Methane production from carbonaceous chondrites using electromethanogenesis

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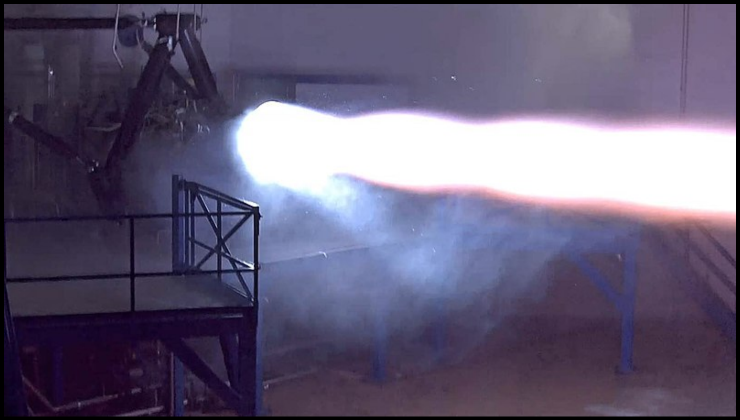
Carbonaceous asteroids and fuel/propellant

- C-type asteroids are suspected to contain water and hydrated minerals in subsurface and permanently shaded craters
- Carbon in the form of organic compounds and inorganic carbon is present
- Propellant and fuel are potentially the first uses
- Carbonaceous chondrite meteorites and analogues available for testing

253 Mathilde
(a C-type asteroid)
Credit: NASA

Methane and water

- Water can be used as a propellant directly or electrolyzed into H_2 and O_2
- Methane (CH_4) would be easier to store and offers higher energy densities (per volume)
  - Probably most publicized: SpaceX Raptor engine
- Methane can be produced by Sabatier reaction, biologically (methanogensis), or by other methods



Credit: SpaceX, public domain

Methane is produced using microbes in industrial quantities

- Landfill biogas
  - Altamont Landfill 22 metric tons LNG/day (source EPA)
- Anaerobic digester biogas
- Biogenic Coal-Bed Methane
  - Strąpoć et al, 2011, Biogeochemistry of Microbial Coal-Bed Methane

Credit: Arizona Department of Environmental Quality

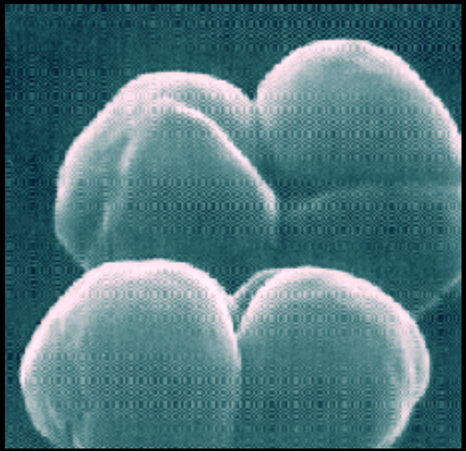
Credit: Jörgen Lundqvist, Oslo, Norway

Methanogenesis vs chemical methane generation

- Pros of microbial methanogenesis
  - Lower temperatures (20-40 C)
  - Lower pressures (around 1 atmosphere)
  - No catalyst needed
  - Potentially more efficient and scalable
  - Possibly easier to construct using *in situ* resources
- Cons
  - Biological systems have inherent complications
  - Other nutrients needed
  - Planetary protection
  - Tends to be extensive, not intensive

Methanogens

- Live on Earth in anaerobic conditions
- In *Archeae* domain
- Substrate
  - Acetate – acetoclastic
  - CO_2 and H_2 – hydrogenotrophic
- Electromethanogenesis
  - Assisted by a current source
  - Can start from $CO_2 + H_2O$

