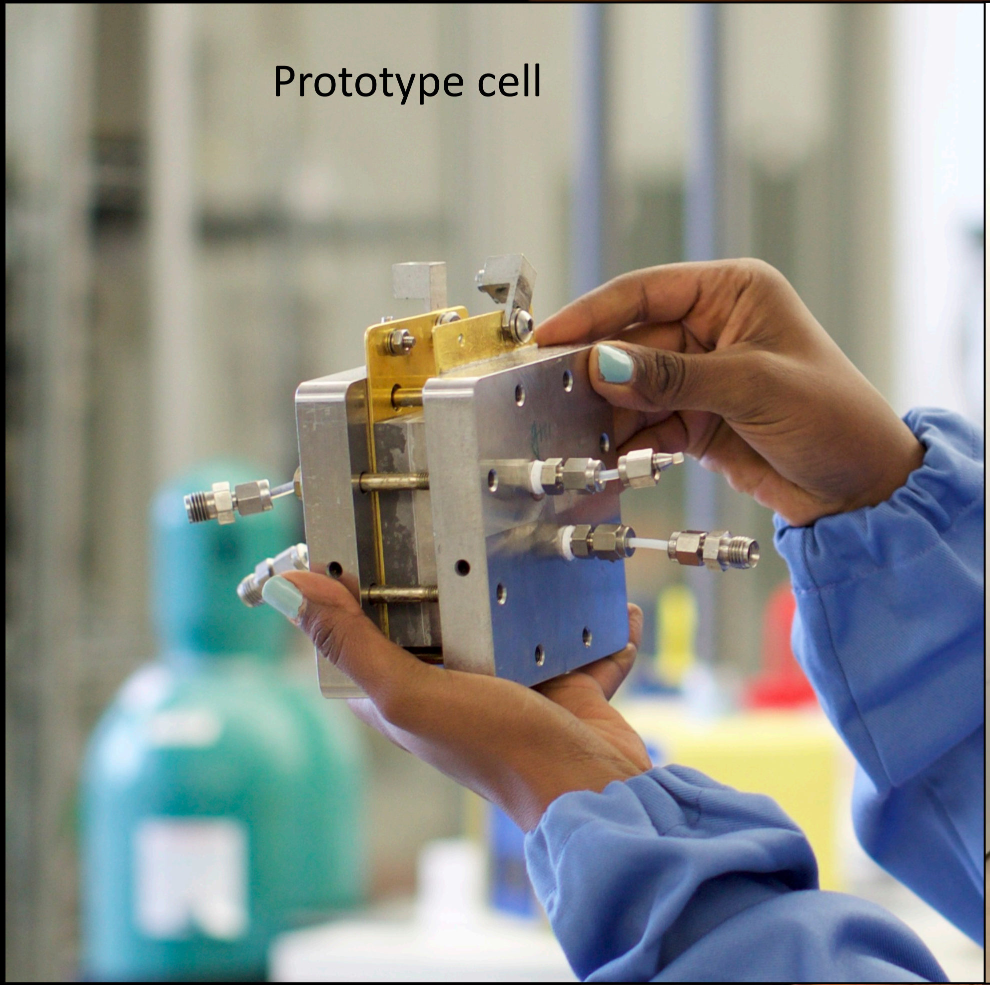
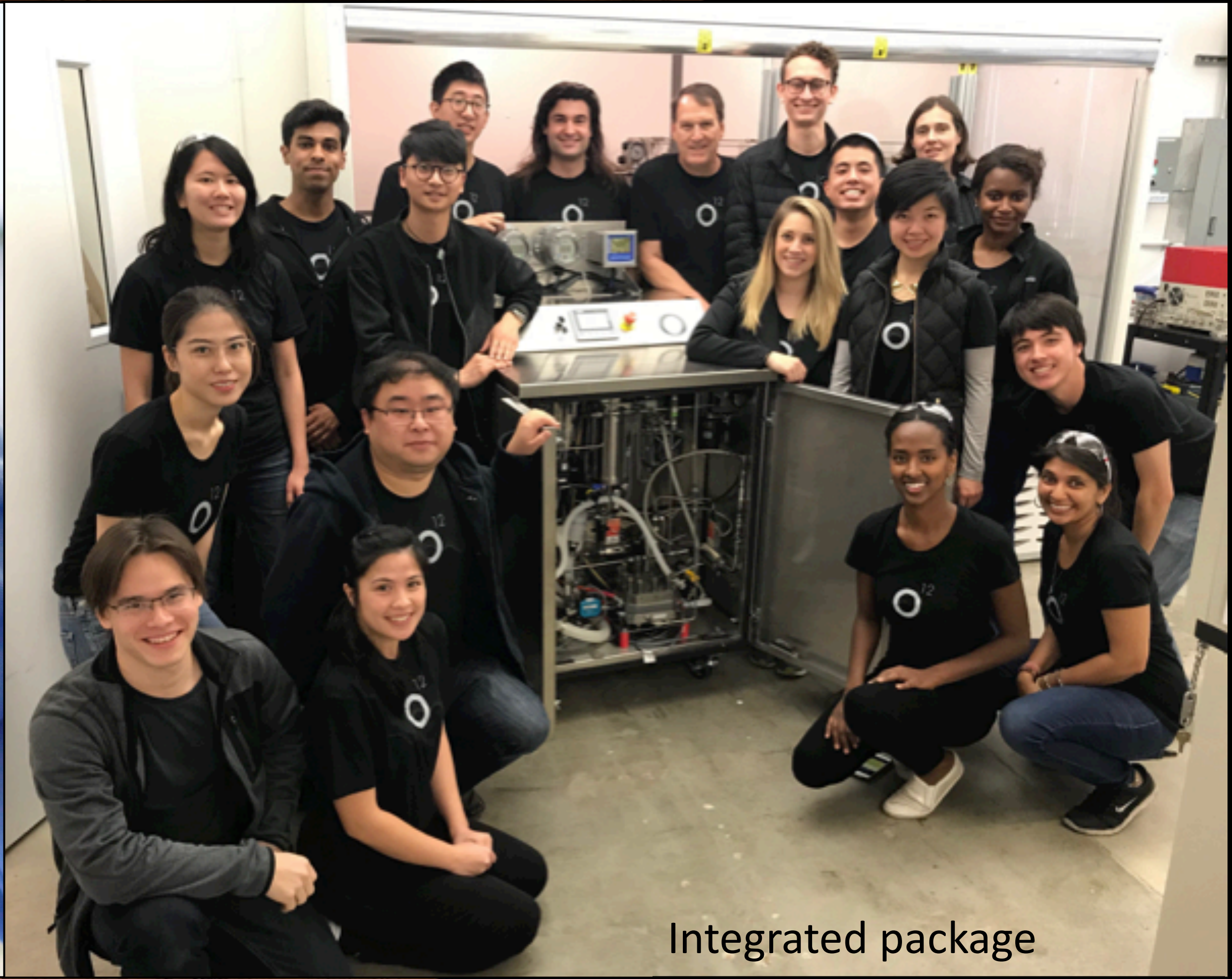
Background and Motivation

