HyStORM - sustainable, decentralized hydrogen generation and storage

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SCIENCE
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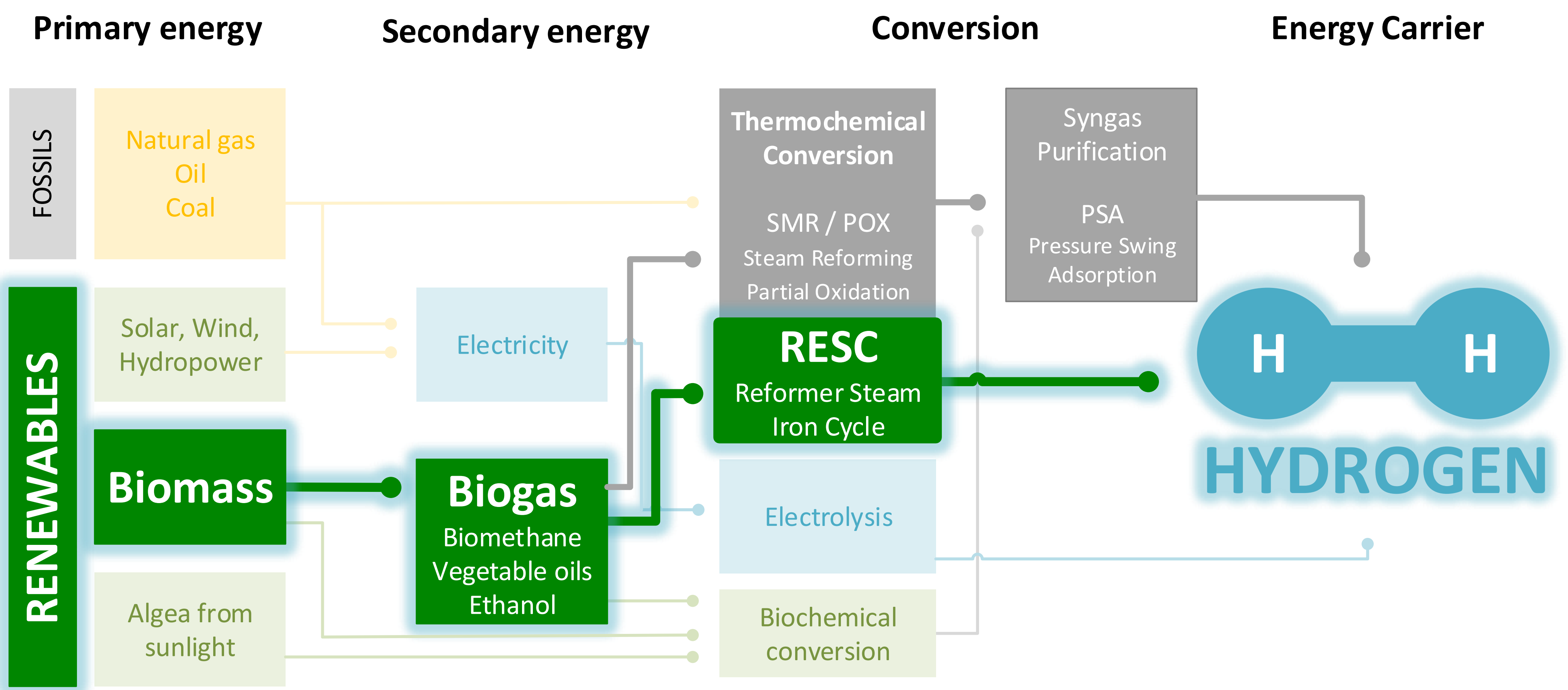
http://ceet.tugraz.at/fuelcells

Outline

- **Introduction**
  From the idea to implementation
- **High-purity hydrogen from renewables**
  Advances in a 10 kW lab demonstration system
- **100 bar high-pressure hydrogen**
  Pre-pressurized *H_2 release*
- **Conclusion and Outlook**