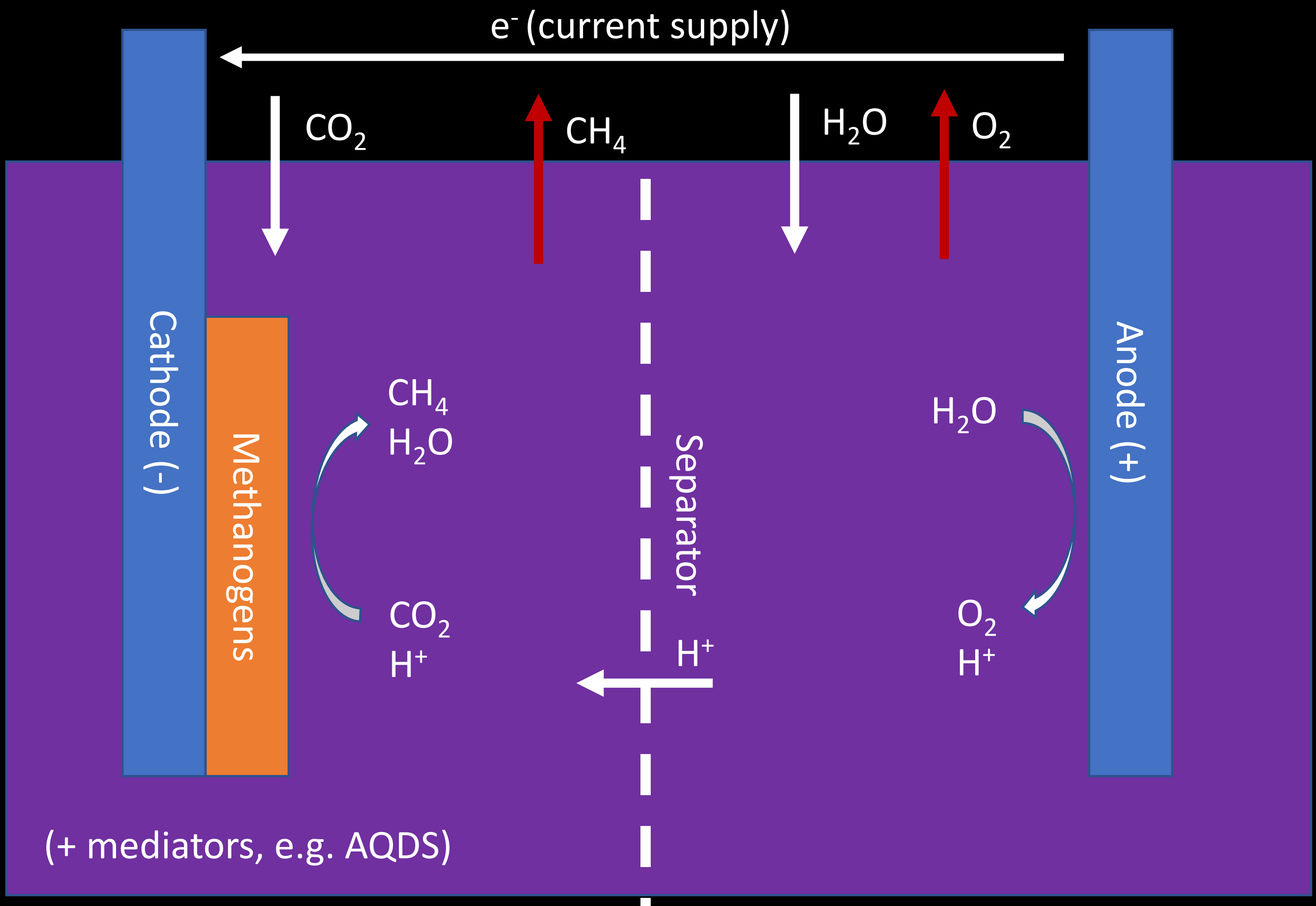


Methanosarcina barkeri
Credit: DOE

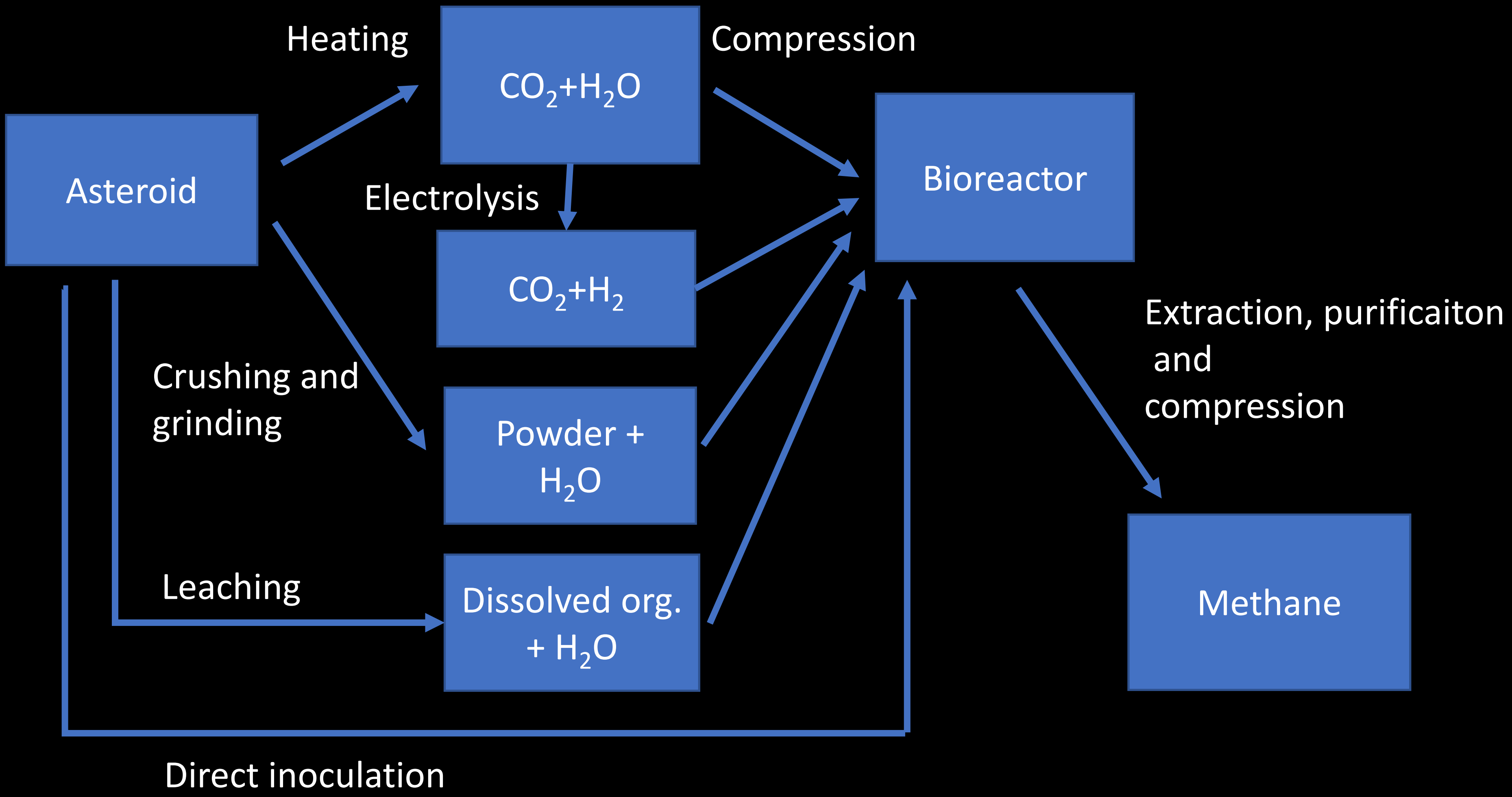
Electromethanogenesis

- Electricity fed to bacteria and methane is produced
  - Cheng et al, 2008 "Direct Biological Conversion of Electrical Current into Methane by Electromethanogenesis"
  - Clauwaert et al, 2009 "Methanogenesis in membraneless microbial electrolysis cells"
- H_2 insertion and processing is not required
- Requires a carbon source and water also
- Methane production in wineries
  - Cusick et al, 2011, "Performance of a pilot-scale continuous flow microbial electrolysis cell fed winery wastewater"

Electromethanogenesis reactor (simplified)



