Space Resources Roundtable, 6 June, 2025

# Exploring Venus with Electrolysis (EVE)

## Atmospheric ISRU for Long Duration Aerial Missions

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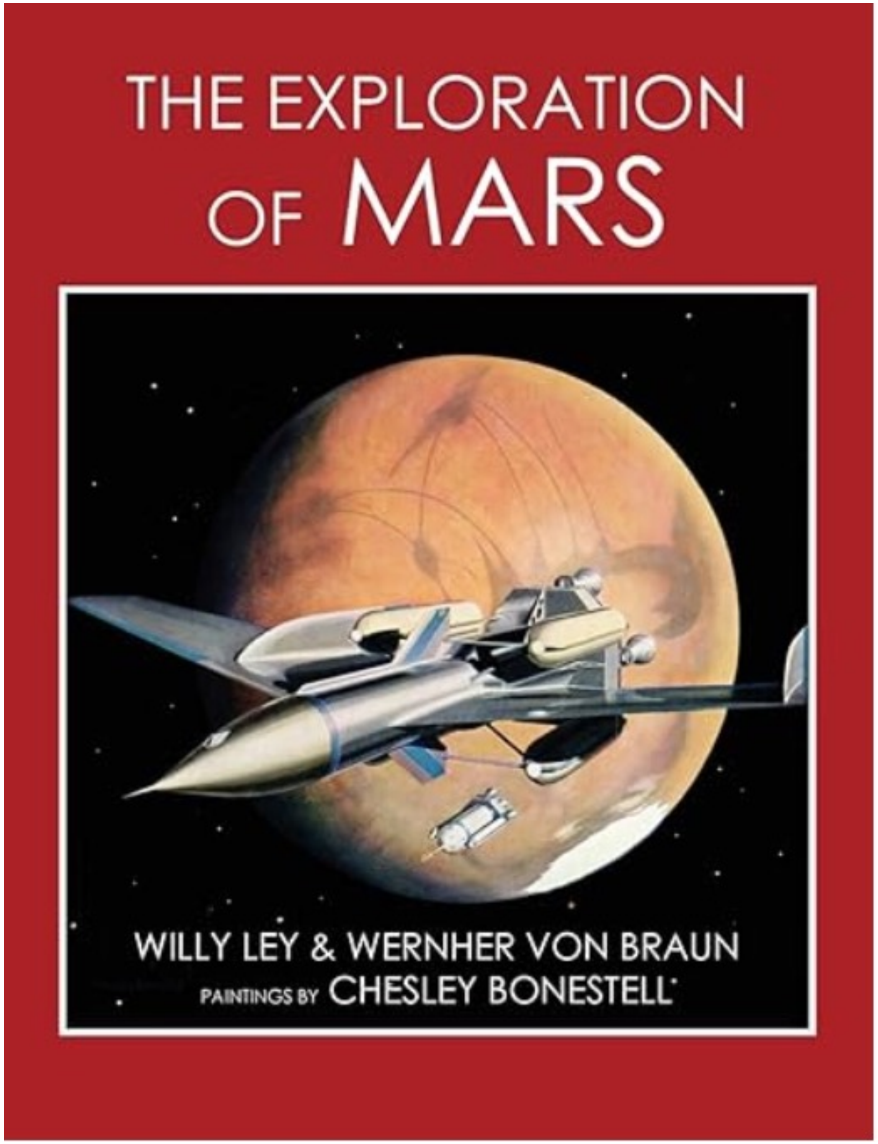
# Destination…




# … Venus??

Credit: https://venusroadmap.org/


LIFE AT SEA CRUISES

# Ballooning over Venus

- Above the cloud layer (50-60 km), Venus is the most habitable place in the solar system outside Earth.
  - Nearly pure $CO_2$ and a little smelly, but Earth-like temperature, pressure, gravity, radiation shielding, lots of solar power, ... and great parasailing!
- The prevailing winds will carry a balloon around the planet every ~100 hrs, simulating a day-night cycle and allowing a robust exploration campaign.
- With a towbody as a keel, the balloon can be steered to different latitudes and even altitudes
- A balloon base can be a launching platform for drones, gliders, and probes

