primordial DEEP TECH

taming the biochemistry of anaerobic life in reservoir and oil geologies

Advanced Research + Invention Agency ARIA

Renaissance Philanthropy

london, uk
8 december 2025
jonathan “jo” melville, ph.d.

Jonathan “Jo” Melville

Ph.D. Chemistry, MIT (2021)

ARPA-E Fellow (2022-2024)

Revolutionizing Ore-to-Steel to Impact Emissions **(ROSIE)**

US$28m for next-generation electro-, plasma-, photochemical methods for green iron & steel

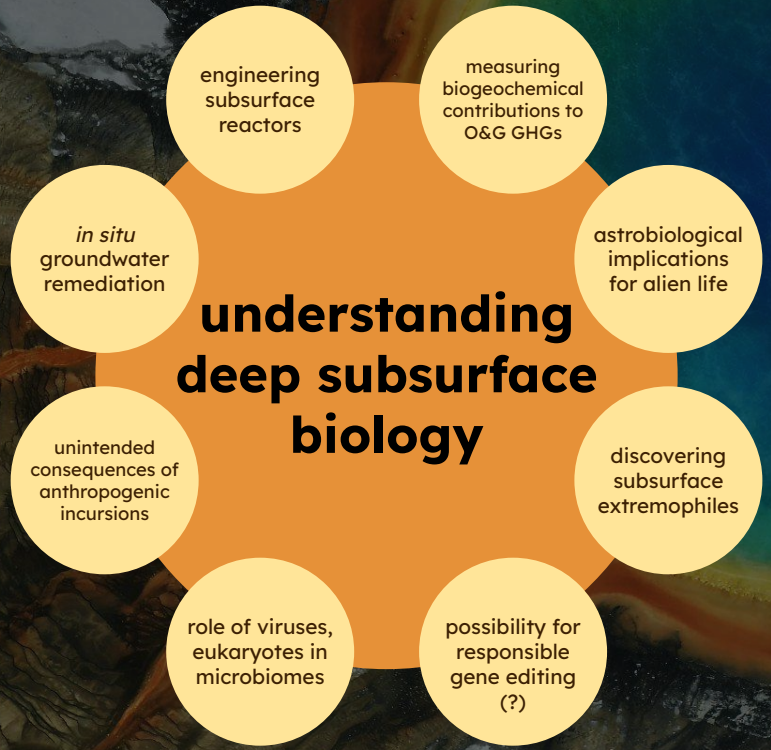
Grid-free Renewable Energy Enabling New Ways to Economical Liquids and Long-term Storage **(GREENWELLS)**

US$41m for non-steady-state and intermittent reactors for low-cost electrofuel synthesis

GEOH2

US$20m for stimulation and extraction of geologic hydrogen

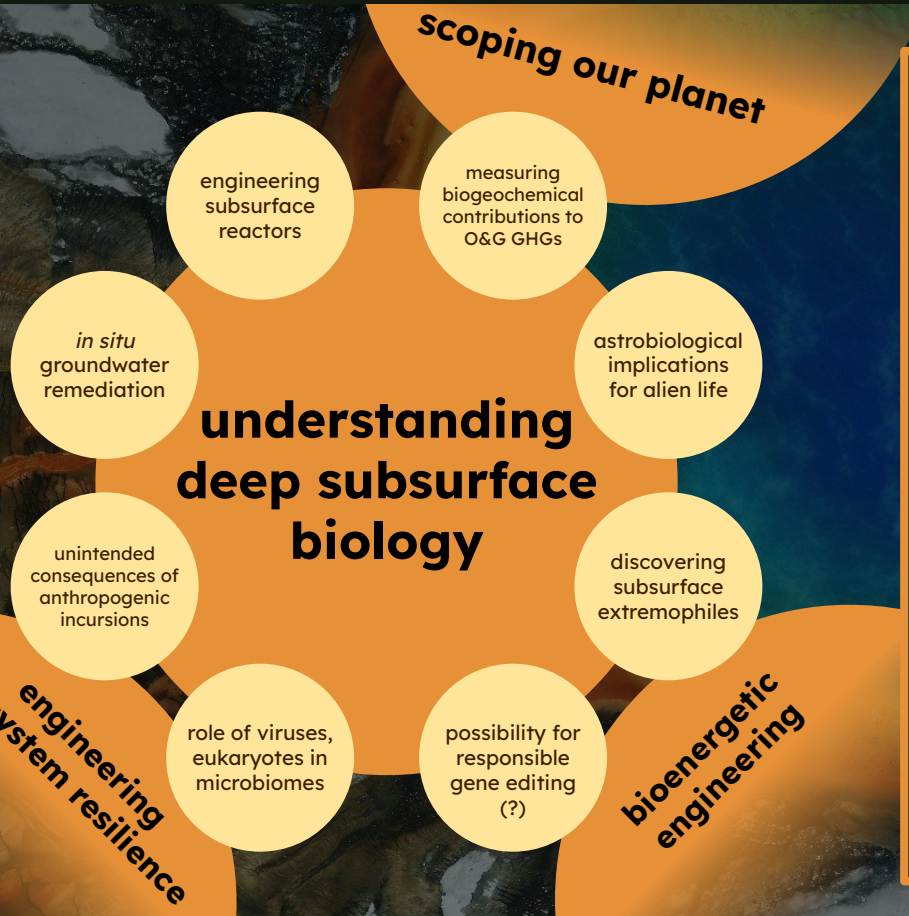
we still don't understand the subsurface



