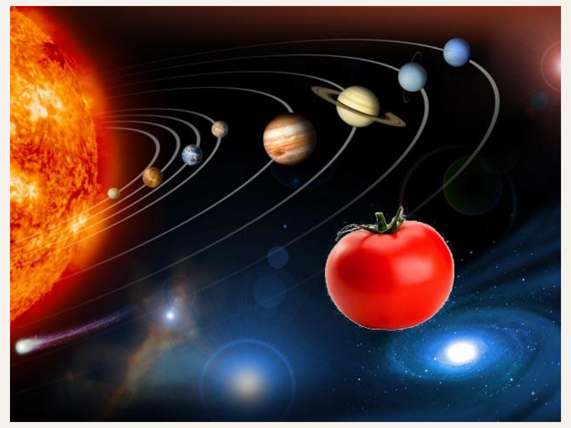
Clara

Towards Zero-Emission Shipping
-with Fuel Cells and Model-Based Design

30+ years of R&D activities

cmr Prototech

- 1988 – Founded by Odd Dahl
- 1991 – Mjøllner:10kW SOFC project for Statoil
- 2004 – Regenerative H2/O2 Fuel Cell & Hydrogen for ESA
- 2006 – Initiation of SOFC for Mars Project by ESA
- 2010 – High Temperature PEM Fuel Cell
- 2014 – RSOFC for Mars by ESA
- 2014 – ZEG Power 20kW module developed

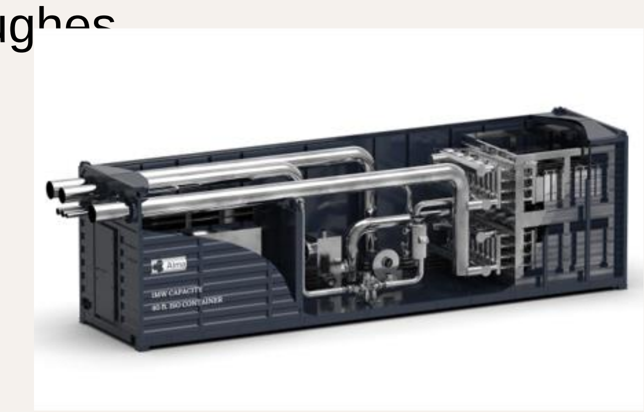


- 2015 – CHEOP Project with industrial partners Shell and Statoil
- 2016 – Green Fish Farm concept established
- 2018 – Havila Kystruten FreeCO2ast
- 2018 – Clean Power AS established
- 2019 – ARTES C&G Technology for ESA

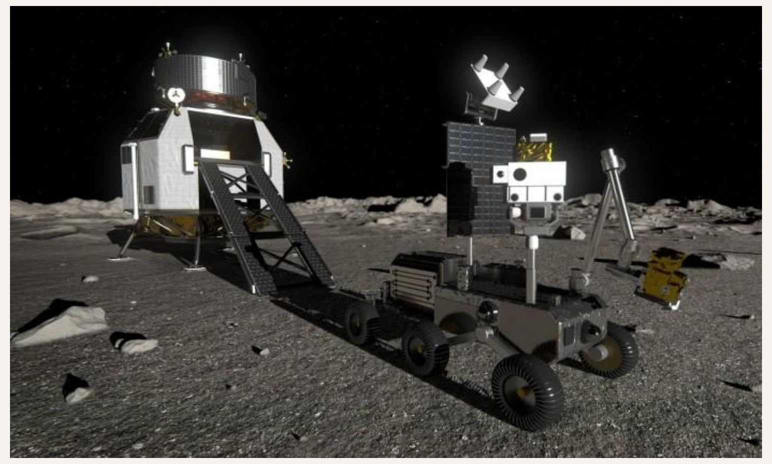
- 2019 – Lunar Nights RFCS contract awarded by ESA

- 2020 – EU- funded ShipFC: Zero- Emission Ammonia Fuel Cell

- 2020 – Sale of Compact Carbon Capture to Baker Hughes



- 2020 – CHEOP-CC Phase 2 with Odfjell, Wartsila, Lundin Energy
- 2021 – Aker signs agreement to acquire Prototech
- 2021 – Prototech changes name to Clara Venture Labs



- 2021 – Alma Clean Power launched from Clara Venture Labs

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Problem:

No viable clean power solution for **deep-sea*** shipping

*90% of global fleet

Total annual greenhouse gages emissions from international shipping to be **reduced with at least 50%** by 2050 compared to 2008

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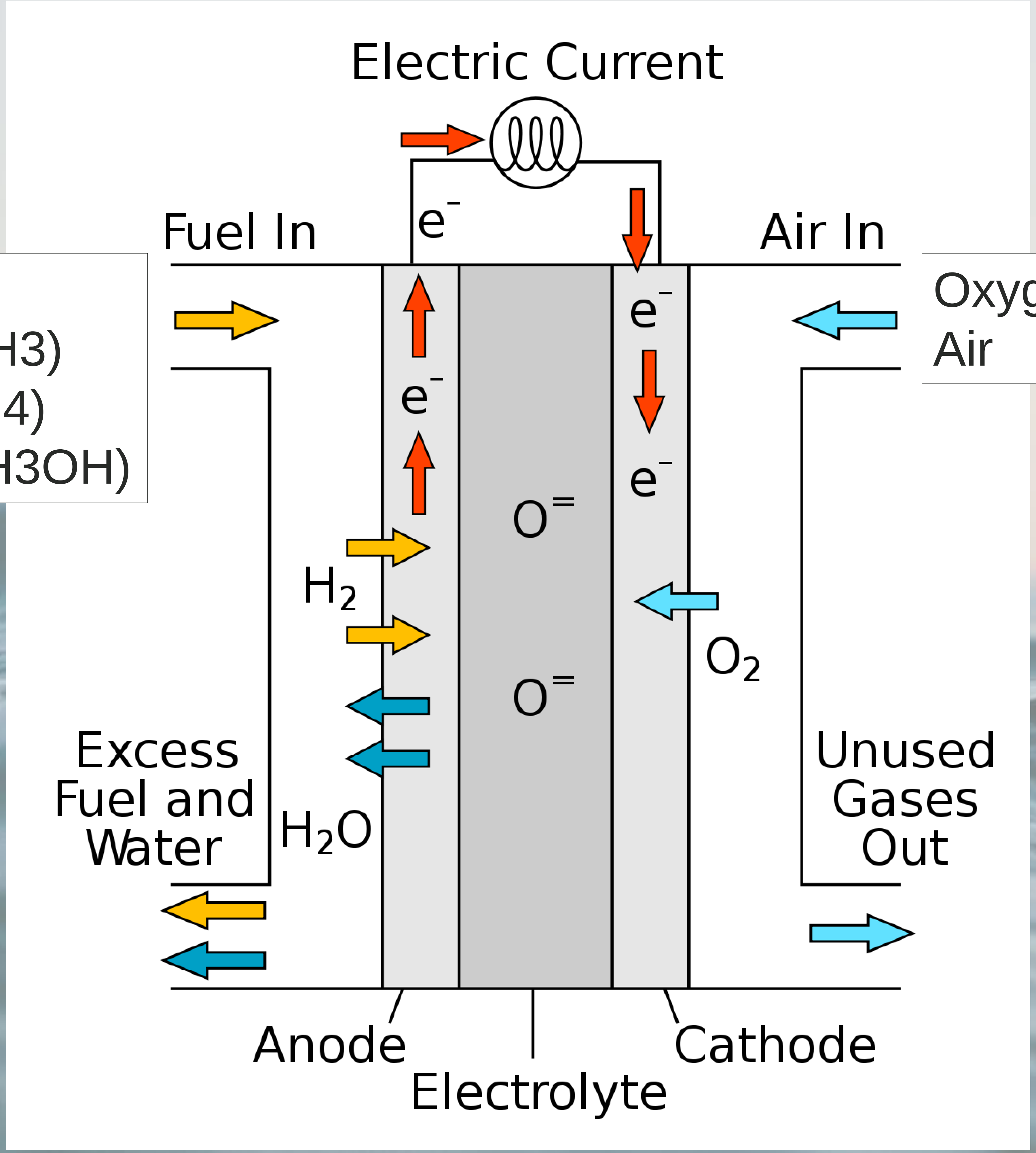
What is a Solid Oxide Fuel Cell (SOFC)?

