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Modellierung und Simulation einer PEM-Elektrolyse-Regelung

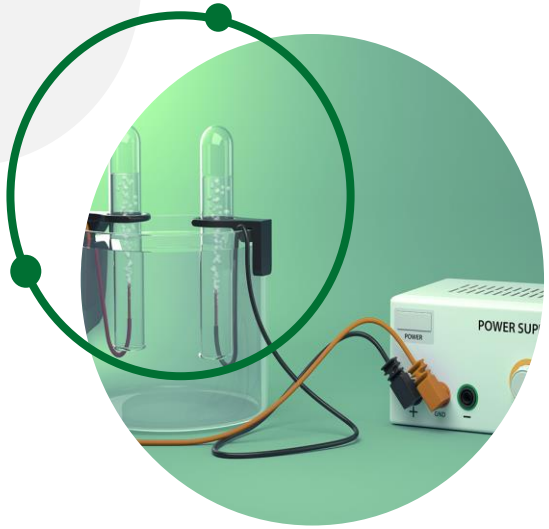
Fabian Seidel

18.11.2021

INTELLIGENCE IN DRIVES

Agenda

- Elektrolyse
- Forschungsprojekt Recycalyse
- Systemaufbau
- Hauptregelkreise
- Simulationsmodell
- Simulation des Gesamtsystems



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Elektrolyse von Wasser
Elektrochemischer Prozess

- Anodenreaktion (Oxidation)

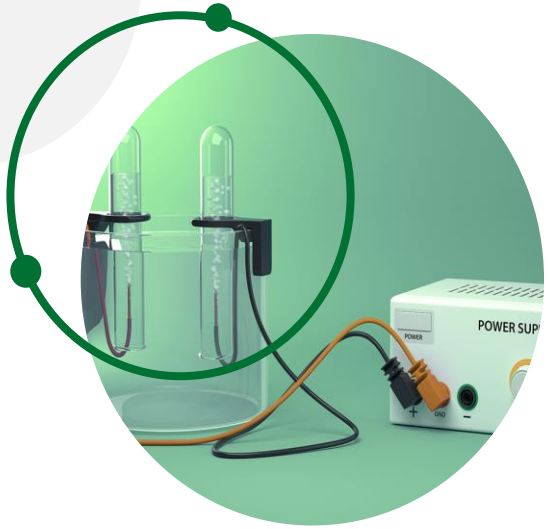
$$2\,H_2O\,(l) \rightarrow 4\,H^+ + O_2\,(g) + 4\,e^-$$

- Kathodenreaktion (Reduktion)

$$2\,H^+ + 2\,e^- \rightarrow H_2\,(g)$$

- Gesamtreaktion

$$2\,H_2O\,(l) \rightarrow 2\,H_2\,(g) + O_2\,(g)$$



(l) – flüssig, (g) - gasförmig

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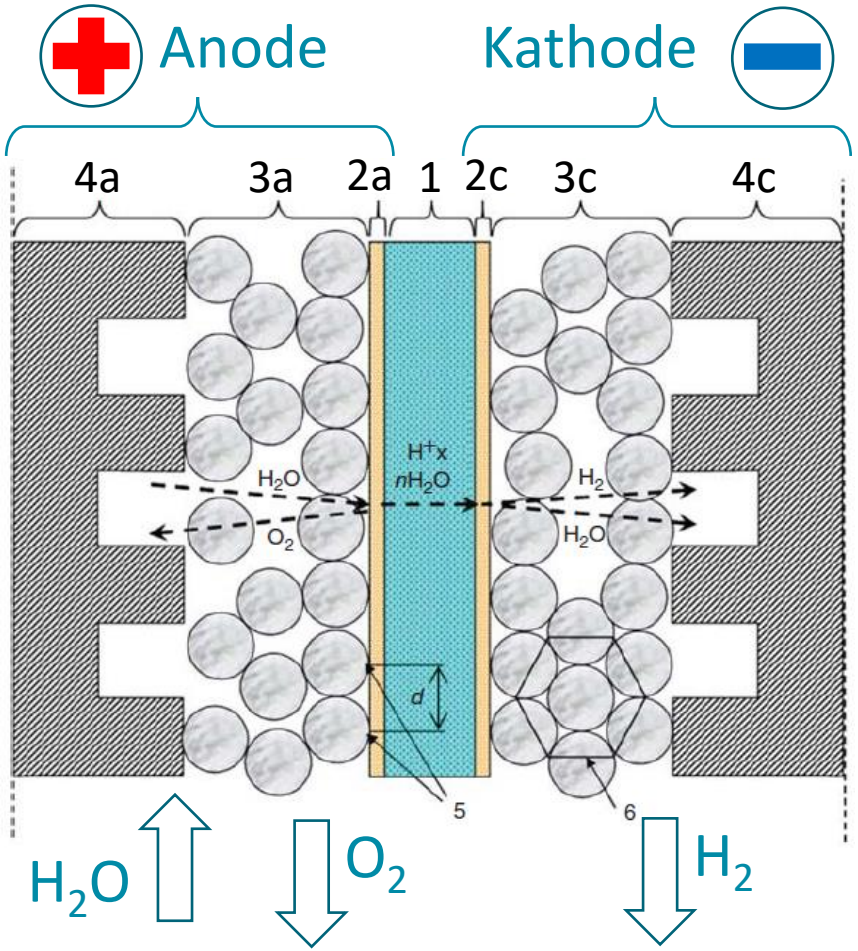
PEMEC Proton Exchange Membrane Eletrolyser Cell



[Hydrogen Production: by Electrolysis]

1. **MEA** (Membran-Elektroden-Baugruppe)
   - protonendurchlässiger Membran
2. **CL** (Katalysatoren-Schicht)
   - poröse Schichten der Elektrokatalysatoren
   - **Anode (a)** -> Sauerstoffentstehungsreaktion
   - **Kathode (c)** -> Wasserstoffentstehungsreaktion
3. **GDL** (Gasdiffusionsschicht)
   - poröse Stromverteiler aus gesinterten Titanpartikeln
4. **Bipolarplatten**
   - zur Stromverteilung und Zellentrennung
   - Kanäle für Wasser und Flüssig-Gas-Gemische

(Dichtungen nicht dargestellt)

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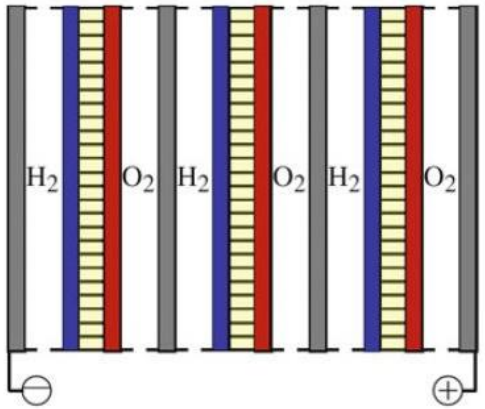
PEMEC - Stackaufbau