MIT HAYSTACK OBSERVATORY

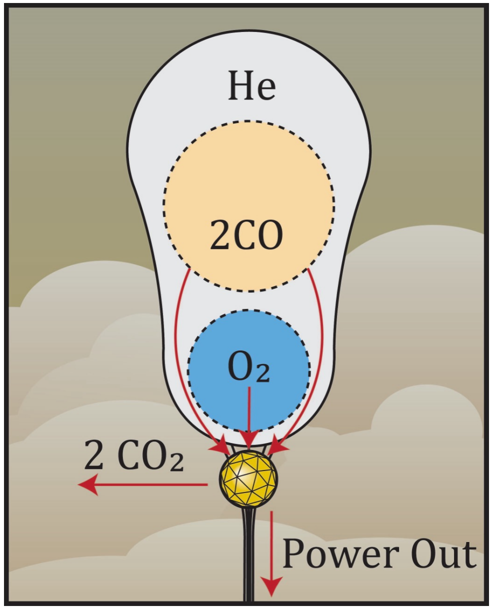
# Science Targets

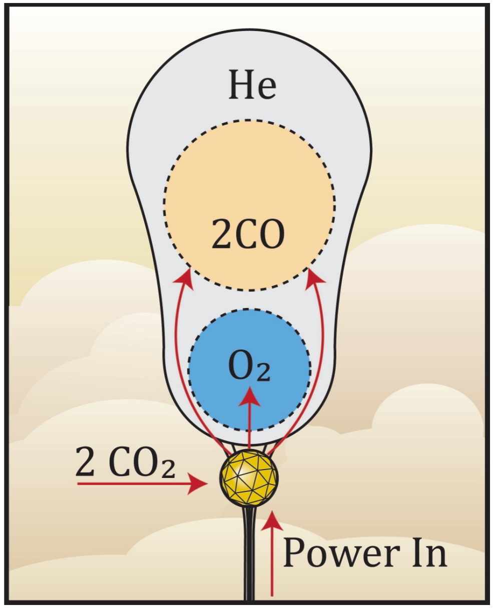
- The surface
  - Radar imaging, seismology with infrasound, towbodies
- The atmosphere
  - Dynamics, chemistry, astrobiology
- Other studies
  - Magnetic properties, radiation, etc.
- Longer term
  - Sample return
- Planetology
  - What we learn from Venus will inform our understanding of climate change on our own planet and will help us recognize “exoVenuses.”

# What is EVE?

EVE enables long-duration balloon exploration of Venus, using CO and $O_2$ **produced from the ambient $CO_2$** for buoyancy.

- Core solid oxide electrolysis technology demonstrated by MOXIE on Mars
- CO and $O_2$ can also power the night-time traverse, offer mobility, and even provide rocket propulsion.



