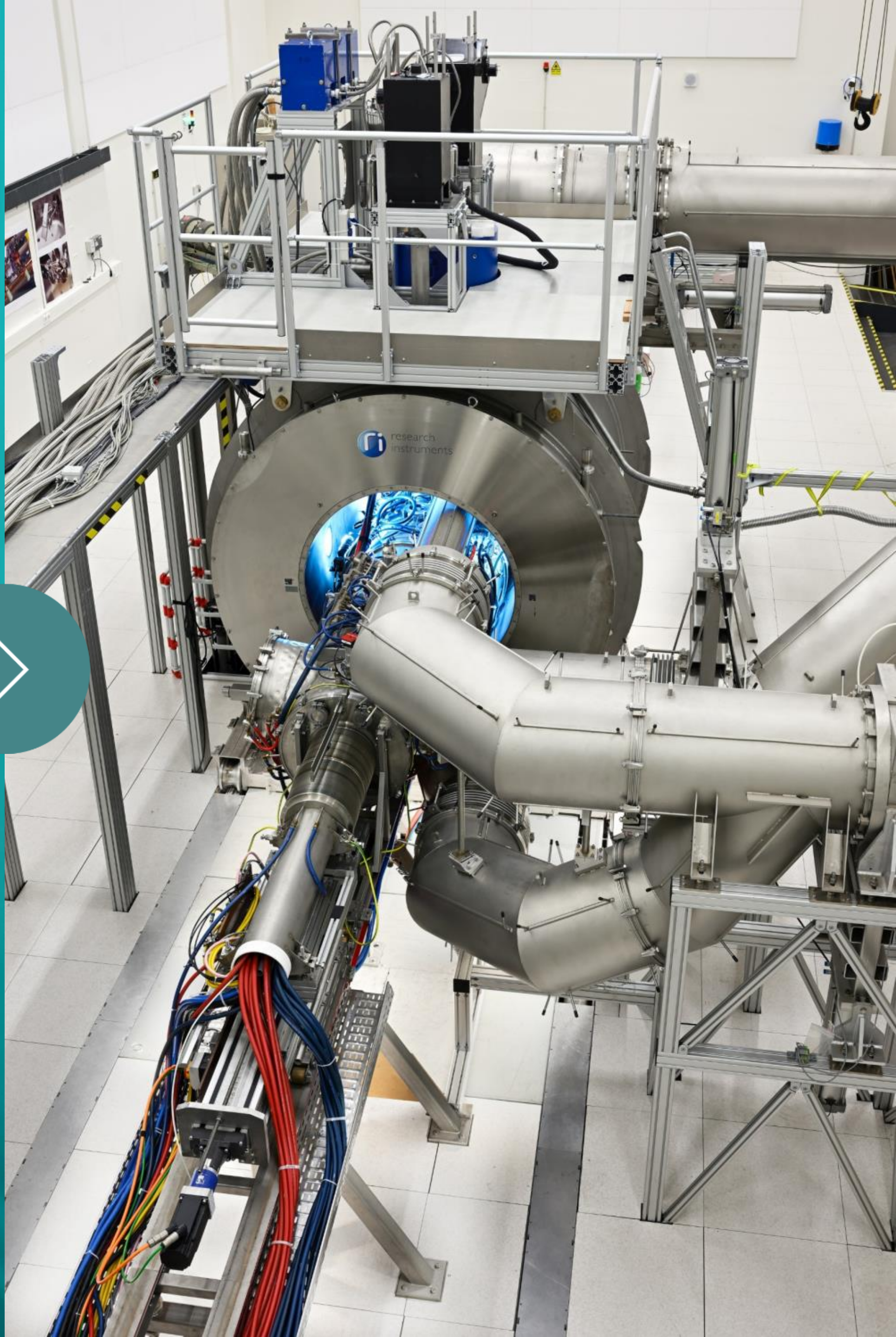
Overview DIFFER facilities

Hans van Eck

Facilities & Instrumentation department



Science for Future Energy

Dutch Institute for
Fundamental Energy Research
(DIFFER)