Stromversorgung
Bipolare Zellanordnung

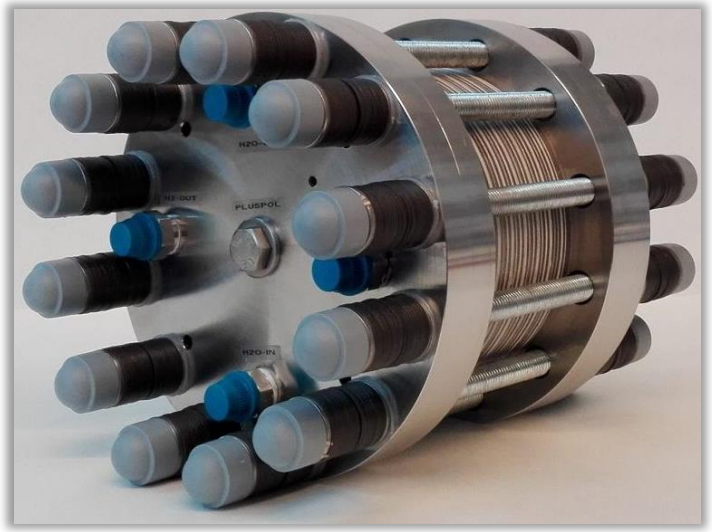


[SpringerVerlag; 2018; Elektrochemische Speicher]

$$U_{Ges} = \sum U_i$$

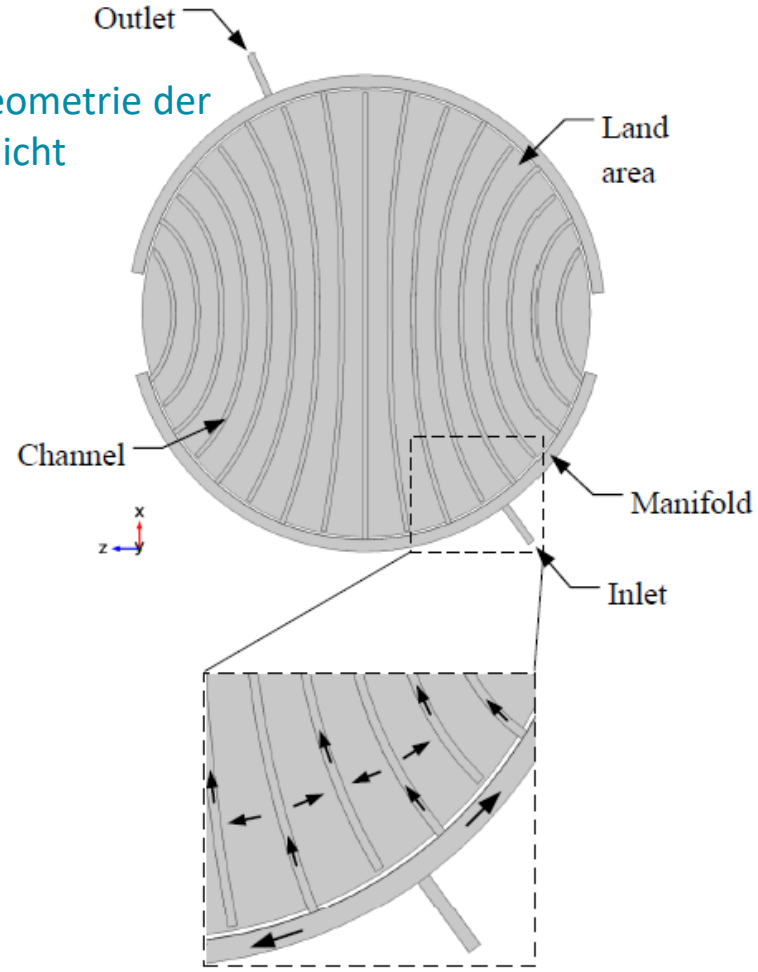
$$I_{Ges} = I_i$$

Stackaufbau



[HIAT gGmbH]

Strömungsfeldgeometrie der Gasdiffusionsschicht



[Flow maldistribution in the anode of a polymer electrolyte membrane water electrolysis cell employing interdigitated channels]

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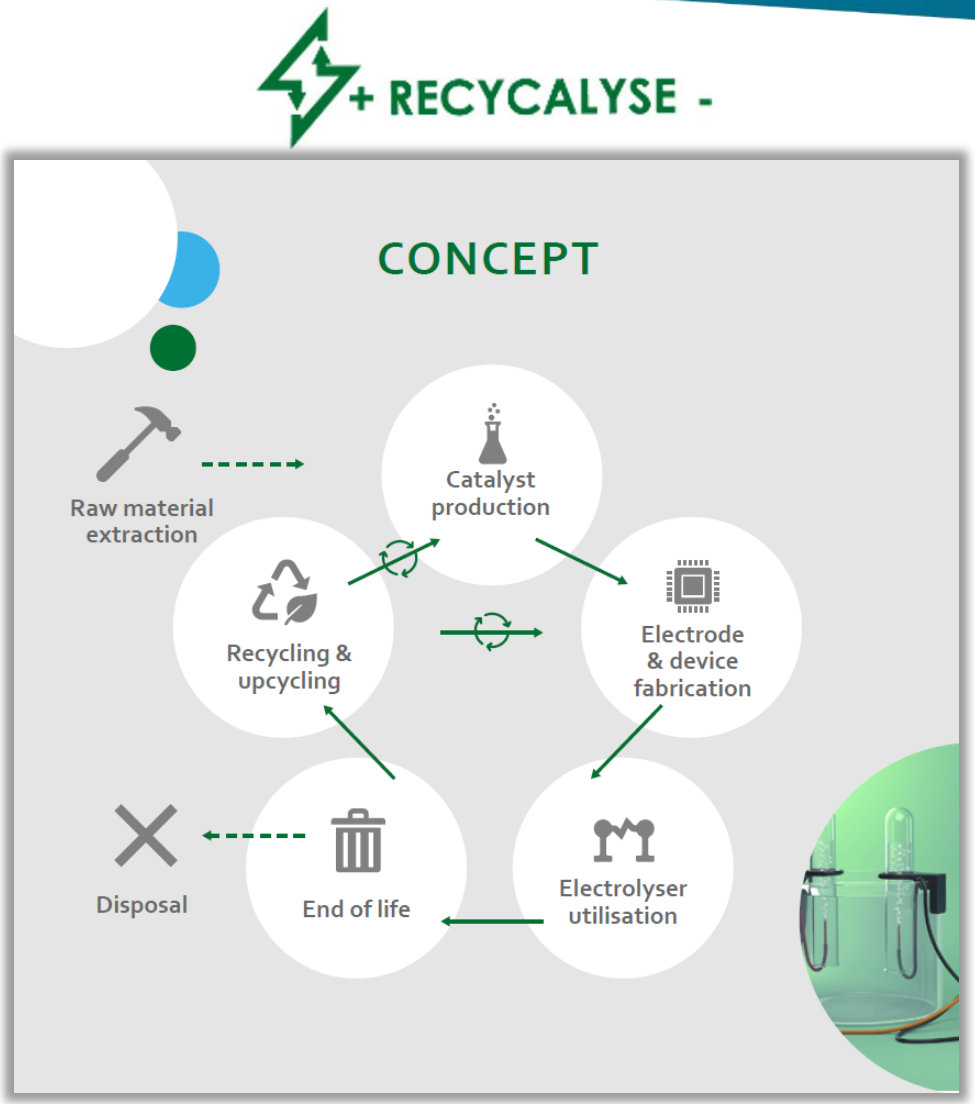
RECYCALYSE
Horizon 2020