- Subcontract with Opus 12, Inc. on a NASA SBIR Phase II grant
- Opus 12 developed an electrochemical device that produced methane, ethylene, oxygen and other gases from CO_2 and water
- Eighteen month project ended in October 2018
- I have a background in electrochemical modeling and life cycle analysis
- I participated in a Keck Institute for Space Sciences study in 2016 examining the production of methane/oxygen propellant on Mars
- Emerging Futures was asked to develop a preliminary engineering design for device requirements on the Mars surface to produce:
    - Pure (>95%) methane and oxygen for use as propellant
    - A useful plastic (e.g., polyethylene) from electrochemical co-products

Opus 12 electrochemical device

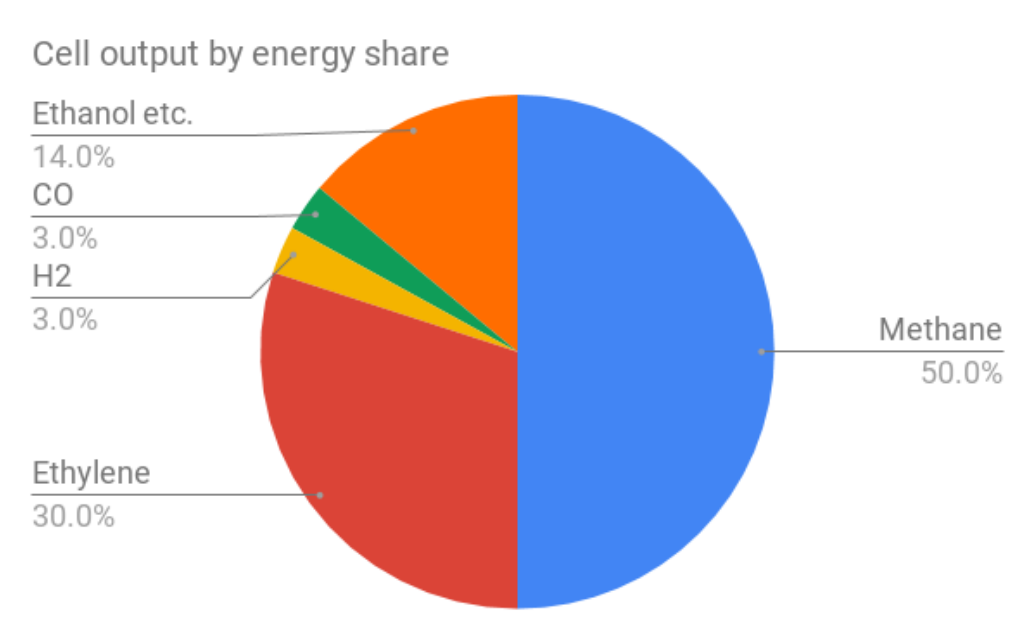


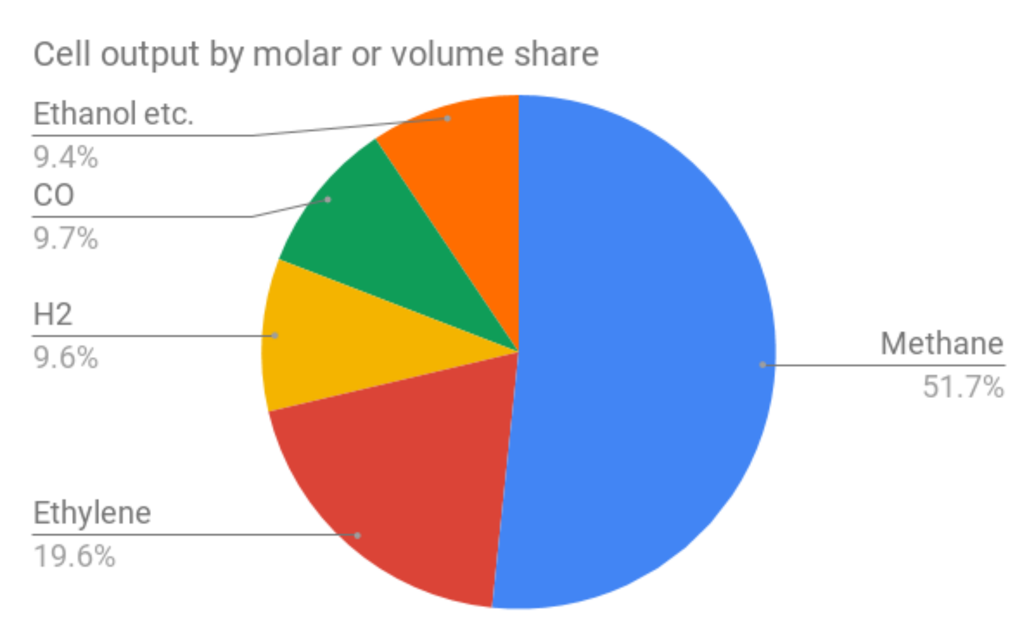


Product selectivity

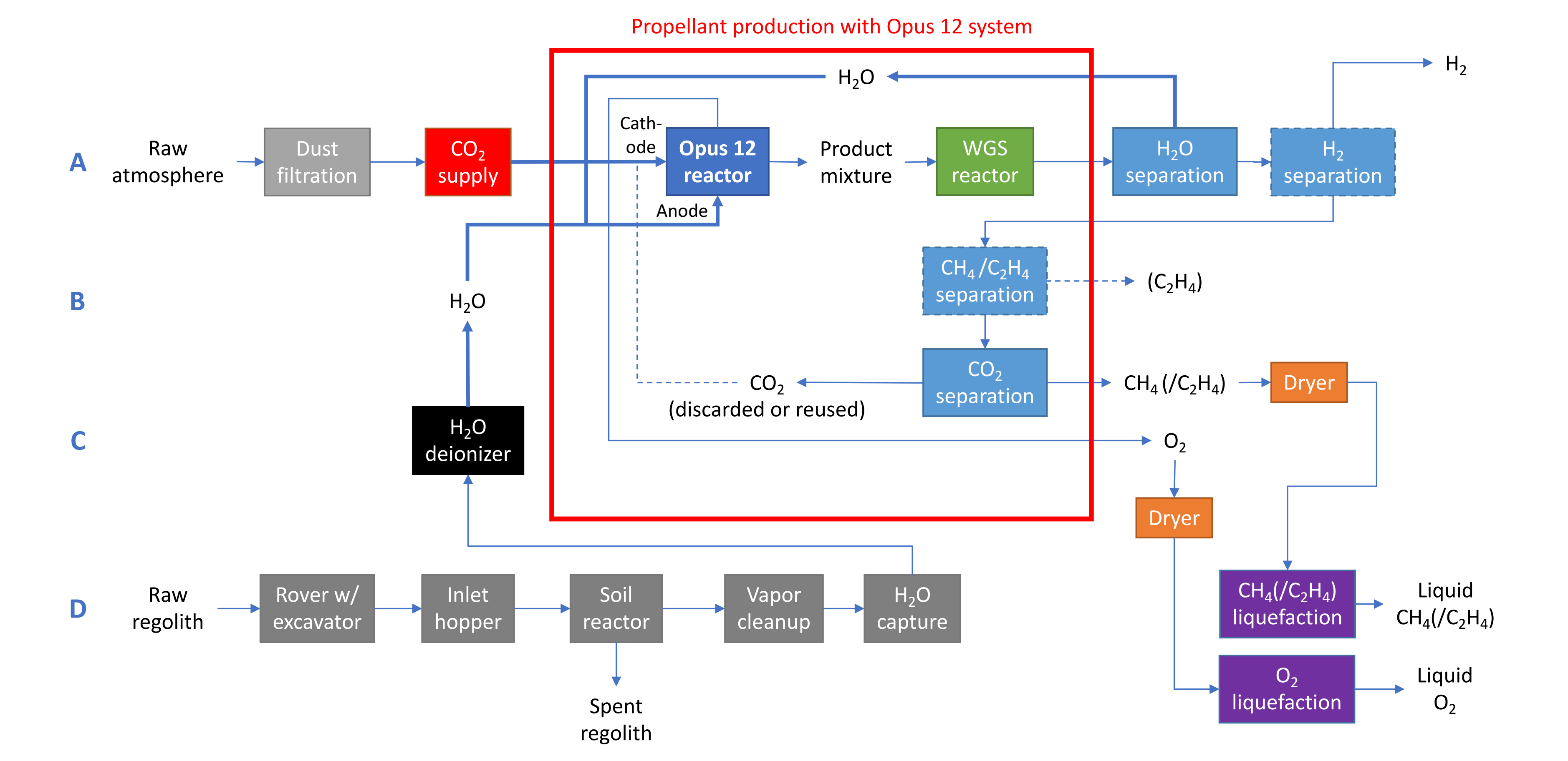
$CO_2 + H_2O$ + electricity → $C_xH_yO_z$ (several species) + O_2