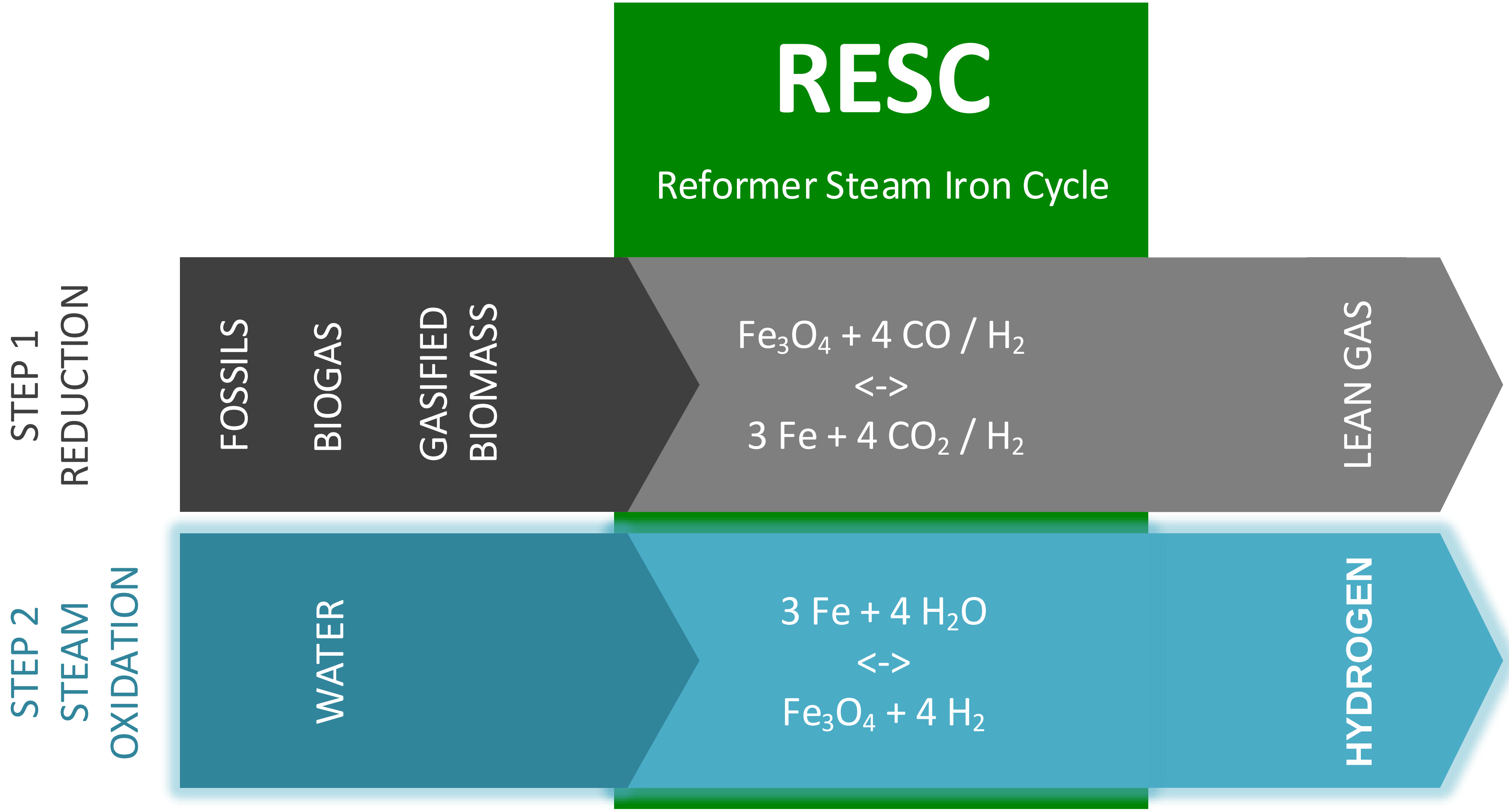
Introduction

RESC process in the context of hydrogen production pathways



Introduction

RESC process in the context