- Entwicklung und Herstellung von hochaktiven Sauerstoffkatalysatoren
- Reduktion oder Verzicht auf „kritische Rohstoffe“
- Preiswerte PEM-Elektrolyse
- Materialrecycling von PEM-Katalysatoren, Elektroden und Gesamtsystem
- Optimierung der Betriebsstrategien und Kosteneinsparpotenial



[Recycalyse]

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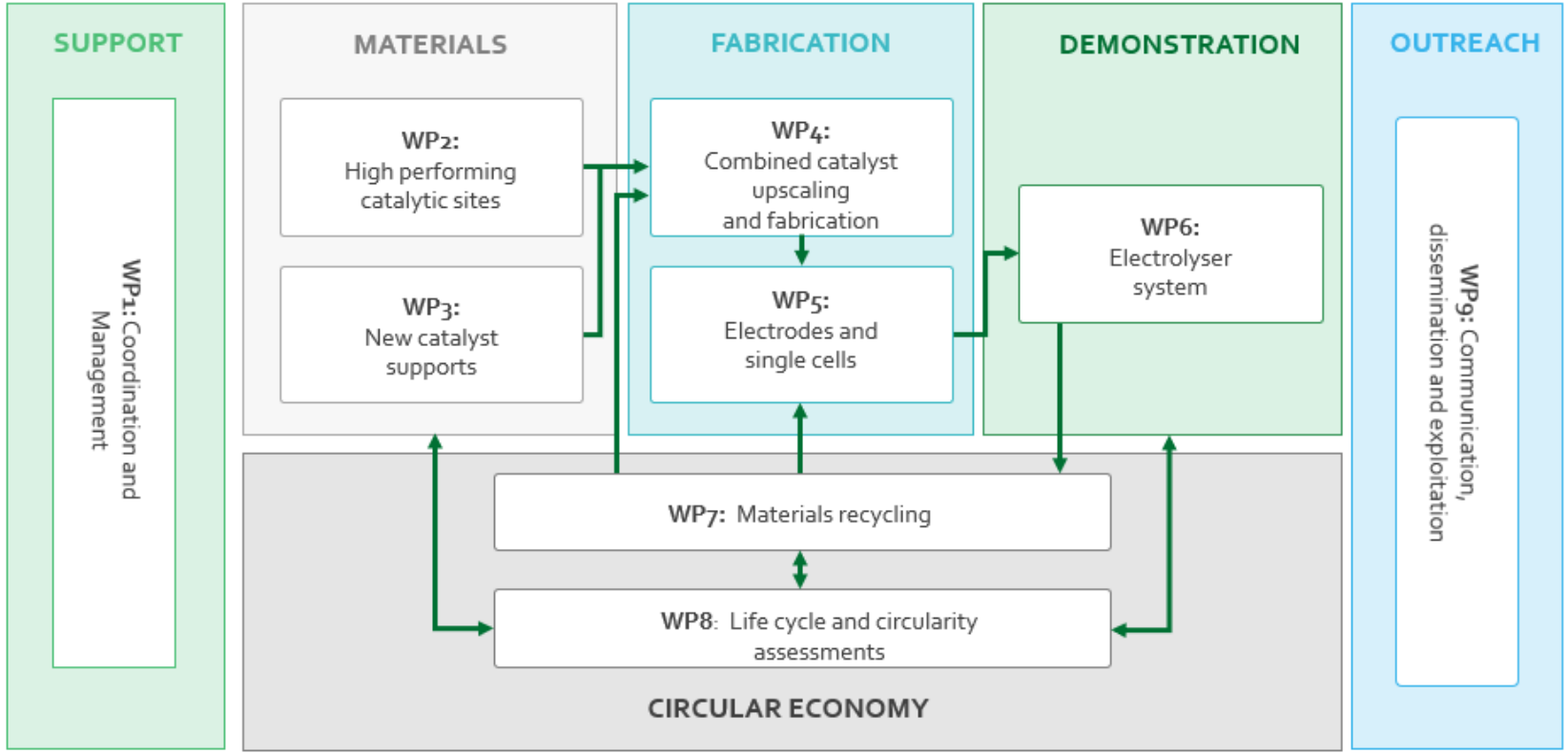
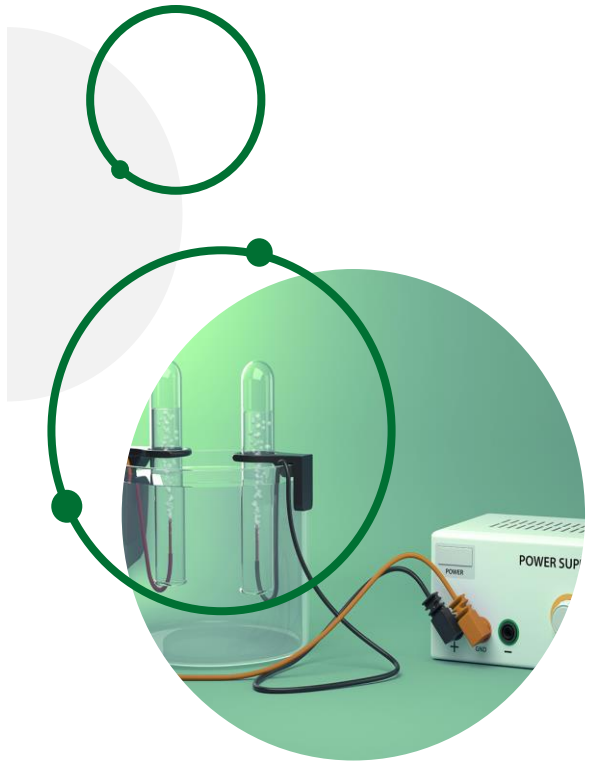
Recycalyse
Projektschwerpunkte





