PRESSURISED HIGH TEMPERATURE CO-ELECTROLYSIS

VC Investors:

General Information about sunfire

Company Facts

90 employees	Stacks · Systems · Fuel · Ceramics · Production · Business
Partners & Investors	Audi · Lufthansa · Boeing · ThyssenKrupp · Vaillant · CEZ Group · idinvest Partners · Total · EDF · KfW · Electranova Capital
Financials	**Total output:** 4 M € (2014) | 6 M € (2015) | > 10 M € expected (2016) **Value:** ~ 60 M € pre-investment, incl. build up ceramic and stack tech. | Grants > 15 M €
Patents	40 patent families (i.e. „process patent sunfire" WO/2008/014854)
Recognition	2015 Global Cleantech 100 Top 100 Company · Step Award Spirit to expand · Ecosummit Award Fame and Fortune for the Best Smart Green Startups · Fast Company · National Geographic

One core – Four products – Multiple markets

Individually	Or integrated into three key products.

Solid Oxide Power Core

sunfire's established solid oxide cell (SOC) stack design

SO Off-Grid Generator

+ Reliable power generation in remote sites
+ 1 – 20 kW

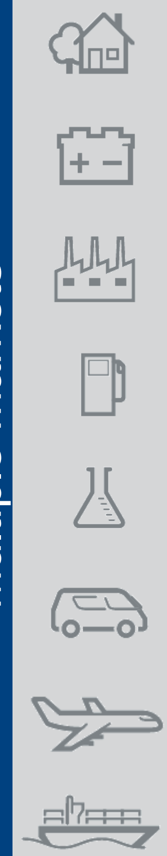
SO Commercial Generator

+ Efficient co-generation for commercial use
+ 20 – several 100 kW

SO Reversible Generator

+ Efficient electrical storage and hydrogen production
+ Grid balance and resilience

Multiple markets



Pressurised
High Temperature
Co-Electrolysis

01. Introduction

- Hydrogen is source in many industrial applications
  - Refineries, chemical industry, steel works, H_2 refueling…
  - Power-to-Gas (e.g. Methane) and Power-to-Liquid (e.g. Naphta, Diesel)
- Most of these processes run under pressure (10 … 100 bar) or require a pressurized supply line or storage
- Compression of gas is a major impact of overall system efficiency
- About 5% overall system efficiency can be saved if hydrogen compression (0 → 10 bar) could be skipped

→ producing pressurized H_2 would be advantageous

- Using steam (e.g. produced by excess heat) instead of water for electrolysis increases efficiency further 5…10%
  - Excess heat may come from further process like the exothermal Methanation

01. Introduction

- For energy storage, H_2 seems to play a minor role

→ conversion to Syngas (and further to methane, diesel etc.) required

    - Existing distribution infrastructure can be used

- In contrast to a PEMFC, HT fuel cells (SOFC) can handle CO that is oxidized to CO_2
- Therefore it is nearby to test the vice-versa process as well

→ use CO_2 as source for electrolysis and produce CO

- Feed of H_2O and CO_2 to electrolyser to produce H_2 and CO (syngas) in one step is called co-electrolysis
    - Other expensive process parts for CO production like RWGS reactor can be skipped

01. Introduction

- High temperature ELectrolysis and METHanation project: www.helmeth.eu
- co-electrolysis targeted outlet gas composition as inlet feed for methanation:

$$FEED: \frac{[H_2] - [CO_2]}{[CO] + [CO_2]} = 3$$

- Reaction that takes place at HTE cell:

$$x \cdot H_2O + y \cdot CO_2 \xrightarrow[Co-electrolysis]{} x \cdot H_2 + y \cdot CO + \left(\frac{x+y}{2}\right) \cdot O_2$$