- Physics
- Chemistry
- Materials
- Engineering

- Fusion Energy
- Solar Fuels
- Infrastructure
- Connecting

200 employees

11 research groups

Eindhoven, TU/e campus

EUROfusion beneficiary

15 M€ annual turnover

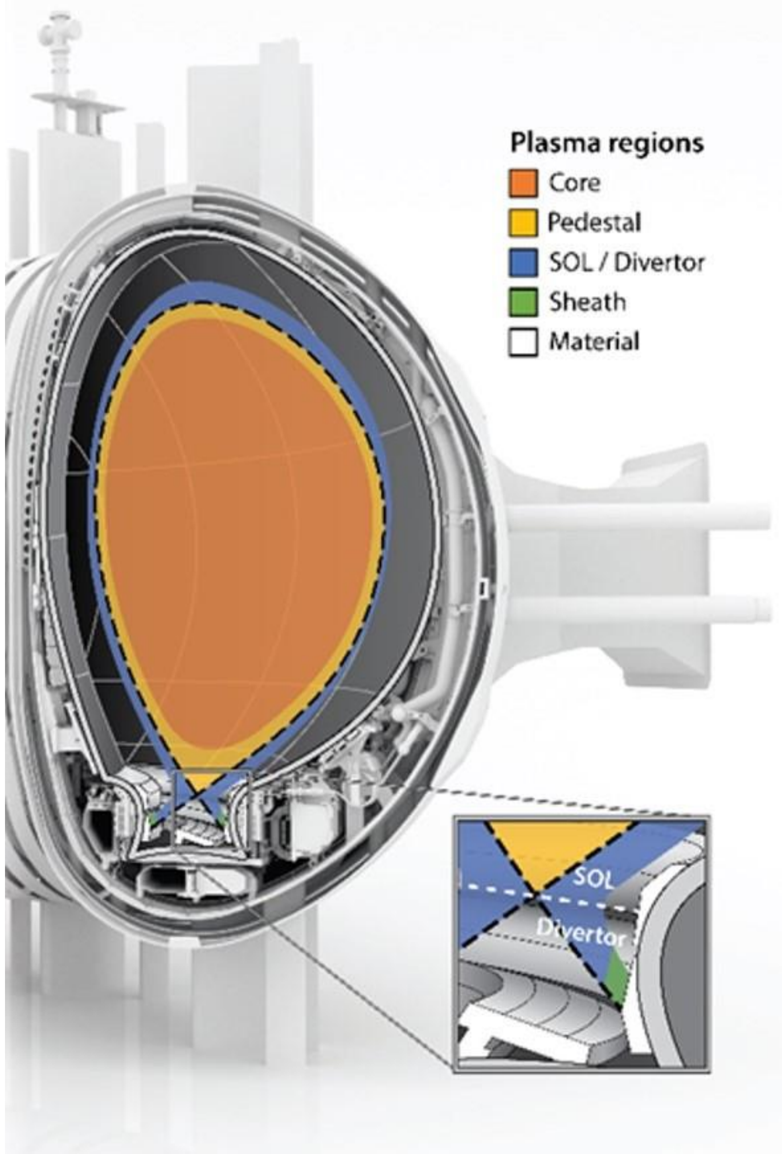
DIFFER Fusion Energy research programme

Towards an integrated solution for heat exhaust from fusion reactors

Focus on three topics crucial to realization of fusion reactor

- Materials for wall and divertor targets
- Sensors for exhaust and performance control
- Edge-core integrated models for control and optimization

These topics are highly intertwined



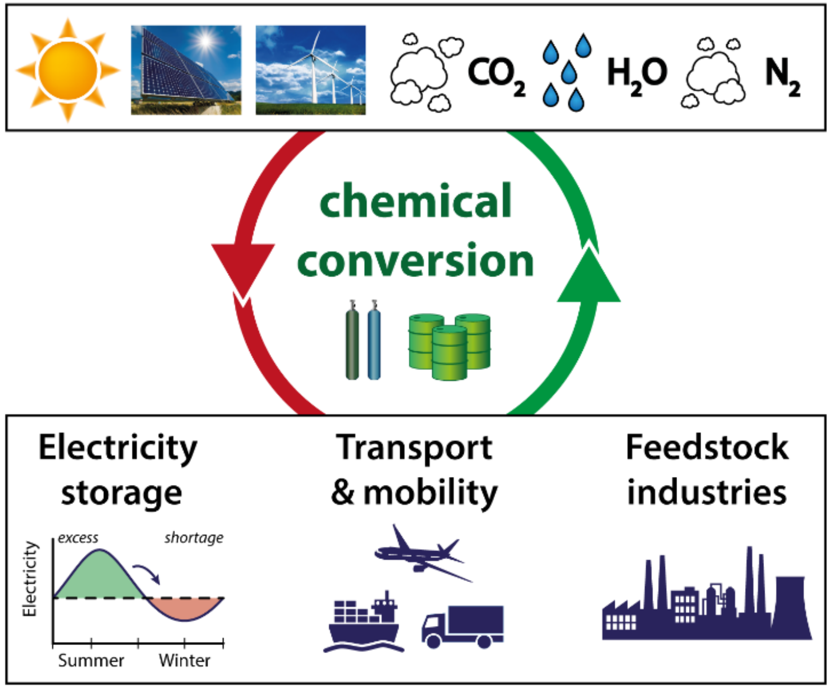
Solar Fuels
Renewable energy → chemicals and fuels