Hydrogen
Ammonia (NH3)
Methane (CH4)
Methanol (CH3OH)



Oxygen
Air

- High temperature (700 – 800 C) allows for internal cracking or reformation
- Available heat at high temperature (high value)
- High efficiency of electricity generation

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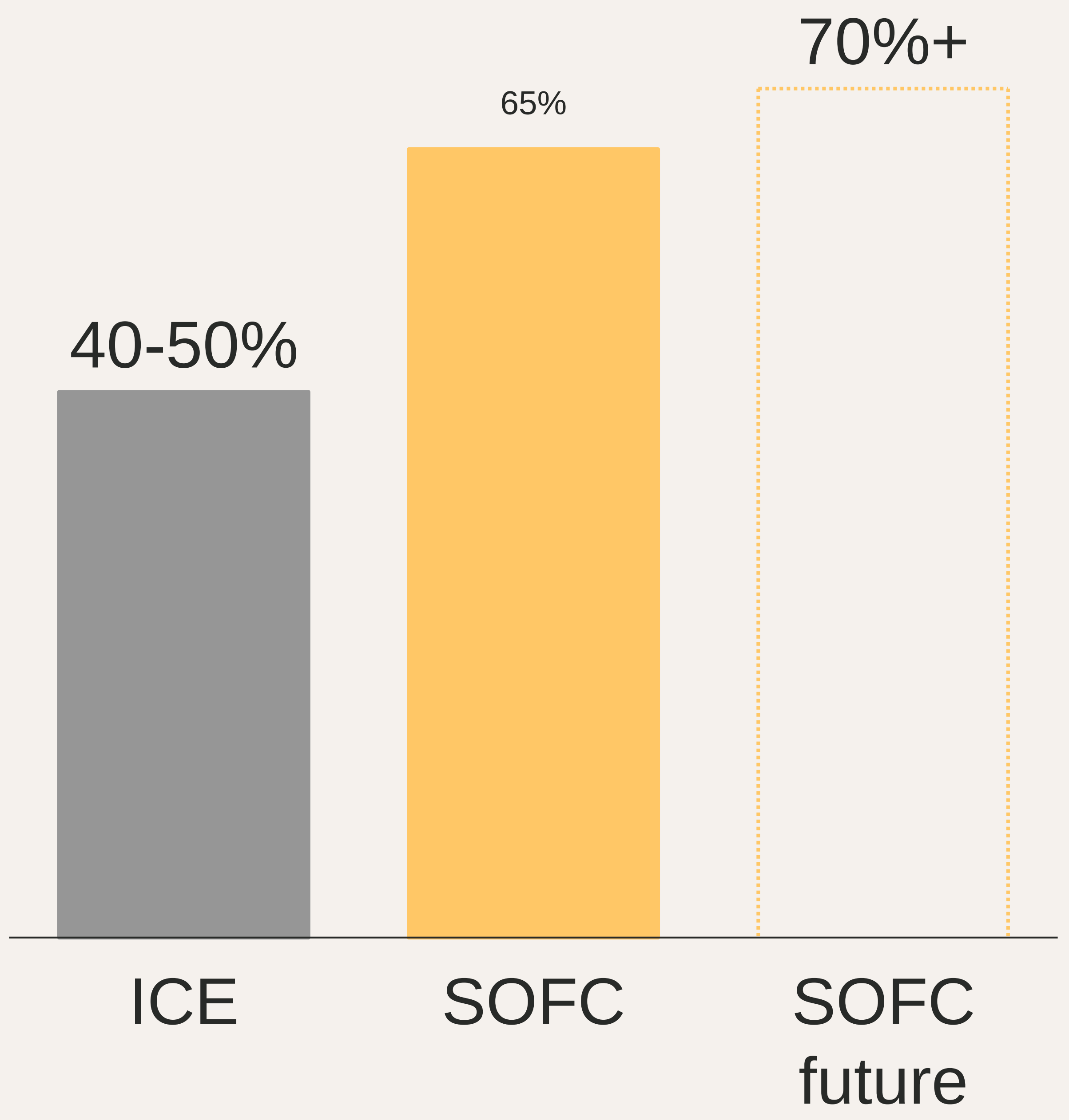
SOFC solve the two main challenges related to decarbonization

SIGNIFICANTLY **HIGHER ENERGY EFFICIENCY**



COMPATIBLE WITH **FUTURE DEEP-SEA FUELS**

FUEL	TECHNOLOGY: SOFC	PEM	ICE
Hydrogen	✓	✓	✓
Future deep-sea fuels Methanol, Ammonia	✓	✗	✓
Transition fuels LNG, LPG	✓	✗	✓
Traditional fuels Diesel, VLSFO	?	✗	✓

