# Future Fuels –
# Solar Steam and Electrolysis for Hydrogen Production


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# Outline

- Motivation and concept
- Experimental setup
- Results of solar components and combined operation with 12-cell electrolyzer
- Conclusion and Outlook

# Role of Hydrogen / Electrolysis in the Energy Transition

**1.** Enable **large-scale renewables integration**

**2.** Act as a **buffer/**increase system **resilience**

Salt cavern

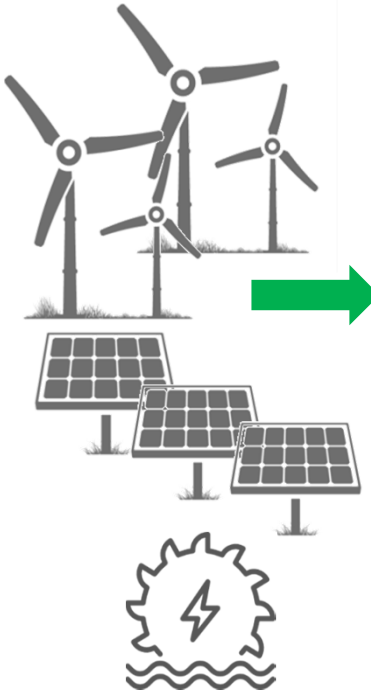
**3. Distribute** energy across sectors and regions

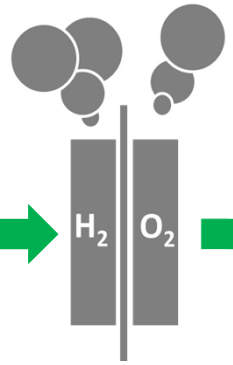
**4.** Decarbonize **transport**

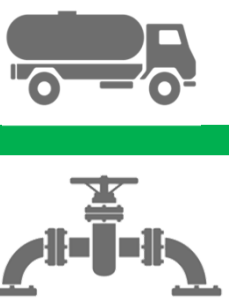
5. Decarbonize **building heating and power**