of hydrogen production pathways



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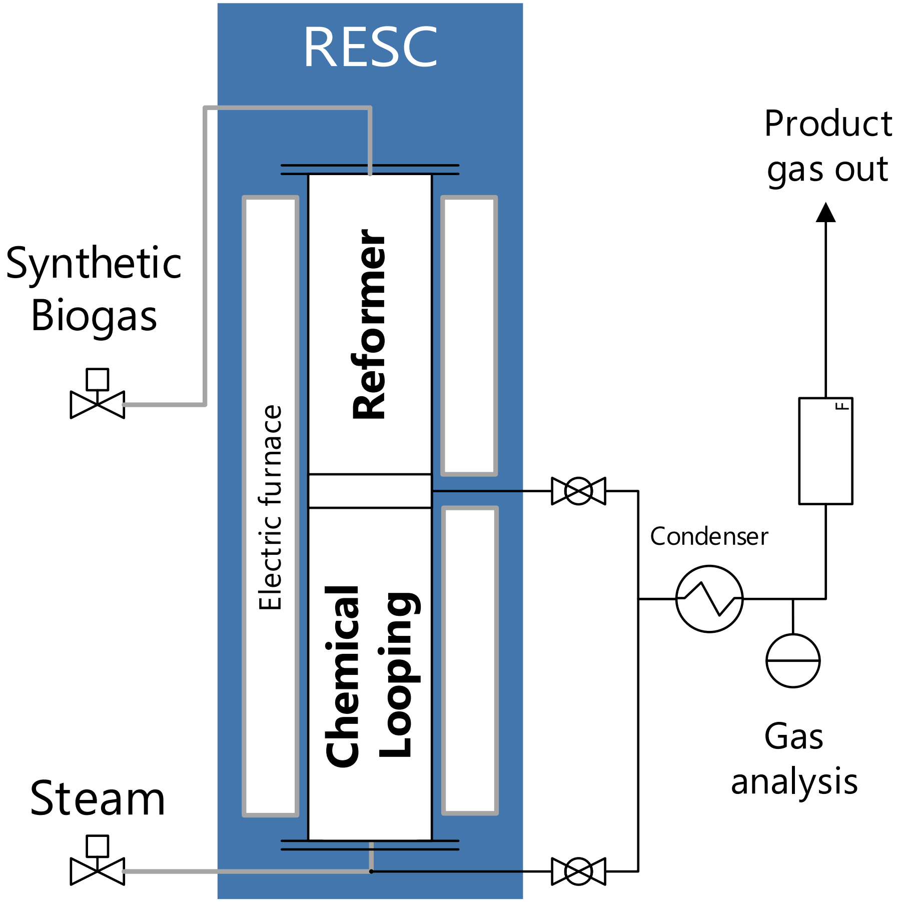
Advances in 10 kW lab system