Core beliefs

- The subsurface has been the primary source of materials and energy for all modern history
- Our knowledge of the subsurface has always been secondary to our ability to extract from it
- The better we understand our natural world, the more harmoniously we can live with it

we still don't understand the subsurface



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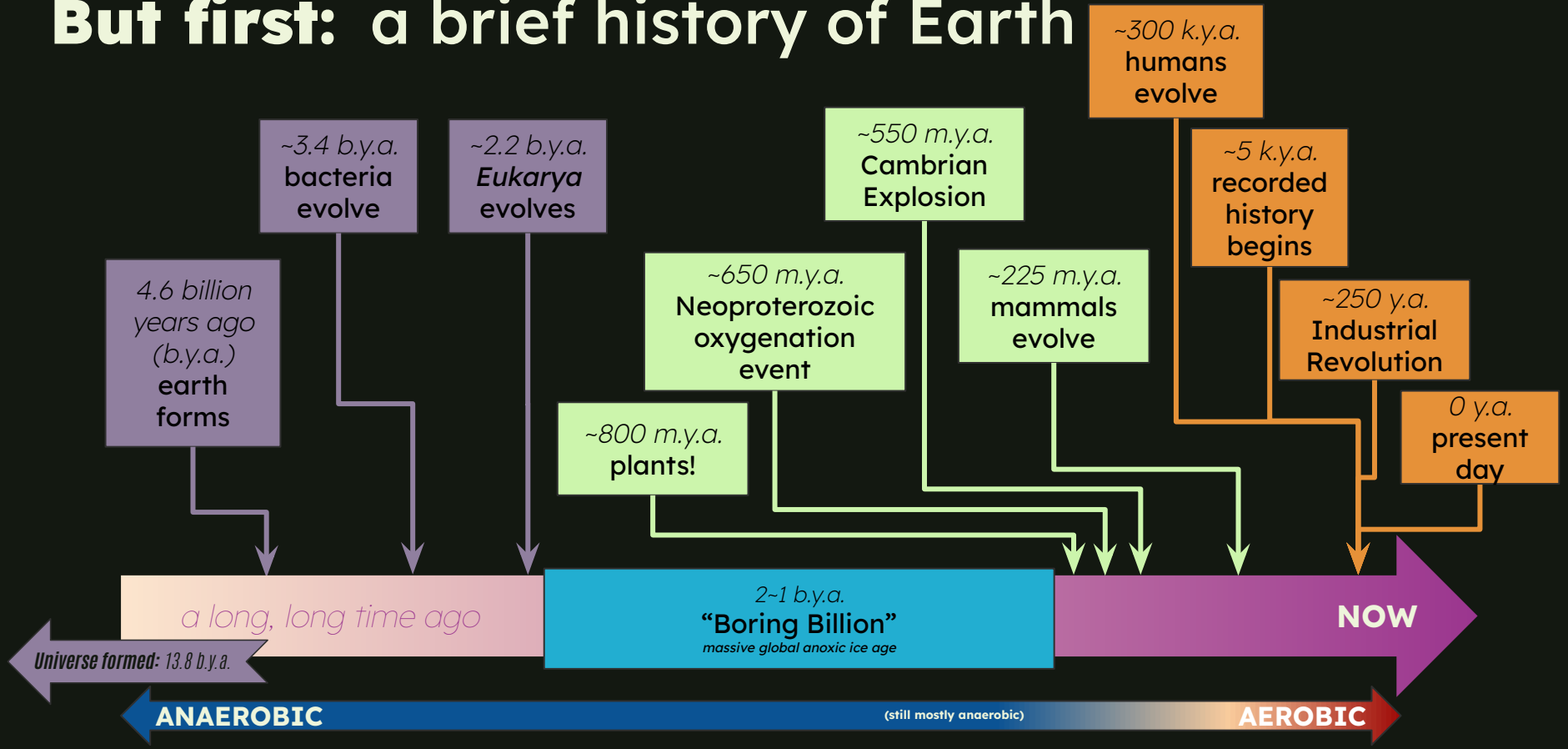
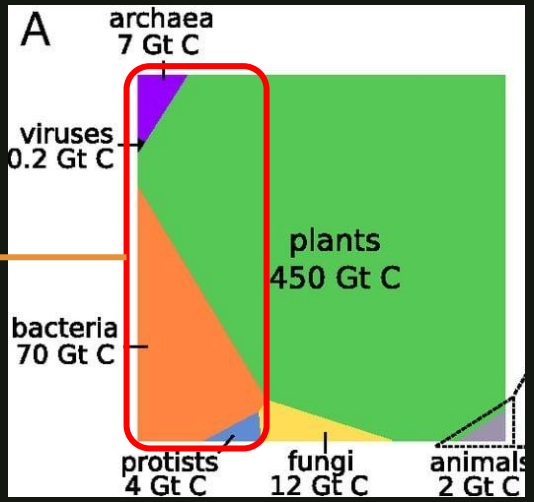
But first: a brief history of Earth

