1 APRIL 2025

IFE-OPEN

Renewable Energy Water Electrolysis
High-Pressure PEM Water Electrolysis

HySchool Days 2025
Porsgrunn, 1-2 April 2025

Øystein Ulleberg
Chief Scientist IFE | Professor UiO

Contents

Institute for Energy Technology

- Private research foundation (established 1948)
- Research on hydrogen storage materials from 1950s
- Research on applied hydrogen systems from 1990s

Divisions

R&D Energy

R&D Nuclear

Technology and Property

Nuclear Operations and Safety

Daughter Companies

Agilera Pharma AS

IFE Invest AS

Hydrogen Technology Department

Production → **Storage** → **End Use**

Water Electrolysis
- Qualification of PEM and AEM Electrolyzer Cells and Stacks
- Accelerated Stress Testing
- Control System Development

Liquid Hydrogen
- Hydrogen Liquefaction by Magnetocaloric Cooling
- Materials Development & Characterization

Solid State Storage
- Metal Hydrides
- Materials Development & Characterization
- System Development

Fuel Cells
- Testing of PEM Fuel Cell Stacks
- *State-of-Health* Monitoring
- Hybridization with Batteries
- Control System Development

Modelling
- Materials, Components & Key Technologies
- Hydrogen Systems & Processes
- Energy Management and Power Controls Systems

RE/H2 System Research at IFE since 1995

- **1995**: Hydrogen energy systems modeling and validation of 7 bar Alkaline Electrolyzer model (**PhD Ulleberg**, with data from PHOEBUS-plant, **FZ Jülich**, Germany)
- **2000**: **Photovoltaic (PV)** Hydrogen Laboratory System with **small-scale 15 bar PEM Water Electrolyzer** (from Fraunhofer ISE) tested at IFE (**RESYS**)
- **2004**: Design of World's first Autonomous Wind/Hydrogen Demonstration (**Utsira island**) using 15 bar Alkaline Water Electrolysis from **Norsk Hydro**
- **2005**: Detailed **Wind / Water Electrolysis Power** and **Control Systems** in **Matlab Simulink** modeling tools developed at IFE for **Statkraft**
- **2008**: **Testing of small-scale atmospheric PEM Water Electrolyzer Prototype** (from **Norsk Hydro**) in Renewable Energy System Laboratory at IFE (**REELYPEM**)
- **2020**: Commissioning and testing of **200 bar** differential pressure **PEM Water Electrolyzer System Laboratory** designed, built, and operated at **IFE (Hynor/NFCH)**
- **2020**: High-pressure **PEM Water Electrolysis Modeling** (**MoZEES**)
- **2023**: PEM water electrolysis system modeling (**HYDROGENi**)
- **2023**: Design and operation of Renewable Energy based **PEM Water Electrolysis** Systems for Industrial Applications (**REHSYS**)

Hynor – IFE's Hydrogen Technology Test Center

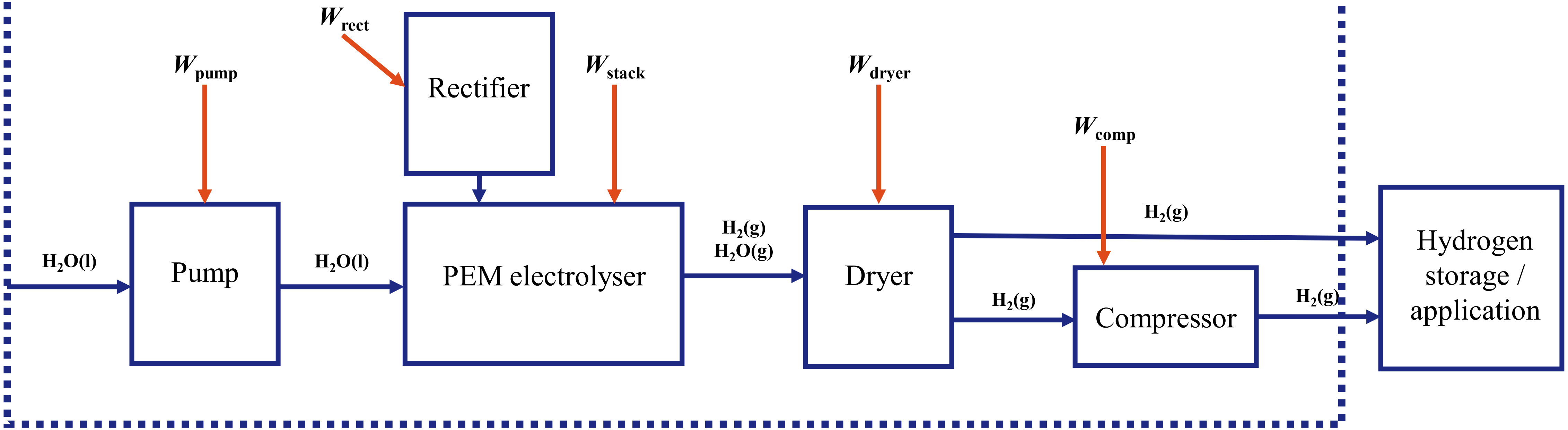
NORWEGIAN FUEL CELL AND HYDROGEN CENTRE
FUEL CELL & ELECTROLYSER SYSTEMS

- **Norwegian Fuel Cell and Hydrogen Centre**
  Open Research Infrastructure
  - PEM Fuel Cell System Laboratory
  - PEM Water Electrolysis System Laboratory

- **IFE Hynor** (past & present)
  - Sorption Enhanced Reforming (ongoing)
  - NH3-cracking & purification (ongoing)
  - Hydrogen Refueling Station (2011 – 2021)
  - Solid Oxide Fuel Cells (2014 – 2016)

Motivation (for pressurized systems)