[Recycalyse]

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Recycalyse Arbeitspaket „Electrolyser System“

Demonstrator

- Herstellung und Test eines PEM-Elektrolysestacks
- Entwicklung eines elektrochemischen Modells und eines Gesamtsystemmodells
- Optimierung der Regelung
- Systembewertung

Ziele

- Skalierbarkeit des Elektrolyseprozesses für erneuerbare Energien demonstrieren
- Reduktion der Kapitalkosten
- Optimierung des gesamten Wasserstoffherstellungsprozesses
- Wasserstoff (Reinheit, Kosten)

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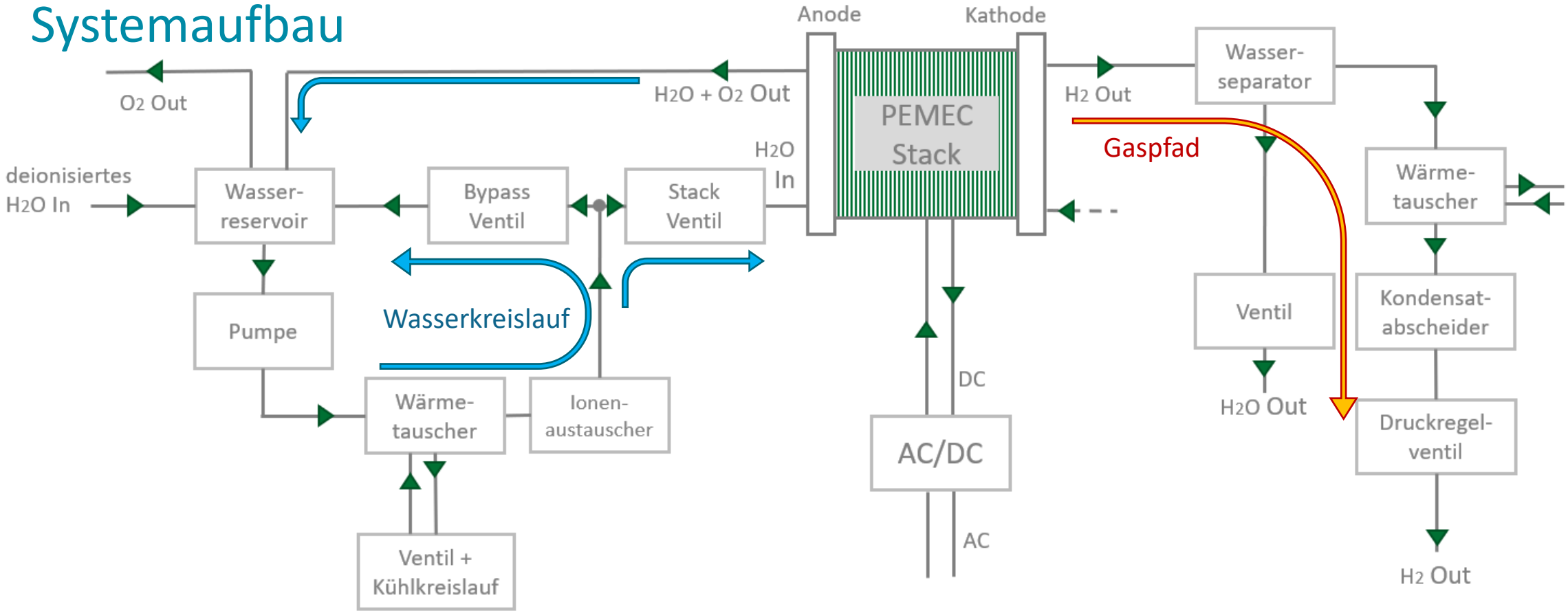
Demonstrator
Systemaufbau



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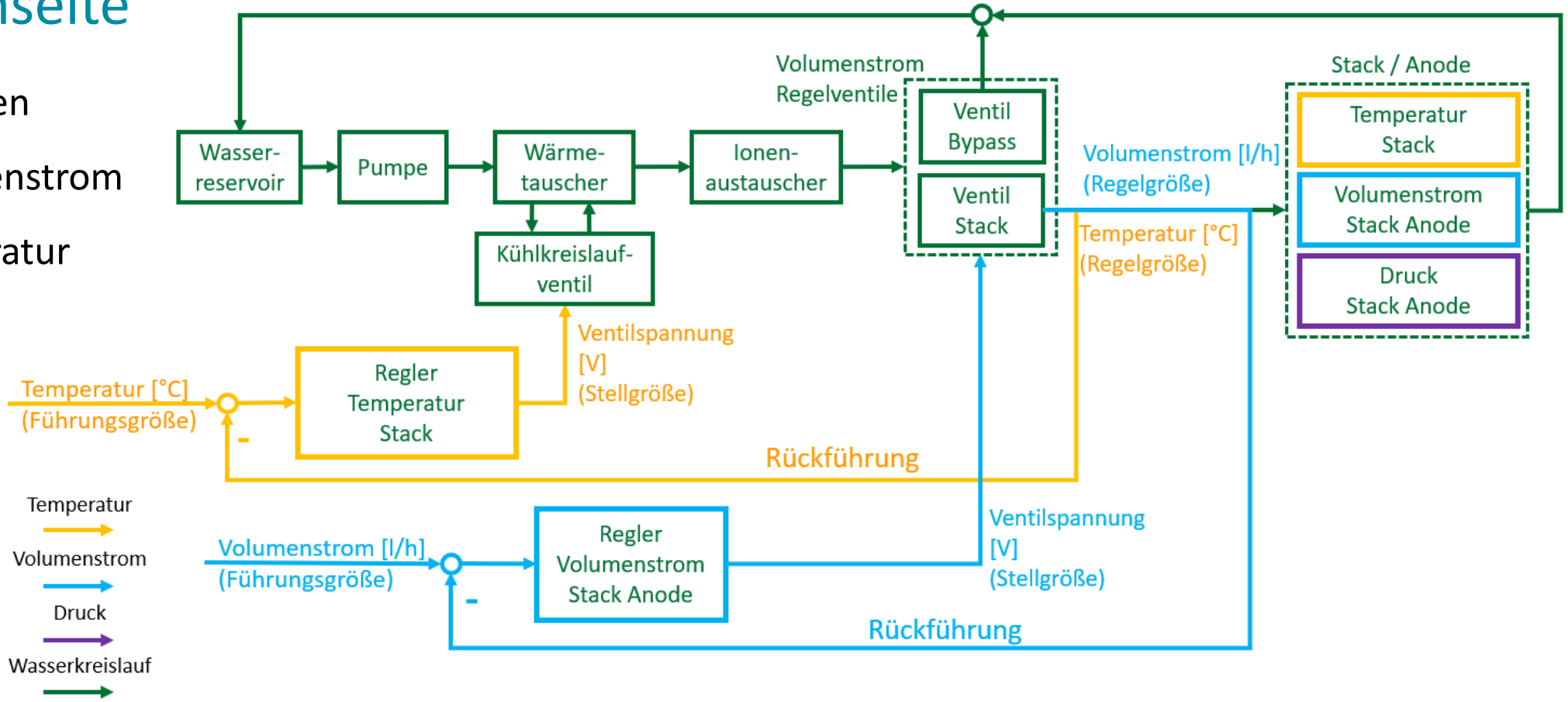
Regelkreise
Anodenseite