Methanogenesis for ISRU



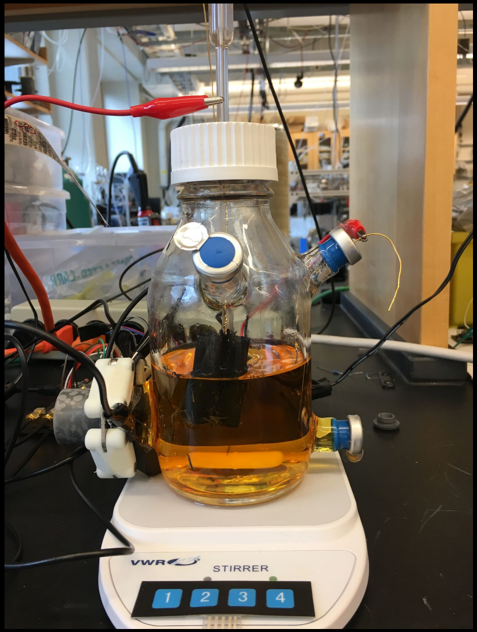
ISRU: Resource extraction

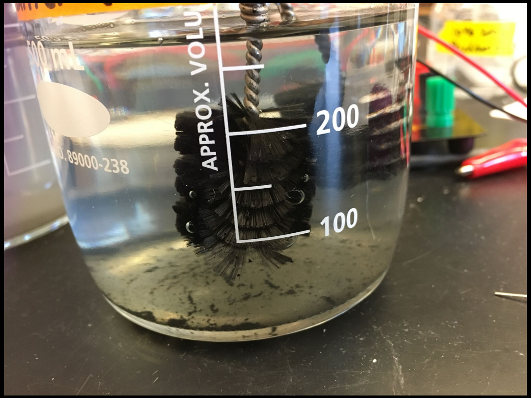
- Experiments by Zacny *et al* demonstrate extraction of water and CO_2 from carbonaceous chondrite analogues
  - Zacny K. *et al*. (2016) “The World is Not Enough (WINE): Harvesting Local Resources for Eternal Exploration of Space”
- Extracted water and CO_2 can be used to make methane
- Energy source still required (of course)

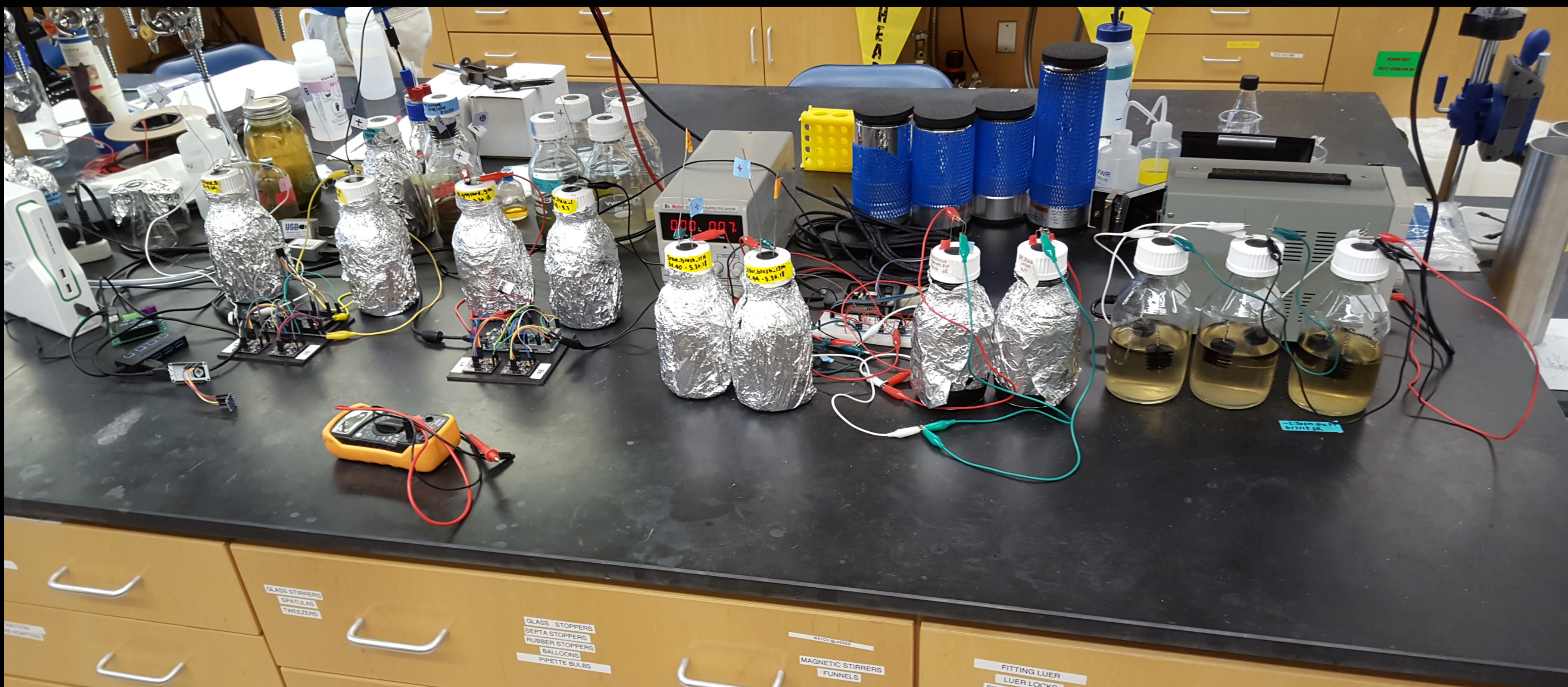
Experiments

Experiments

- Goal
  - Manufacture CH_4 from resources obtainable from asteroids
  - Water and CO_2 + electricity
  - Assess viability of industrial scale production