Clean conversion: CO_2-neutral fuels and chemistry

- Seasonal and regional energy storage
- Energy dense fuels for long haul transport and mobility
- Sustainable feedstock for green industry

Technological challenge

Make renewable fuels and chemicals cheaper than the fossil equivalents



Section A

Current (user) facilities

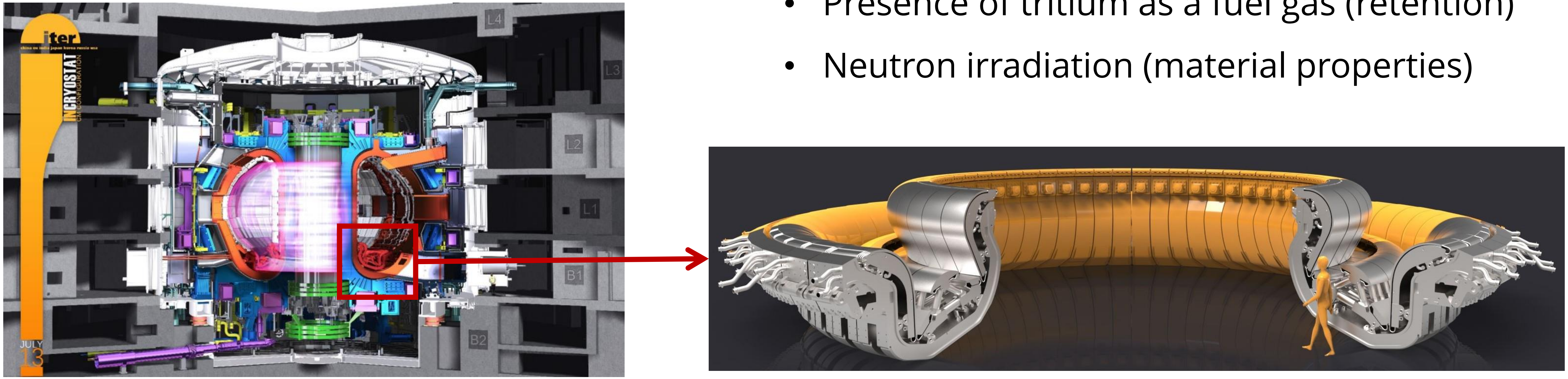
The power exhaust challenge for fusion energy

Understanding PSI is important:

- Lifetime: erosion + damage of PFC's
- Safety: tritium retention + dust formation

New challenges for future machines:

- Extended operational regimes (flux)
- Extended operational time (fluence)
- Presence of tritium as a fuel gas (retention)
- Neutron irradiation (material properties)