Lab demonstration system



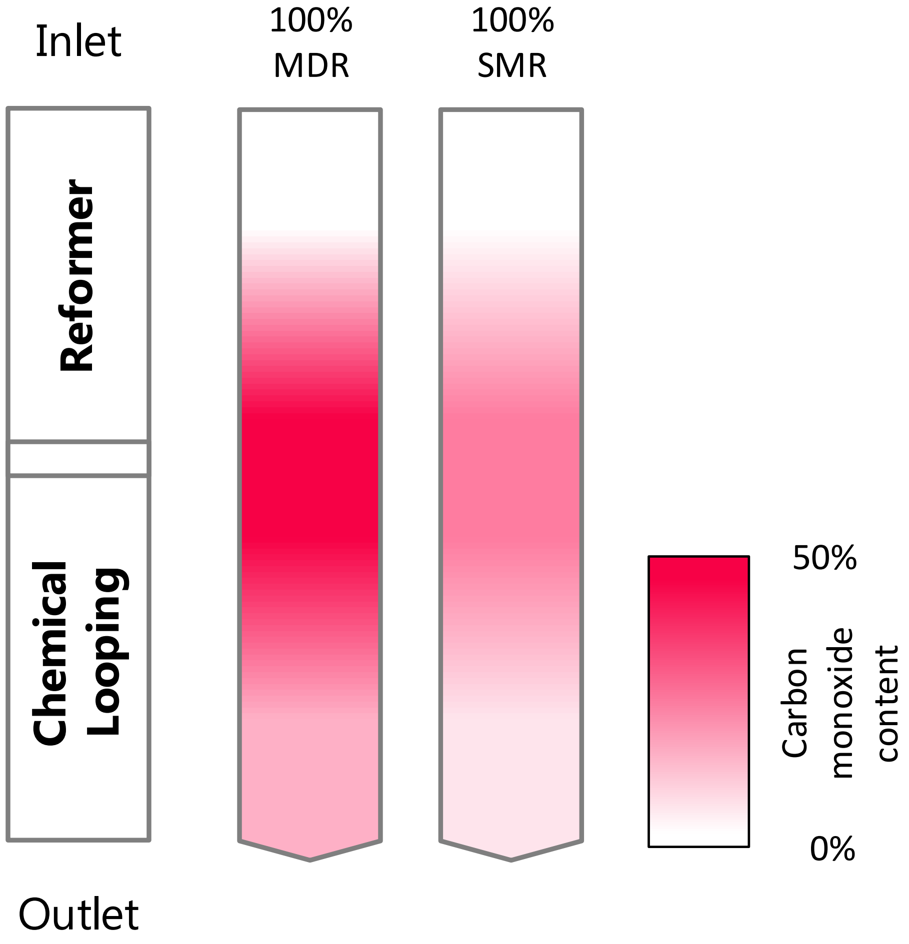
Simplified process scheme and lab system

Advances in a 10 kW lab system

Hydrogen purity

- **Low S/C ratio for optimized performance**
- MDR of biogenic feedstocks induces **elevated carbon monoxide content**
- **Avoidance of low temperature areas** in the system is crucial for hydrogen purity

Boudouard	$\mathbf{2\,CO \rightarrow C + CO_2}$	$\Delta H_{R,298} = 75\ kJ\ mol^{-1}$
MDR	$CH_4 + CO_2 \rightarrow 2\,CO + 2\,H_2$	$\Delta H_{R,298} = 206\ kJ\ mol^{-1}$
SMR	$CH_4 + H_2O \rightarrow CO + 3\,H_2$	$\Delta H_{R,298} = 247\ kJ\ mol^{-1}$