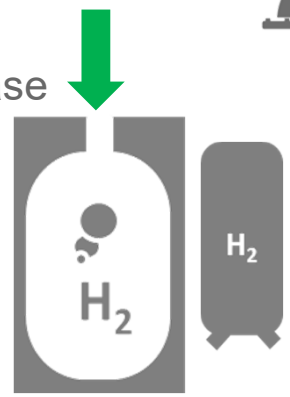
6. Decarbonize **industry**

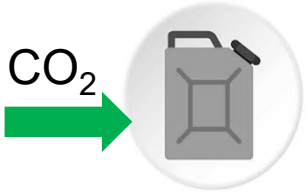
7. **Feedstock,** using captured carbon





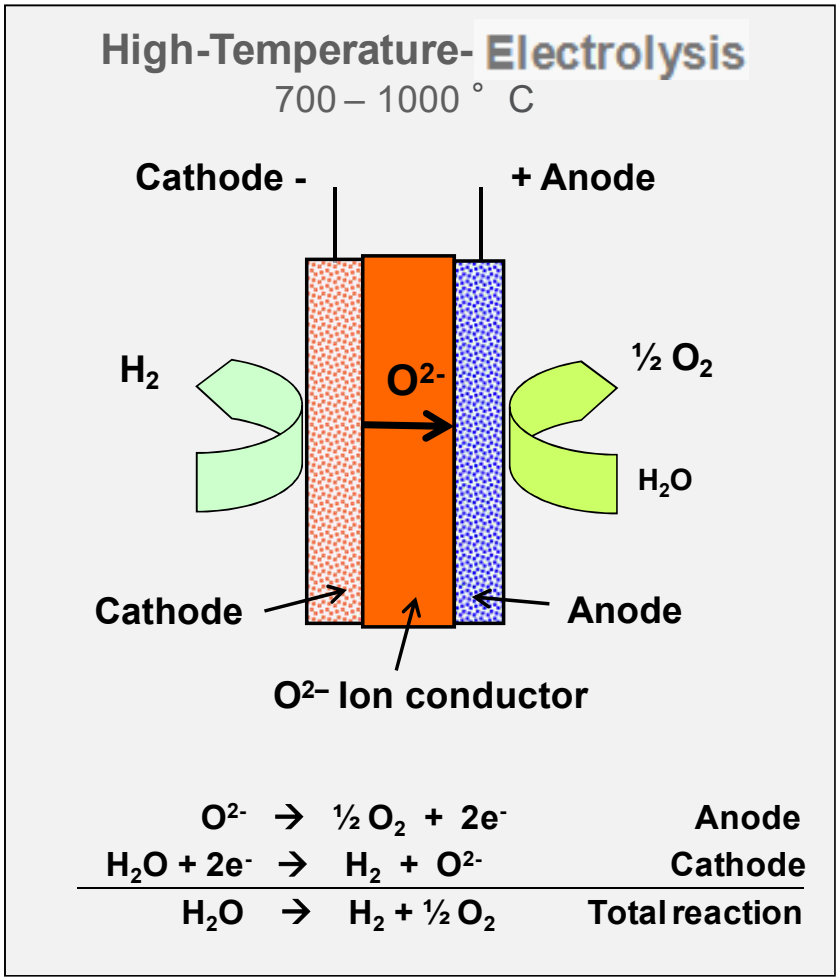






# Solid Oxide Electrolysis at High Temperature

+ Improved reaction kinetics at high temperature
+ Less electrical energy needed (ΔG) with increasing temperature
+ Highest electric efficiencies with high temperature heat source
+ Adiabatic operation is possible




# Thermodynamics of Electrolysis

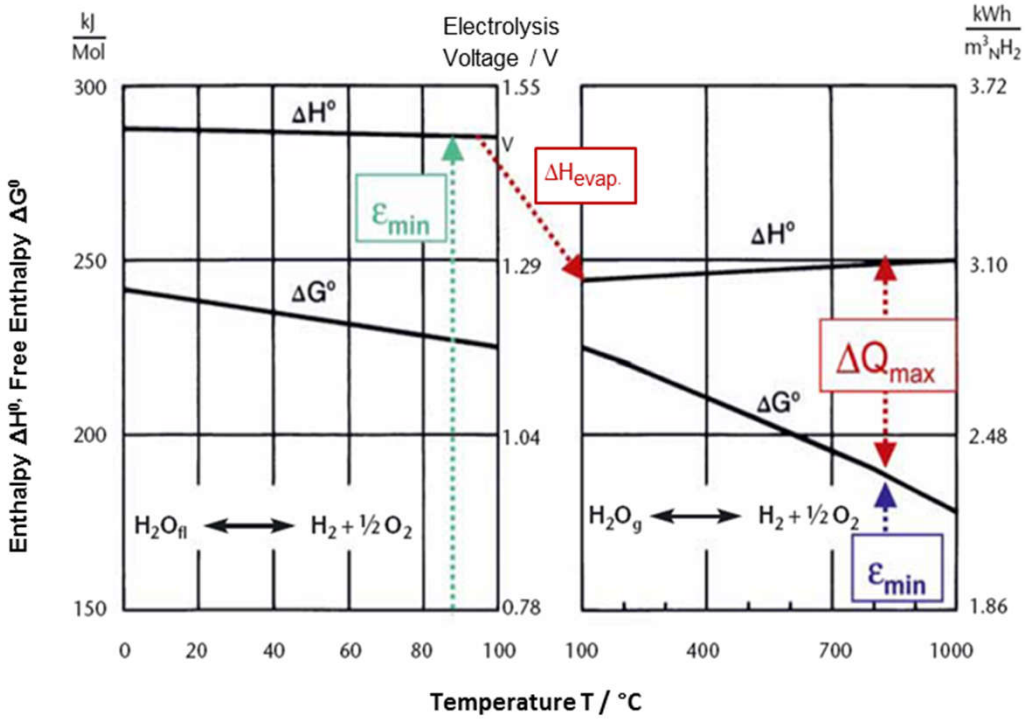
$$E_{rev} = \frac{\Delta G^0}{n\,F} = 1{,}23\ \text{V}$$