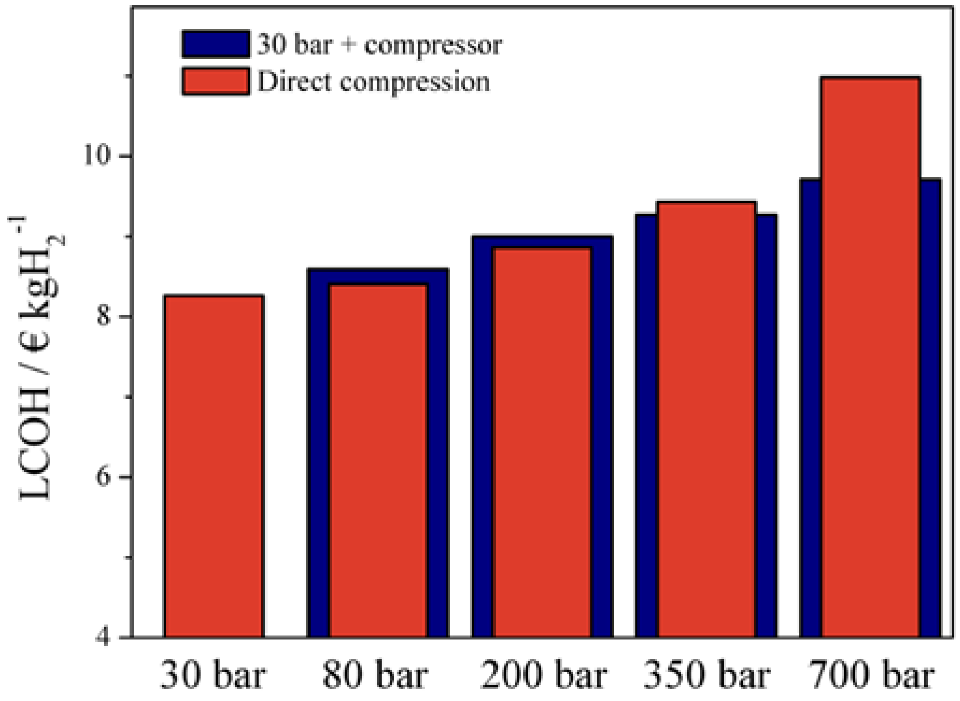
- **Reduce cost and complexity** of supplying **high-pressure** RE-based **hydrogen**
- Comparison of high-pressure PEMWE vs. conventional PEMWE + mechanical H2-compressor

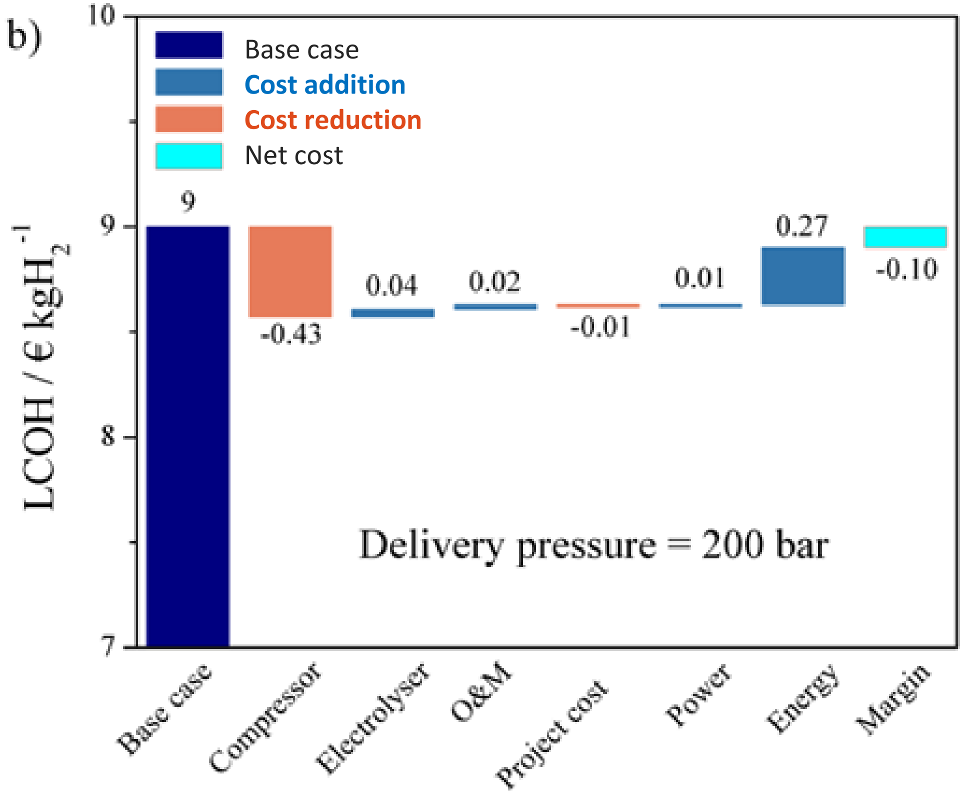


Hancke R., Holm T., Ulleberg Ø. (2022) The case for high-pressure PEM water electrolysis, *Energy Conversion and* Management, Volume 261, 1 June 2022, 115642

Background

- **Techno-economic study**: PEM water electrolysis up to **200 bar** can be **cost-effective**
- Suitable for industrial applications that require **80 – 200 bar** hydrogen