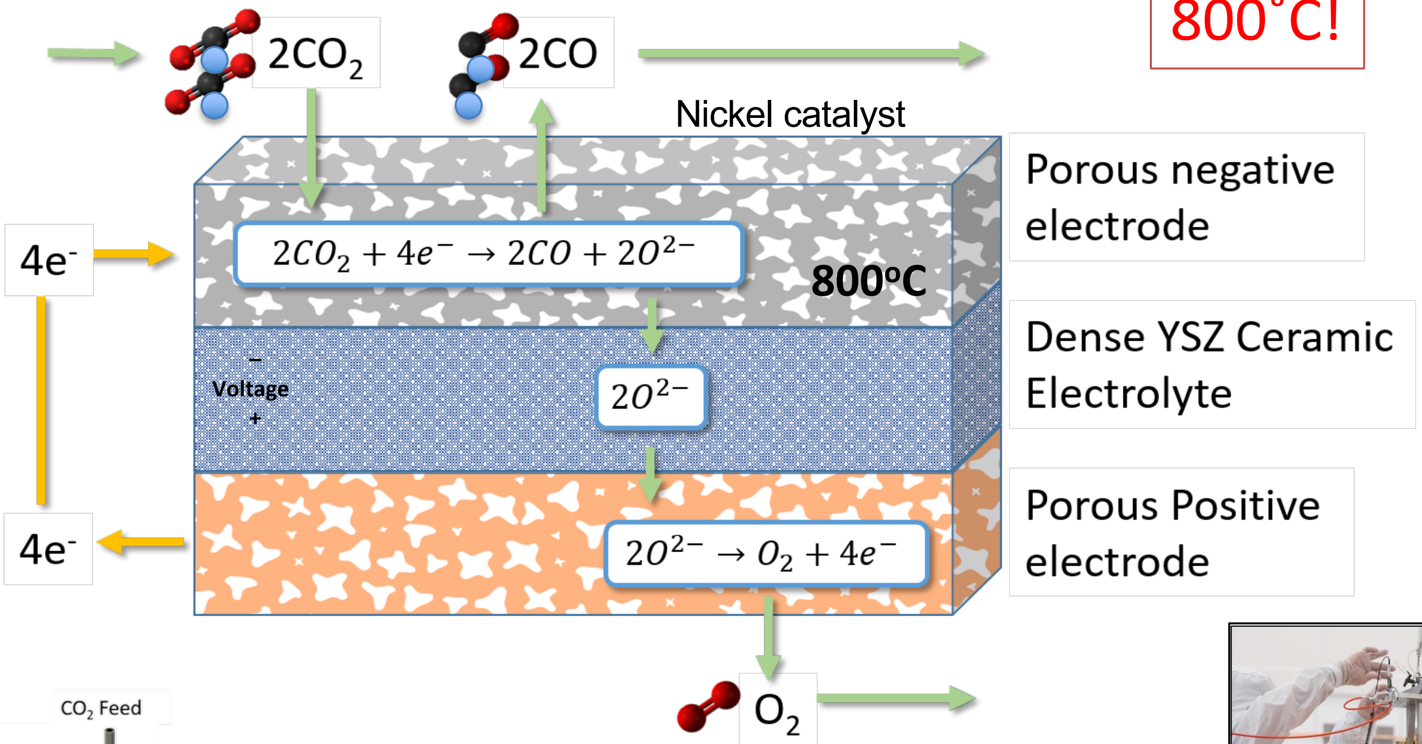



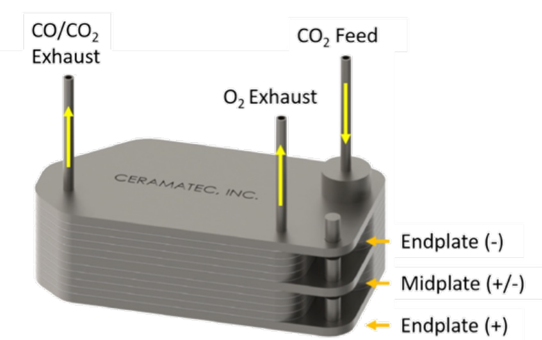

J. Izraeleitz et al, *Test Flights… of a Prototype Venus Aerobot*, LPSC 2023

*EVE will generate CO and $O_2$ from the ambient $CO_2$ and use it both for buoyancy and to power a fuel cell as it traverses the night side.*

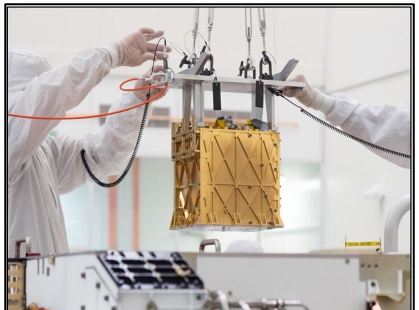
# Solid Oxide Electrolysis (SOE)

800˚C!