Regelgrößen

- Volumenstrom
- Temperatur



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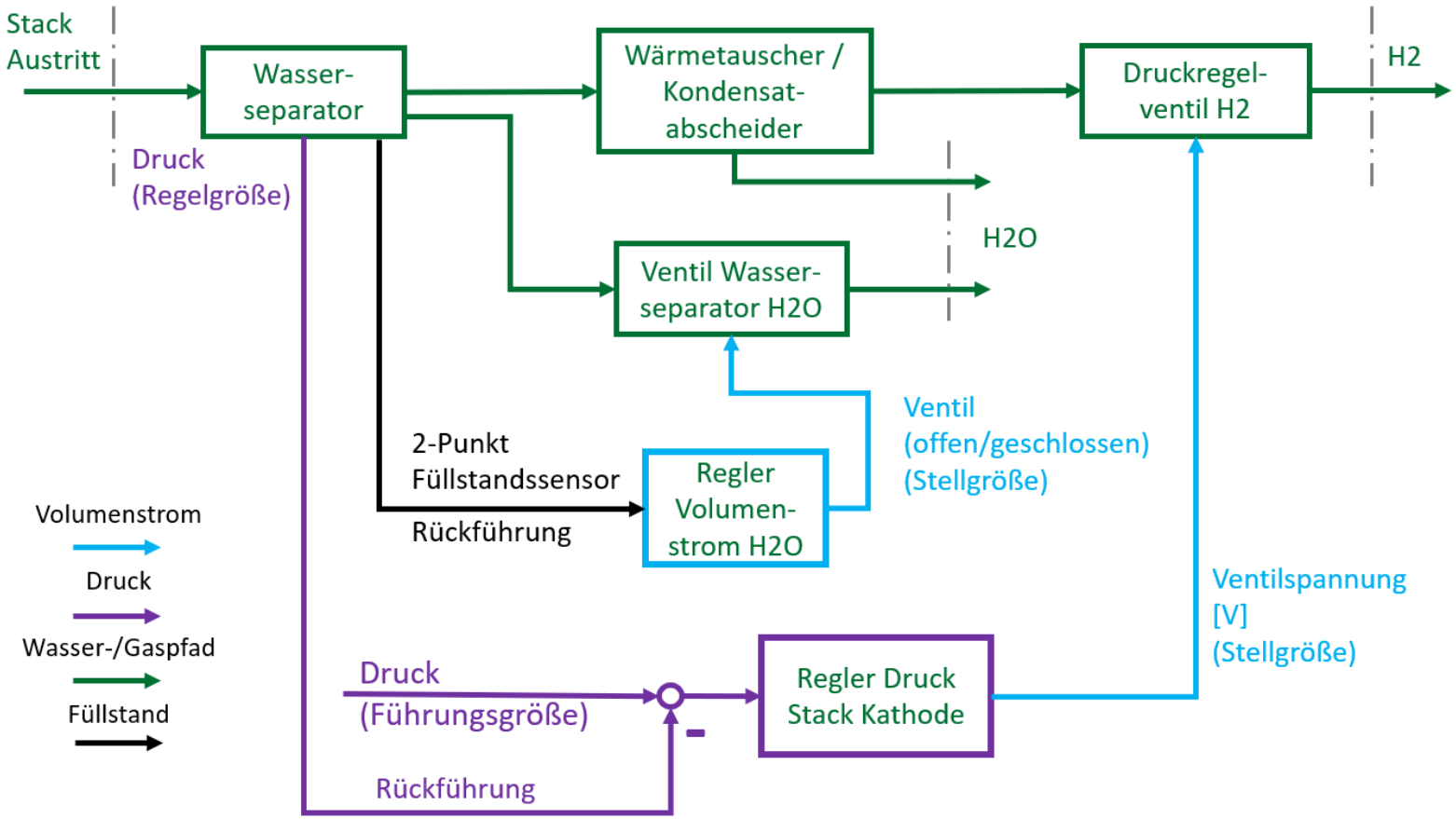
Regelkreise
Kathodenseite