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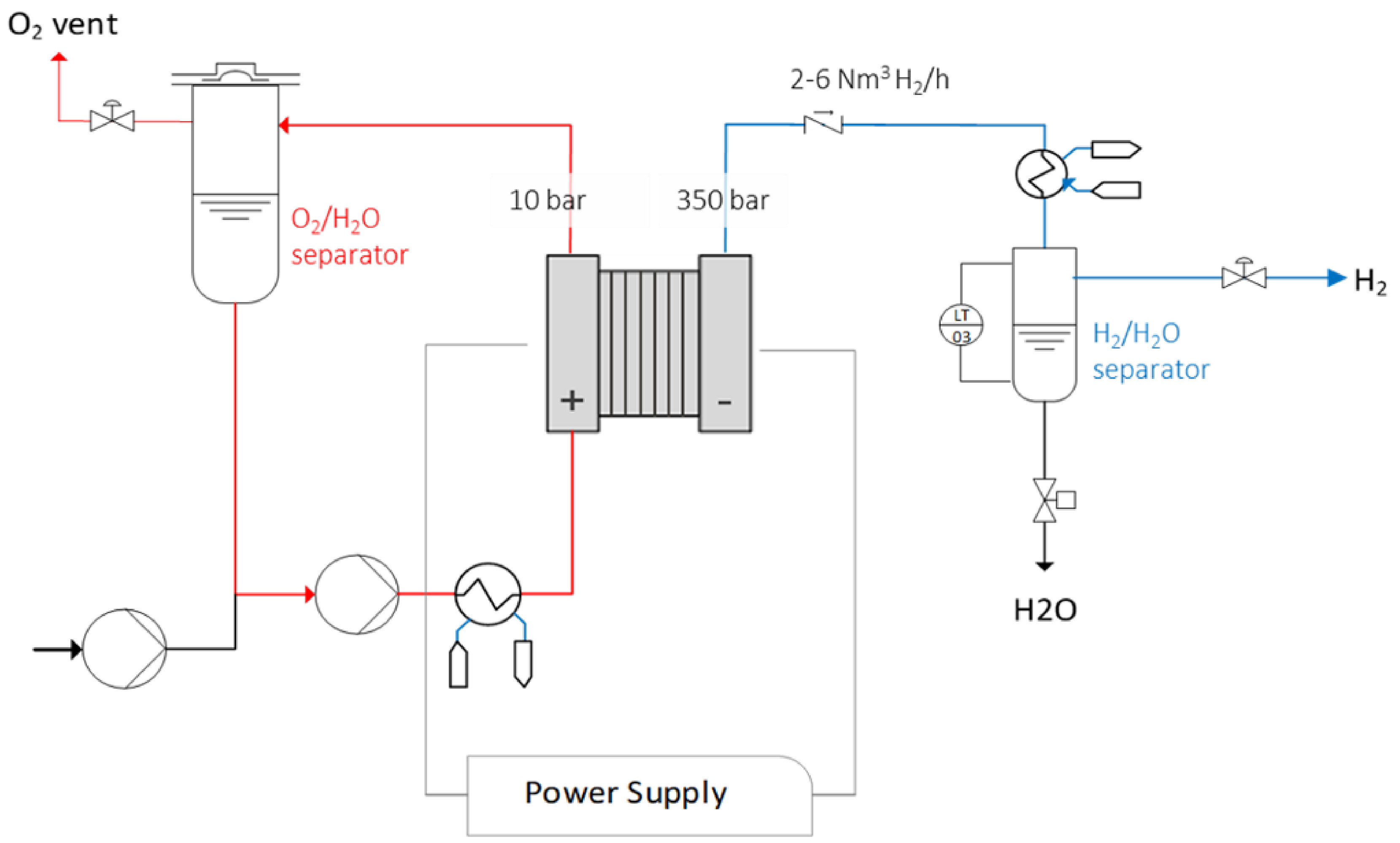
High-Pressure PEMWE Test Rig – Stack & System

- **Stack Design**:
  - Prototype/reference stack
  - Reinforced membrane with recombination catalyst
  - Electrode area: 86 cm^2
  - No. cells in series: 34 cells
  - Max. pressure: **350 bar**

- **Stack Operation**:
  - Current: 160 A (1.86 A / cm^2)
  - H2-production: 2.1 Nm^3/h
  - Max. pressure: **200 bar**

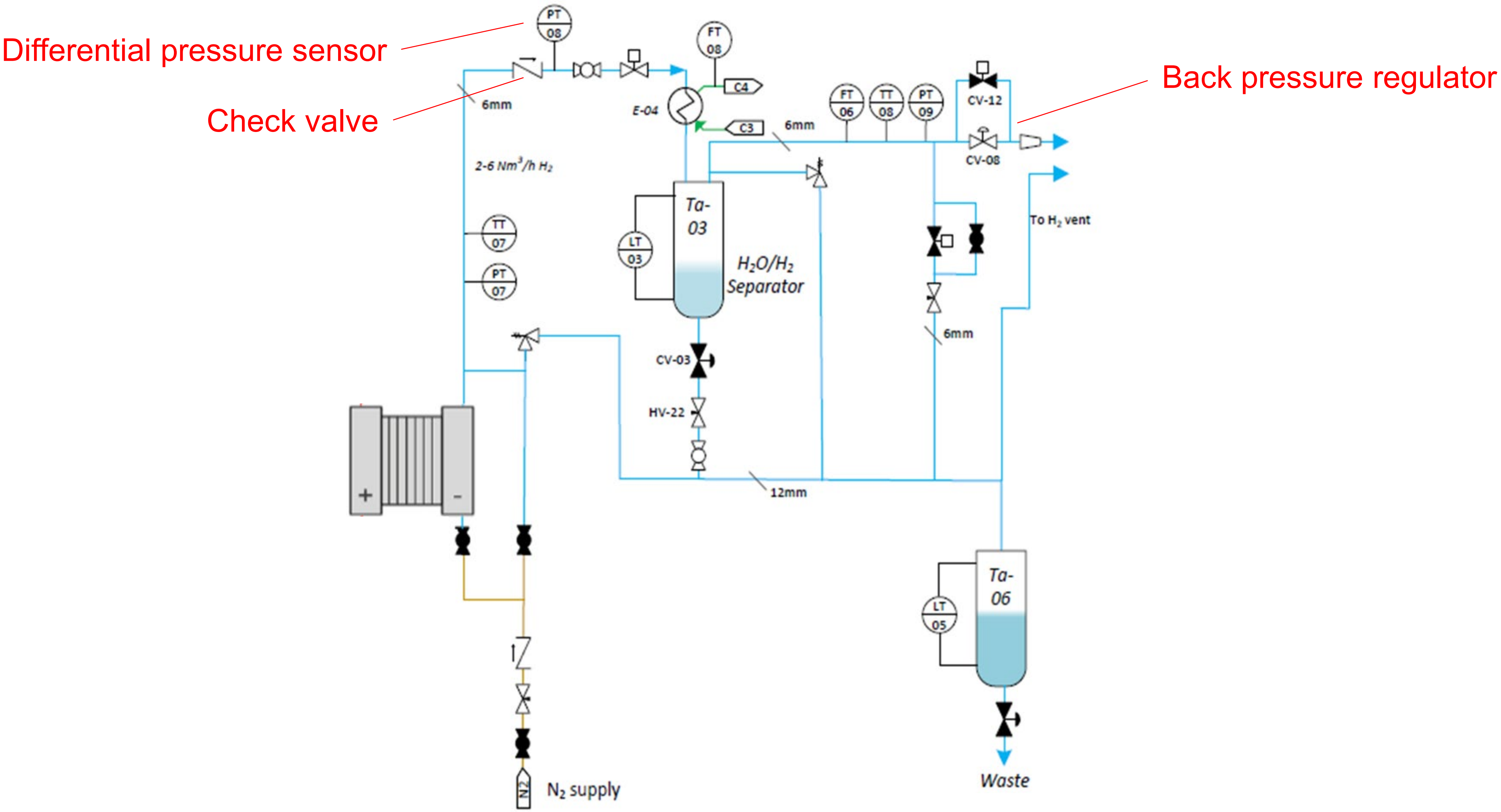
Ulleberg Ø. (2019) High Differential Pressure PEMWE System Laboratory, In Proceeding of *EFCF – Fuel Cell, Electrolyzers H2 Processing Forum*, 2-5 July, Luzern