Fuel cells (SOFC, PEM)

MULTIPLE **OTHER BENEFITS**

- **Low maintenance** with no moving parts
- **Silent** and **no vibrations**
- **Modularity** enables new ship design possibilities
- **Carbon capture** potential (high CO_2 concentration)

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In-house early-stage venture lab

Clara Venture Labs in brief

- Established >30 years ago, Clara Venture Labs is a **venture lab delivering technology innovation, R&D projects, and venture support services**
- Impressive track record of **building breakthrough technology ventures from discoveries in the lab**, including carbon capture, hydrogen production, and fuel cell technology solutions
- Systematically developing new **innovations** in partnership with Atoma Capital and leading institutions

>3,600 m^2 of laboratories and testing facilities

Materials Characterization Lab

Lab Scale Experimentation Facility

Manufacturing Facilities

Energy Lab

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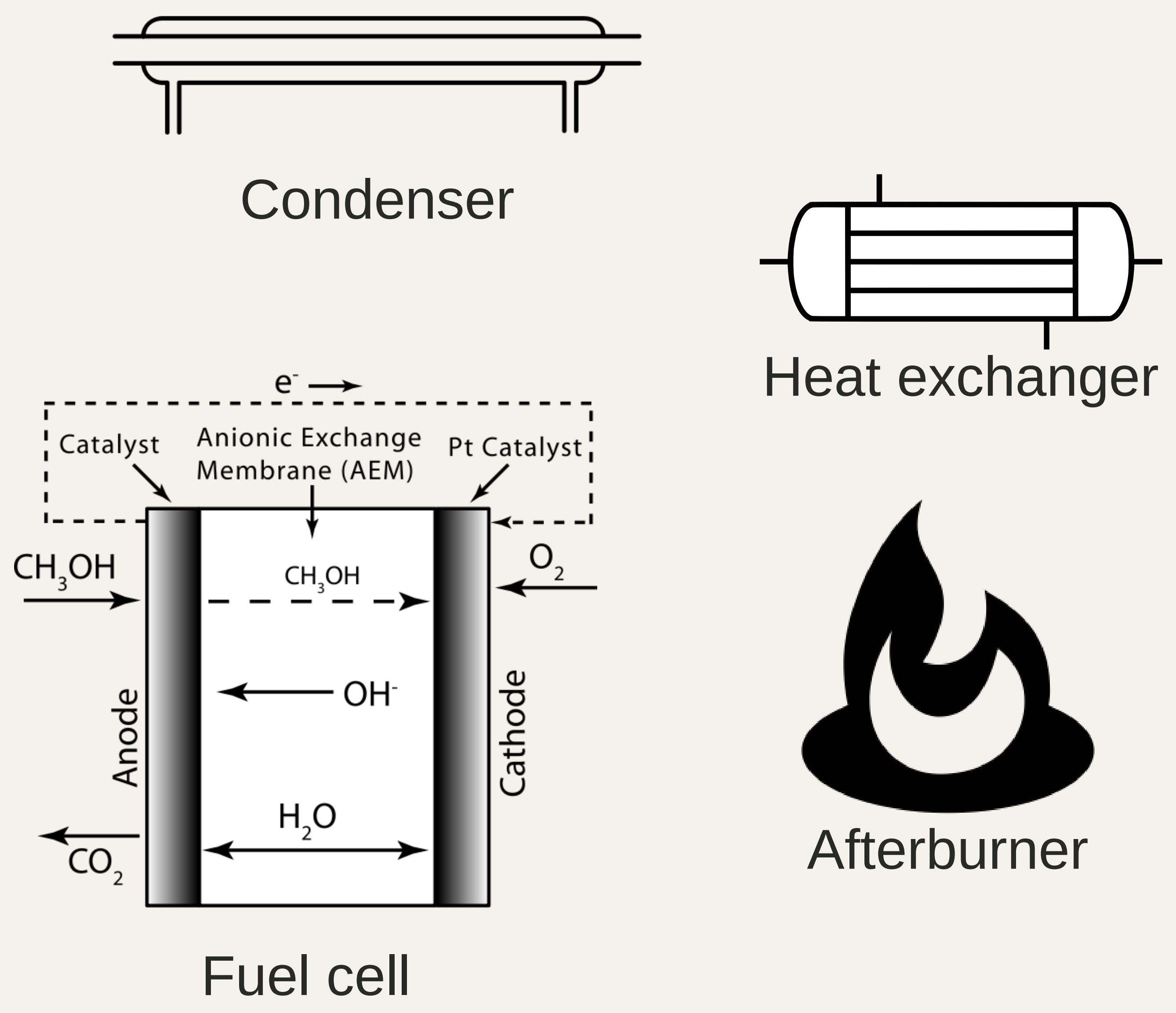
Thermodynamics



National Institute of Standards and Technology
U.S. Department of Commerce

Gas Phase Heat Capacity (Shomate Equation)

$C_p° = A + B*t + C*t^2 + D*t^3 + E/t^2$

$H° − H°_{298.15} = A*t + B*t^2/2 + C*t^3/3 + D*t^4/4 − E/t + F − H$

$S° = A*ln(t) + B*t + C*t^2/2 + D*t^3/3 − E/(2*t^2) + G$

C_p = heat capacity (J/mol*K)
H° = standard enthalpy (kJ/mol)
S° = standard entropy (J/mol*K)
t = temperature (K) / 1000.

View plot Requires a JavaScript / HTML 5 canvas capable browser.

View table.

Temperature (K)	298. - 1300.	1300. - 6000.
A	-0.703029	85.81217
B	108.4773	11.26467
C	-42.52157	-2.114146
D	5.862788	0.138190
E	0.678565	-26.42221
F	-76.84376	-153.5327
G	158.7163	224.4143
H	-74.87310	-74.87310
Reference	Chase, 1998	Chase, 1998
Comment	Data last reviewed in March, 1961	Data last reviewed in March, 1961

ΔH　　S　　c_p

```
py.CoolProp.CoolProp.PropsSI('C','T',373,'P',101325,'Water')

coder.extrinsic('py.CoolProp.CoolProp.PropsSI')
```