Regelgrößen

- Druck
- Füllstand



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Simulink-Modell

Regeleinrichtung

Strom-Steuerung

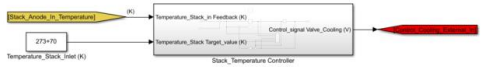
Kathoden-Regelung

Füllstand Reservoir

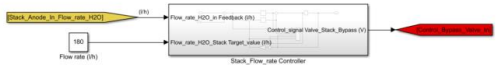
Druck

Anoden-Regelung

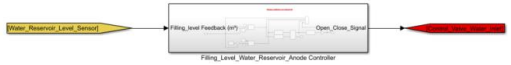
Temperatur



Volumenstrom

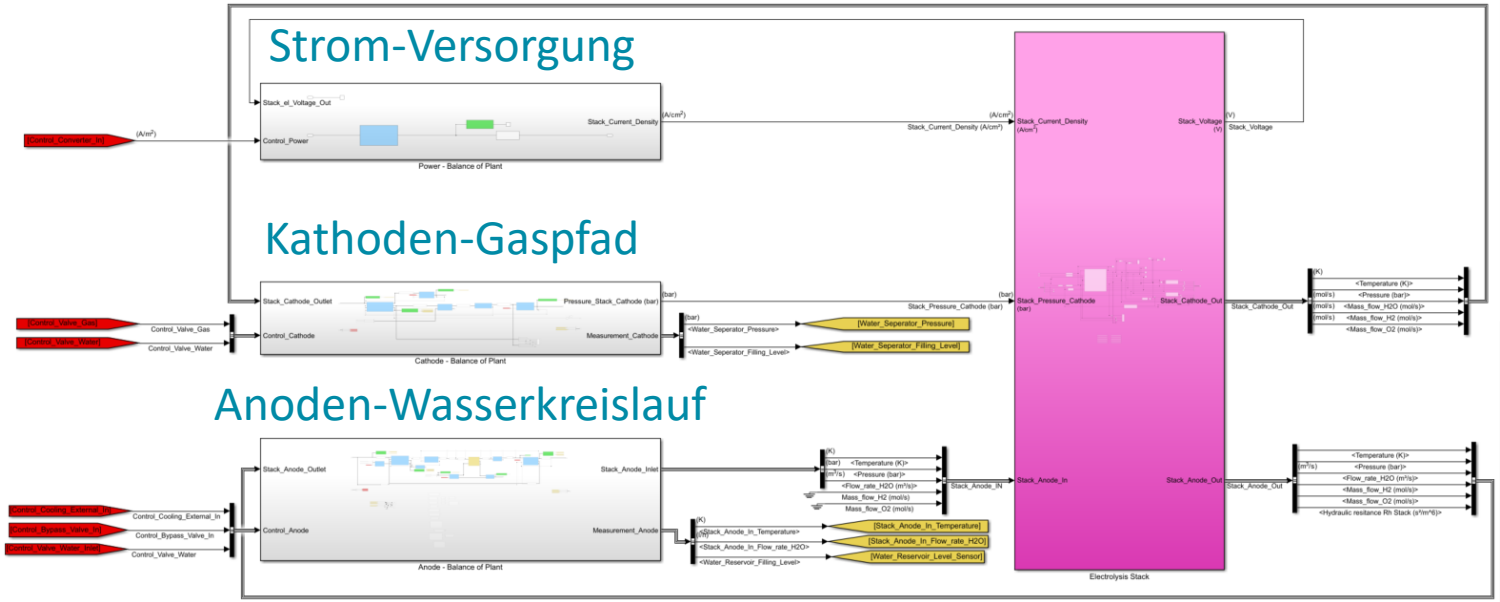


Füllstand Reservoir



Regelstrecke

Elektrolyseur



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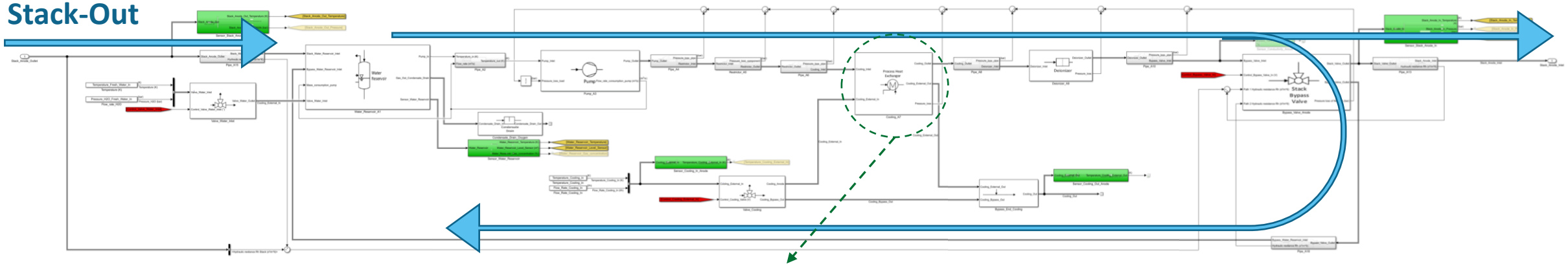
Simulink-Modell

Anoden-Wasserkreislauf

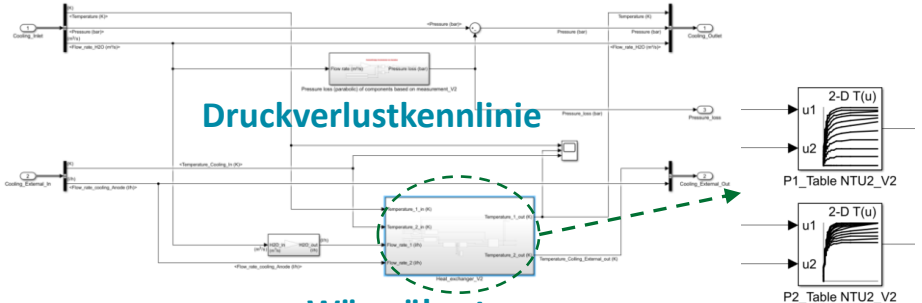
Stack-Out

Stack-In



Wärmetauscher-Modell

- Dynamisches Volumenstrommodell
- Druckverlustkennlinie aus Messergebnissen
- Dynamisches Temperaturmodell mit parametriertem Plattenwärmetauscher