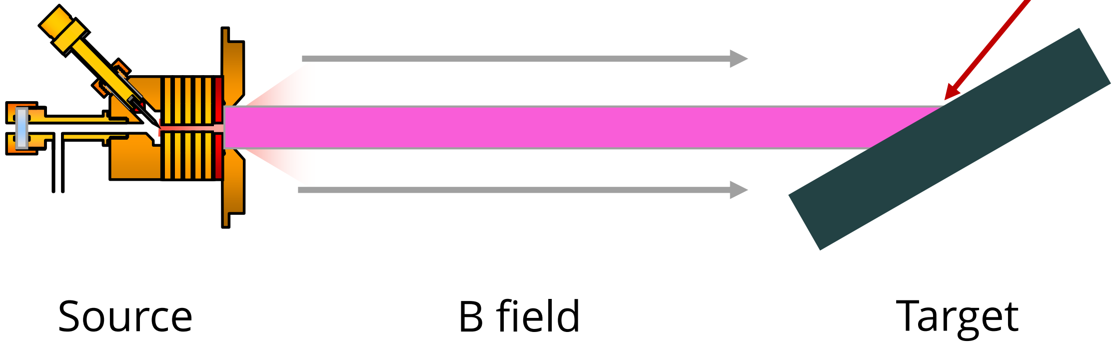
ITER divertor

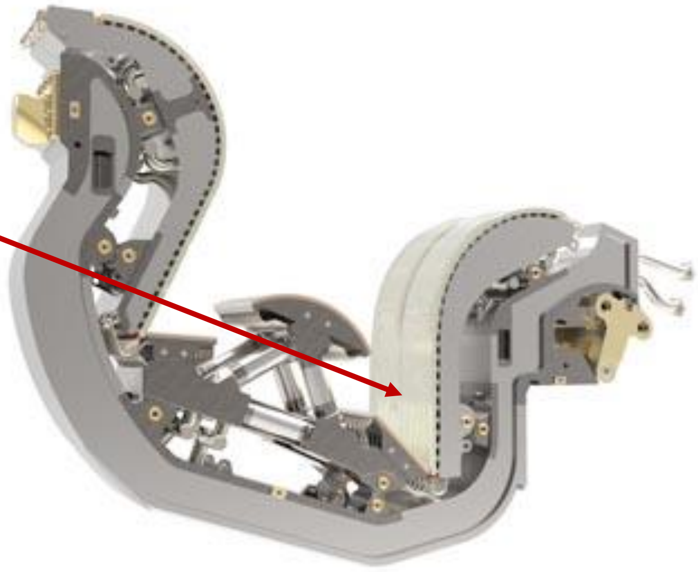
The role of linear machines in fusion research

Current fusion devices:
- Do not cover expected operational conditions
- Cannot reach required high fluence
- No easy access and easy target exchange