SOE: $CO_2 \rightarrow CO + O$
SOFC: $CO + O \rightarrow CO_2$



*MOXIE installation in the Perseverance rover*

# Questions under investigation

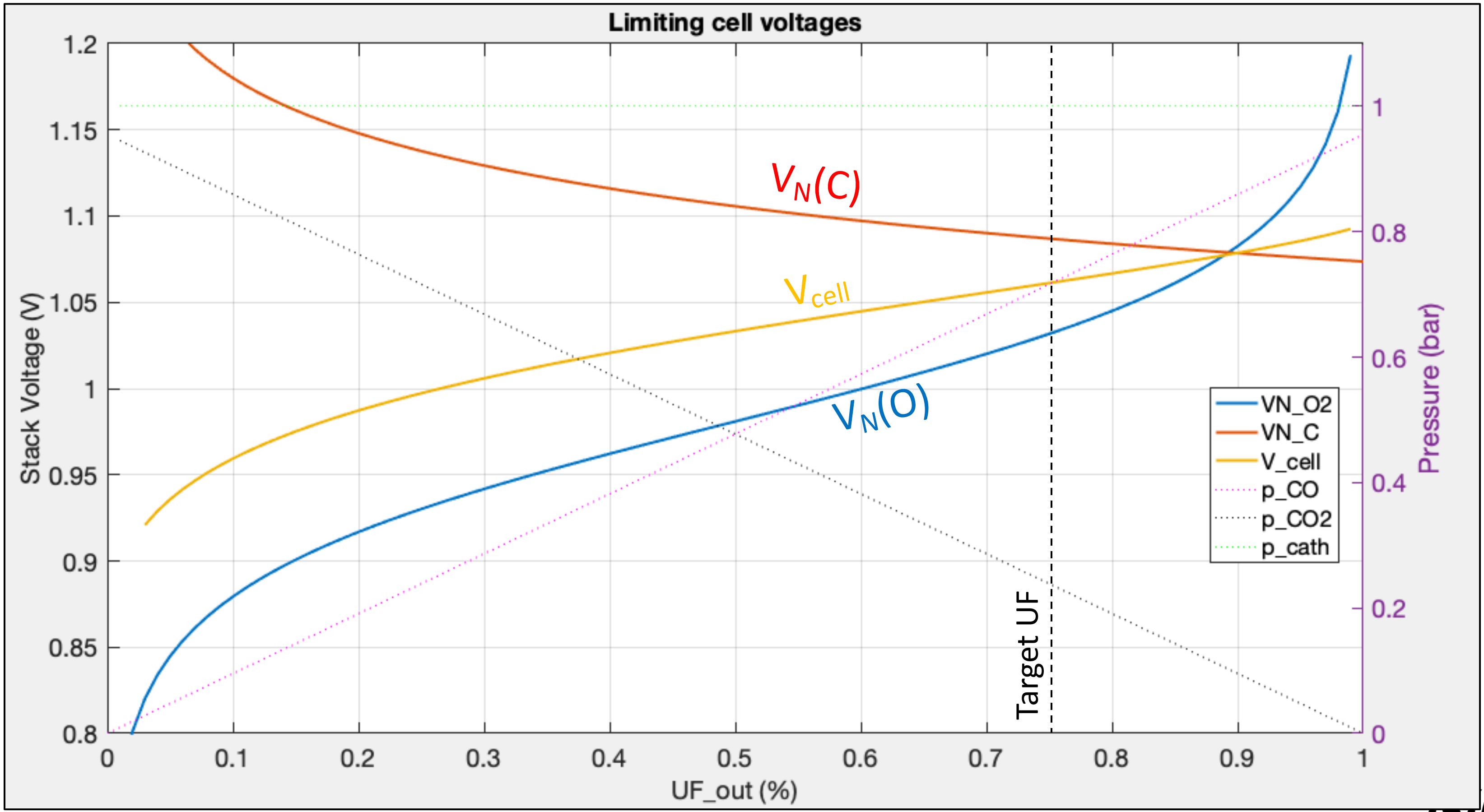
- <u>**Utilization fraction (UF):**</u> Can we make the CO sufficiently pure to be buoyant?
- **Poisoning:** Can the technology survive $SO_x$ exposure (~150 ppm)?
- **Power:** How to best store $O_2$ & CO for power generation? Bags? Tanks? Are ISRU batteries (Li-$CO_2$) better than fuel cells for stored power?
- How to provide mobility? Propellors? Rockets? Towbodies? Can we sample the surface from EVE?
- What is the optimal science instrumentation?