$$E_{TN} = \frac{\Delta H^0}{n\,F} = 1{,}48\ \text{V}$$

$$\eta = \frac{E_{TN}}{E_{Zelle}}$$

$\Delta G^0$ : Gibbs Free Reaction Energy

$\Delta H^0$: Reaction Enthalpy

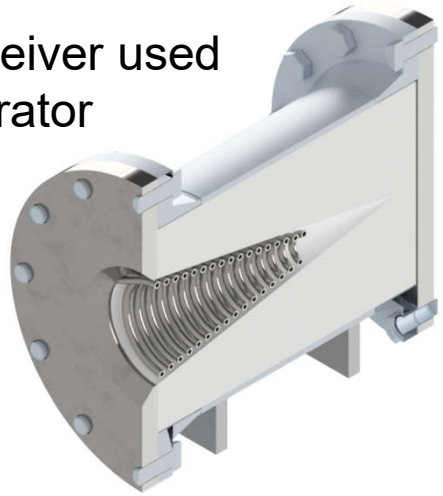


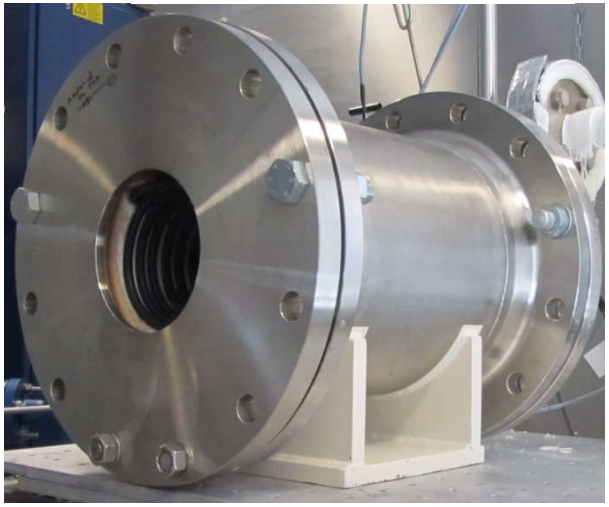

Source: W. Schnurnberger, U. Wittstadt und H. Janßen (2004) Wasserspaltung mit Strom und Wärme. In: Themenheft 2004: Wasserstoff und Brennstoffzellen - Energieforschung im Verbund, url: http://www.fv-sonnenenergie.de/publikationen/gesamt_07.pdf.

# Laboratory at Solar Research in Cologne with Solar Simulator and Solar Receiver

# Solar Simulator and Solar Steam Generator

Spiral solar receiver used as steam generator





- 10 xenon short-arc lamps with elliptical reflectors
- Short wave radiation of about 20 kW
- Heat-flux density of 4.3 MW / m² on a 1 cm ² area

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# Specification of 12-Cell Stack from SolidPower

Fuel electrode supported cell:

- NiO/8YSZ fuel electrode
- 8YSZ electrolyte
- GDC/LSCF air electrode

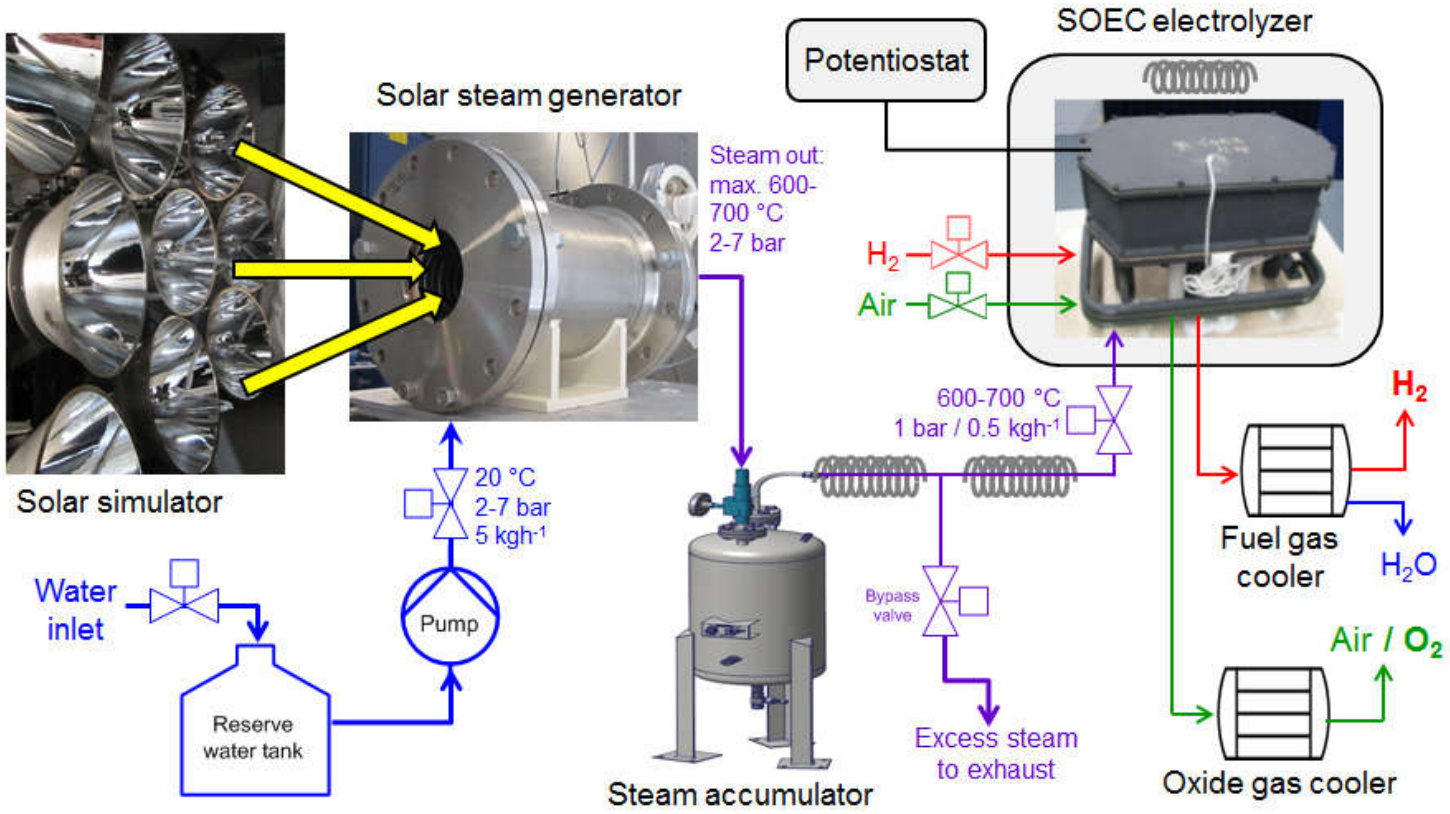
80 $cm^2$ active area

12 repeat units

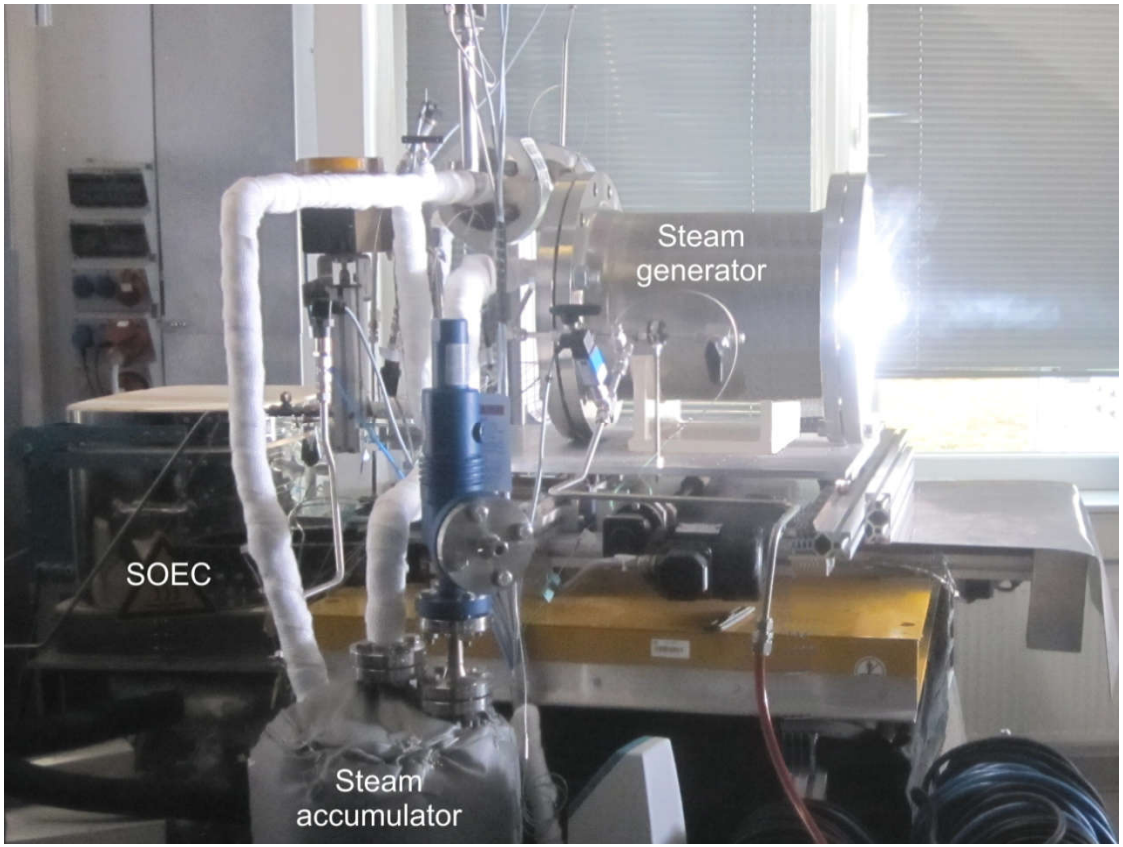
Internal gas manifold for fuel gas

External gas manifold for air

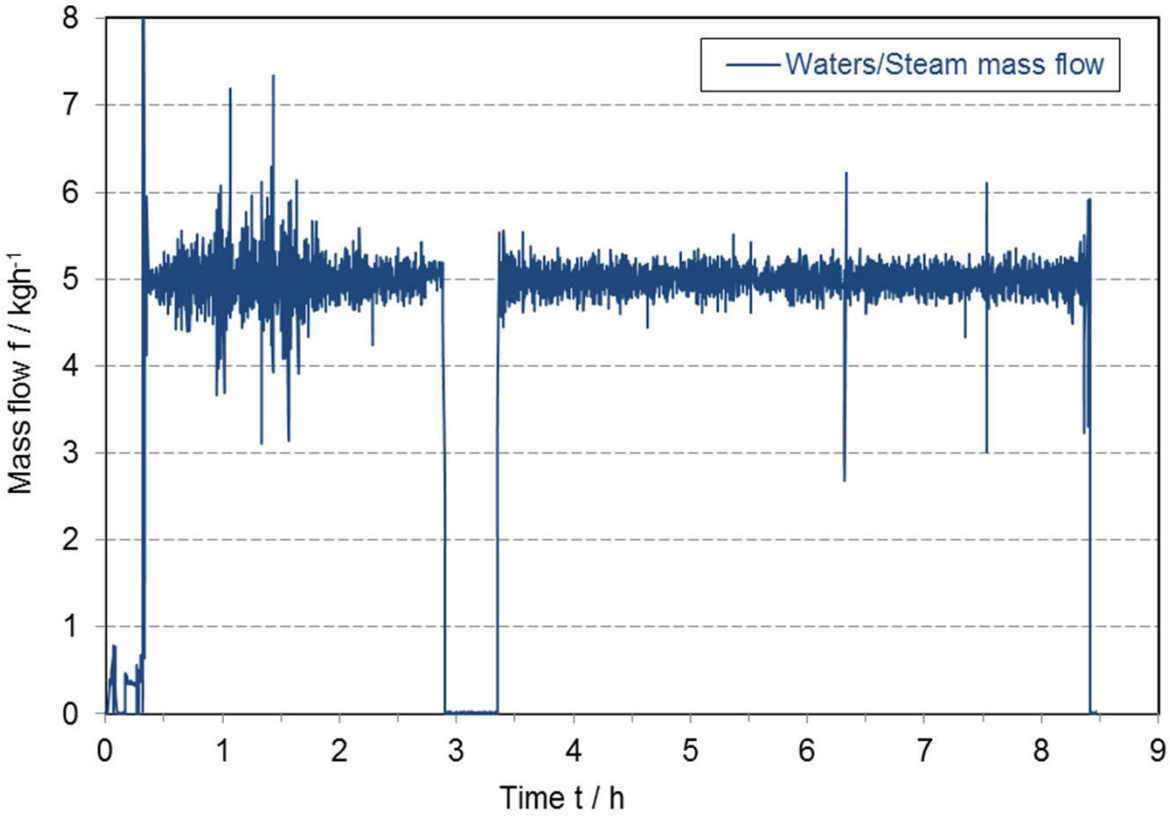

# Experimental Setup of the Solar Heated Solid Oxide Electrolyzer System



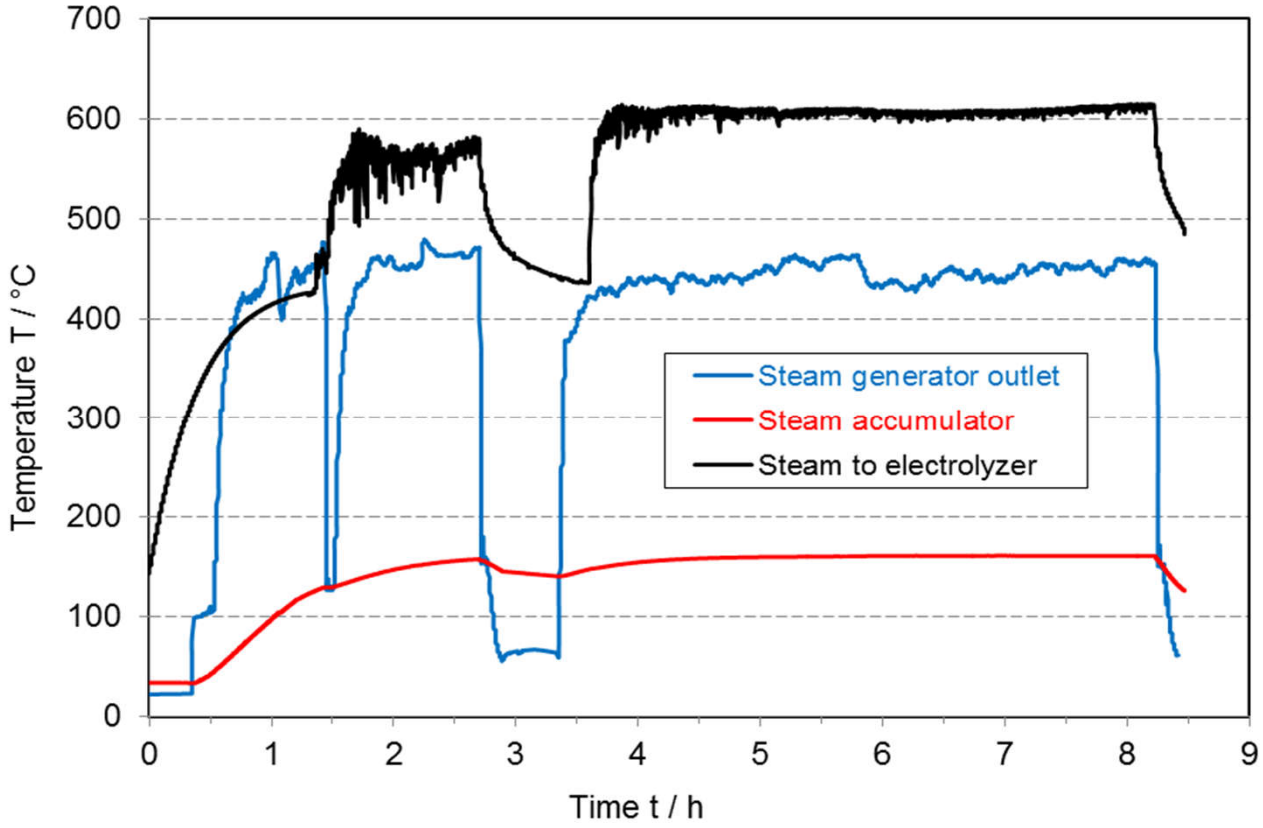