- Can adjust catalyst to produce >50% methane (CH_4) or ethylene (C_2H_4)
- We assumed a representative snapshot of product selectivity:

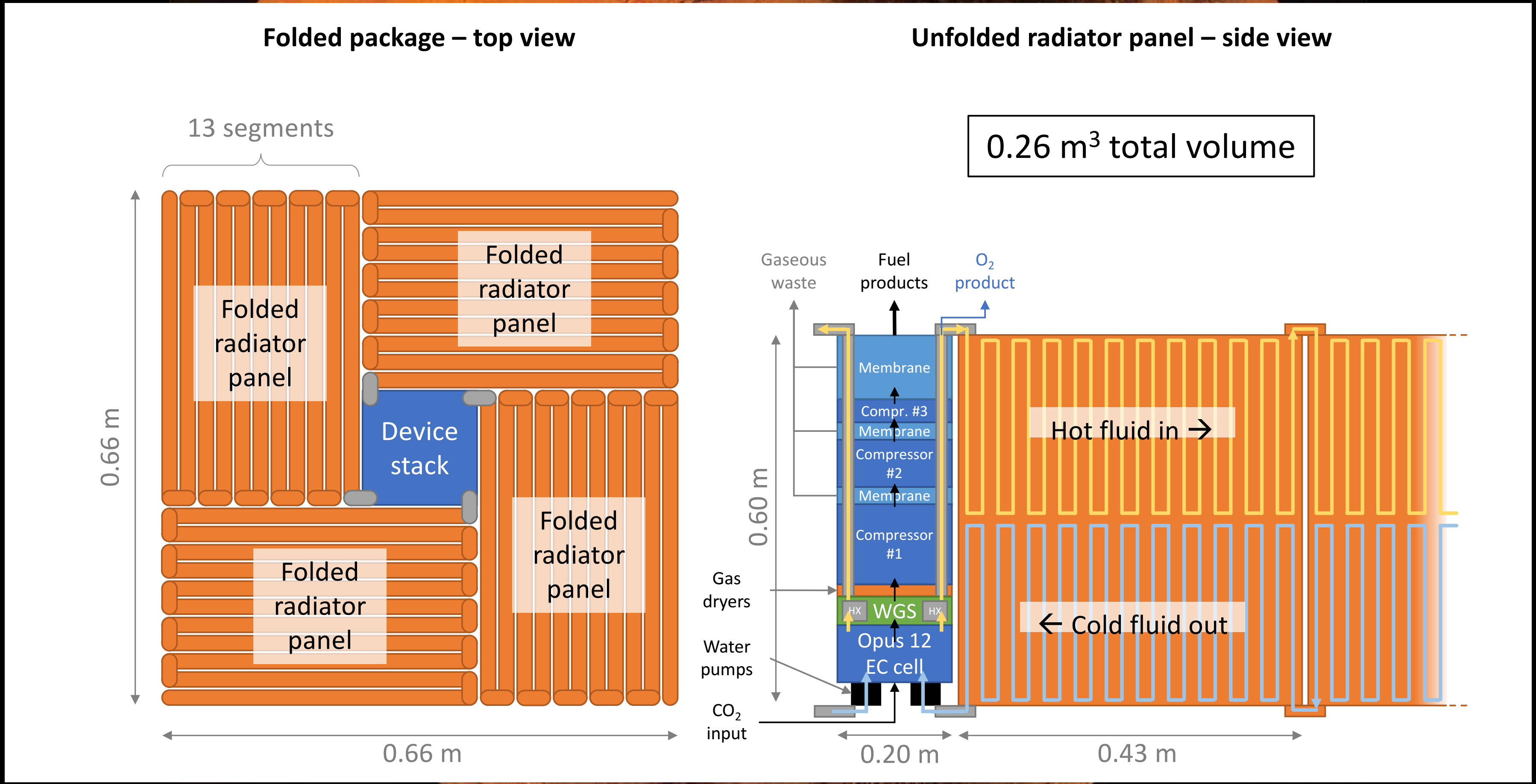




CO_2-to-propellant system in context



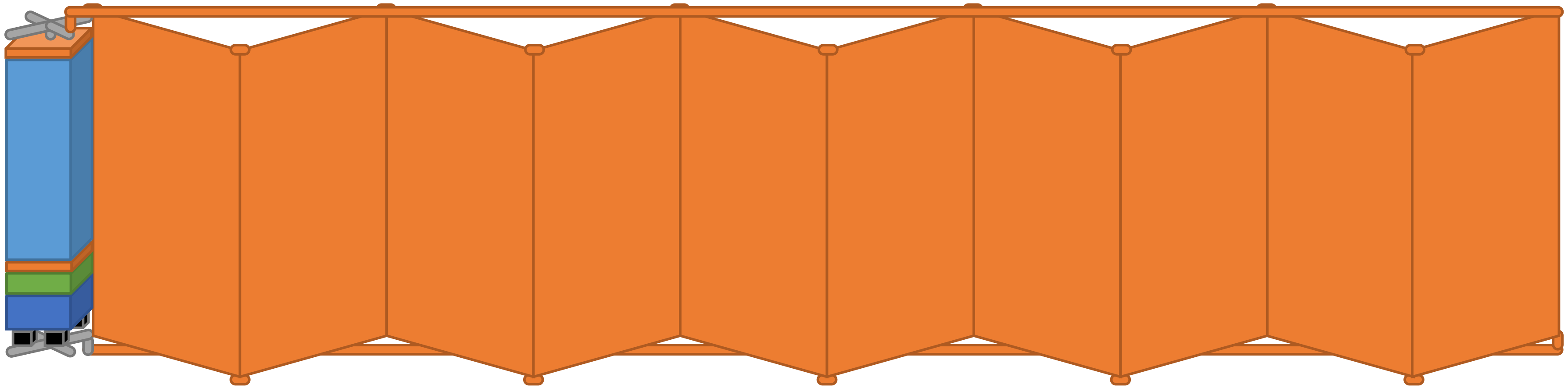
Stowed view of device