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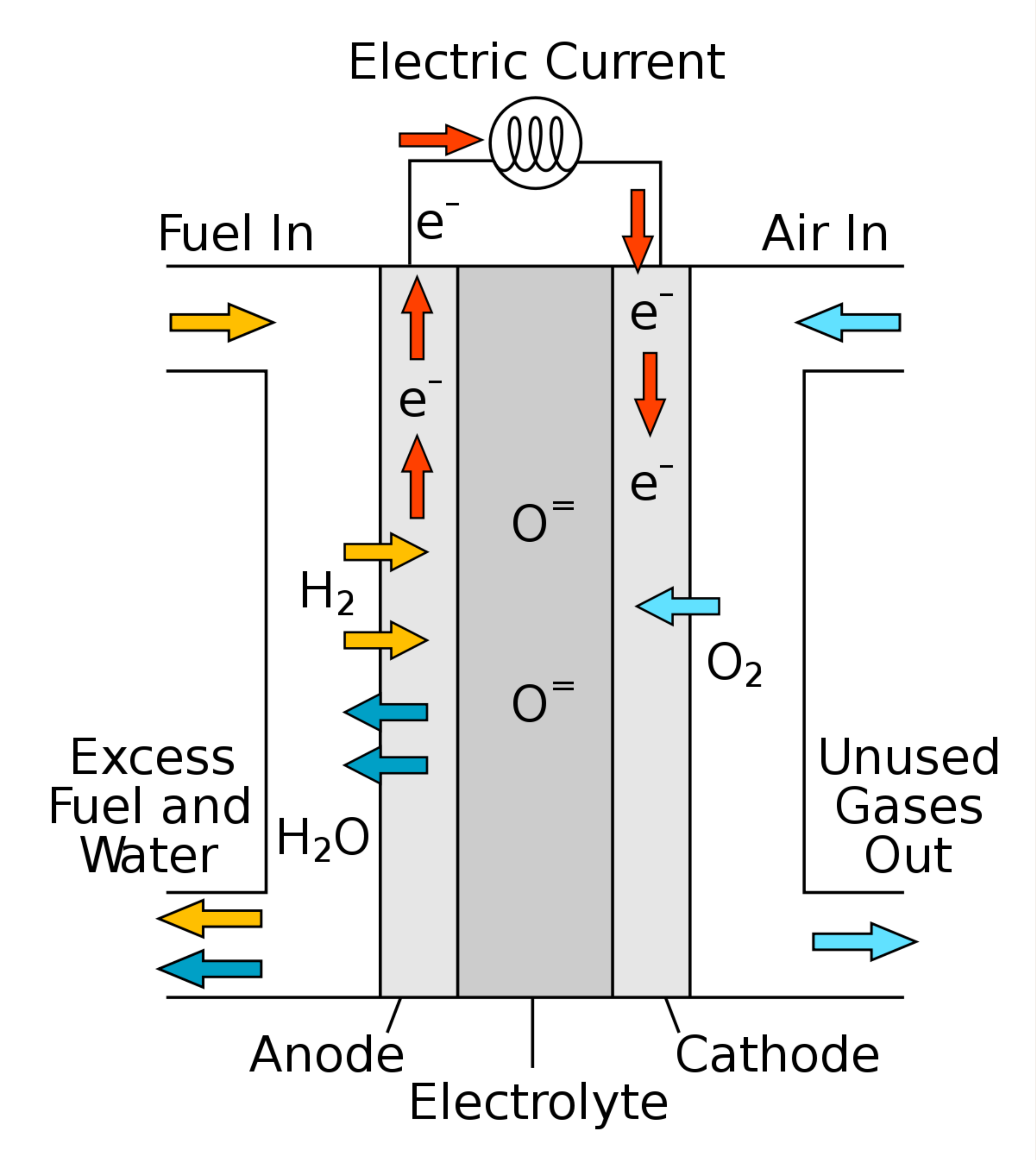
Fuel cell - Thermodynamics