- Water gas shift (WGS) reaction takes place even at OCV condition

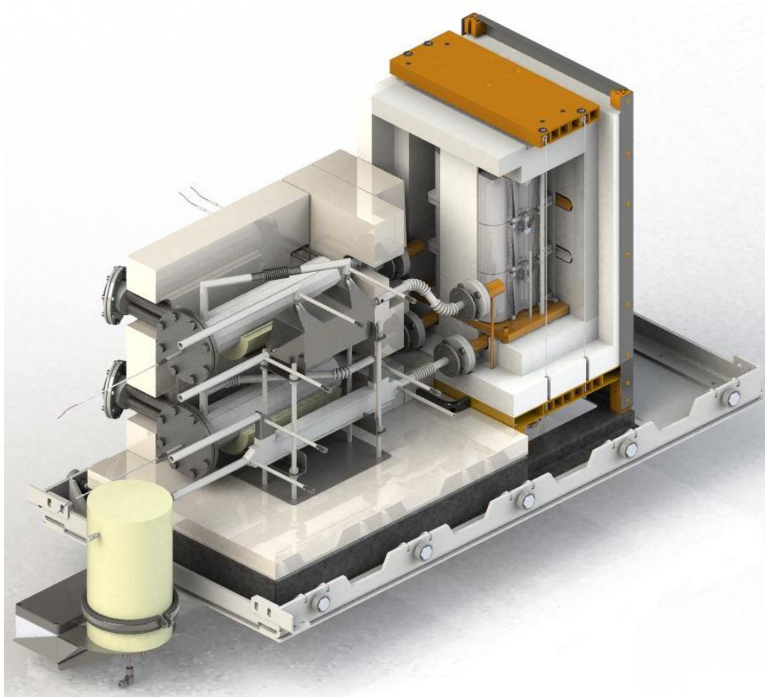
$$H_2 + CO_2 \leftrightarrow H_2O + CO$$

→ main reaction at cell is likely to be steam electrolysis

02. Experimental: Stack and HotBoP components

- sunfire SOC-stack:
  - Electrolyte Supported Cells
  - 128 cm² active area / cell
  - 30 cells / stack
  - Hydrogen electrode: Ni-GDC
  - Oxygen electrode: LSCF
  - Electrolyte: 3YSZ
    (or 5YbSZ or 6Sc1CeSZ)

- Hot BoP components developed by sunfire
  - plate-type heat exchangers
  - electrical gas heaters
  - electrical evaporator
    (for independent operation)