➡ Need for linear machines

Similar PSI conditions





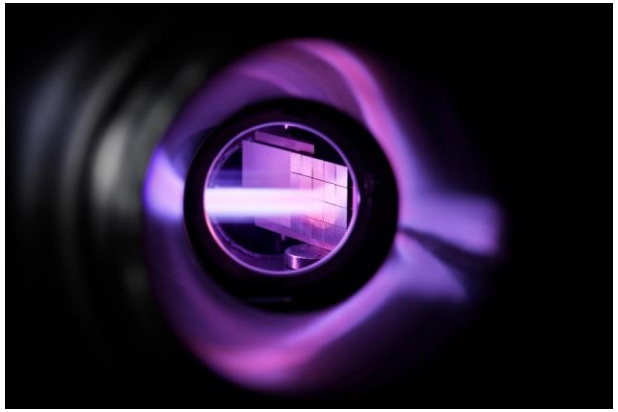
+ Control of plasma parameters

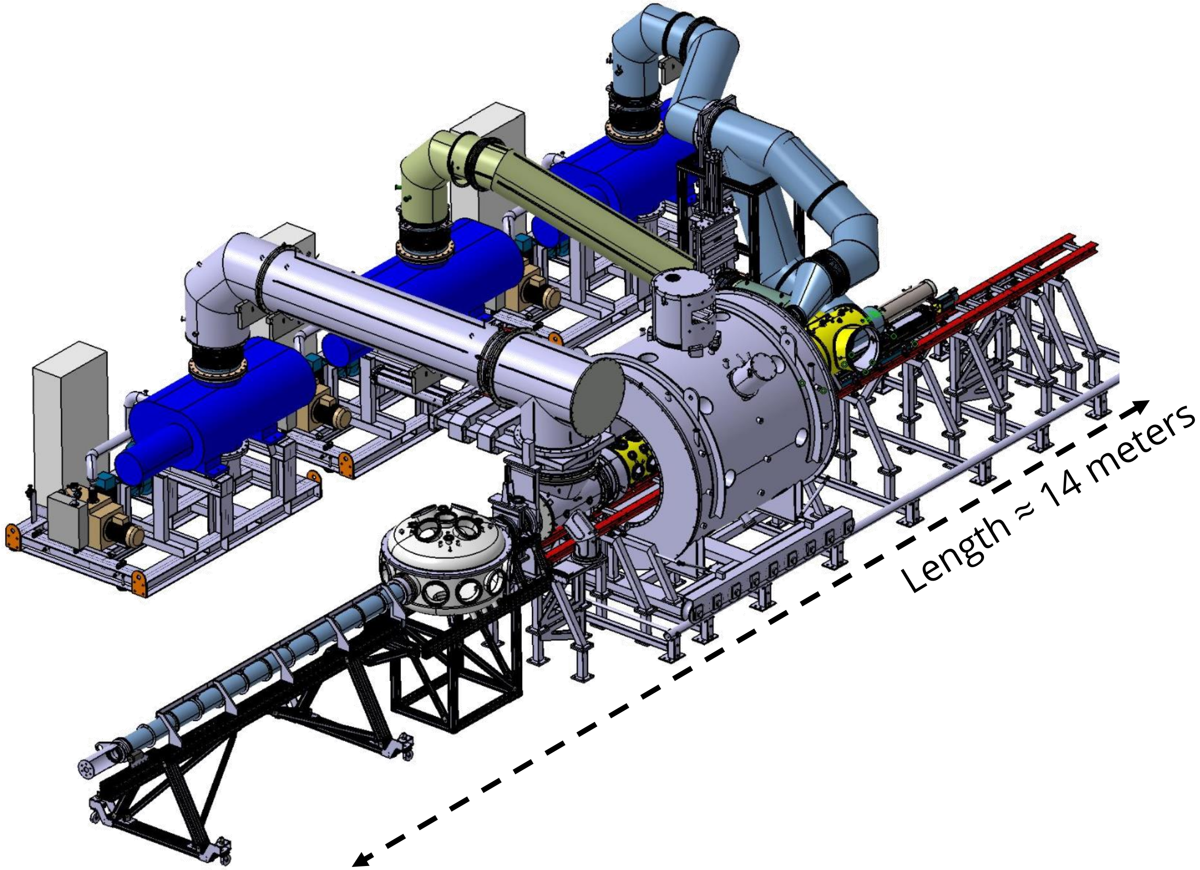
+ Good diagnostic access

+ Easy target exchange

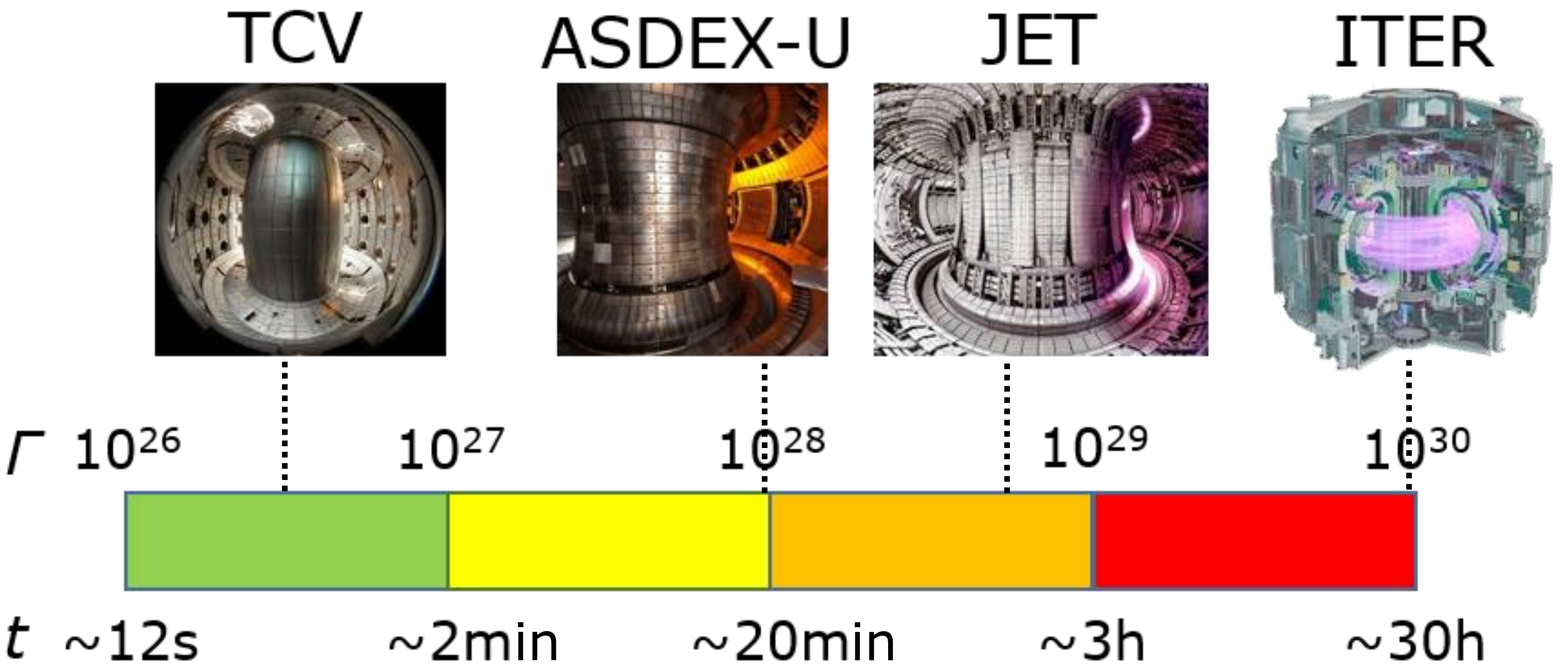
Magnum-PSI

- Unique high flux and high fluence linear plasma device
- Heat and particle fluxes comparable to ITER/DEMO divertor
- Transient plasma loading capabilities