Lookup-Table + Physikalische Berechnungen

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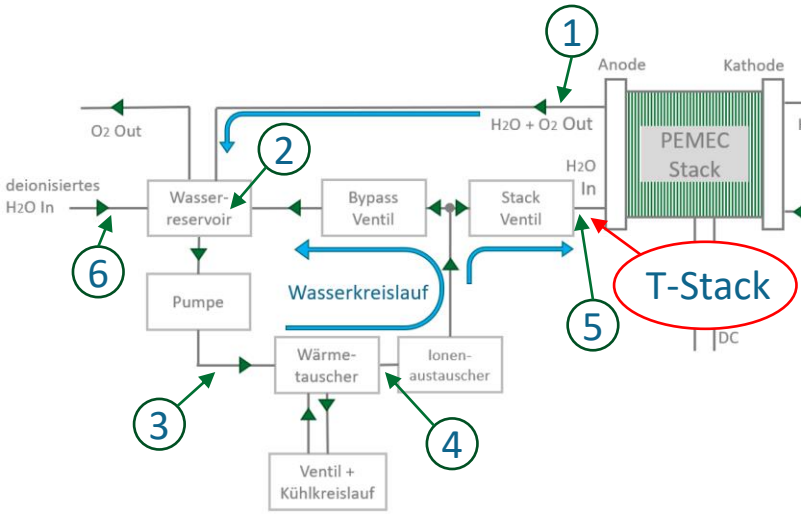
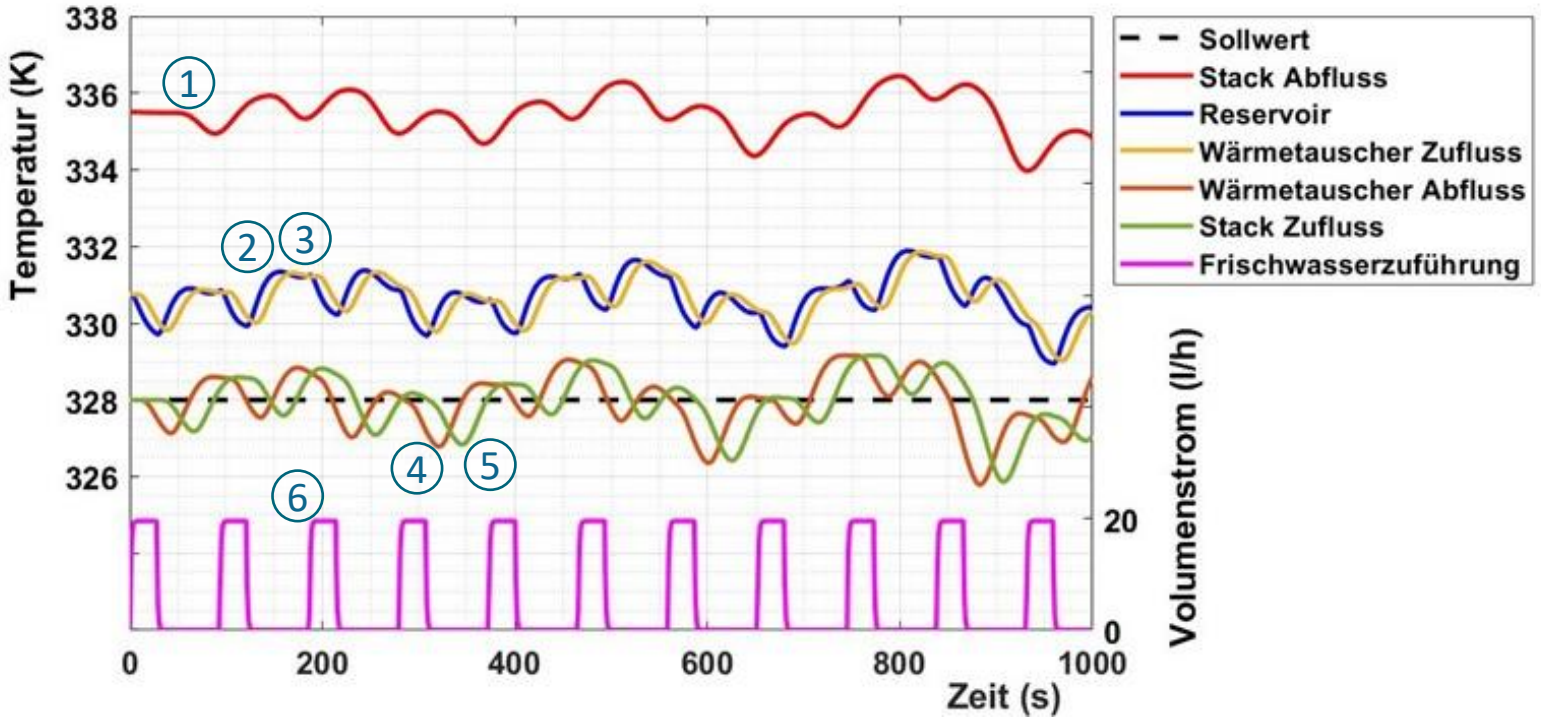
Simulation Temperaturregelung

Basiskonzept / Sensor am Elektrolysestackzufluss





Stackzuflusstemperatur schwankt um +/-2 K und korreliert mit Frischwasserzuführung sowie Einfluss der Totzeit zwischen Wärmetauscher und Temperaturmessort erkennbar.

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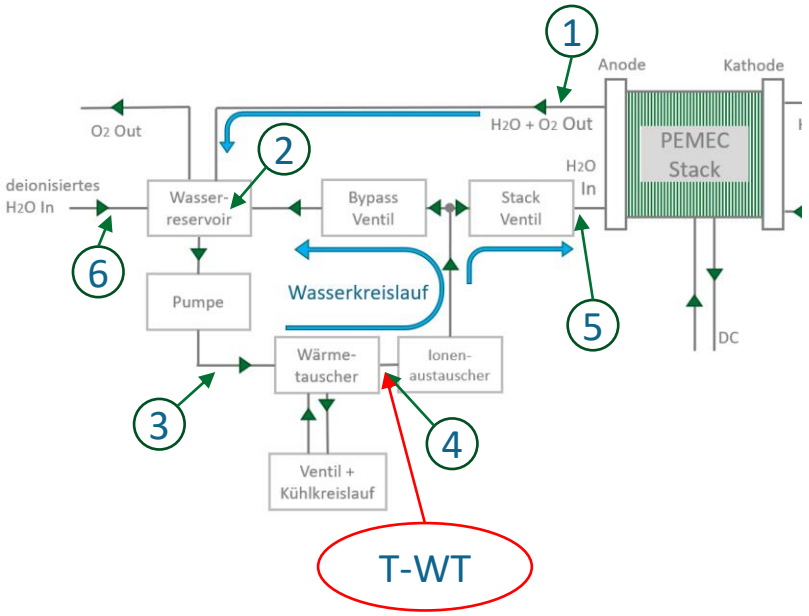
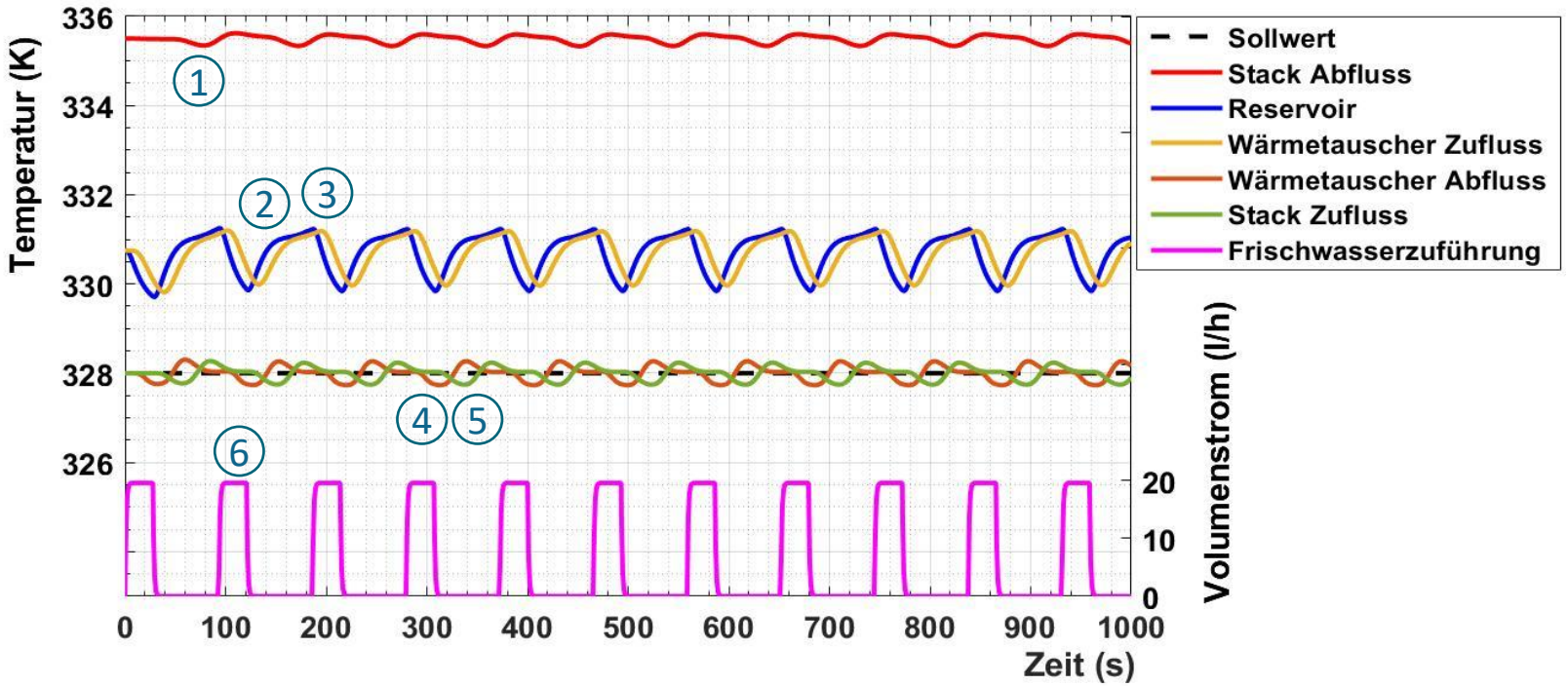
Simulation Temperaturregelung