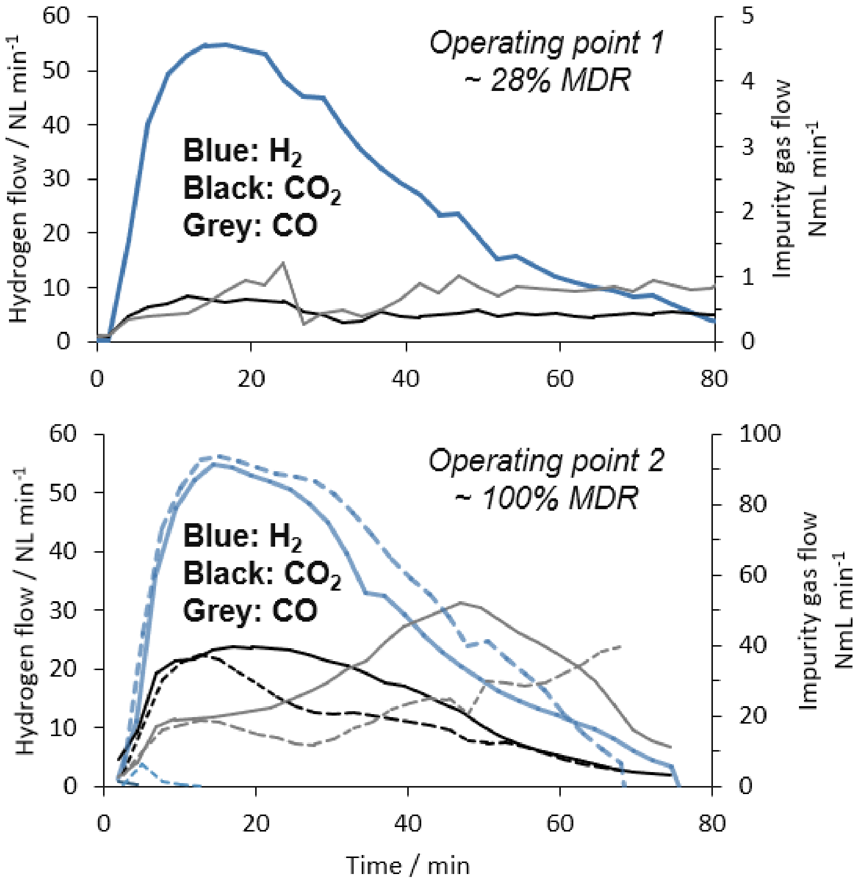
Advances in a 10 kW lab system

Hydrogen purity

- MDR ratio <28%: **Excellent hydrogen purity (>99.998%)**
- MDR ratio ~76%: **Good hydrogen purity (>99.996%),** unsteady behavior of impurities
- MDR ratio 100%: **Significant carbon deposition and lower purity (<99.98%)**

Operating point	*Biogas CH_4:CO_2*	*O/R ratio*	*MDR ratio*
1	75:25	1.2	28%
2	45:55		100%
3	75:25	1.6	21%
4	45:55		76%

Hydrogen product gas stream in oxidation phase



Graphics adapted from: Bock et al., 2019, RSC Advances, DOI:10.1039/C9RA03123E (**CC BY 3.0**)

Advances in a 10 kW lab system

Hydrogen storage and long-term experience

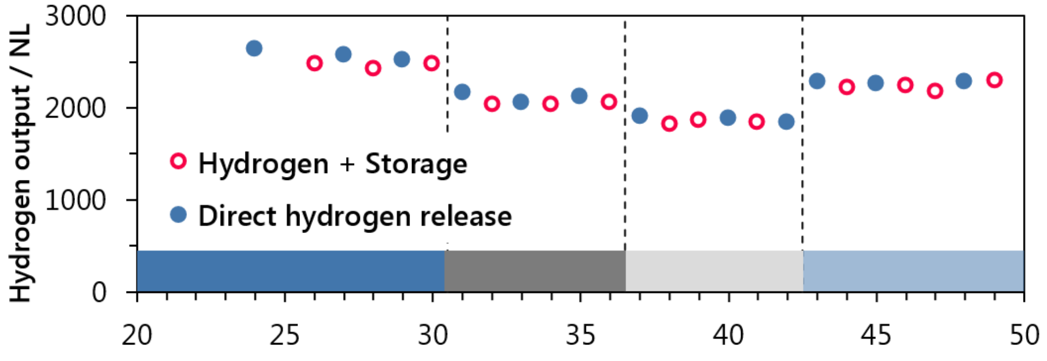
- **Up to 60% feedstock utilization**
  for high-purity H_2 - 99.999%