- Extensive diagnostic suite (incl. in situ ion-beam analysis)





High fluence, high power regime accessible



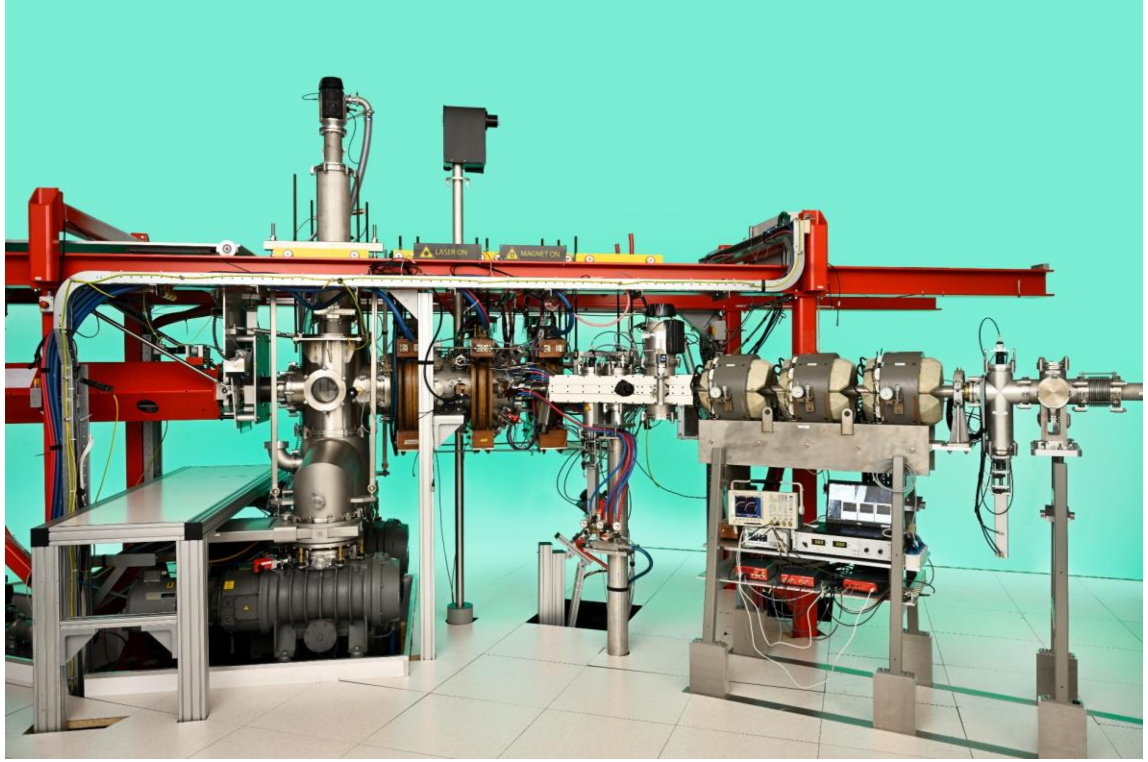
Time needed for Magnum-PSI to reach the divertor fluence after 5000 discharges in four different fusion reactors at a heat load of 10 MW m^{-2} (T_e=1.0 eV, n_e=10.6x10^{20} m^{-3} and Γ=8.6x10^{24} m^{-2} s^{-1}). Tokamak data taken from [G. De Temmerman et al *Plasma Phys. Control. Fusion* **60** 044018 (2018)]