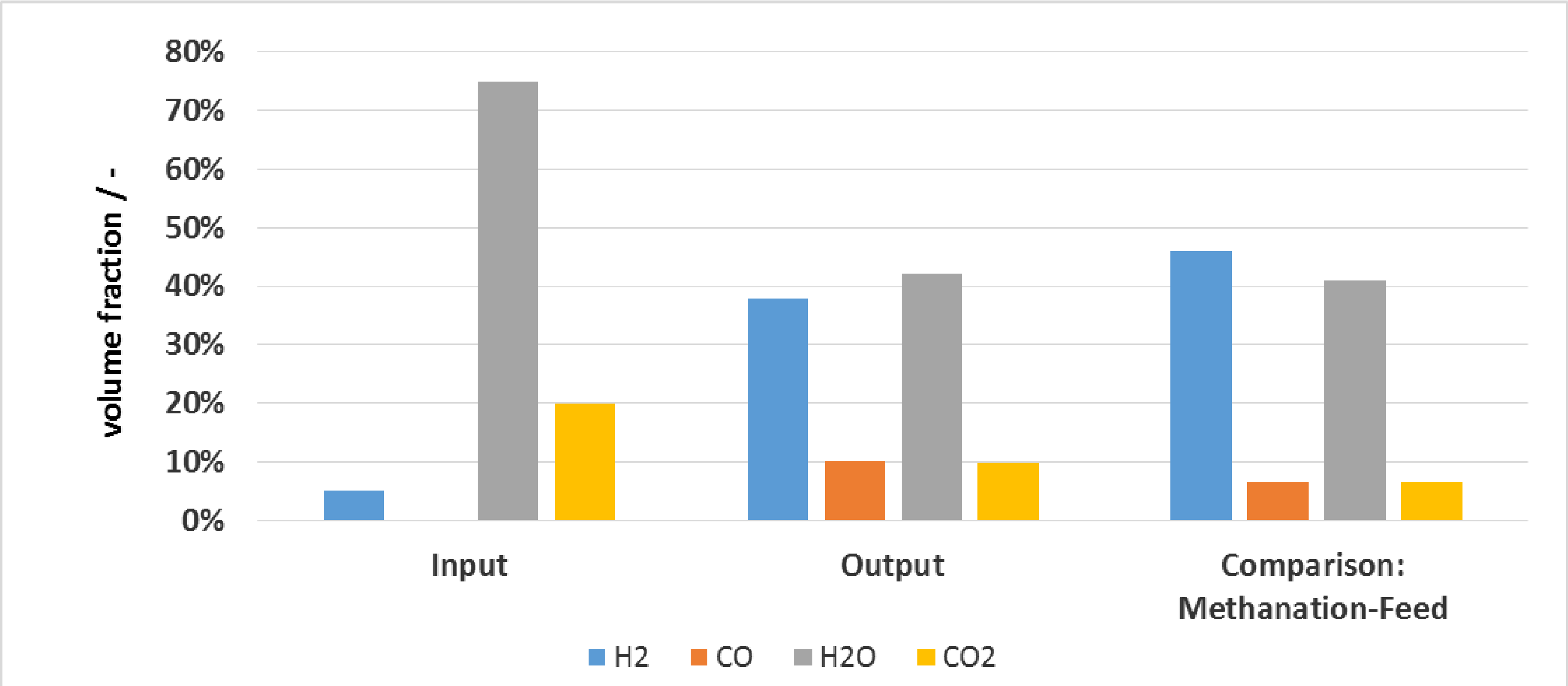
02. Experimental: pressure vessel

- Pneumatic pressure control valves
- Pressure vessel in container
- Fluid supply panel
- H_2 / H_2O condenser
- Container ventilation inlet

- Operation pressure fixed to max. 16 bar
  (approved by TÜV due to pressure equipment directive)

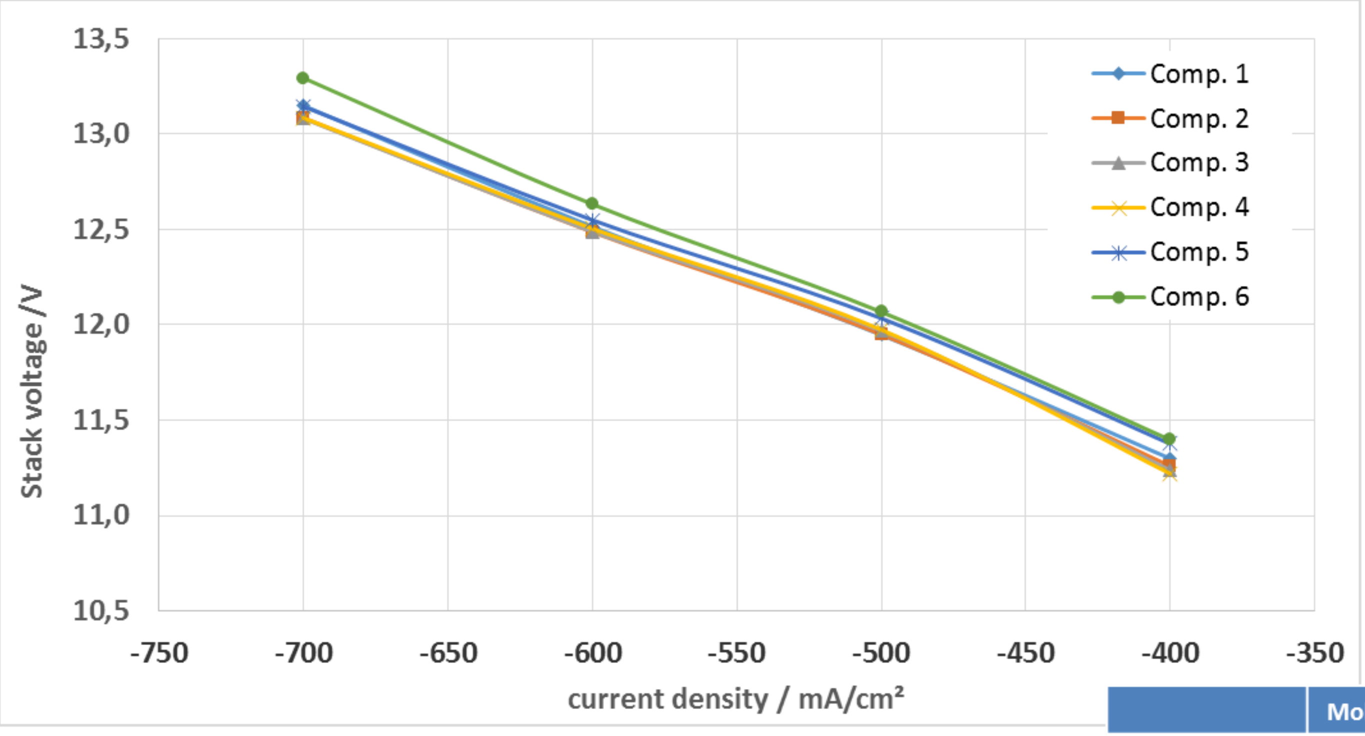
03. Results: co-electrolysis outlet composition