# Approach to high UF (target 75%)

- Safe operation is limited by the carbon threshold $V_N(C)$ and the oxygen threshold $V_N(O)$, both at the outlet
- Independently controllable quantities (MOXIE):
  - Current *or* Voltage (V)
  - Flow *or* Utilization Fraction (UF)
  - iASR *or* Stack Temperature
- In EVE (and the lab)
  - Anode pressure (in MOXIE it's determined by $O_2$ flow)
  - Cathode pressure (in MOXIE it's determined by inlet flow)

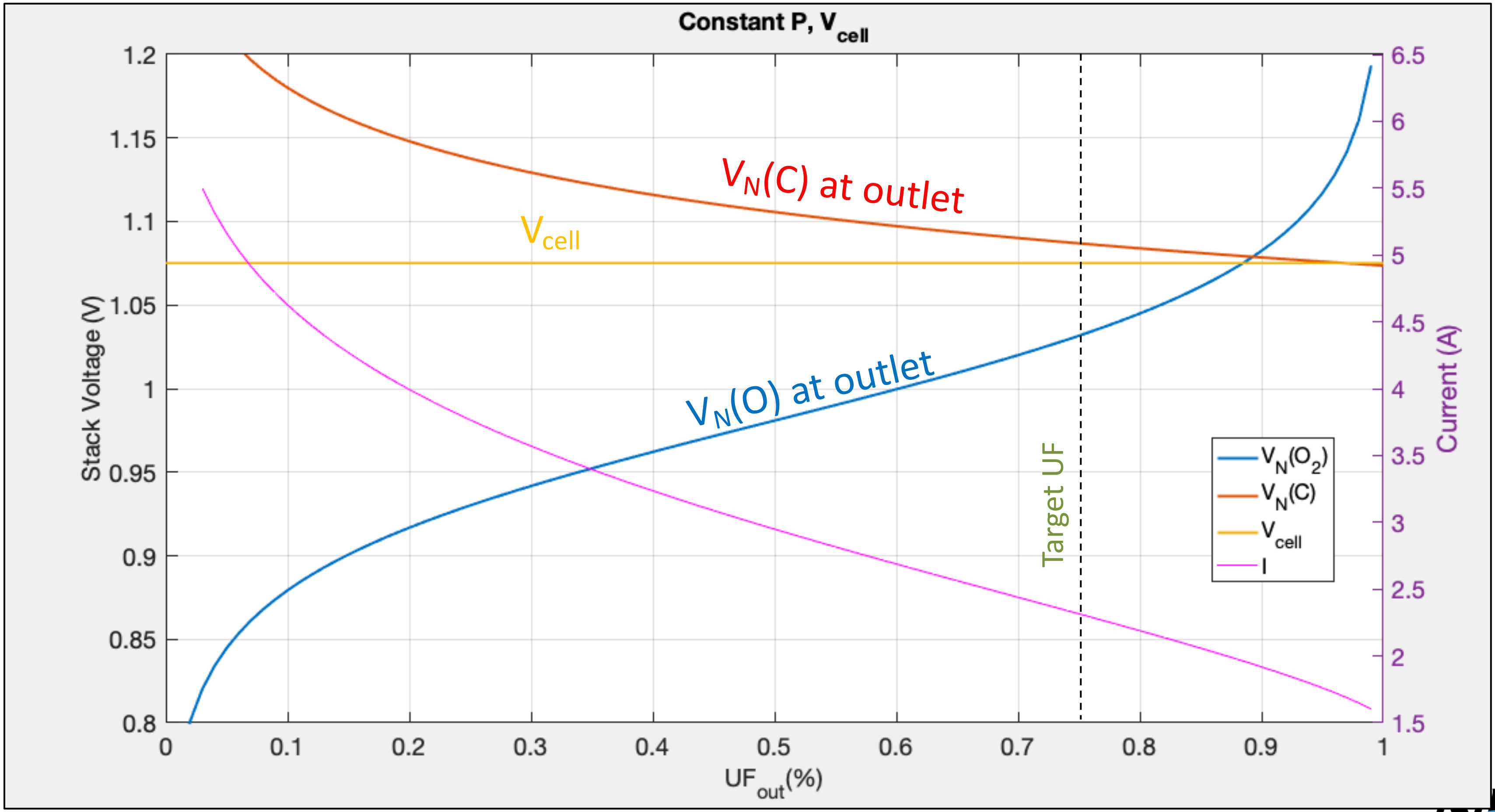
# Typical MOXIE configuration

- Fixed I=2A, P=1 bar, flow=55 g/hr. Assume iASR = 1
- But $V_N(C)$ and $V_N(O)$ change with $P_{cathode}$ and $P_{anode}$