Upgraded Pilot-PSI (UPP)

- Ion beam measurements in combination with high-flux plasma
    - Retention dynamics
    - Dynamic outgassing measurements
    - Dynamics of preferential sputtering

- Operando/in situ ion beam (proton) damaging
    - Simultaneous damage and fuel implantation

- Nano-structuring of materials (e.g. electrodes)



Materials for wall and divertor targets

- Characterize effect of high heat and particle loads (including transients) on materials (e.g., sputtering, retention, surface modification)
- Test ITER divertor: tungsten mono blocks
- Simultaneous “neutron” (protons from IBF) and plasma loading
- Develop liquid metal divertor solution

Ion Beam Facility (IBF)

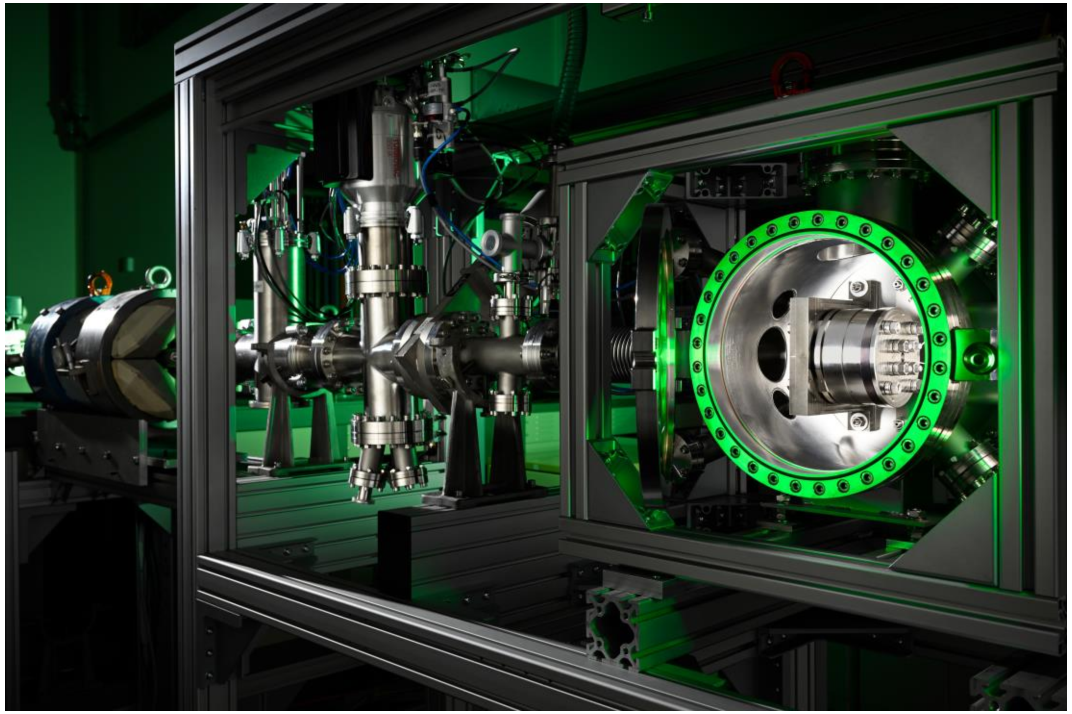
- In situ ion beam analysis (IBA) at **Magnum-PSI**, coupling non-destructive depth profiling of elements with high flux/fluence plasma
- Unique operando IBA in **UPP**
- Ex situ IBA in **IBAS**
- Simultaneous irradiation and corrosion experiments in **DICE** (only one in Europe)
- On-going development of operando electrochemical IBA (**e-IBA**)

3.5 MV Singletron

Differ Irradiation-Corrosion Experiment (DICE)