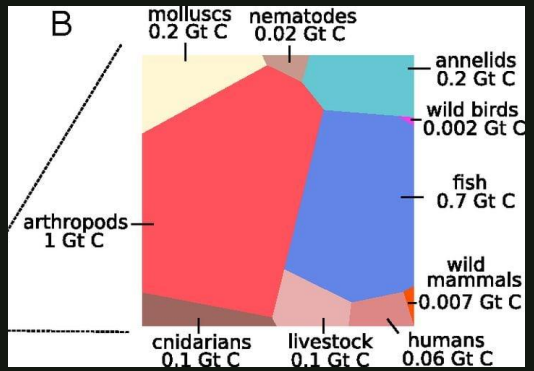


[1] *Sci. Rep.*, **2018**, *8*, 4432. doi:10.1038/s41598-018-22695-x; [2] *Phil. Trans. R. Soc. B: Bio. Sci.* **2006**, *361*, 903. doi:10.1098/rstb.2006.1838; [3] *J. Microbiol.* **2023**, *169*, 001172. doi:10.1099/mic.0.001172

Microbes live in the deep subsurface by the gigaton

microbes outnumber animals 40:1 by mass

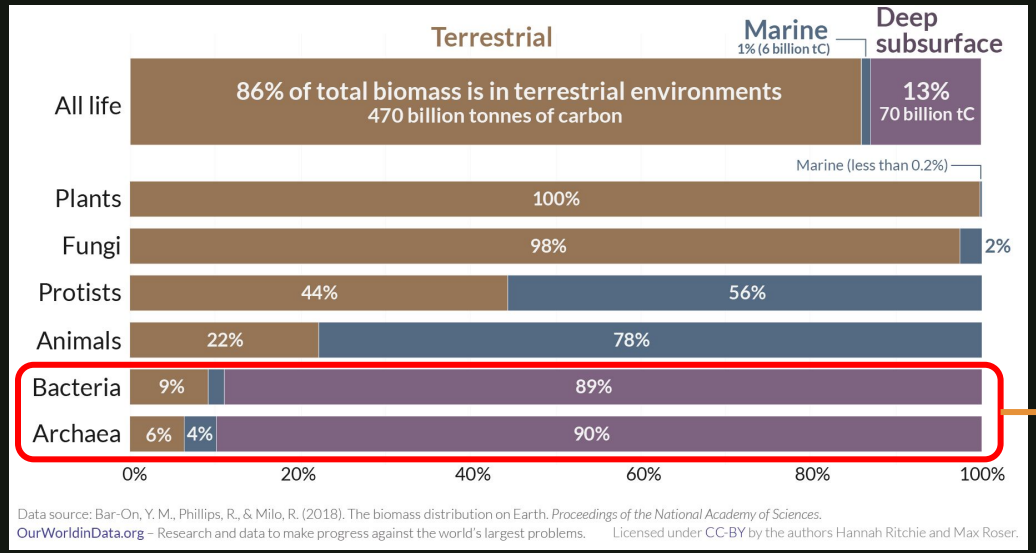


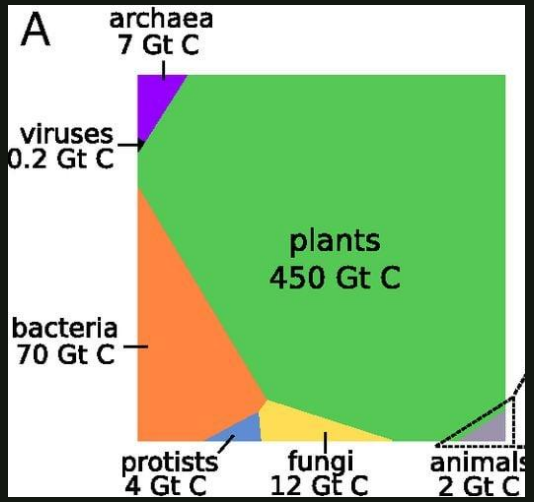


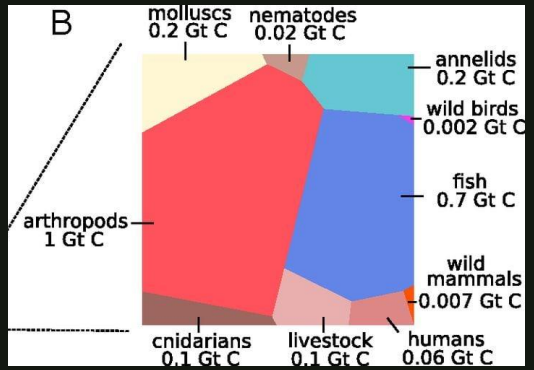
[1] *Sci. Rep.*, **2018**, *8*, 4432. doi:10.1038/s41598-018-22695-x
[2] *Proc. Natl. Acad. Sci*, **2018**, *115*, 6506. doi:10.1073/pnas.1711842115

Microbes live in the deep subsurface by the gigaton

90% of microbes live in the deep subsurface







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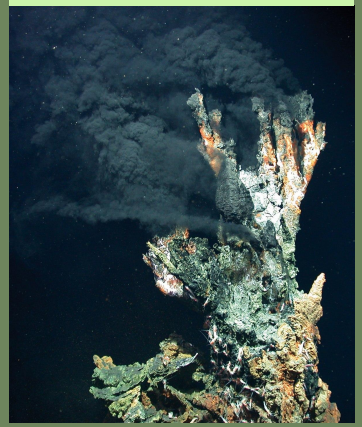
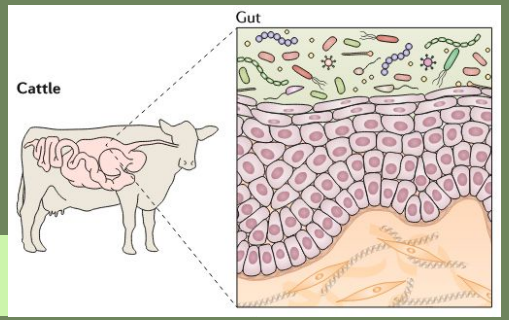
“The preserved metabolisms of an anaerobic world”