Deployed view of CO_2-to-propellant device

Heat transfer fluid is H_2O from EC cell

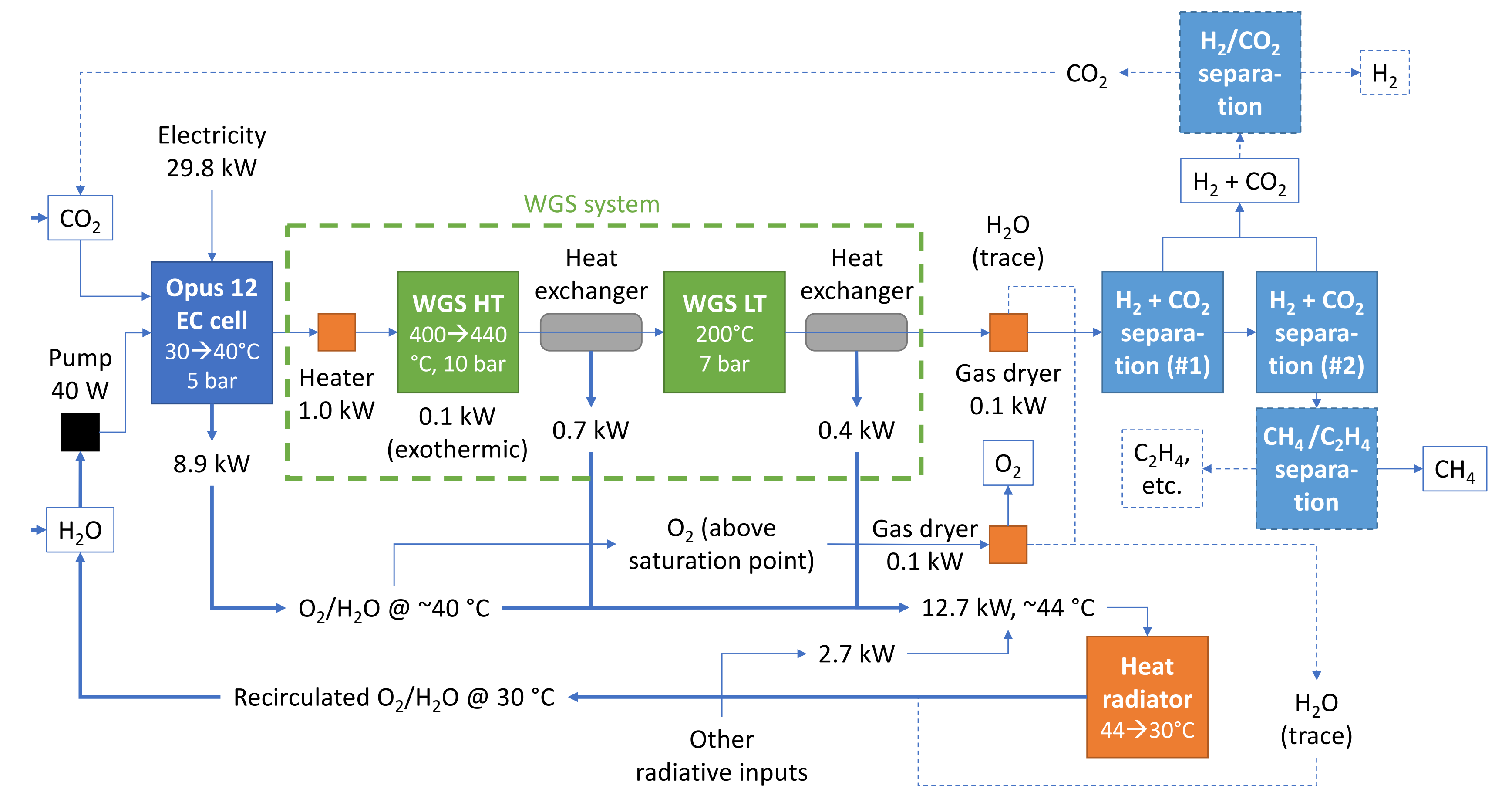
Extendable rods to deploy radiator panel →



Each panel is ~5.6 m long (fully extended) x 0.6 m high

Total pipe length is ~1.6 km (total for all panels). Total area is 27 m^2 (both sides).