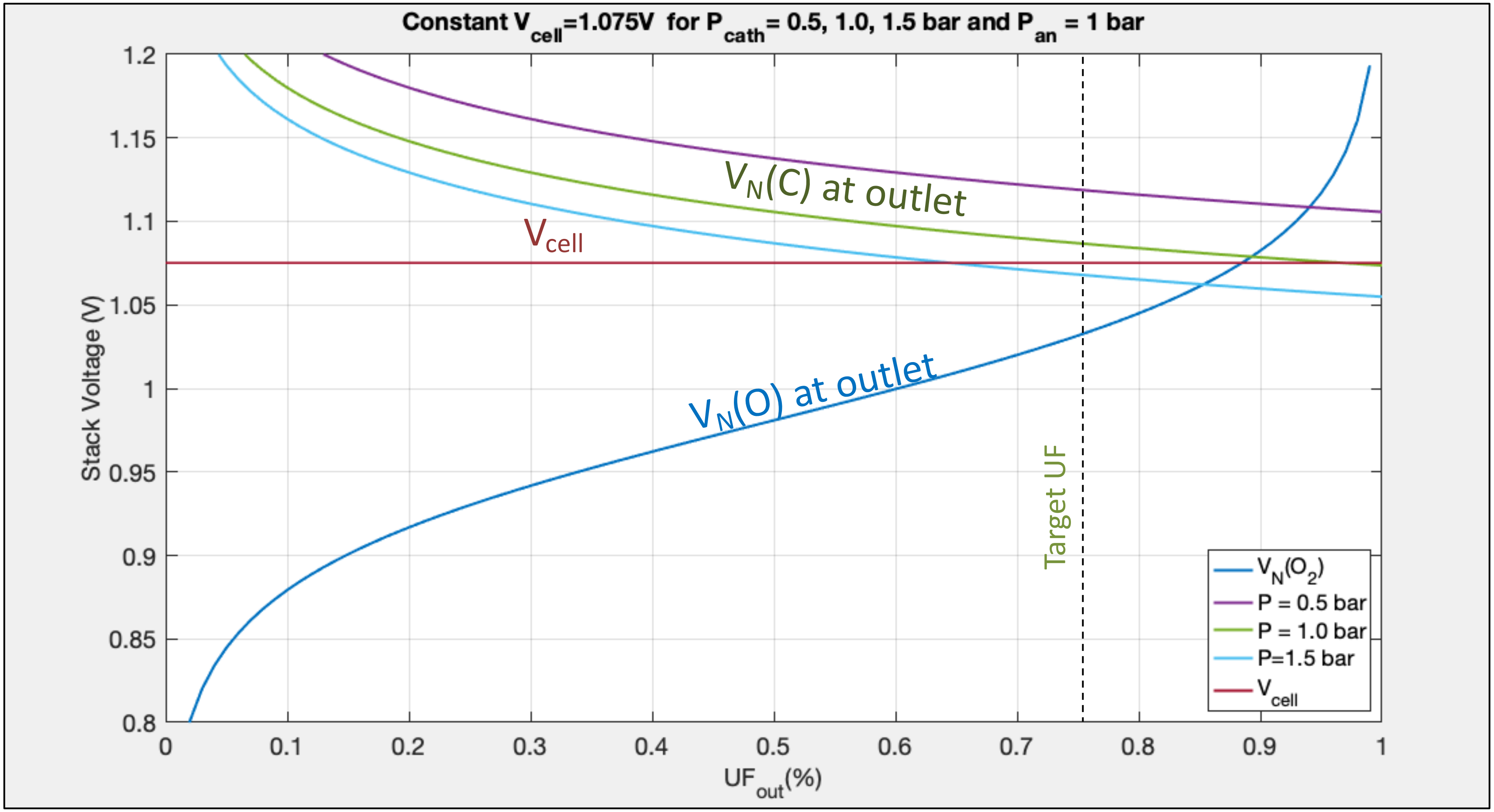
# With Fixed $P_{cathode}$, $V_{cell}$, UF

- P = 1 bar, iASR = 1, $V_{cell}$ = 1.075V
- Penalty is low current at high UF. Compensate by larger $A_{cell}$.