- **1000 hours time-on-stream,**
  over one year of discontinuous operation

- **Loss-free energy storage**
  equal to 1000 bar PH_2

- **On-time hydrogen generation**
  e.g. for decentralized systems

Excerpt of long-term test series



Feedstock utilization

$$\eta_{H2} = \frac{n(H_{2,prod}) * HHV_{H2}}{n(H_{4,cons}) * HHV_{CH4}}$$

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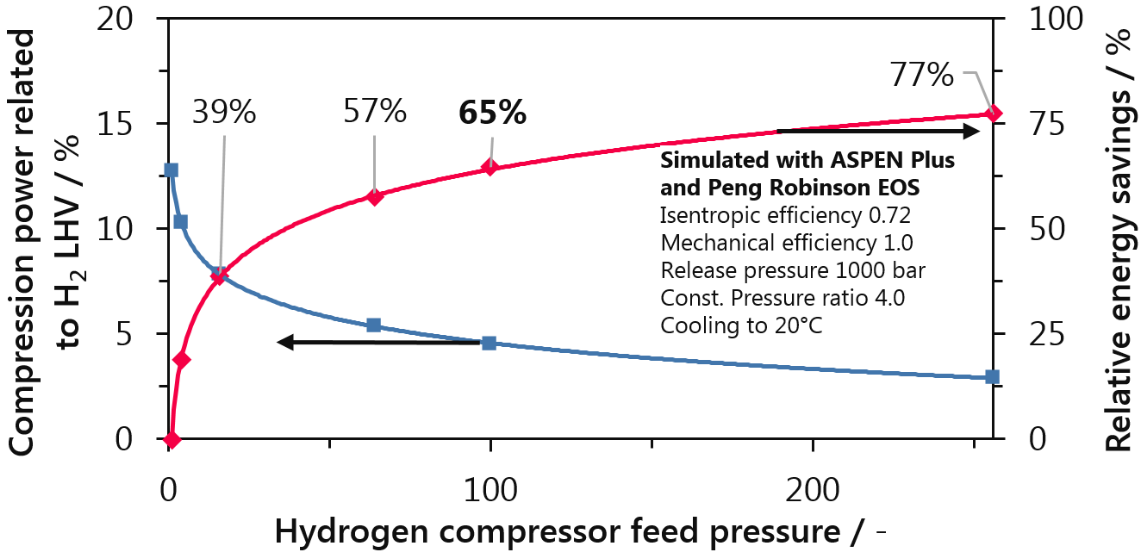
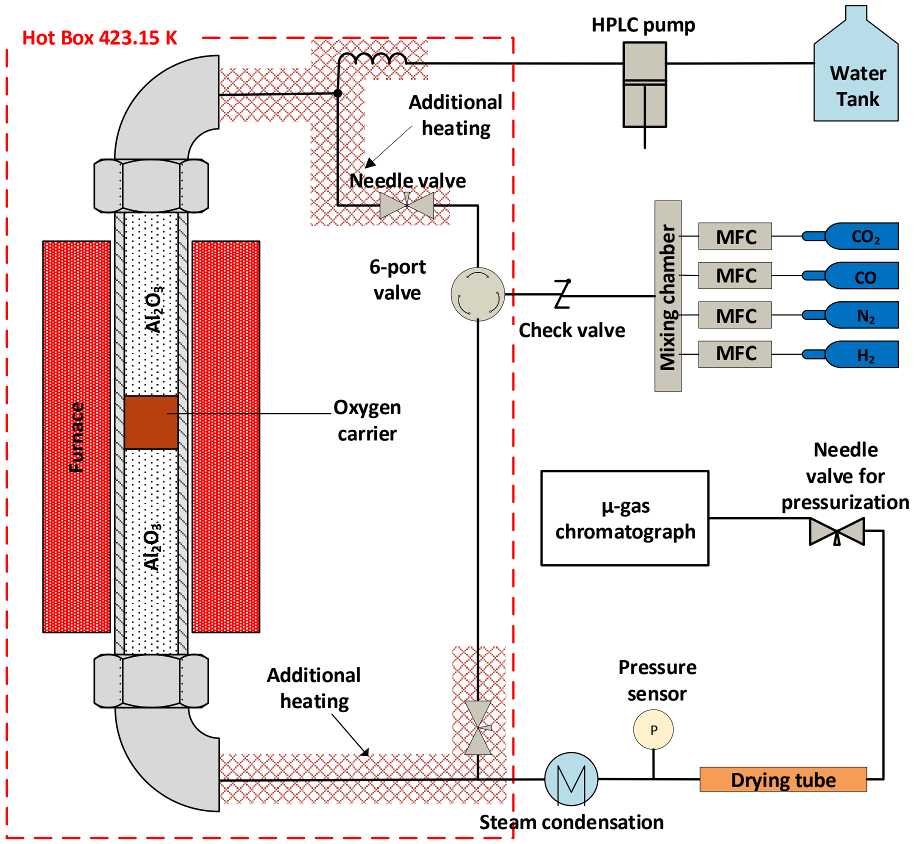
100 bar high-pressure hydrogen