# SOEC Electrolyzer and Solar Steam Generator During Operation



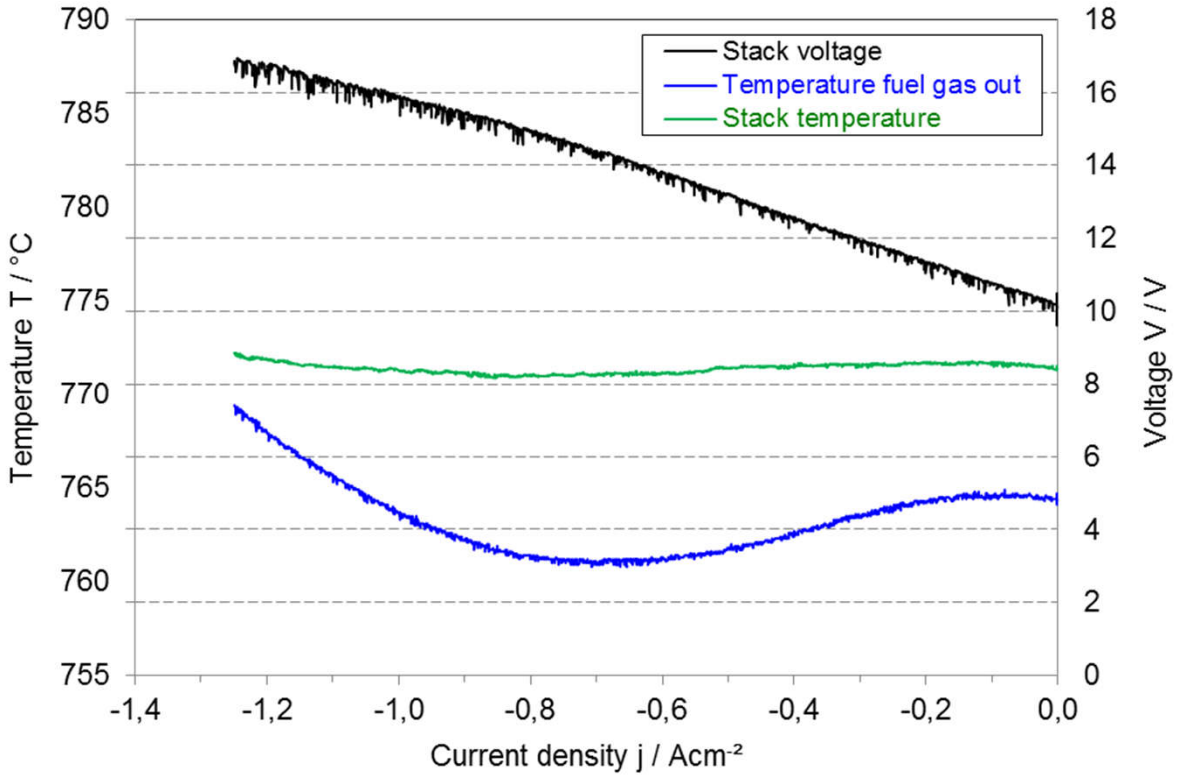

# Mass Flow of Water/Steam Through the Solar Steam Generator



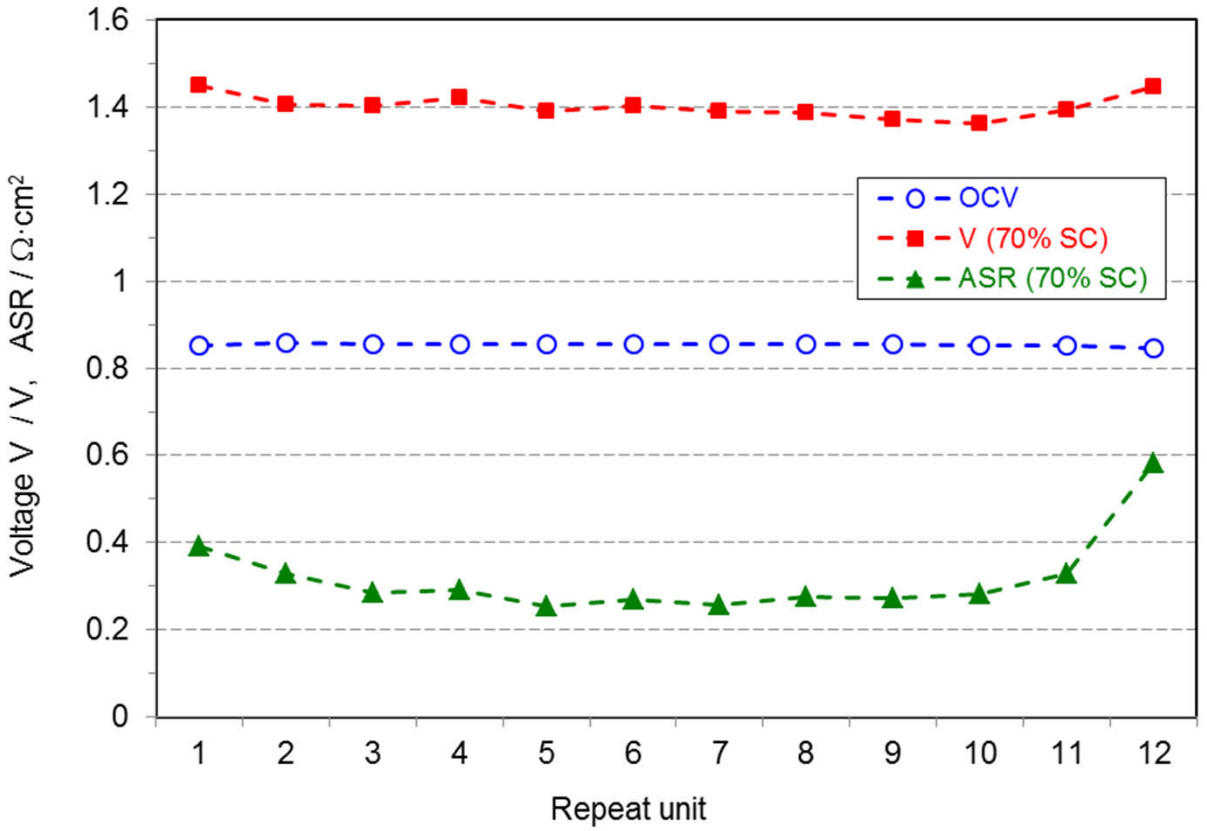

# Relevant Temperature Measurements in the Solar Steam Generation System




# Current-Voltage Behavior of 12-cell SOEC Stack at 770° C with 12.0 slpm $H_2O$ + 1.4 slpm $H_2$ and 