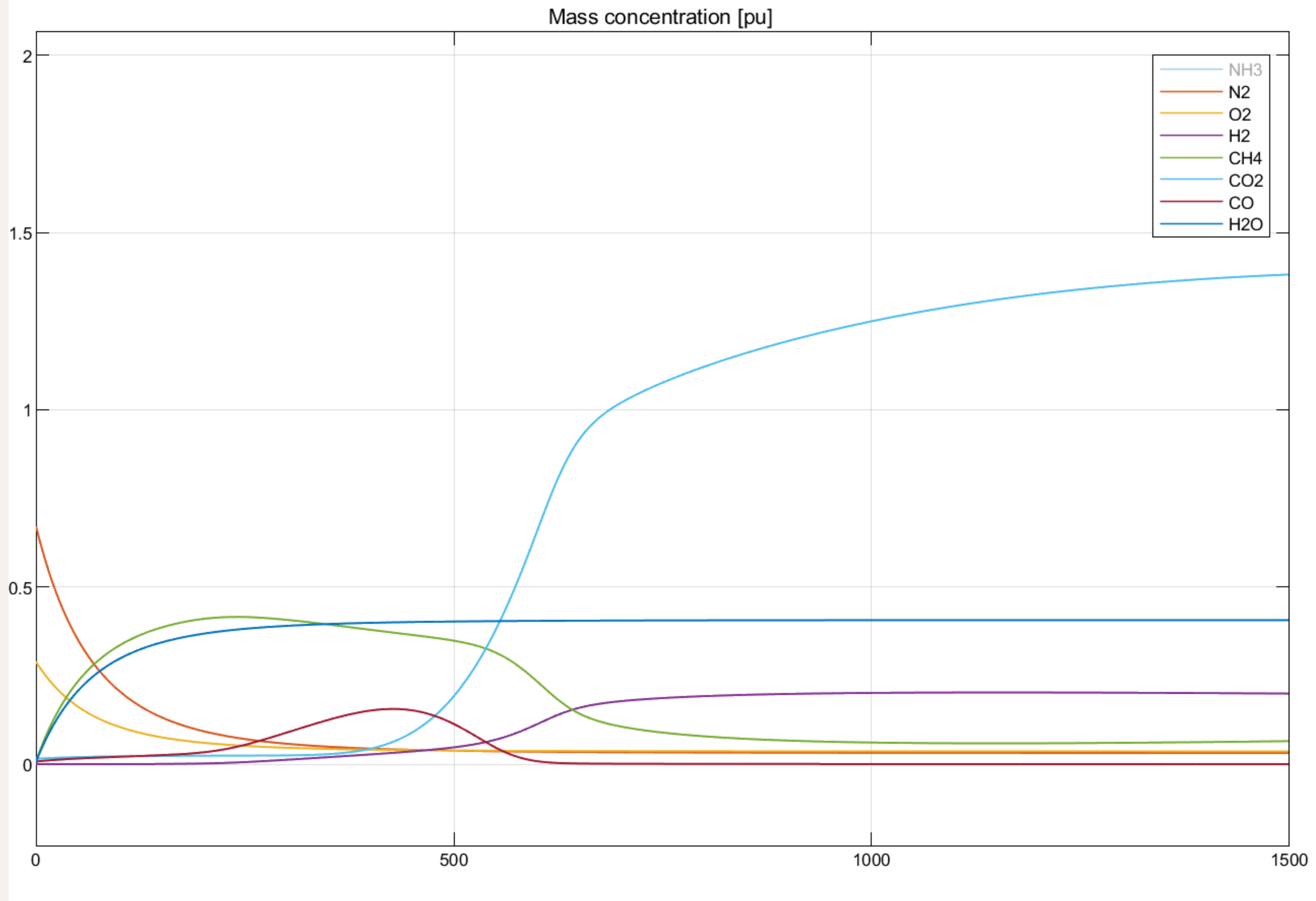


$$2NH_3 \rightarrow 3H_2 + N_2$$ Endothermic

$$CH_4 + H_2O \rightarrow CO + 3H_2$$ Endothermic

$$CO + H_2O \rightarrow CO_2 + H_2$$ Exothermic

$$2H_2 + O_2 \rightarrow 2H_2O$$ Exothermic



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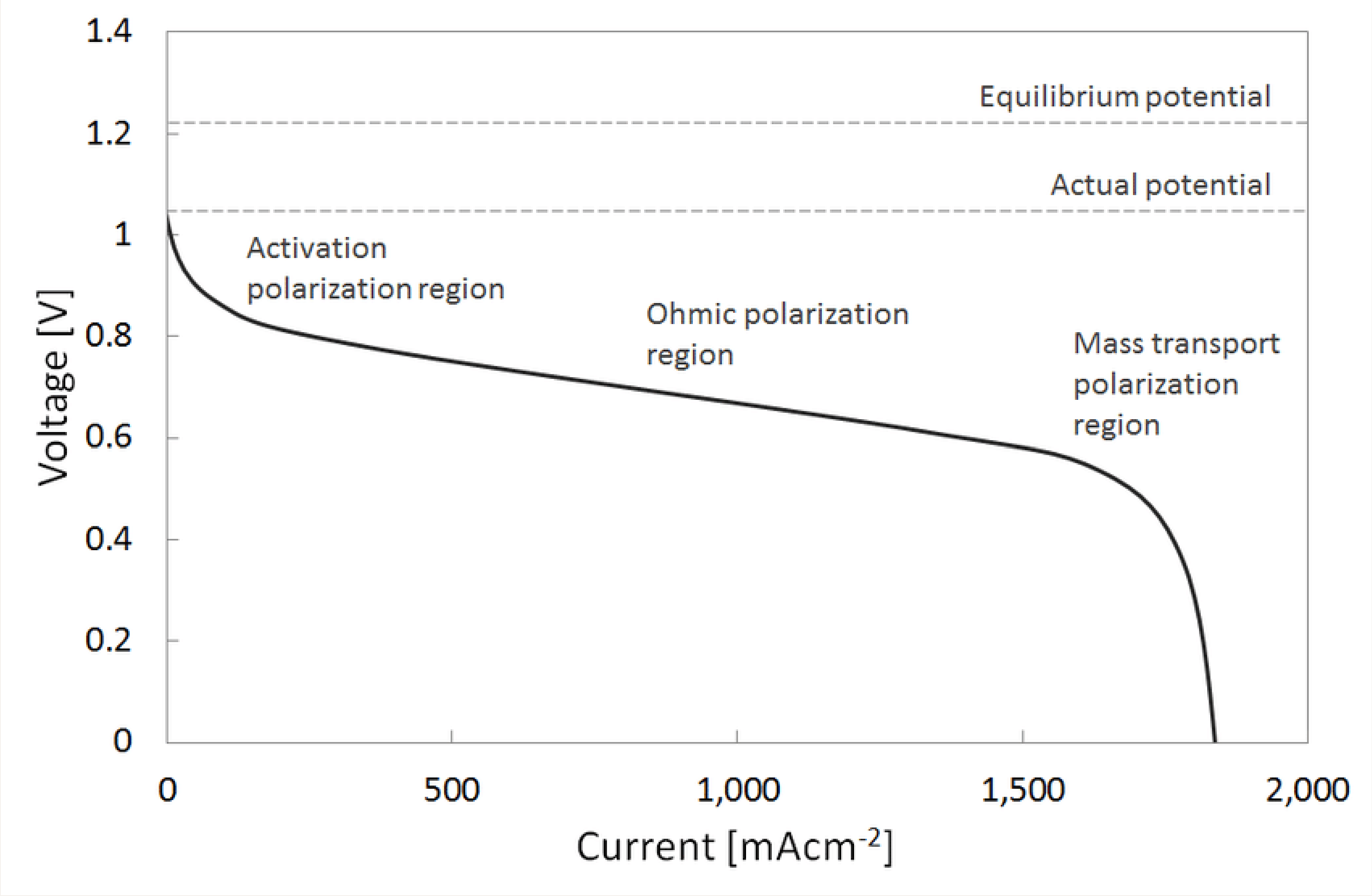
Fuel cell - Electrochemistry



$$E_{tot} = E_{rev} - E_{\Omega} - E_{cons} - E_{act}$$

$$E_{rev} = \frac{\Delta G_0}{4F} - \frac{TR}{4F} \cdot \ln\left(\frac{p_{H_2O}^2}{p_{H_2}^2 \cdot p_{O_2}}\right)$$

$$E_{\Omega} = \frac{I}{area} \cdot \left(ASR_{Tref} \cdot \exp\left(1.08 \cdot \frac{F}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) + ASR_{time}\right)$$