- Operation point: j = - 500 mA/cm²; T = 860° C; ambient pressure



- Output composition (gas analysis) close to desired values for methanation feed
- Composition can be tuned by varying the inlet gas composition

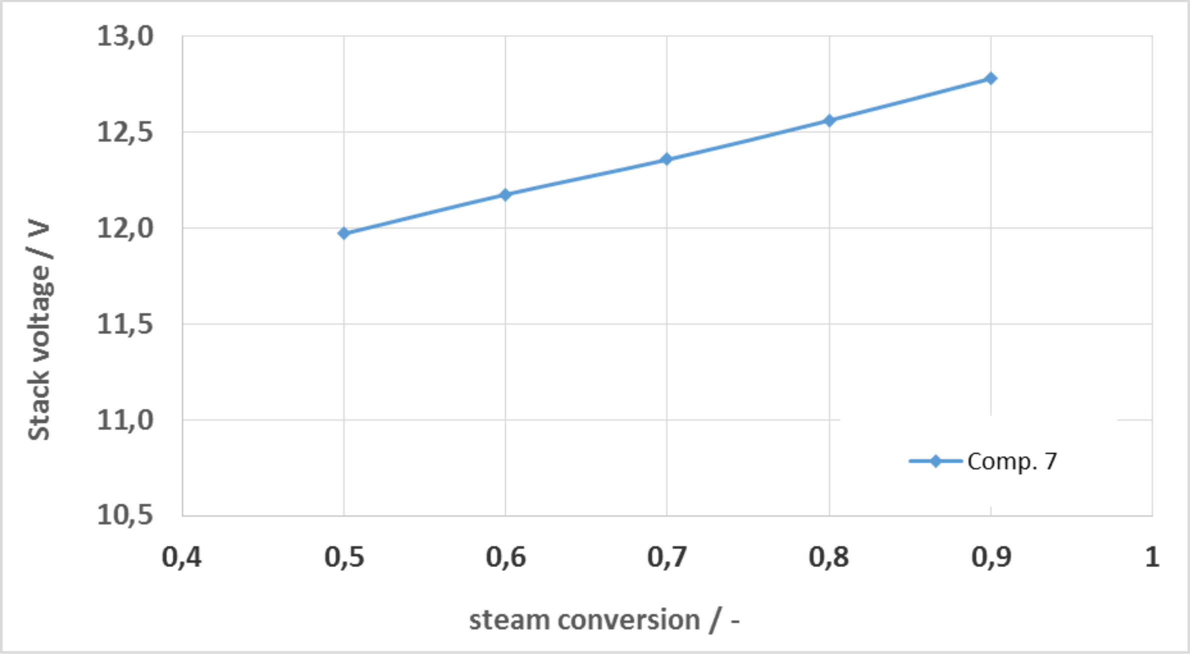
03. Results: I-V curves for different compositions



	Molar fractions in %			
Composition	H_2	H_2O	CO	CO_2
1	5	95	0	0
2	5	75	0	20
3	5	55	0	40
4	5	35	0	60
5	5	15	0	80
6	0	55	5	40

- Variation of inlet gas compositions
- Wide range of compositions possible without any sign of significant influence on stack performance