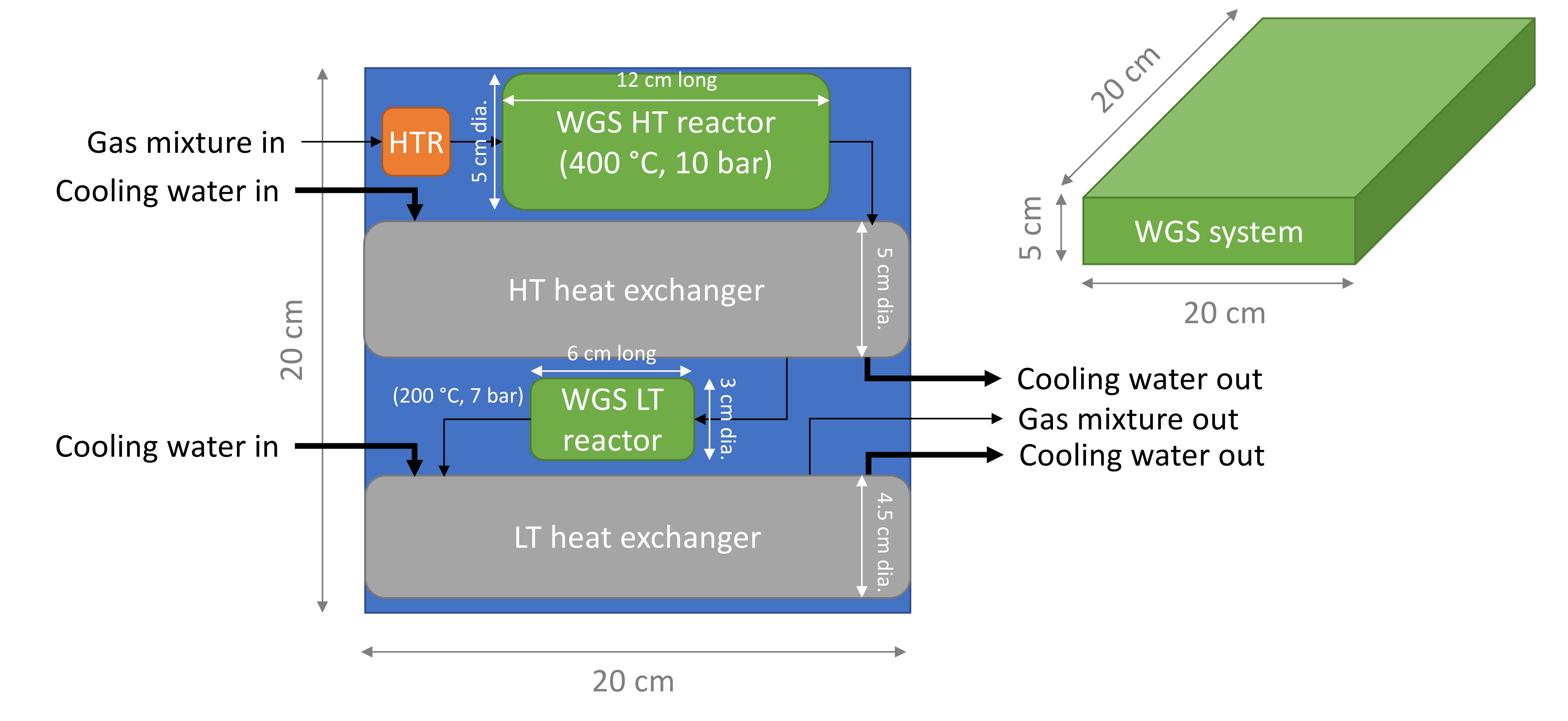
CO_2-to-propellant reactor design



- Assumed 70% efficient EC cell with 30 kW total energy budget (13 kW heat rejected)
- Difficult to separate CH_4 and C_2H_4; left gases mixed
- Gases other than CO easily separated