High-Pressure PEM Water Electrolysis – System Concept



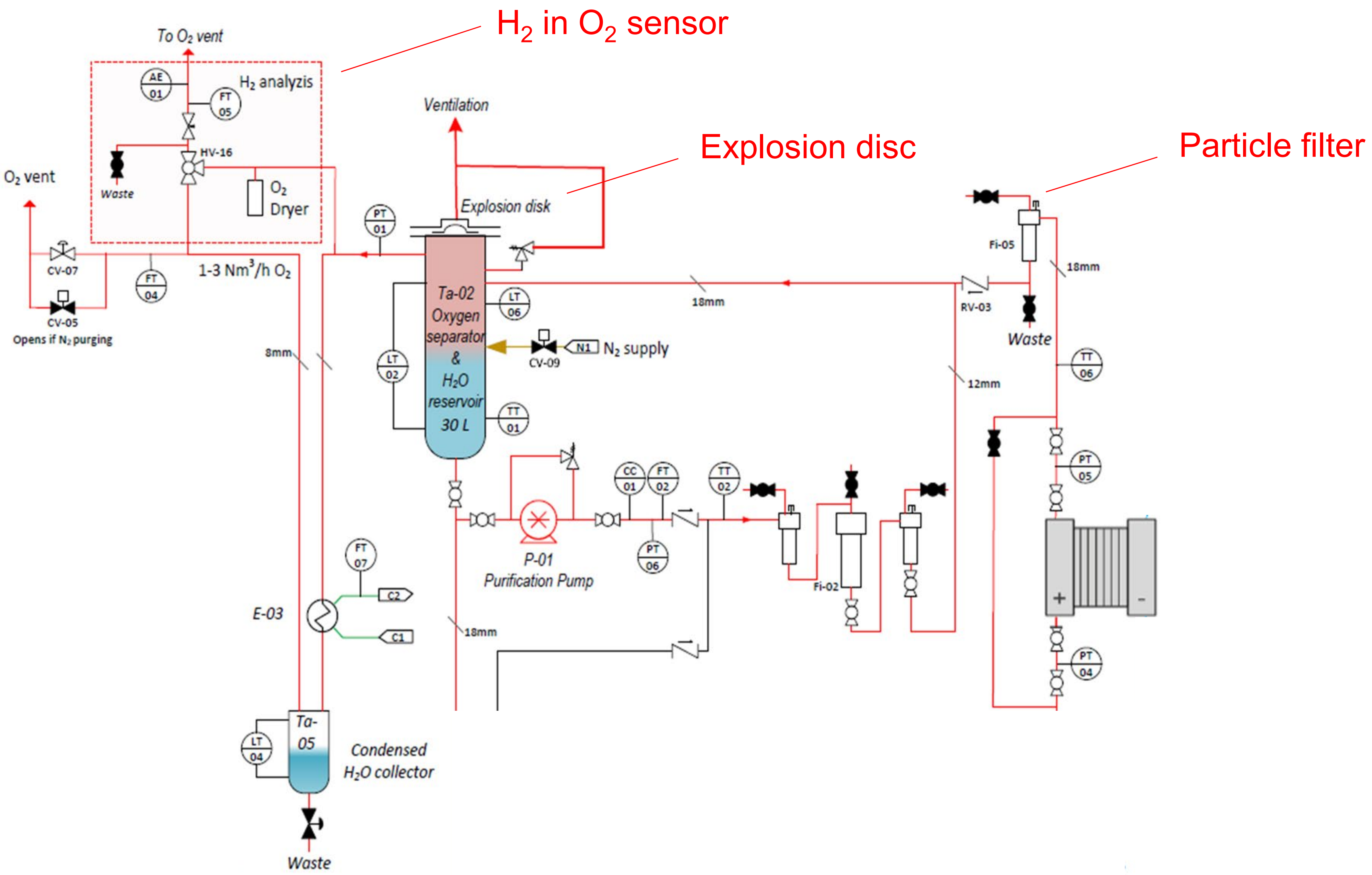
Ulleberg Ø. (2019) High Differential Pressure PEMWE System Laboratory, In Proceeding of *EFCF – Fuel Cell, Electrolyzers H2 Processing Forum*, 2-5 July, Luzern

High-Pressure PEMWE – Safety Systems on H_2-side



Ulleberg Ø. (2019) High Differential Pressure PEMWE System Laboratory, In Proceeding of *EFCF – Fuel Cell, Electrolyzers H2 Processing Forum*, 2-5 July, Luzern