Pre-pressurized H_2 *release*

- System-integrated **100 bar pre-pressurized release demonstrated in lab system** by water feed liquid compression

- **Significant energy savings** for **1000 bar allocation**

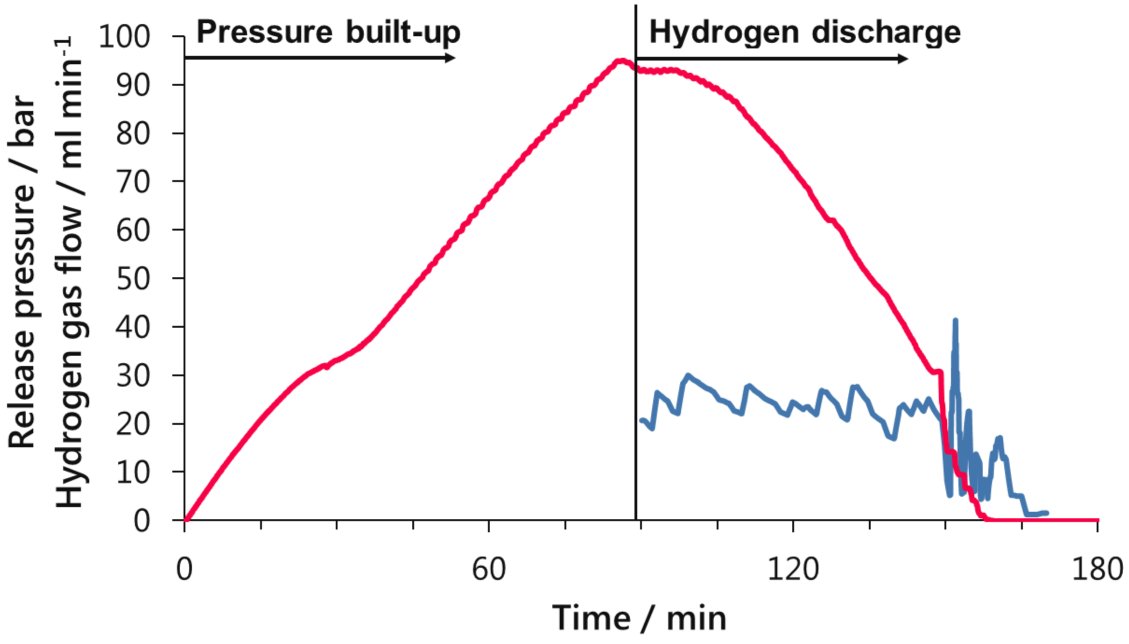




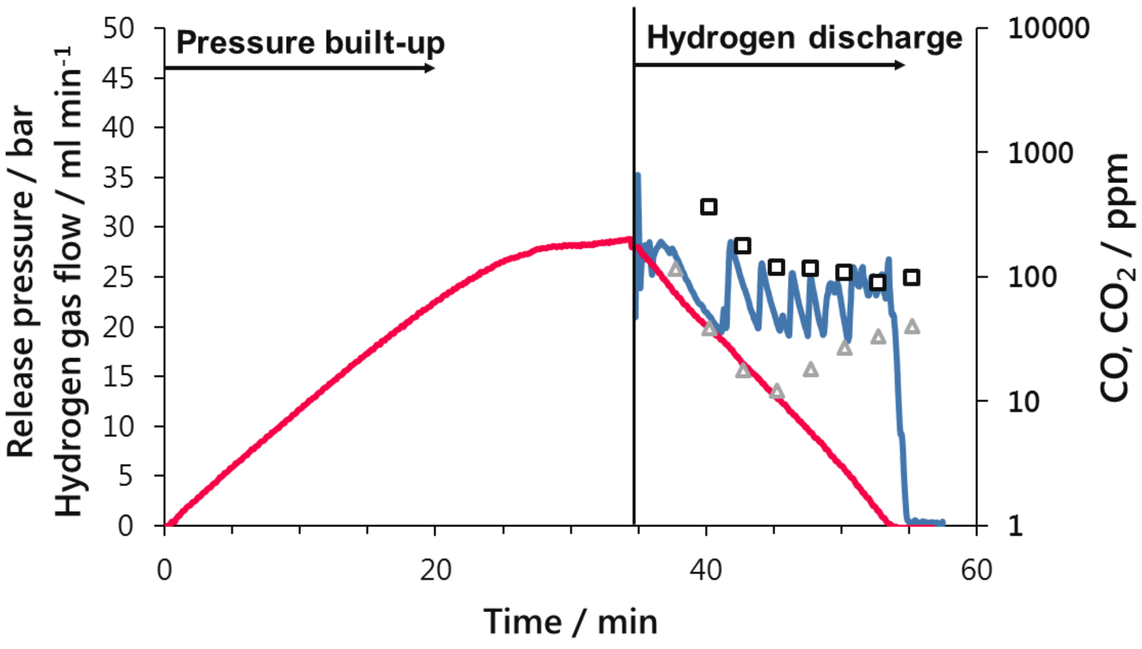
Graphics from: Zacharias et al., 2019, Int. J Hydrogen Energy, DOI:10.1016/j.ijhydene.2019.01.257 (**CC BY-NC-ND 4.0**)

100 bar high-pressure hydrogen

Pre-pressurized *H_2 release*



Hydrogen release after full reduction



Hydrogen release after reduction with CO_2 sequestration