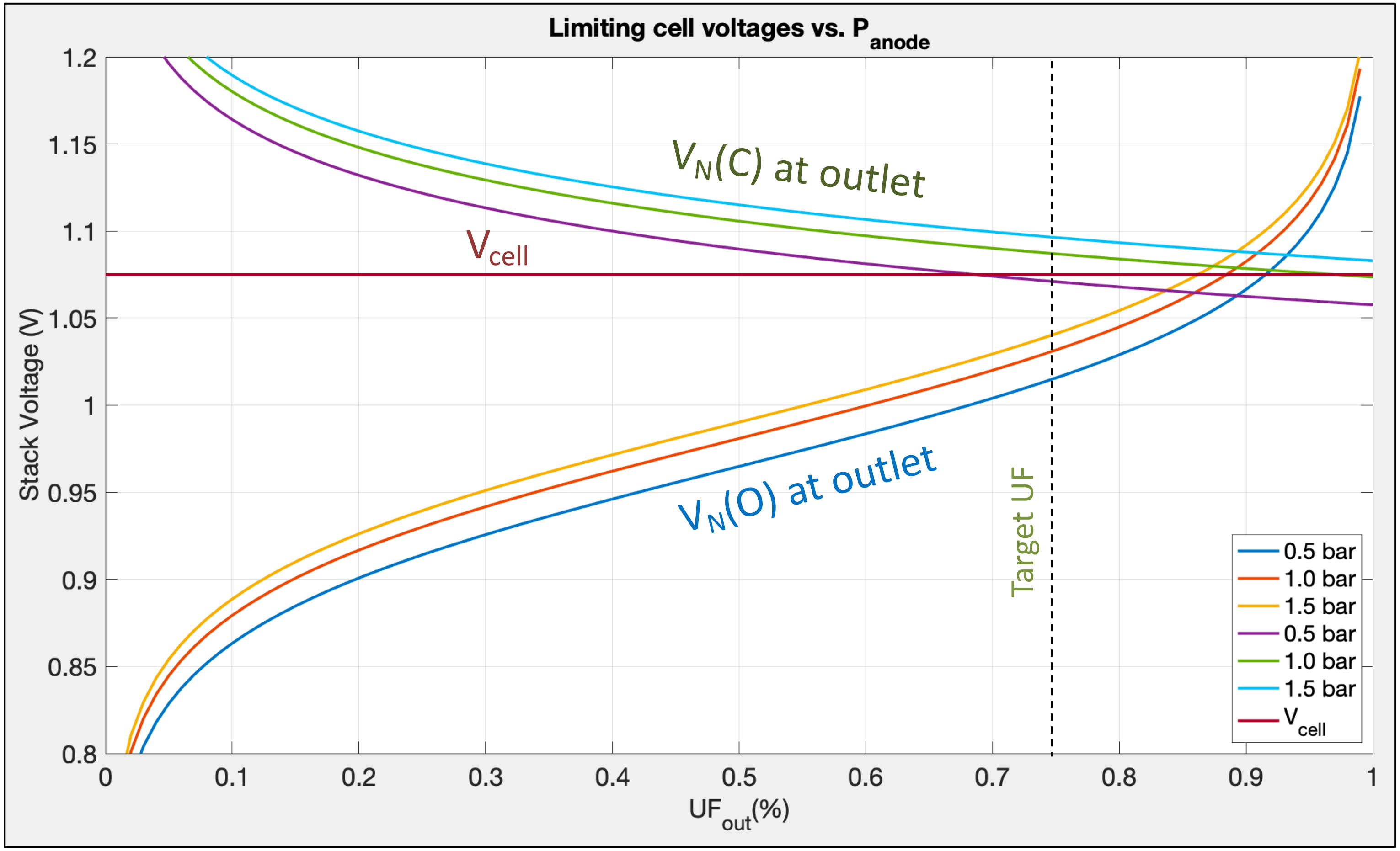
# Why we need to control $P_{cathode}$

- Cathode pressure affects $V_N(C)$
- Anode pressure (not shown) shifts both $V_N(C)$ and $V_N(O)$ together



# Why we need to control $P_{anode}$

- Anode pressure affects both $V_N(C)$ and $V_N(O)$ together
  - In theory, we can set $V_{cell}$ with feedback. In practice, what do we measure?