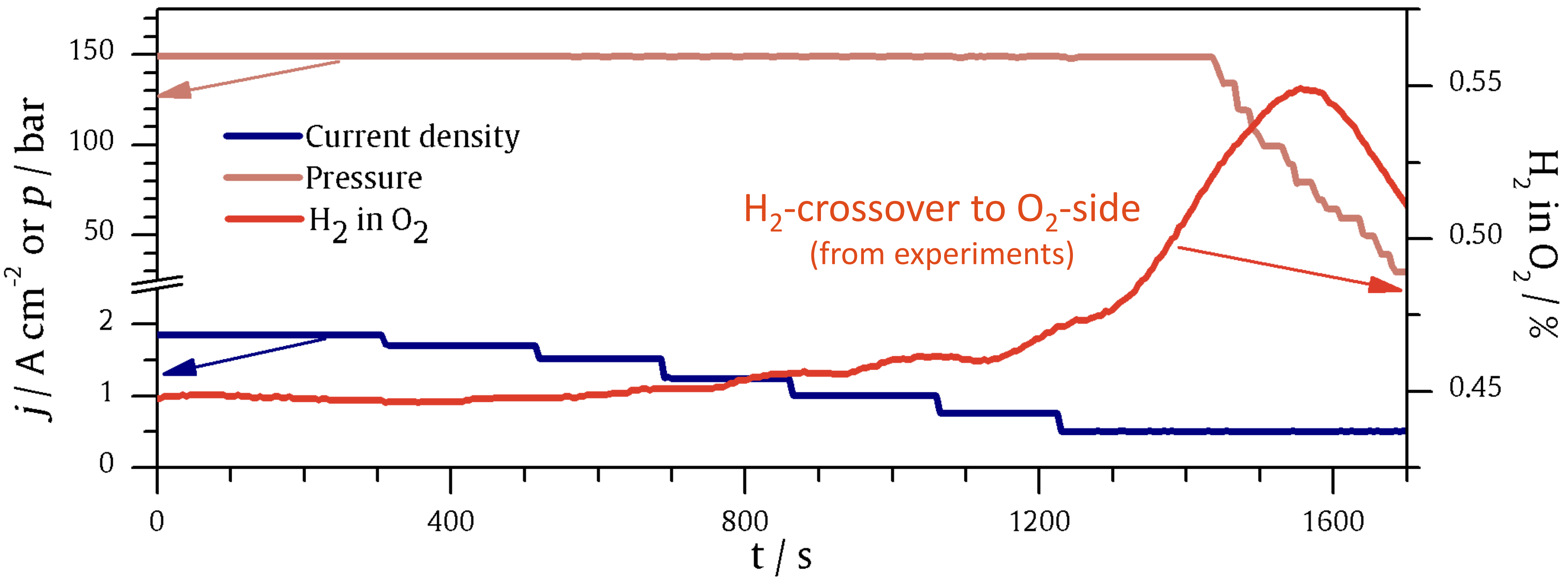
High-Pressure PEMWE – Safety Systems on O_2-side



Ulleberg Ø. (2019) High Differential Pressure PEMWE System Laboratory, In Proceeding of *EFCF – Fuel Cell, Electrolyzers H2 Processing Forum*, 2-5 July, Luzern

Hydrogen Safety

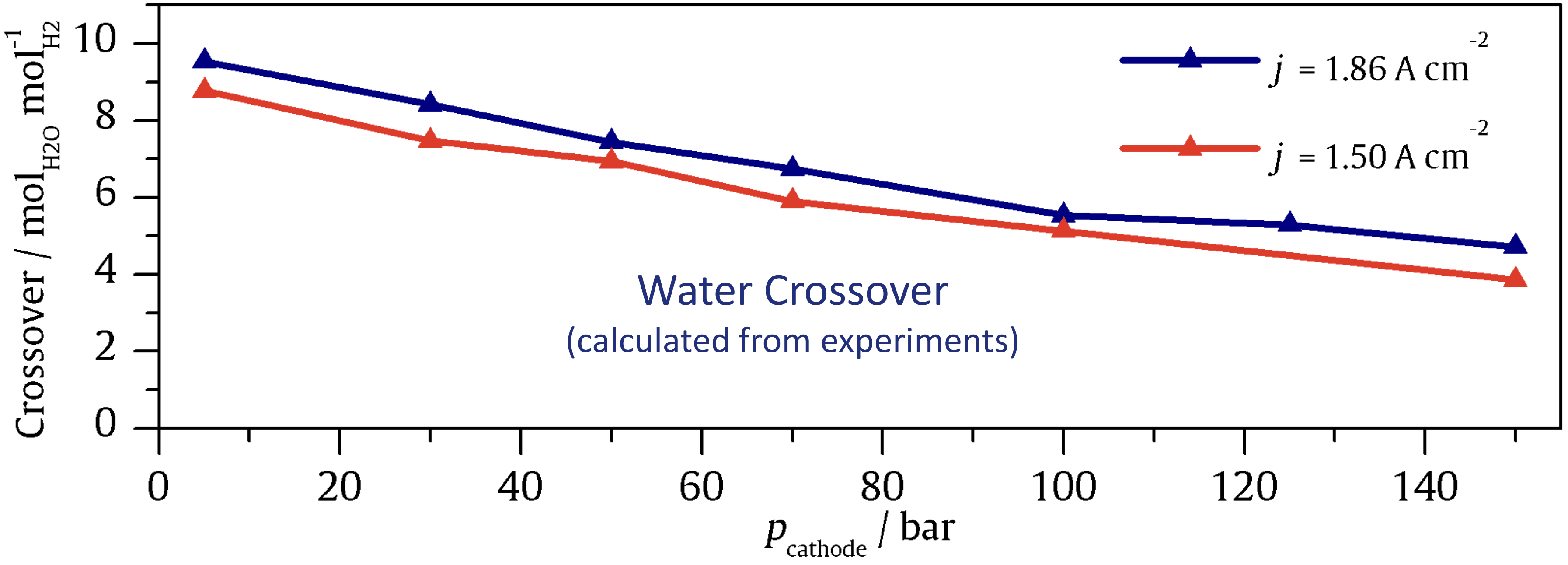
- **Reverse flow** of **H2** through membrane to **O2 side** during **ramp down** of stack power