Hydrothermal vents

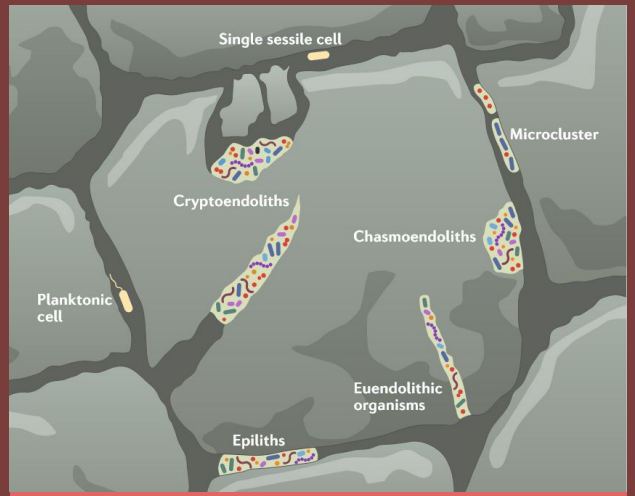


Anaerobic digesters

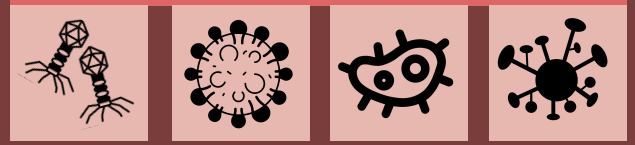


Gut Flora & Rumen

Extensively studied



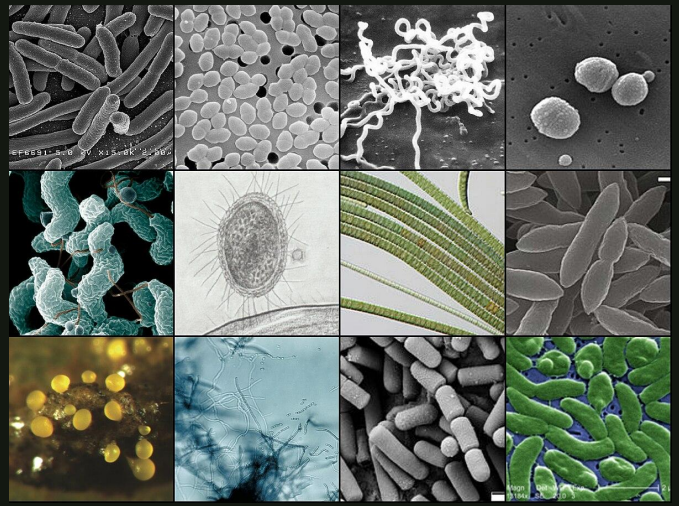
Deep subsurface



Almost entirely unexplored

[1] *Nat. Rev. Microbiol.* **2019**, *17*, 247. doi:10.1038/s41579-019-0158-9; [2] *J. Geol. Sci.* **2018**, *175*, 716. doi:10.1144/jgs2018-061; [3] *ISME*, **2024**, *18*, wrae091. doi:10.1093/ismejo/wrae091; [4] *Microbiol.*, **2023**, *169*, 001172. doi:10.1099/mic.0.001172;

“The preserved metabolisms of an anaerobic world”



Methanogens
$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$

Methanotrophs
$CH_4 + 2\ O_2 \rightarrow CO_2 + 4\ H_2$

Acetogens
$2\ CO_2 + 4\ H_2 \rightarrow CH_3COOH + 2\ H_2O$

Acetoclastic Methanogens
$CH_3COOH \rightarrow CH_4 + CO_2$

Sulfate Reducers
$H_2SO_4 + CH_3COOH \rightarrow 2\ CO_2 + H_2S + 2\ H_2O$

Rarer metabolisms
- microbes can make C_2H_6, C_2H_4, C_3H_8, MeOH, EtOH, …

[1] *Nat. Rev. Microbiol.* **2019**, *17*, 247. doi:10.1038/s41579-019-0158-9; [2] *J. Geol. Sci.* **2018**, *175*, 716. doi:10.1144/jgs2018-061; [3] *ISME*, **2024**, *18*, wrae091. doi:10.1093/ismejo/wrae091; [4] *Microbiol.*, **2023**, *169*, 001172. doi:10.1099/mic.0.001172;

“The preserved metabolisms of an anaerobic world”