GLASS STIRRERS
SPATULAS
TWEEZERS
GLASS STOPPERS
SEPTA STOPPERS
RUBBER STOPPERS
BALLOONS
PIPETTE BULBS
MAGNETIC STIRRERS
FUNNELS
FITTING LUER
LUER LOCKS

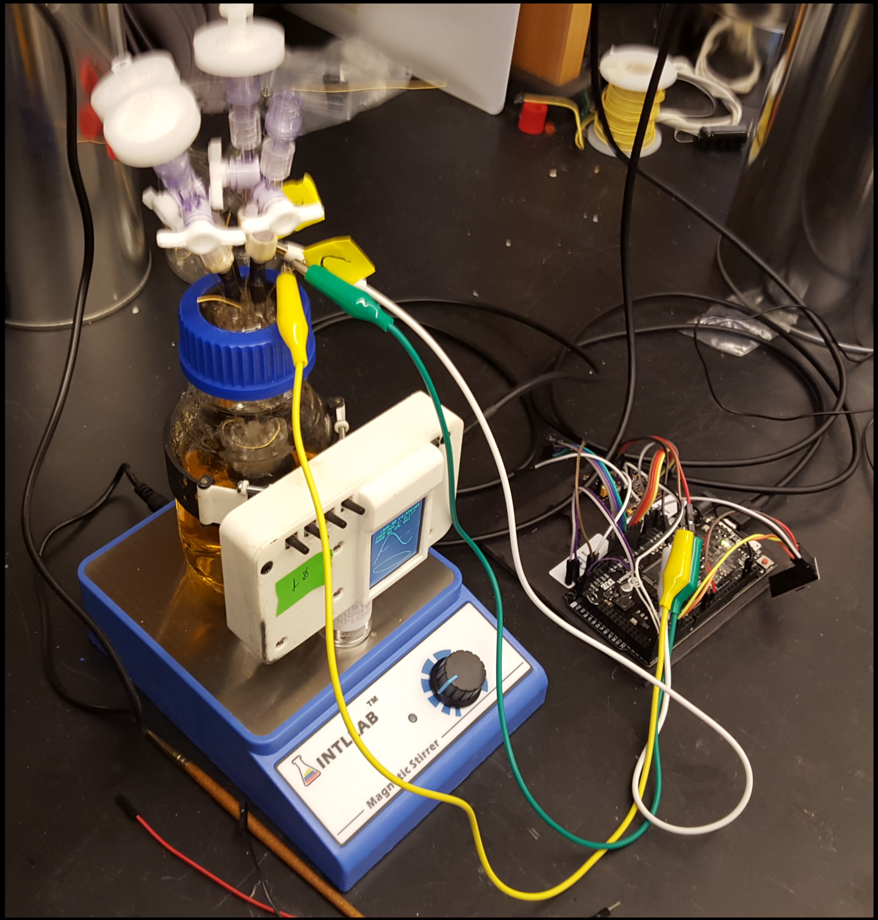
Preliminary results and problems

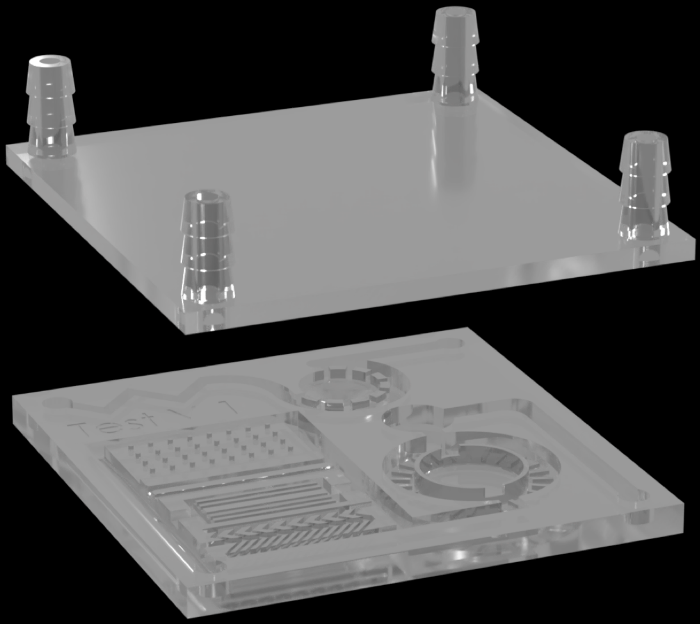
- Preliminary bioreactors constructed
- Experiments consistently produce methane
- Production rate per reactor volume is very small
  - 40 mL/L per day in present experiments
  - Systems are known to produce up to 0.3 L per L of culture per day
- Total amount of methane produced given starting materials (other than H_20 and CO_2) is limited

Current work

- Optimize setup
- Prototype 3D printed bioreactors
- Figure out limiting factors
- Find optimal bacterial culture/community

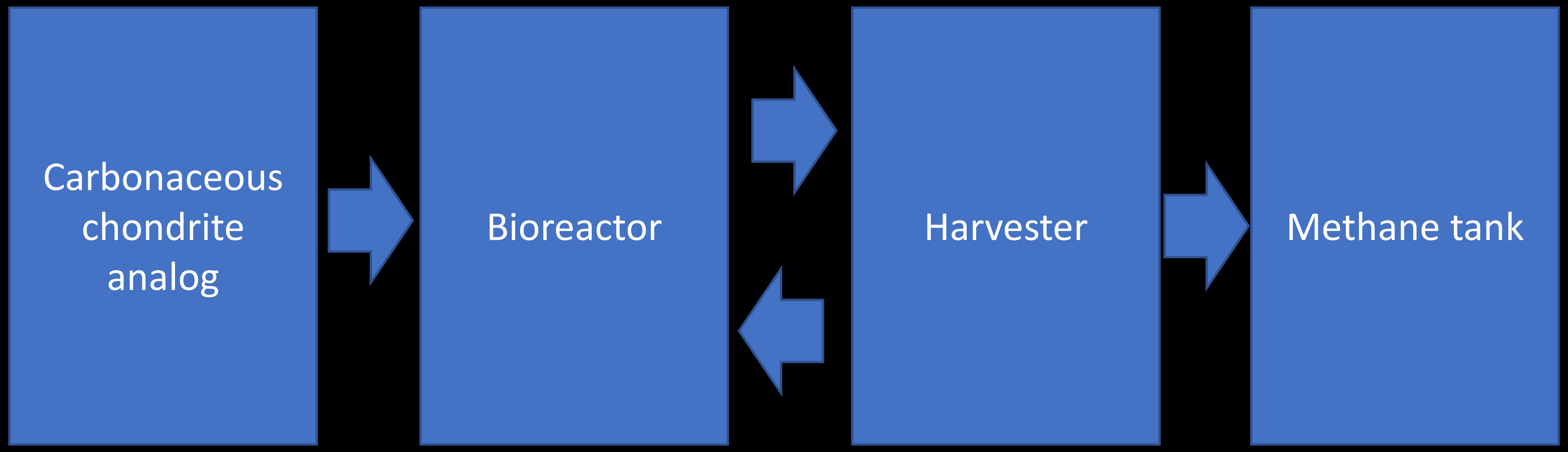
3D printed bioreactors and microfluidics





Other future steps

- Try with gas fed from asteroid analog material or a carbonaceous chondrite meteorite
- Integrate methane extraction step for harvesting



Other potential (example)

- Methane to lactate
  - Henard et al 2016 “Bioconversion of methane to lactate by an obligate methanotrophic bacterium”
  - Lactate to PLA -> one of the most common 3D printing substrates
- Variety of biological end-products is extreme
- H_2O + CO_2 can also fuel oxygenic photosynthesis
- Bootstrap potential

Conclusion

- Methane is already generated in industrial quantities using bacteria
- This could be used for ISRU
- Methane production with ISRU-relevant starting materials has been successful
- Optimization underway to increase yields and understand the process better
- Economics unclear but has specific ISRU-related potential benefits