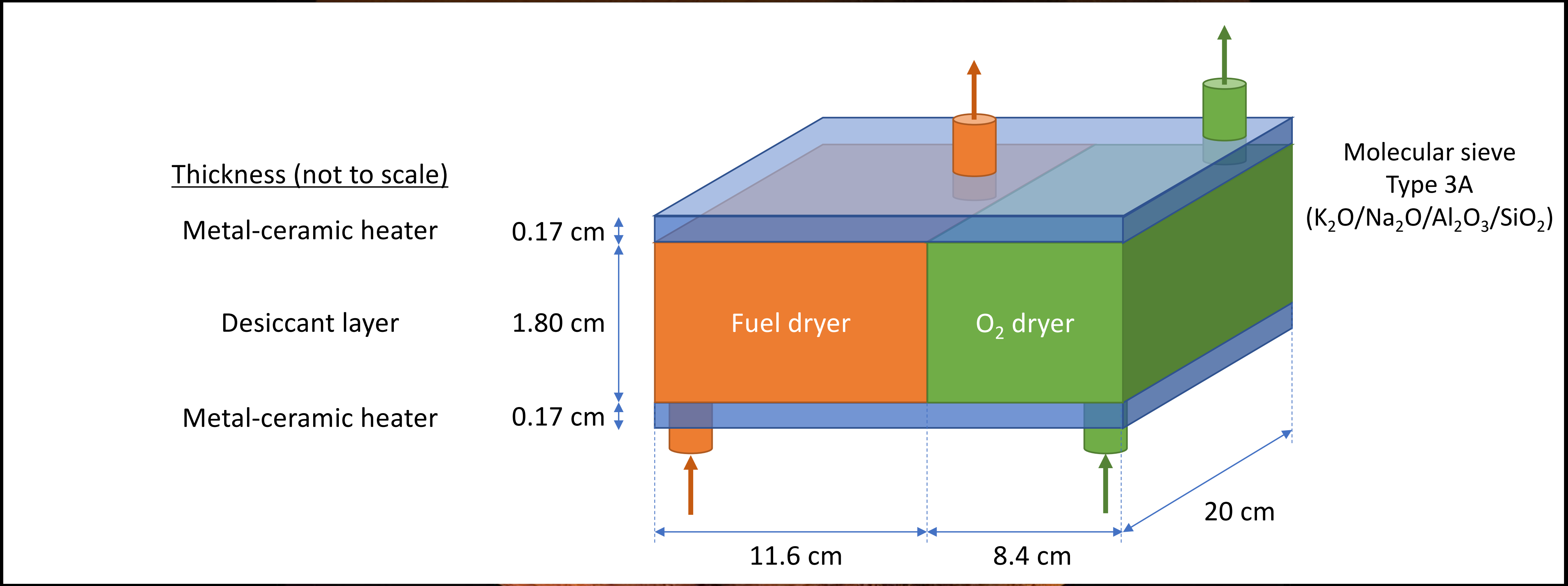
Water-gas shift sub-assembly

$CO + H_2O \rightarrow CO_2 + H_2$ (used to convert CO to CO_2 for easier removal)



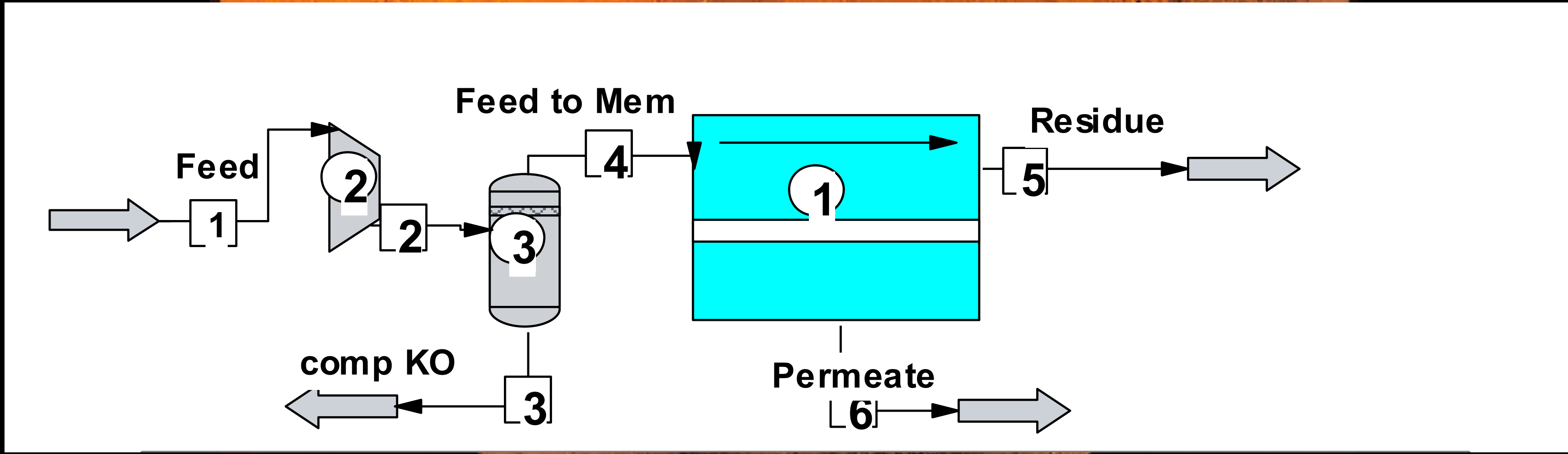
Gas dryer sub-assembly

Dessicants cycled once per hour to recover H_2O (can be reinjected or discarded):



Membrane separation sub-assemblies

- Design by Tim Merkel (MTR, Inc.)
- Separates nearly 100% of H_2 + CO_2, 91% of ethanol and 96% of water
- CH_4 and C_2H_4 separated via 2-stage membrane separation with 10% losses
- Membrane areas are 1 m^2 each (an additional 4 m^2 membrane area available)