Hancke R., Bujlo P., Holm T., Ulleberg Ø. (2024) High-pressure water electrolyzer performance up to 180 bar differential pressure, *Journal of Power Sources*, Volume 601, 2024, 234271

Water Management

- **Water transport through membrane** from anode to cathode **decreases with increased pressure**
- Lower humidity in produced H2 → **Reduced need for H2 drying**



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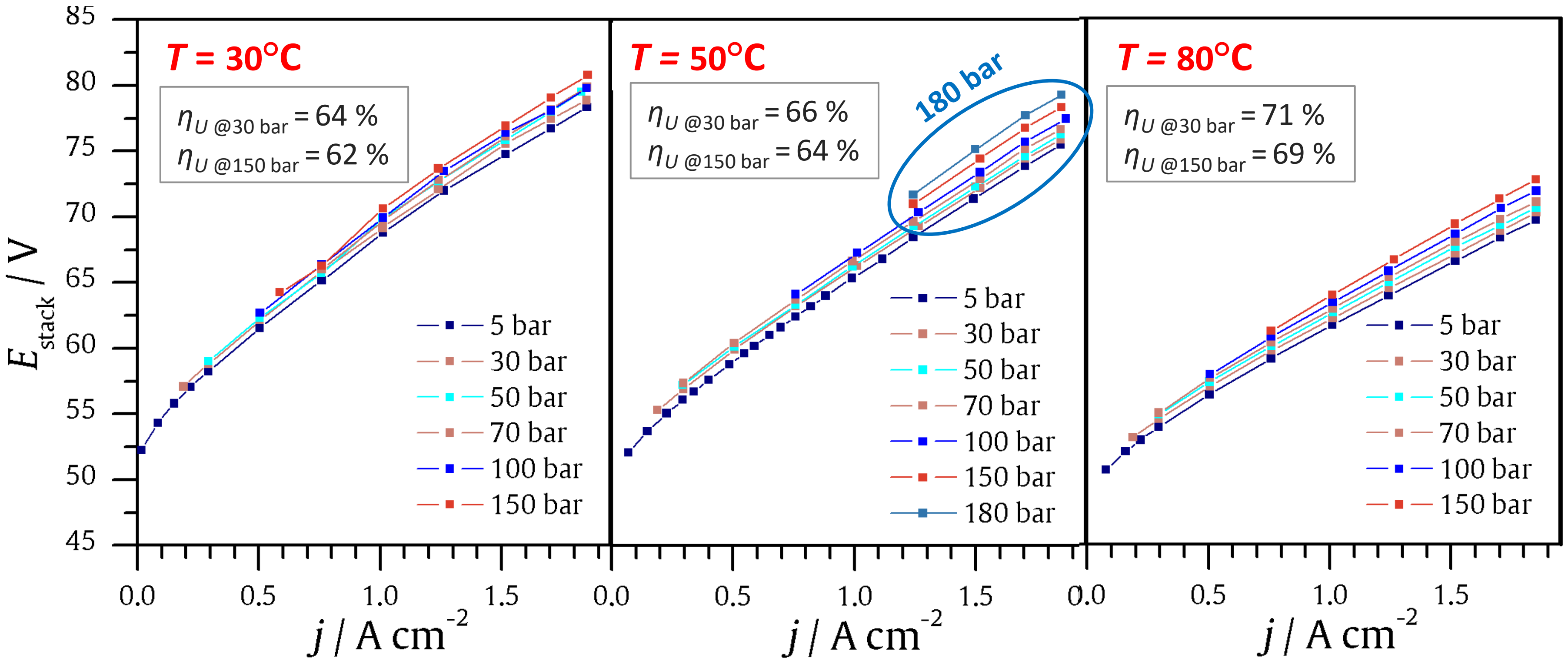
High Pressure PEM Water Electrolysis Performance

- **Pressure**
  - Increased Pressure → Increased Energy Cost
  - e.g., from **30 to 150 bar** → ca. **2 kWh/kg$_{H2}$**
- **Temperature**
  - Increased Temperature → Reduced Energy Cost
  - e.g., from **50 to 80°C** → ca. **4.4 kWh/kg$_{H2}$**