$$E_{cons} = -\frac{RT}{zF} ln\left(1 - \frac{I}{I_L}\right)$$

$$E_{act} = a \cdot log(I) + b$$

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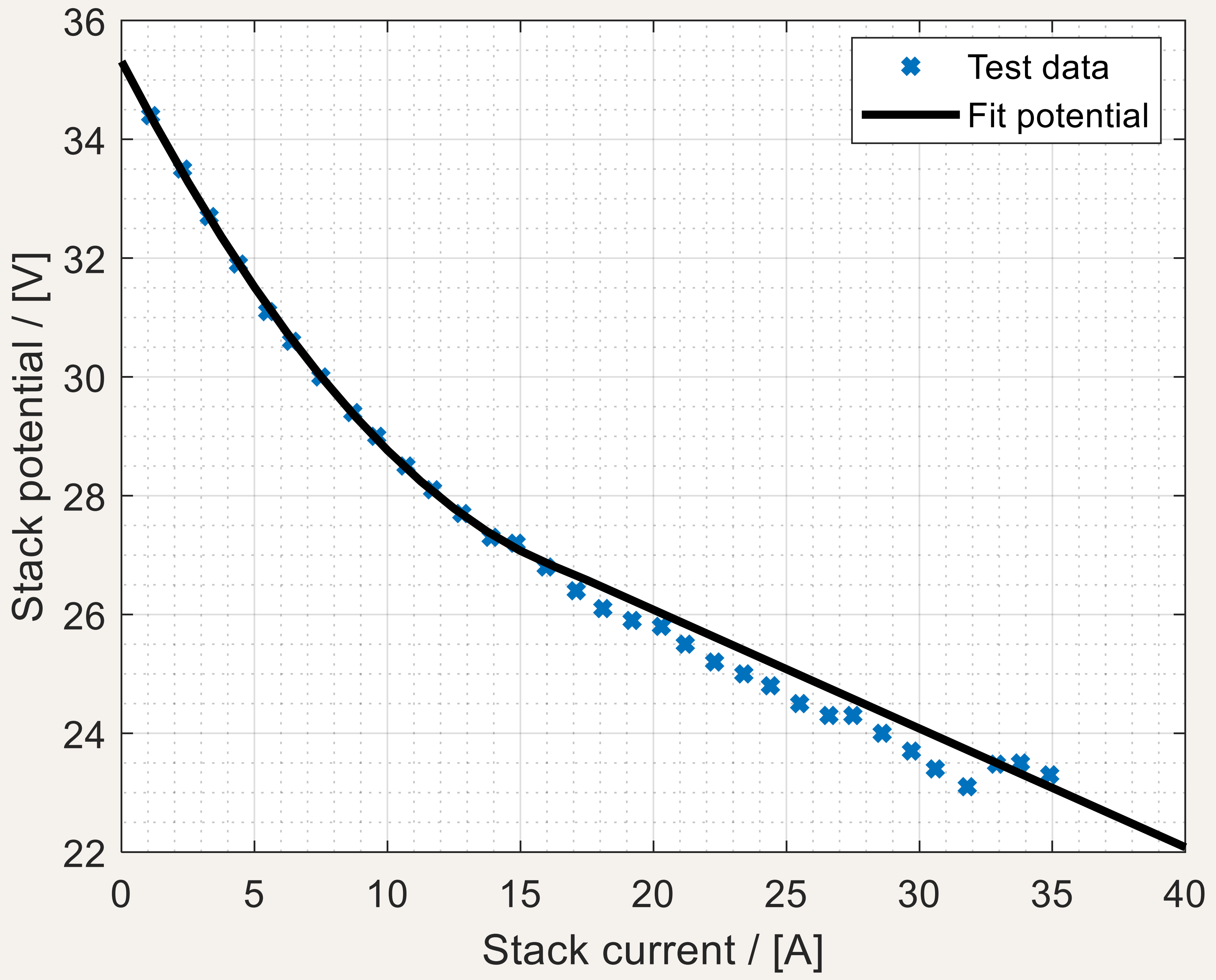
Fuel cell - Measurements



$$Power = eletric\ current \cdot potential$$

All other energy is transformed to thermal energy.

Hence you can find the temperature of the fuel and air out from your fuel cell.