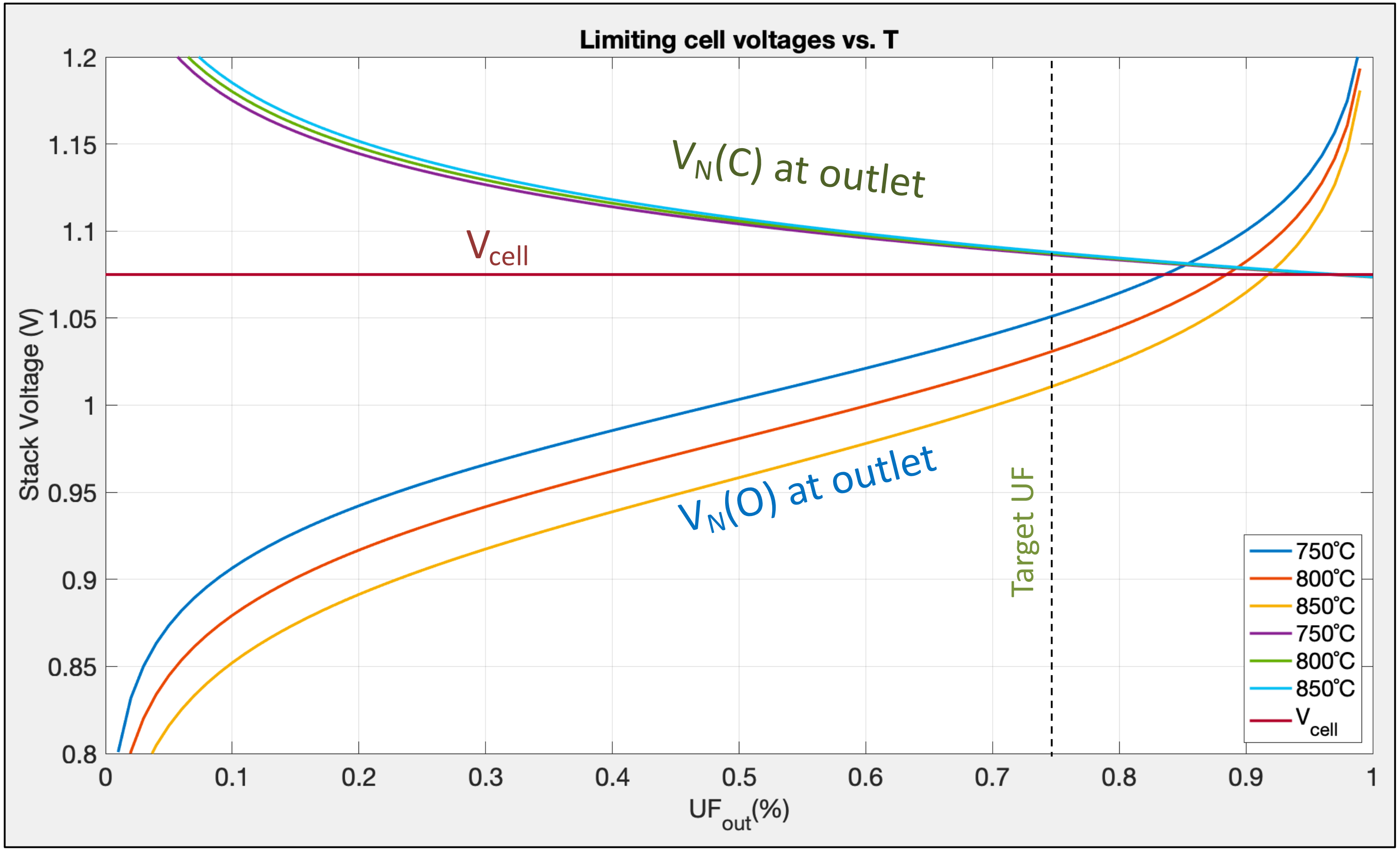
# Questions?

More EVE

# BACKUP

# What if we change T?

- Not a major effect



# Significance of iASR

- Only thing that changes is current ($O_2$ production)