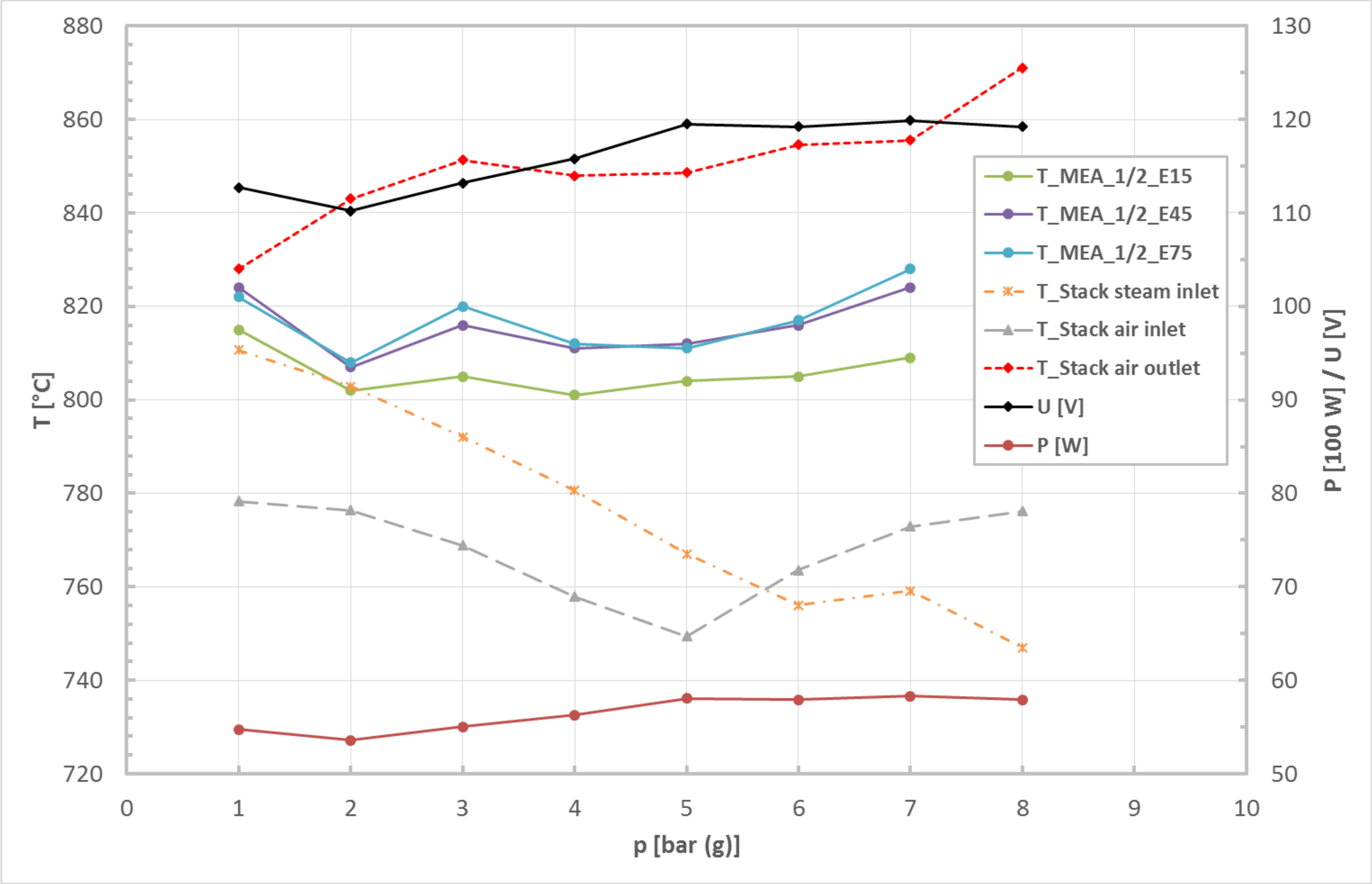
03. Results: co-electrolysis variation of conversion



- Variation of steam conversion
- Moderate increase of stack voltage
- High conversion rates also possible for co-electrolysis

	Molar fractions in %			
Composition	H_2	H_2O	CO	CO_2
7	5	80	0	15

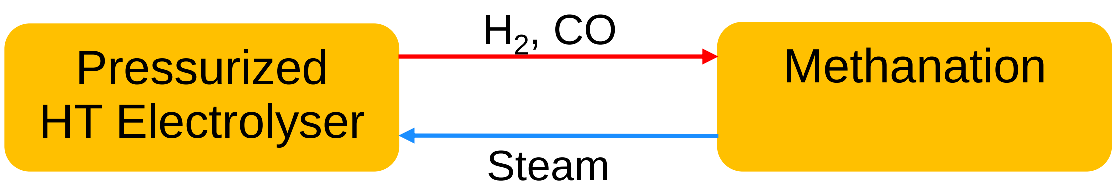
03. Results: pressurized electrolysis



- Pressure increase 1…8 bar (g) shows no significant influence on stack performance
- Gas inlet temperatures are decreasing due to worse measurement conditions and worse performance of microporous thermal insulation material

04. Summary

- sunfire SOC stacks offer the possibility of CO_2 and co-electrolysis
- Outlet composition can be well tuned, but prediction of co-electrolysis outlet composition hardly possible, must be tested and measured
- Operation of a full scale stack under pressure up to 8 bar works; higher pressure operation under preparation



- Coupling and thermal integration of Methanation unit and pressurized high temperature Electrolyser leads to a considerably higher overall system efficiency for PtG

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HELMETH

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Thank you for your interest!