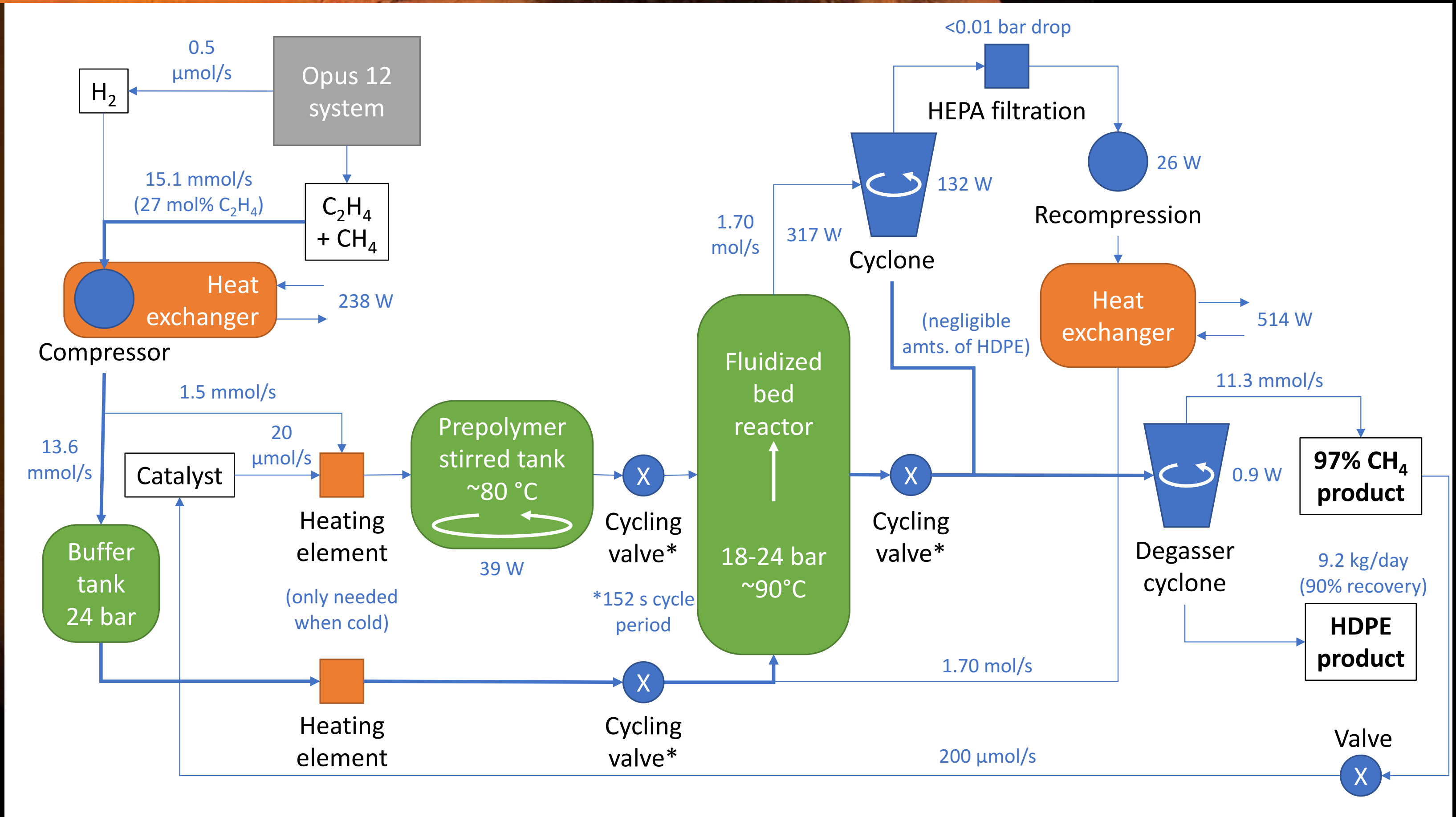
Mass budgets of CO_2-to-propellant device

Component	Mass (kg)	Component	Mass (kg)
Water pump	0.9	Gas dryers	3.0
EC stack	124.0	Gas compressors	11.6
WGS reactors	1.1	Membrane separations	5.9
Heat exchangers	0.3	Radiator panels	264.9
WGS heater	0.5	Total	412.2

Product or reagent	Flow rate (kg/day)	Mass (kg) after 480 days
Methane (CH_4)	14.6	7,030
Ethylene (C_2H_4)	9.7	4,660
Hydrogen (H_2)	0.77	370
Required O_2	56.8	26,300
Additional O_2	66.6	32,000
Recovered H_2O	2.5	1,200

Design of the CO_2-to-plastics device

- C_2H_4 (+ 0.01% H_2) polymerizes to HDPE at <100 °C and ~20 bars
- Small amounts of metal-based catalysts are lost (80 g/day) and must be supplied from Earth
- CH_4 and CO_2 are inert and used as carrier gases



Mass budget of CO_2-to-plastics device

Component	Mass (kg)	Component	Mass (kg)
Initial compressor	1.88	Precompression heat exchanger	0.84
Prepolymer tank	0.30	Main heat exchanger	0.84
Buffer tank	1.93	Recompressor	0.21
FB reactor	2.35	Degasser	0.05
Cyclone	7.03	Total	17.06
HEPA filter	1.64	Additional radiator mass	19.0

Product or reagent/catalyst	Flow rate (kg/day)	Mass (kg) after 480 days
High-density polyethylene	9.0	4,300
Methane (97%)	14.6	7,030
Metal catalysts (Earth-supplied)	0.077	37

Thank you!

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