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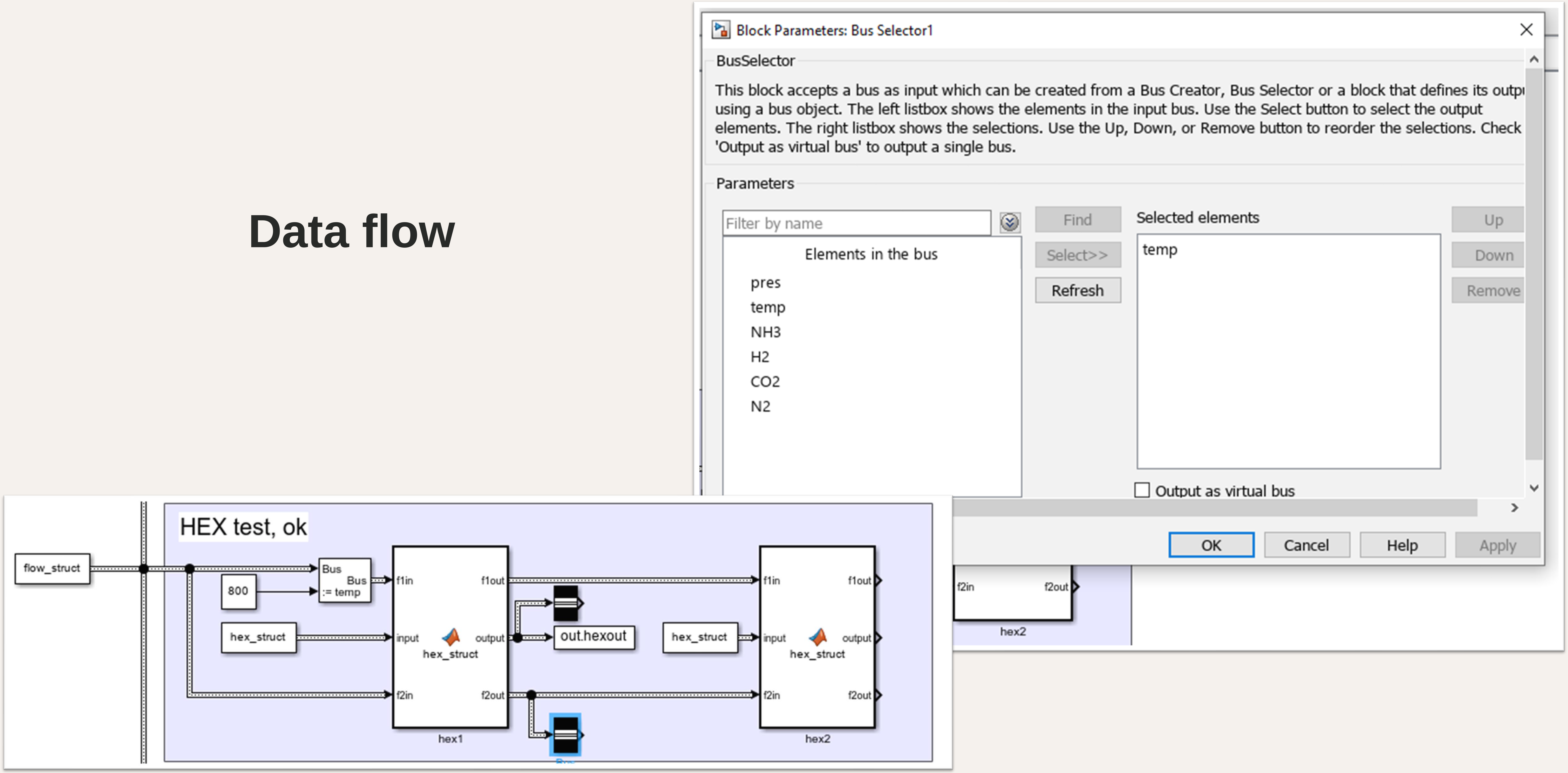
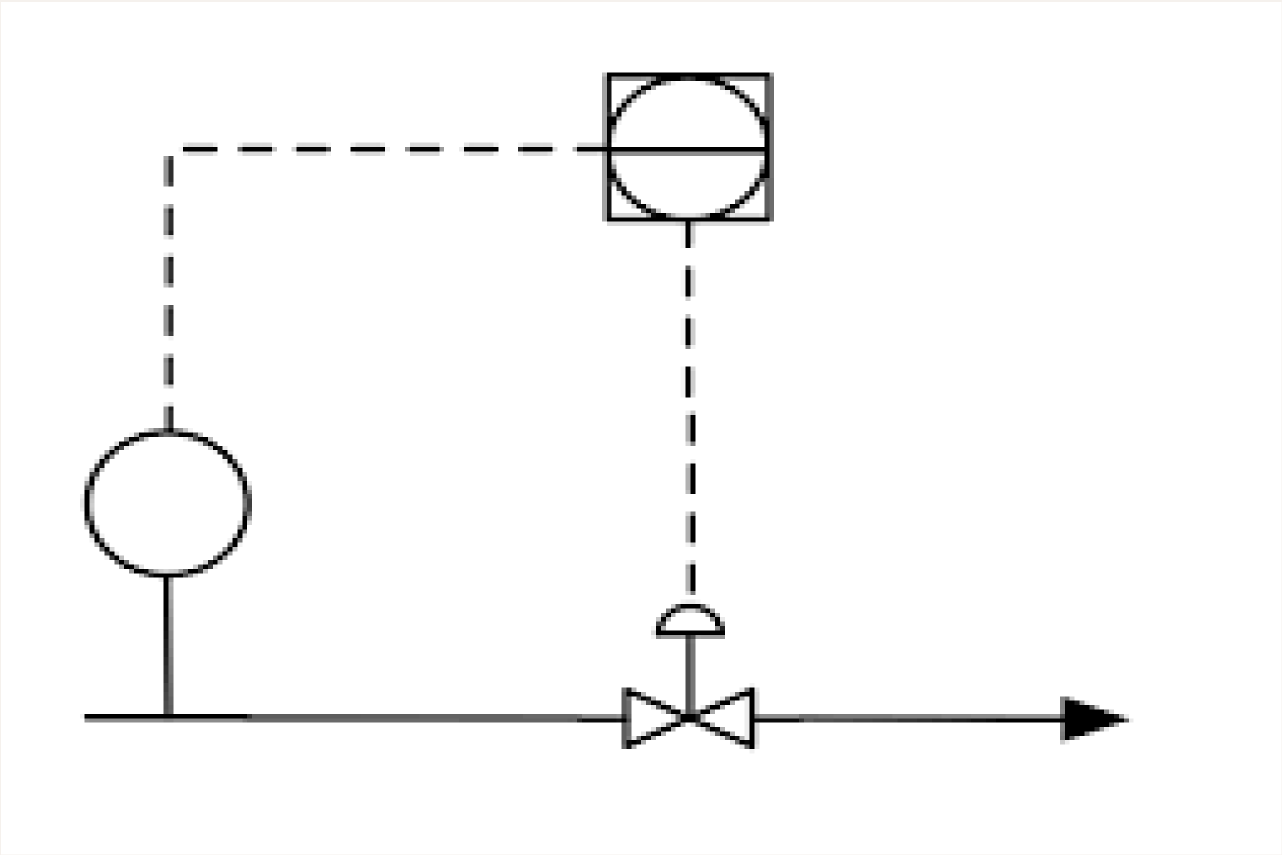
Data flow



Block Parameters: Bus Selector1
BusSelector
This block accepts a bus as input which can be created from a Bus Creator, Bus Selector or a block that defines its outpu
using a bus object. The left listbox shows the elements in the input bus. Use the Select button to select the output
elements. The right listbox shows the selections. Use the Up, Down, or Remove button to reorder the selections. Check
'Output as virtual bus' to output a single bus.
Parameters
Filter by name
Find
Select>>
Refresh
Elements in the bus
pres
temp
NH3
H2
CO2
N2
Selected elements
temp
Up
Down
Remove
Output as virtual bus
OK
Cancel
Help
Apply
HEX test, ok
flow_struct
Bus
Bus
:= temp
800
hex_struct
f1in
f1out
input
output
hex_struct
f2in
f2out
hex1
out.hexout
hex_struct
f1in
f1out
input
output
hex_struct
f2in
f2out
hex2

Different utilisation of MATLAB/Simulink though projects



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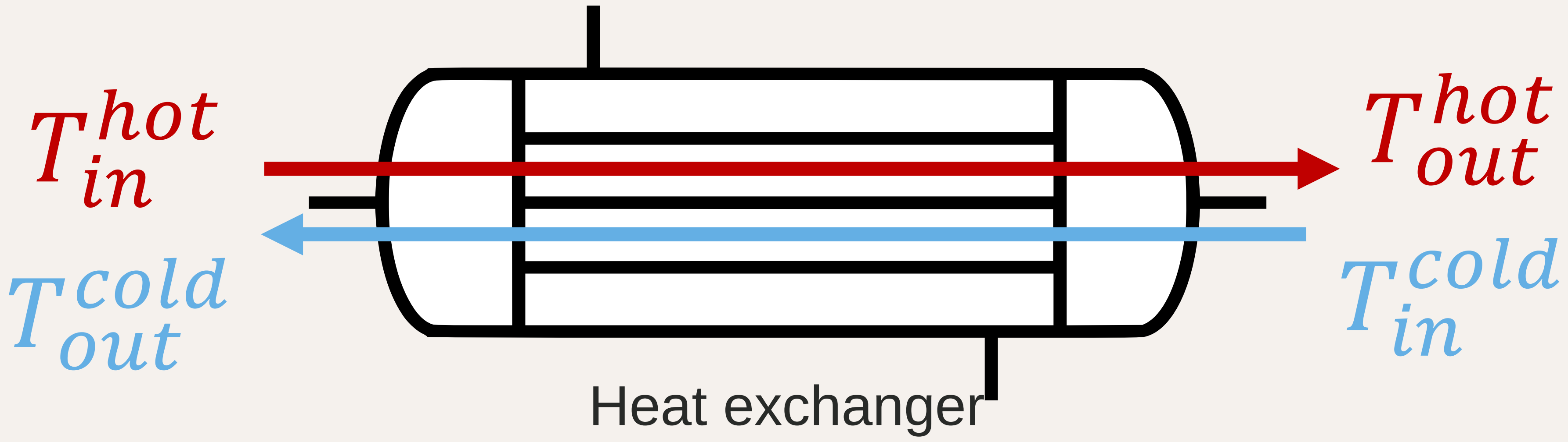
Example of modelling in the start and end of a project