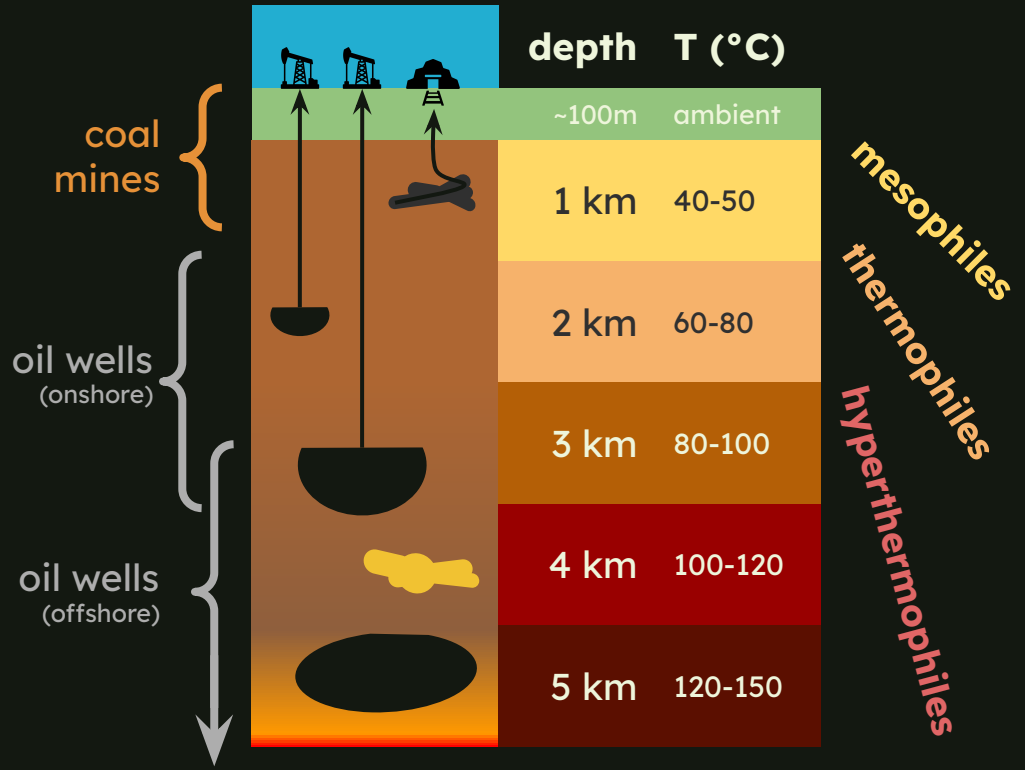
Sulfate-reducing microbes are the primary cause of fossil gas souring, which costs the global oil & gas industry **>$60bn/yr**.

Sulfate Reducers

$H_2SO_4 + CH_3COOH \rightarrow 2\ CO_2 + H_2S + 2\ H_2O$

[1] *Front. Microbiol.* **2014**, *5*, 1. doi:10.3389/fmicb.2014.00089; [2] Birkeland, N.-K. Sulfate-Reducing Bacteria and Archaea. In *Petroleum Microbiology*; John Wiley & Sons, Ltd, **2005**; pp 35–54. doi:10.1128/9781555817589.ch3

Microbes proliferate everywhere we drill & mine

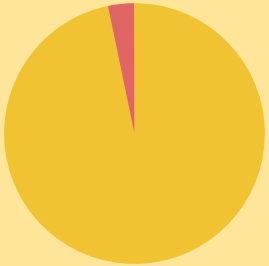


Subsurface microbiomes are diverse

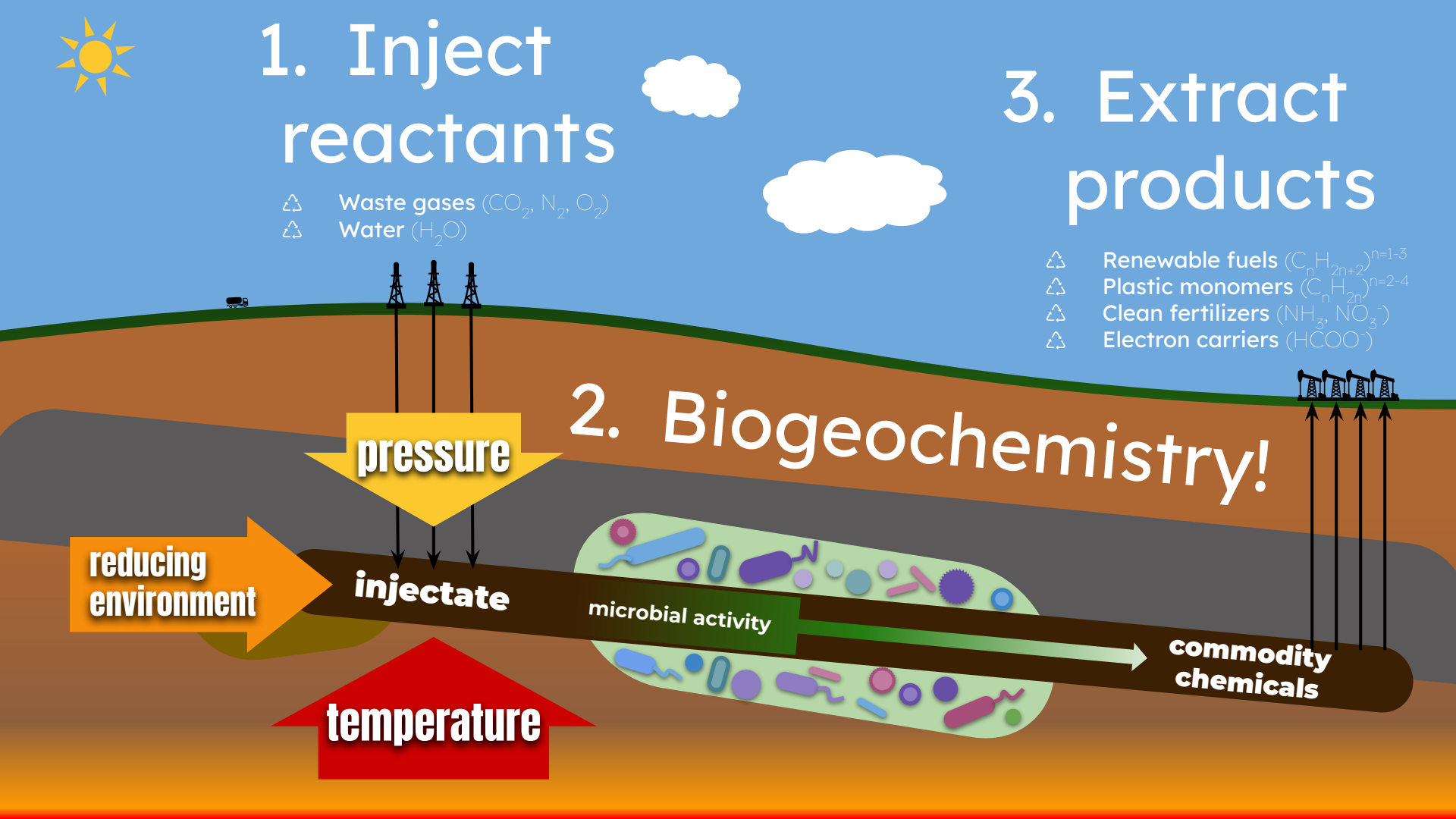
Microbes cooperate to eat (**syntrophy**) and form symbiotic consortia. **20~80%** of subsurface microbes live in biofilms.