Zacharias et al., 2019, Int. J Hydrogen Energy, DOI:10.1016/j.ijhydene.2019.01.257 (**CC BY-NC-ND 4.0**)

Conclusion

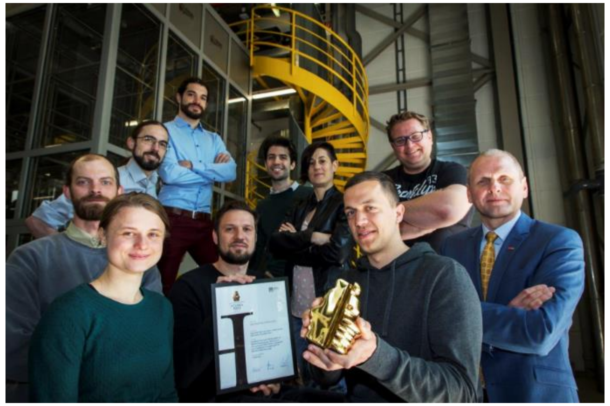
- **Hydrogen from decentralized available resources** for low-temperature fuel cells
  - **High product gas purity (99.999%)**
  - **Feedstock utilization up to 60%**
  - Zero- or **negative carbon dioxide emissions** with CCS/CCU
  - **Loss-free energy storage**
  - **On-time hydrogen generation**
- **Pressurized release at 100 bar** demonstrated

Acknowledgements

AVL

RG H2

Project partners and team



HOUSKA award 2017

State Prize Mobility 2017

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