If T_{out}^{hot} is set, you know how much heat the cold fluid gets if we assume no losses:

$$Q = \Delta H \cdot mass = (\Delta H_{out} - \Delta H_{in}) \cdot mass$$

And you can calculate T_{out}^{cold}

$$T_{out}^{cold} = T_{in}^{cold} - \frac{Q}{c_p^{cold} \cdot mass}$$

$$Q = \epsilon \cdot C_{min}\left(T_{fuel} - T_{water}\right)$$

$$\epsilon = \frac{1 - exp\left(-N \cdot (1 - C)\right)}{1 - C \cdot exp\left(-N(1 - C)\right)}$$

$$N = \frac{h}{C_{min}}$$

[W/K]
Dependent on
- area
- material

$$T_{out}^{fuel} = T_{in}^{fuel} - \frac{Q}{c_p^{fuel} \cdot mass}$$

Additional work

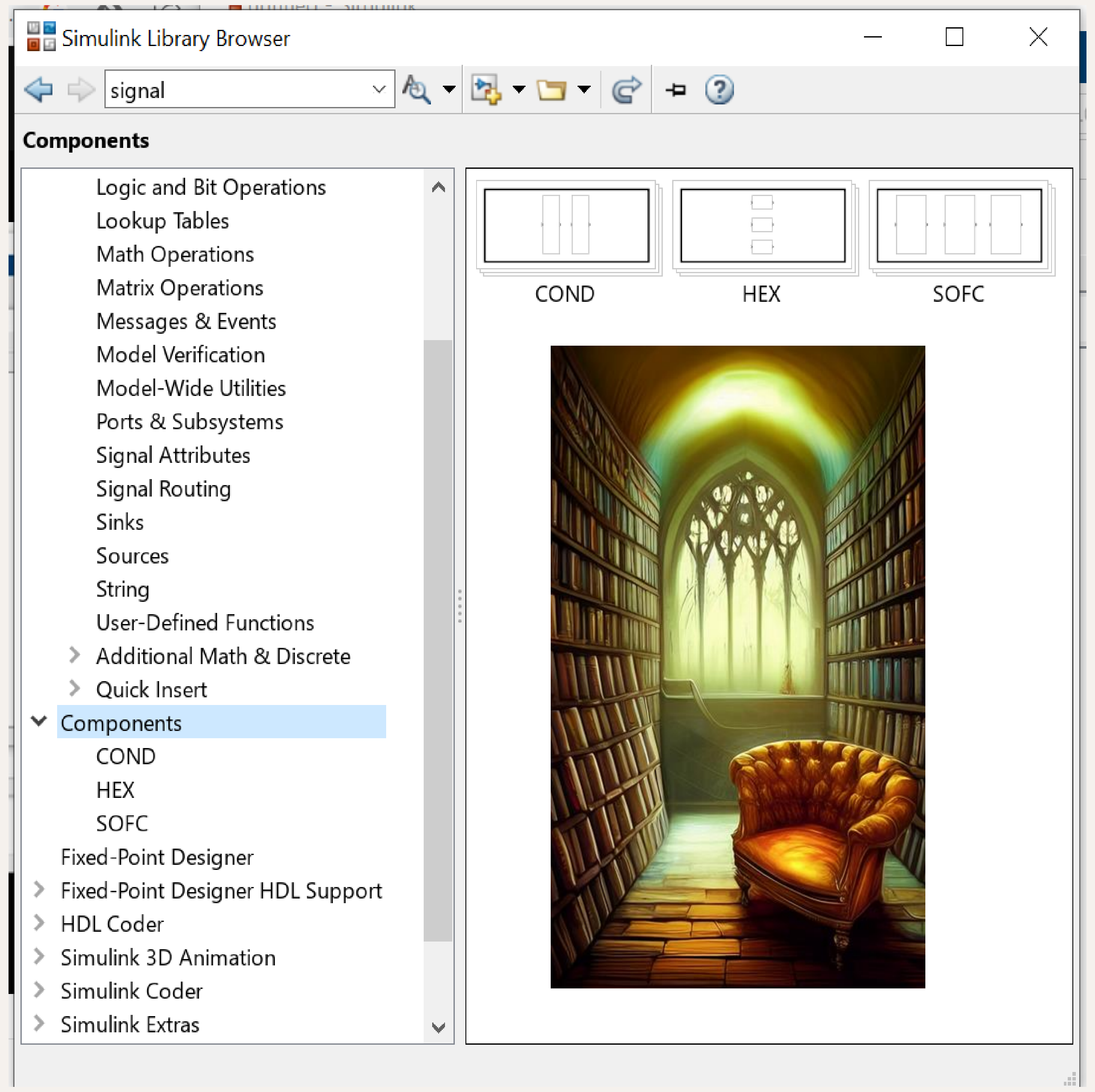
SIMSCAPE

- Make our own Gas mixture
- Include their thermodynamic properties
- Calculations of reaction rates

Azure DevOps

Git

- Large system with many people with different areas of expertise
- Important to be able to test new code with code written by other experts



Custom Libraries

What have we gotten out from our MATLAB/Simulink models?

1. Prediction: Give new investors and customers good estimates of future systems efferences, fuel utilization and available heat
2. Techno-economic insights for downsizing components and selecting commercial off-the-shelf (COTS) products
3. Simplified component manufacturing by setting mass flow, pressure, and temperature early on in the project.
4. Leveraging value in test data: Learn from lab tests, implement the data in our models for improvement to the next model

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Thank you for your attention

30+ years fuel cell experience

Competent and capable organization

Platform backed by Aker and ICP

Maritime DNA

Future proof technology