...or not

Candidatus desulforudis audaxviator: a naturally occurring monoculture comprising **>99.9%** of samples from a S. African gold mine at **2.8km depth**



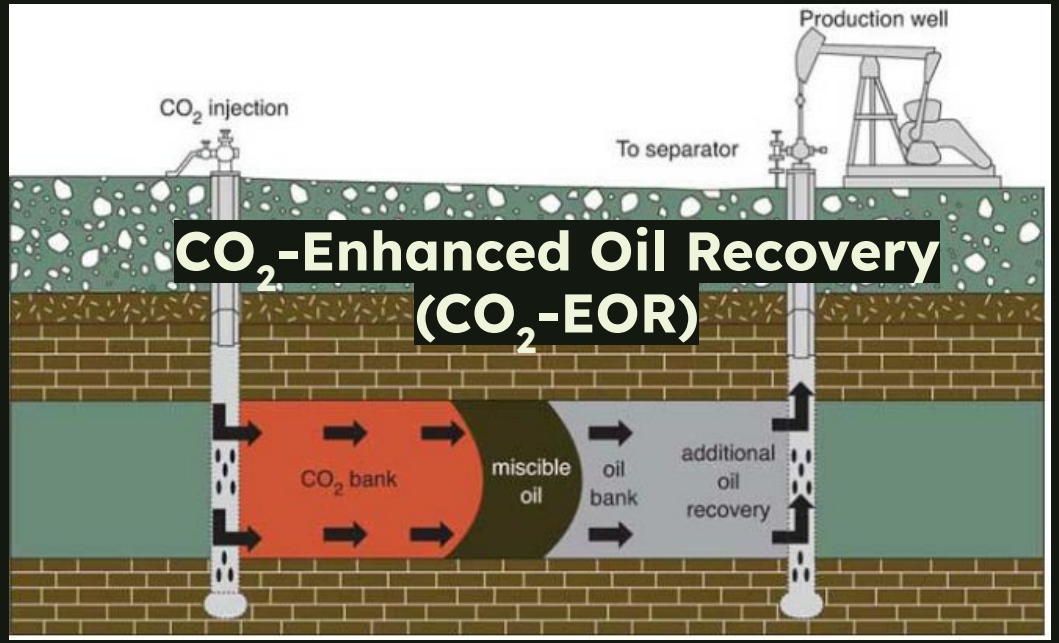
[1] *New Biotechnol.* **2019**, *49*, 1. doi:10.1016/j.nbt.2018.07.005; [2] *Int. Biodeterior. Biodegradation* **2025**,*197*, 105958. doi:10.1016/j.ibiod.2024.105958; [3] *Antonie van Leeuwenhoek*, **2000**, *77*, 103. doi:10.1023/A:1002434330514; [4] *Science*, **2008**, *322*, 275. doi:10.1126/science.1155495


1. Inject reactants
Waste gases (CO_2, N_2, O_2)
Water (H_2O)
3. Extract products
Renewable fuels $(C_nH_{2n+2})^{n=1-3}$
Plastic monomers $(C_nH_{2n})^{n=2-4}$
Clean fertilizers (NH_3, NO_3^-)
Electron carriers ($HCOO^-$)
2. Biogeochemistry!
pressure
reducing environment
injectate
microbial activity
commodity chemicals
temperature

“That will never happen.”

75%

% of all captured CO_2 used for EOR



~~"That will never happen."~~ It's already happening.