20 slpm Air




# Characteristic Electrochemical Values of the Repeat Units of the SOEC stack at 770° C

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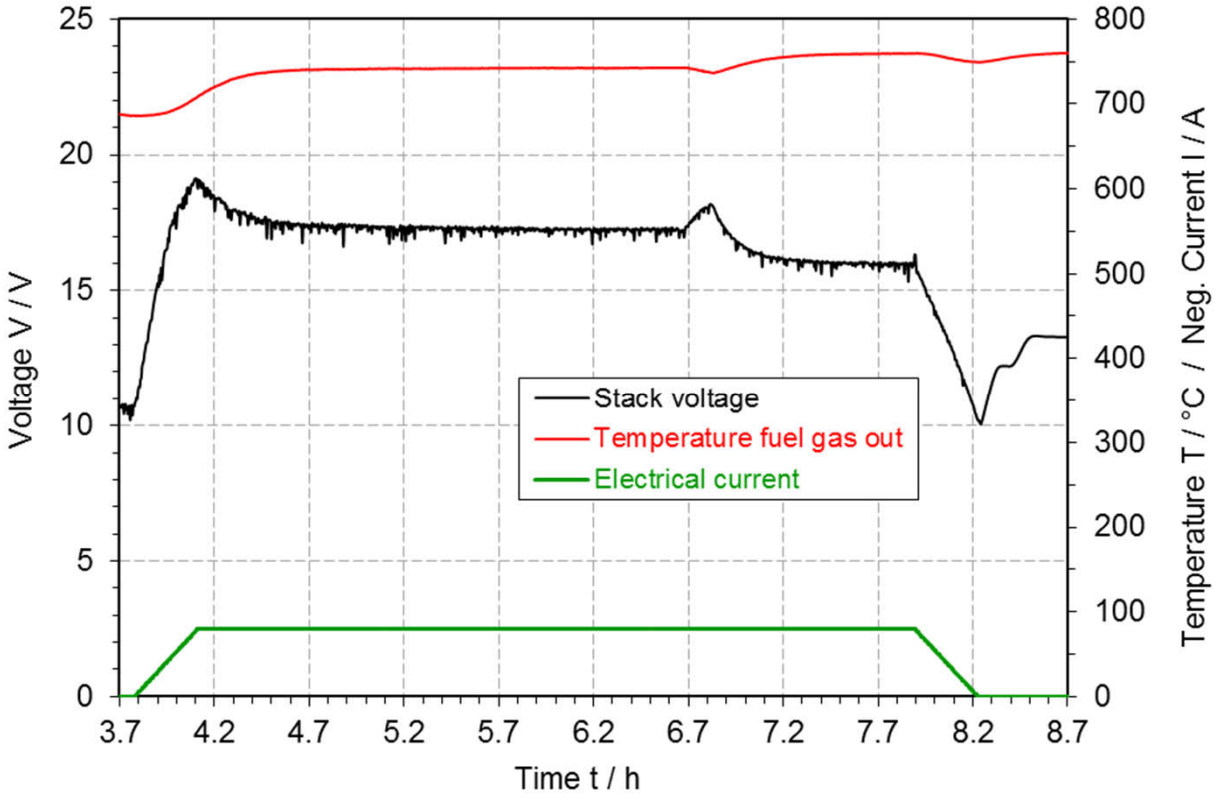
# Behavior of the SOEC Stack During Steady-State Operation for 4 h at 700° C and -1.0 Acm$^{-2}$




# Conclusion and Outlook

- A solar similator and a solar steam generator were connected and successfully operated with a 12-cell SOEC stack.
- At a current density of -1.25 A $cm^{-2}$ and 770 °C hydrogen was produced with a steam conversion rate of 70 % and an electrical stack efficiency of 93 %.
- Several improvements are planned for further work:
  - Optimization of control of steam generator for minimized steam supply instabilities
  - Improvement of thermal insulation to minimize thermal losses.
  - Development of advanced steam accumulator for operation at 700 °C
  - Increase of overall system efficiency
- Demonstration of co-electrolysis operation with integrated solar heat for syngas production

# Future Vision: Hydrogen and Fuel Production with Solar Heat Integration in Large Power Plants


# Acknowledgment

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***Thank you for your attention***