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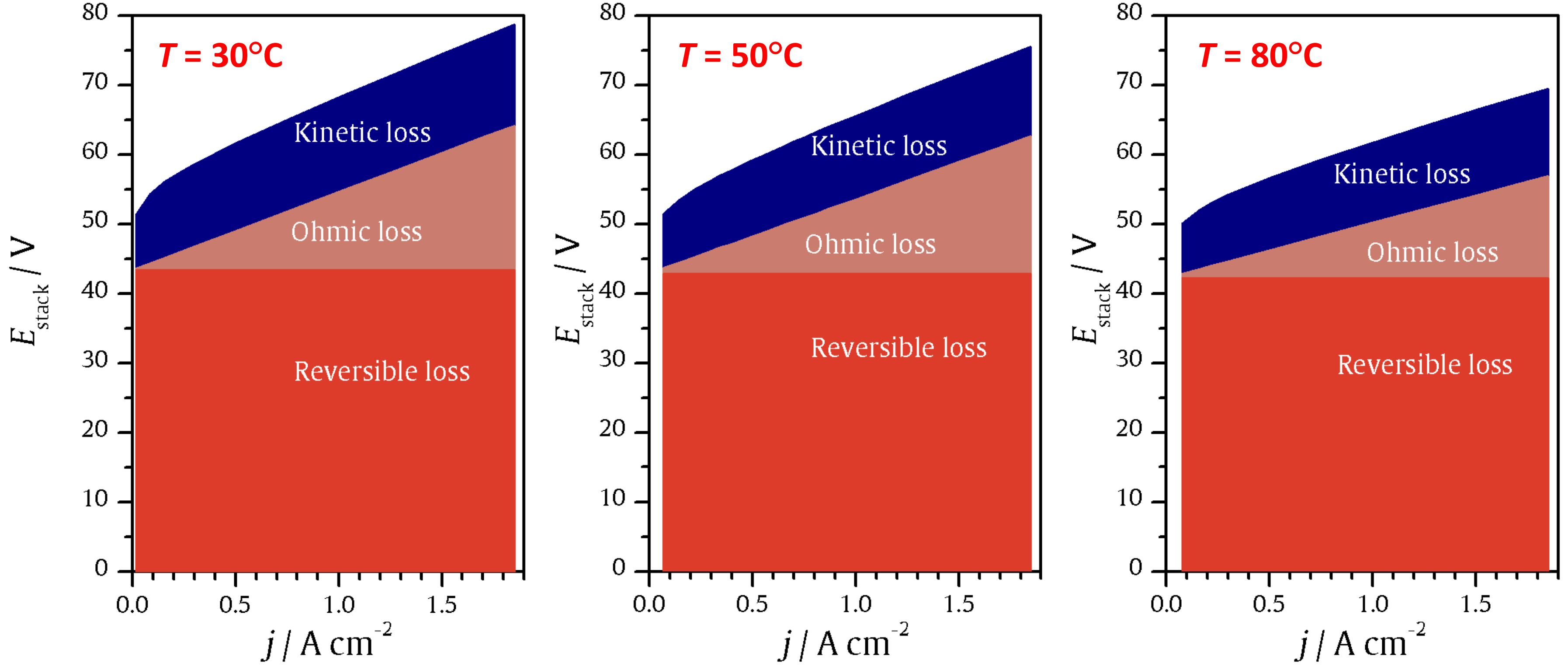
Stack Voltage vs. Current Density (from Modeling)

- **Increased Temperature** has a positive effect on all polarization losses

$R_\Omega = 0.0039$ Ohm
$i_a^{ex} = 2{,}6 \times 10^{-11}\ A\ cm^{-2}$

$R_\Omega = 0.0027$ Ohm
$i_a^{ex} = 2 \times 10^{-8}\ A\ cm^{-2}$



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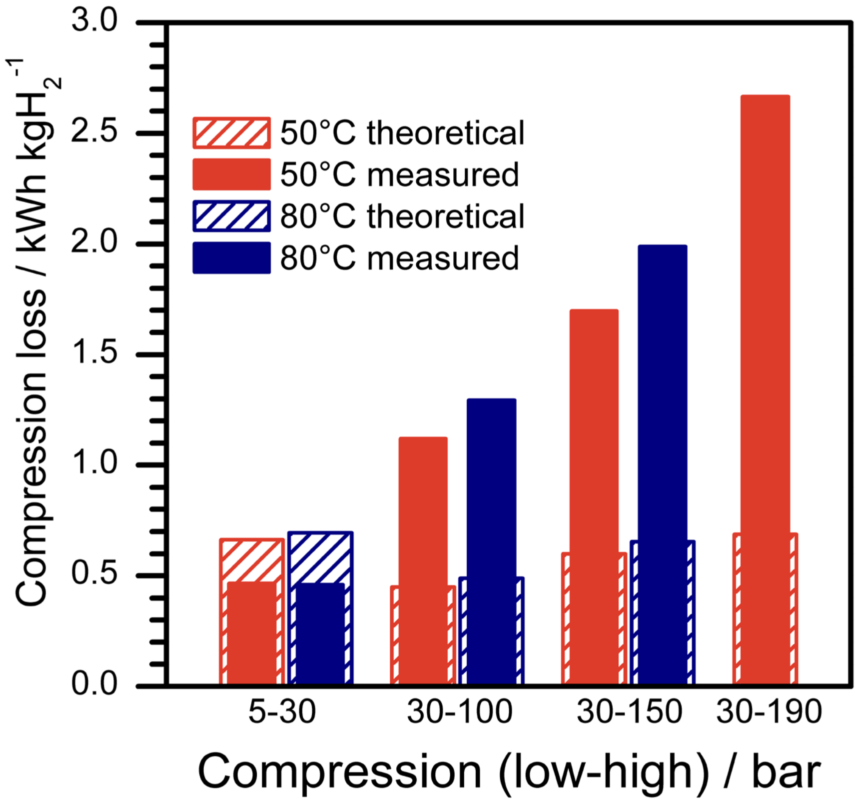
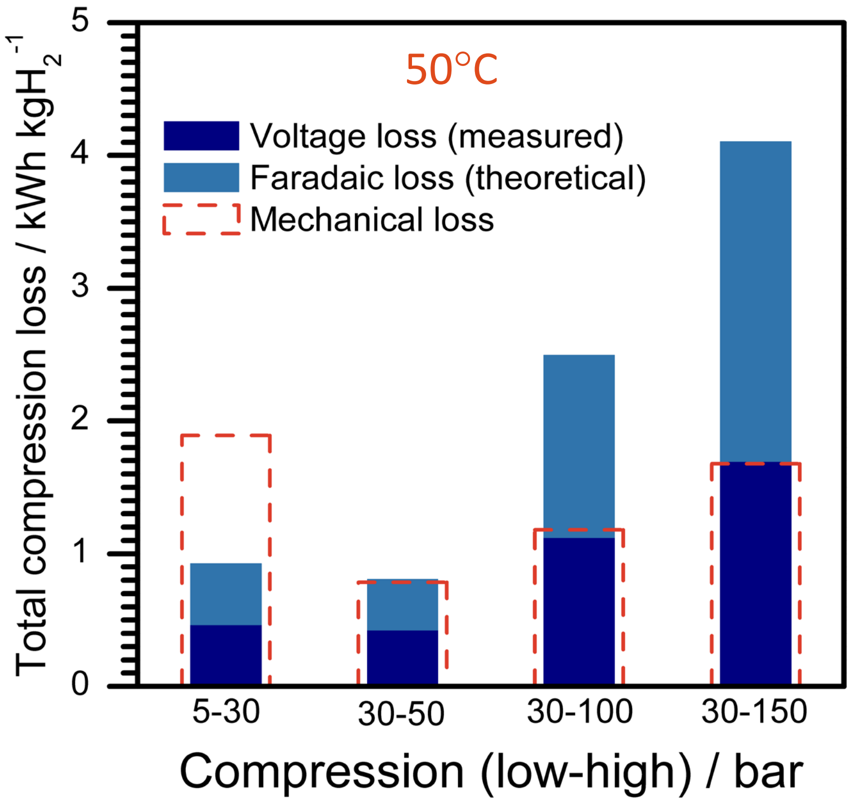
Experimental vs. Modeling Results