Rapid microbial methanogenesis during CO_2 storage in hydrocarbon reservoirs

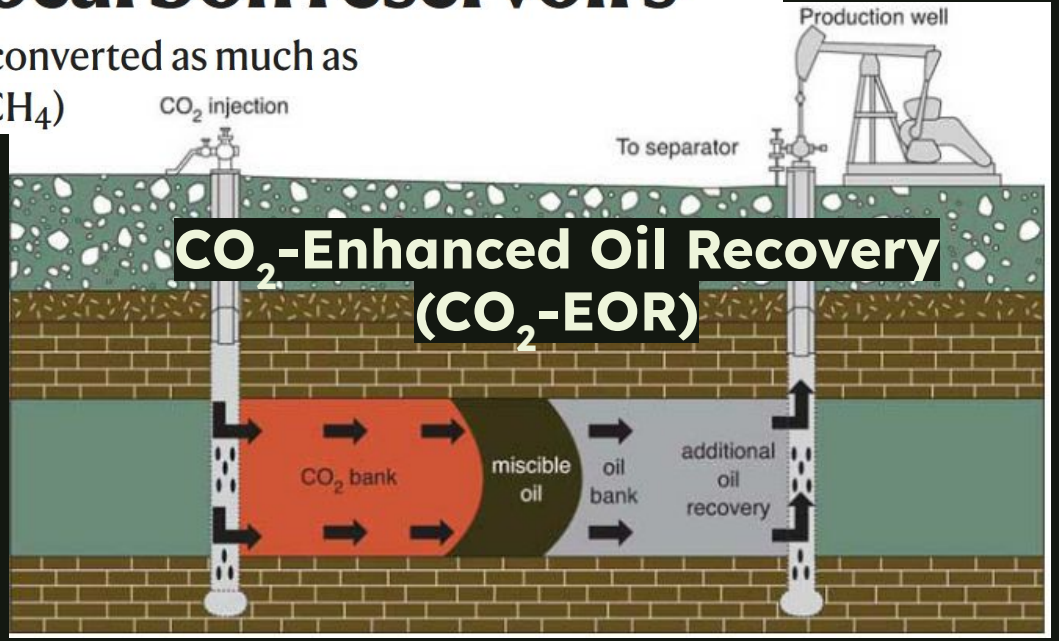
We show that microbial methanogenesis converted as much as 13–19% of the injected CO_2 to methane (CH_4)

75%
% of all captured CO_2 used for EOR

83×
20yr GHG impact of CH_4 vs CO_2

zero
# of CCUS regulatory specs that consider microbial methane

no
what I will say if you ask if CH_4 dissolves & mineralizes like CO_2



[1] *Nature* **2021**, *600*, 670. doi:10.1038/s41586-021-04153-3; [2] *Environ. Sci. Technol.* **2023**, *57*, 9459. doi:10.1021/acs.est.2c08652; [3] *Appl. Geochem.* **2014**, *51*, 155. doi:10.1016/j.apgeochem.2014.09.015; [4] *Global Status of CCUS*, **2021**, Global CCS Institute.

Funding Structure:

£50M ARIA programme

£35M	£15M
direct nondilutive R&D funding	distributed borehole testbed consortium

Distributed Borehole Testbed Consortium

- **All-for-all consolidated testbed access**
- Diverse industrial geologies
  - (O&G, CCS, geoH_2, geothermal, …)
- Communal baseline datasets
- Sterile pre-contamination controls
- Spatial and temporal sampling resolution

The Bottleneck

drilling boreholes is ***expensive***
(can cost >£10 million per borehole)

→ *only oil & gas companies do it*
(getting site access is onerous)

The Solution

select diverse biogeochem R&D portfolio
(interdisciplinary teams with cutting-edge meta-omics & geofluidics techniques)

→ *negotiate collective testbed access*
(**every** performer gets access to **every** testbed site)

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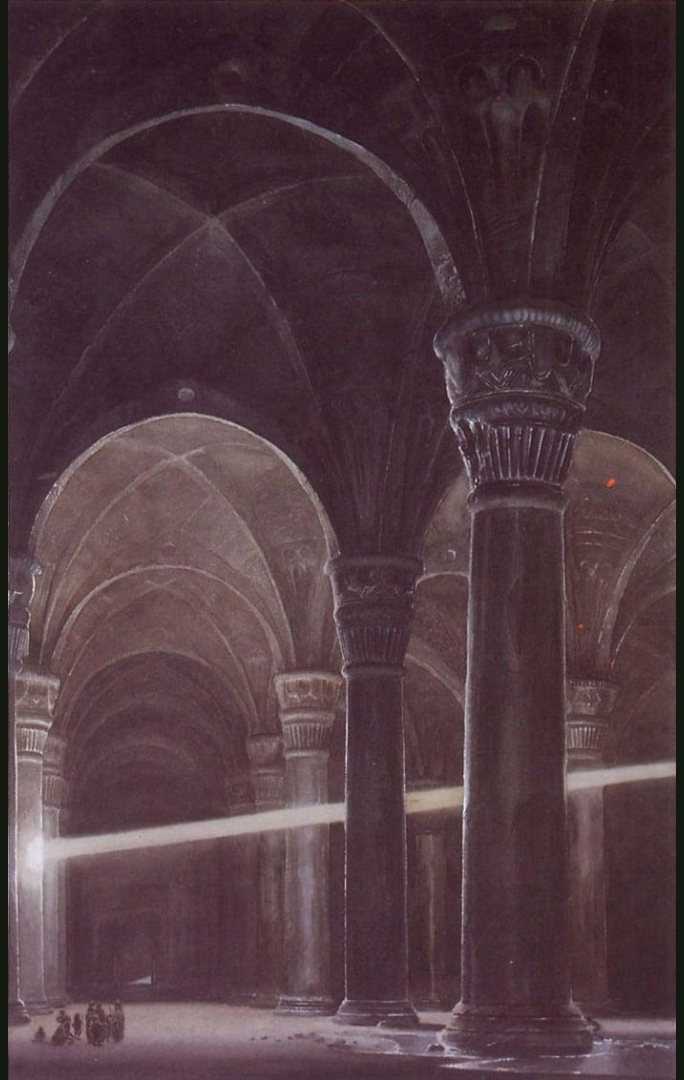
"The Dwarves tell no tale; but even as *mithril* was the foundation of their wealth, so also it was their destruction:

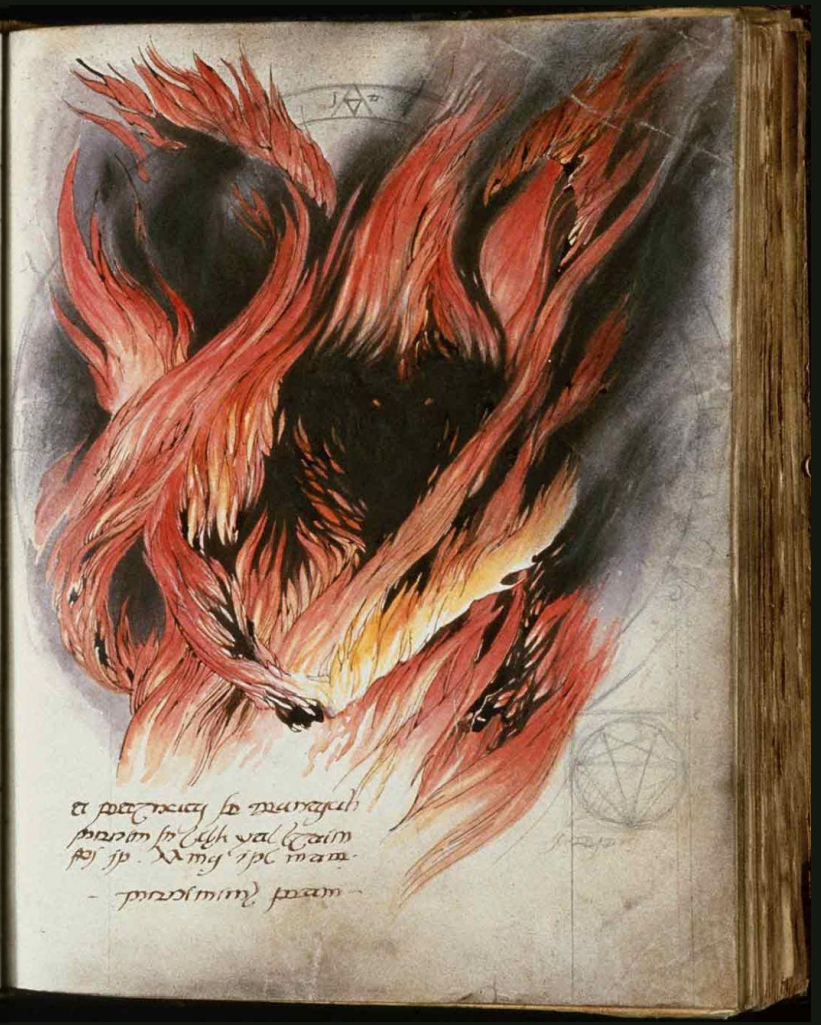


they delved **too greedily and too deep** , and disturbed that from which they fled."

Tolkien, J. R. R. *The Fellowship of the Ring*, **1954**, p. 413.

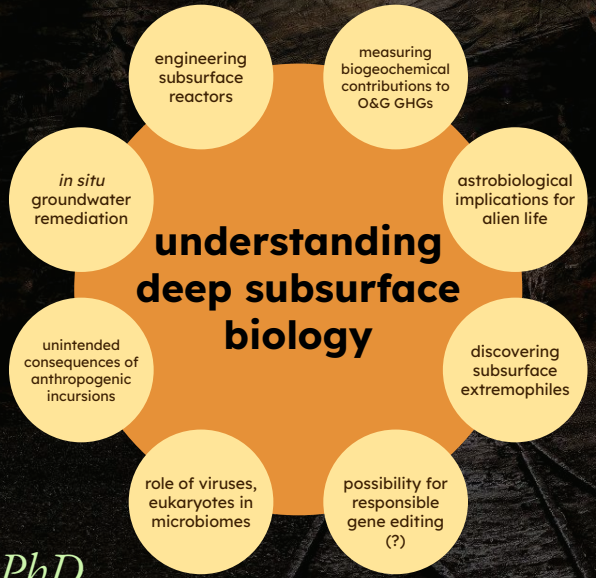
taming the

Biochemistry of **A**naerobic **L**ife in **R**eservoir & **O**il **G**eologies



Primordial Deep Tech:

taming the BALROG



a whitespace pitch by
Jonathan "Jo" Melville, PhD

Special Thanks


Pat McGrath


Eric Boyd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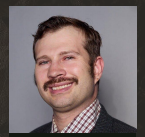
Joe Meyerowitz


Denali Brown


Sophie Nixon

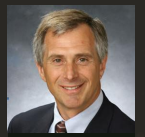

Marc von Keitz


Elizabeth Troein


Joe Rollin


Dan Nothaft


Doug Wicks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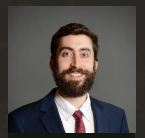
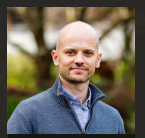

Daniel Garcia


Sean Bay


Pok Man Leung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Renaissance Philanthropy — *Aleš Flídr, JP Chretien, Josh Elliott, Ishan Sharma, Ronit Kanwar ...*

and many (25+) others!