Optimierung / Sensor am Wärmetauscher





Stackzuflusstemperatur schwankt um +/- 0,5 K und korreliert mit Frischwasserzuführung.

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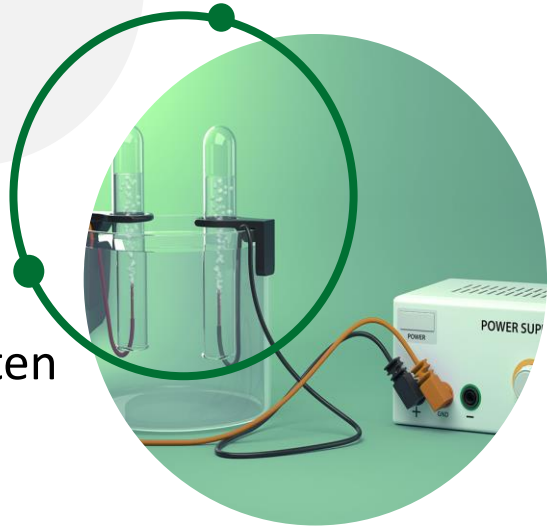
Ausblick

- Validierung am Prüfstand
- Regelungskonzepte
  - Modellbasiert
    - Kompensationsregler
    - Smith-Prädiktor
    - Prädiktive Regelung
  - Störgrößenaufschaltung
  - Kaskadenregelung
  - Kennfeldregelung
- Weiter Untersuchungen zu Optimierungs- und Effizienzsteigerungsmöglichkeiten
- Erweiterung der Modelleigenschaften



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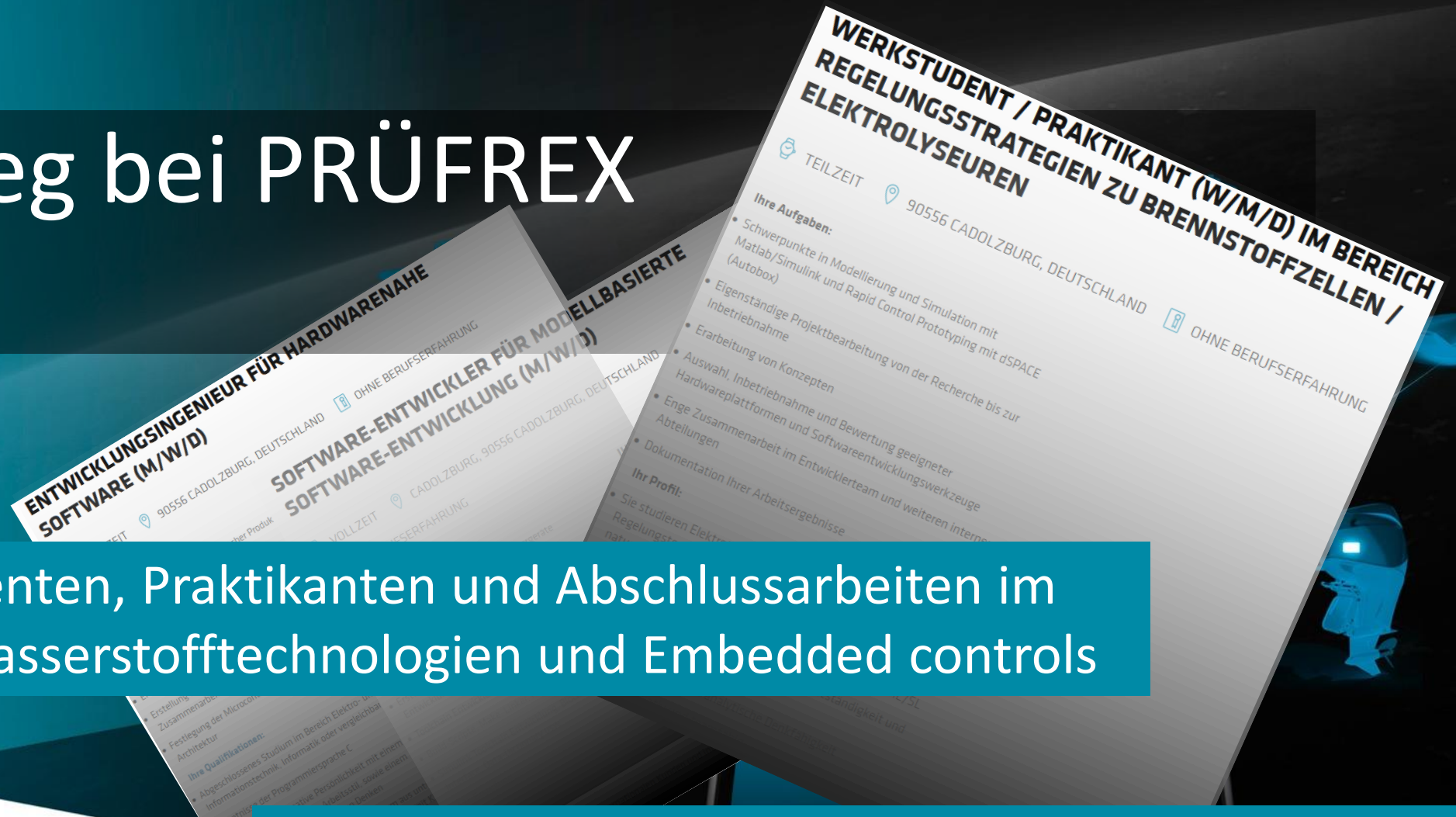

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