- Deviations from **Nernst** equation observed
- Deviations due to ohmic or kinetic overpotentials?

$$U_{\mathrm{rev}} = U_{\mathrm{std}} + \frac{RT}{2F} ln \left(\frac{P_{\mathrm{H_2}} \sqrt{P_{O_2}}}{P_{\mathrm{ref}}{}^{3/2} a_{\mathrm{H_2O}}} \right)$$





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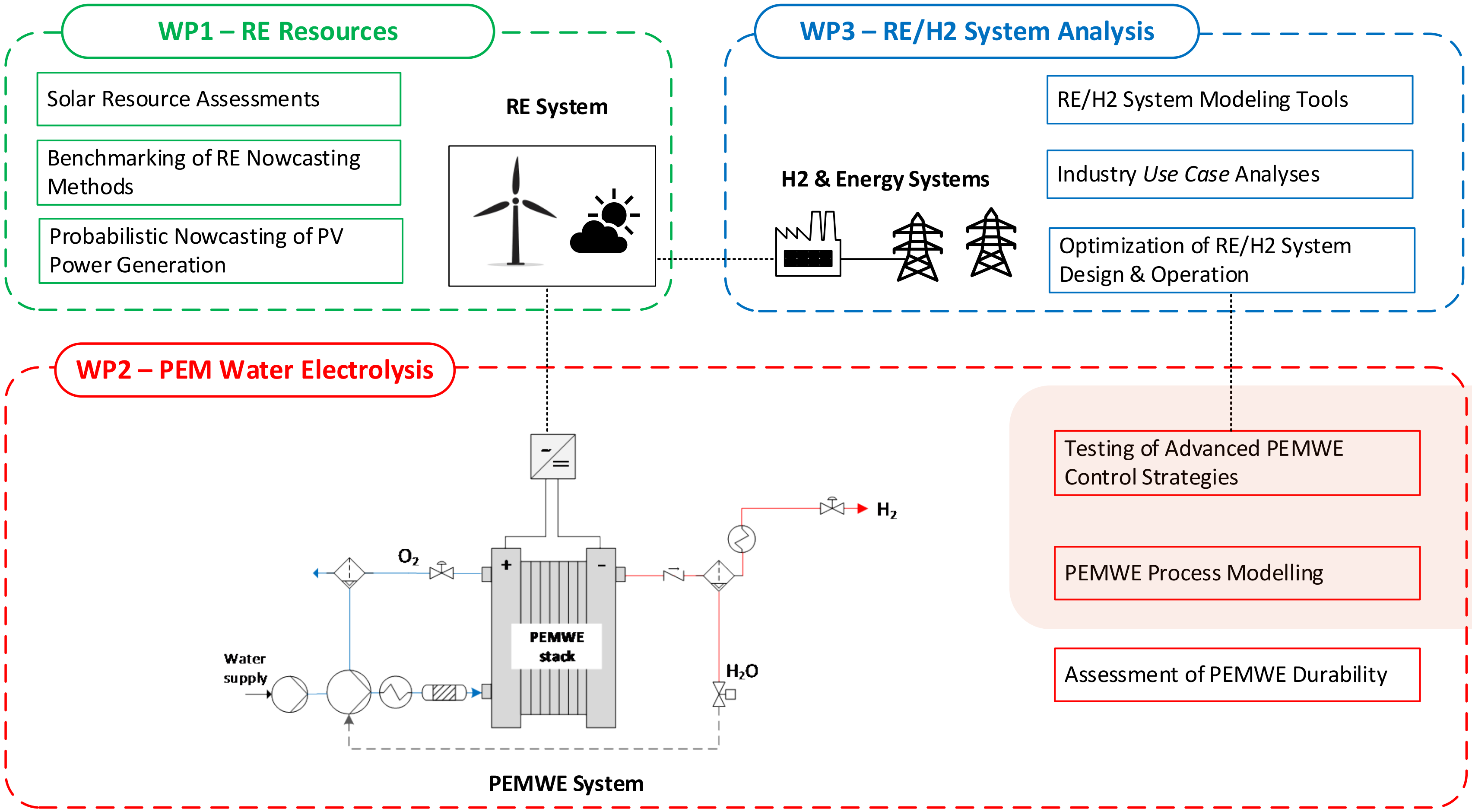
Summary & Conclusions

- **Hydrogen Compression Costs**
  - Electrochemical compression of hydrogen in PEMWE systems can be **cost effective** up to **80-200 bar**
- **PEMWE System Laboratory** at IFE Hynor
  - Test stacks up to **200 bar** and **33 kW**
  - **Test** control strategies wrt. **efficiency**, **safety**, and **stack durability**
- **PEMWE Stack Testing**
  - Testing & **characterization** from **5-180 bar @30, 50**, and **80°C**
  - **Loss in efficiency** from 30 to 150 bar: ca. **2 kWh/kg$_{H2}$**
  - **Water drag** (anode to cathode) from 30 to 150 bar: **50% reduction**
  - **Safe operation** (low H_2 in O_2): **25% power turn down** possible **@150 bar**

Outlook

- **REHSYS** – New project on Renewable Energy based PEM Water Electrolysis



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Amalie Møller
University of Oslo

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FME CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

MoZEES Mobility Zero Emission Energy Systems

NORWEGIAN FUEL CELL AND HYDROGEN CENTRE
FUEL CELL & ELECTROLYSER SYSTEMS

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