Develop wall material technologies for a thorium (molten-salt) reactor

- **Simultaneous** salt-corrosion and 3 MeV p-irradiation
- Dynamic salt
- Higher currents: 3-40 μA/cm^2 (~1 dpa/day)
- Operation time: up to 100 hours
- Temperatures: up to 1000ºC
- Adaptable design (salt, water, liquid metal)

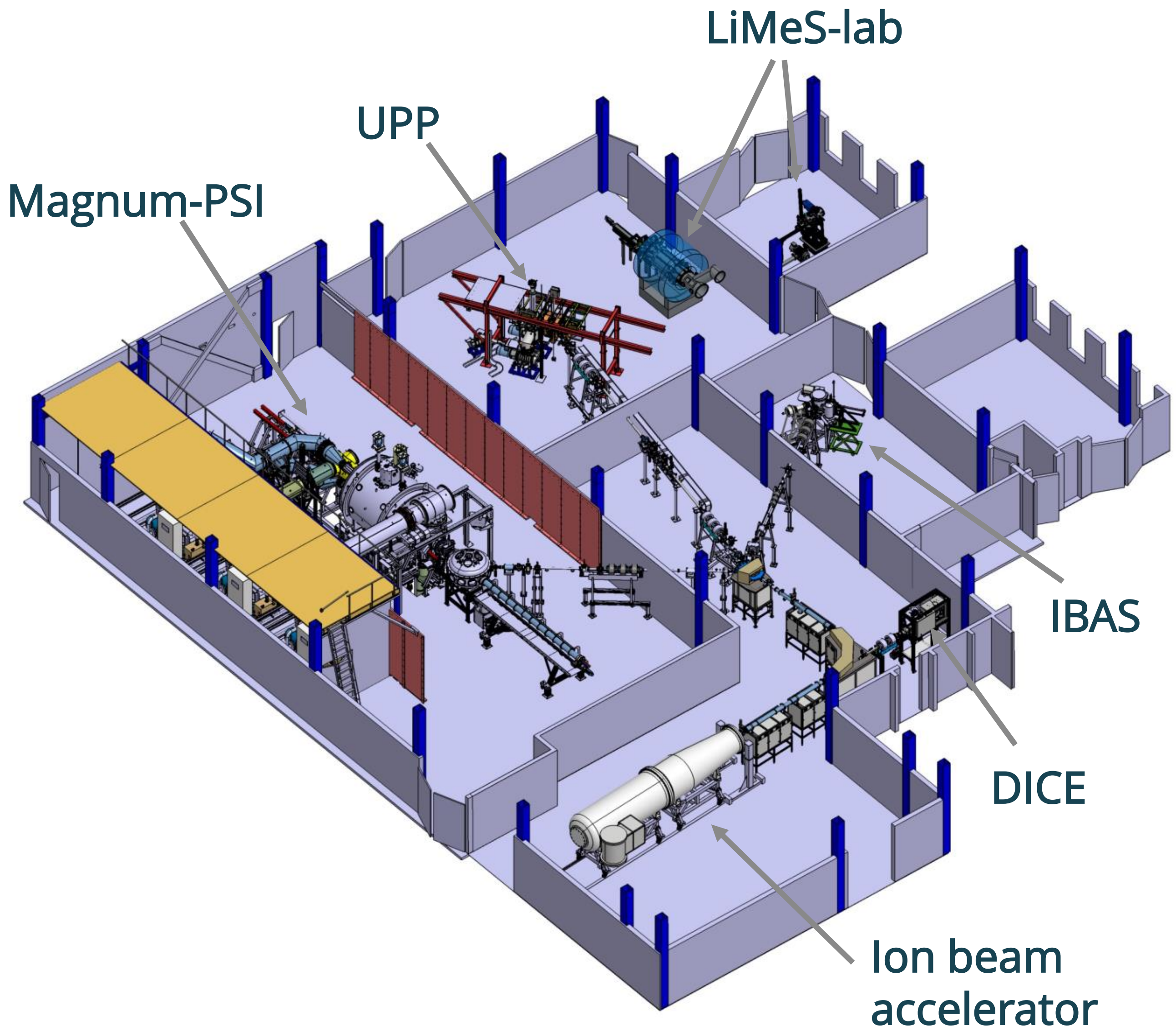


Combined user facilities

Facilities open for industry

Apply for access:

https://www.differ.nl/#front-facilities



Section B

Future (user) facilities

Liquid metal divertors as an alternative strategy for fusion

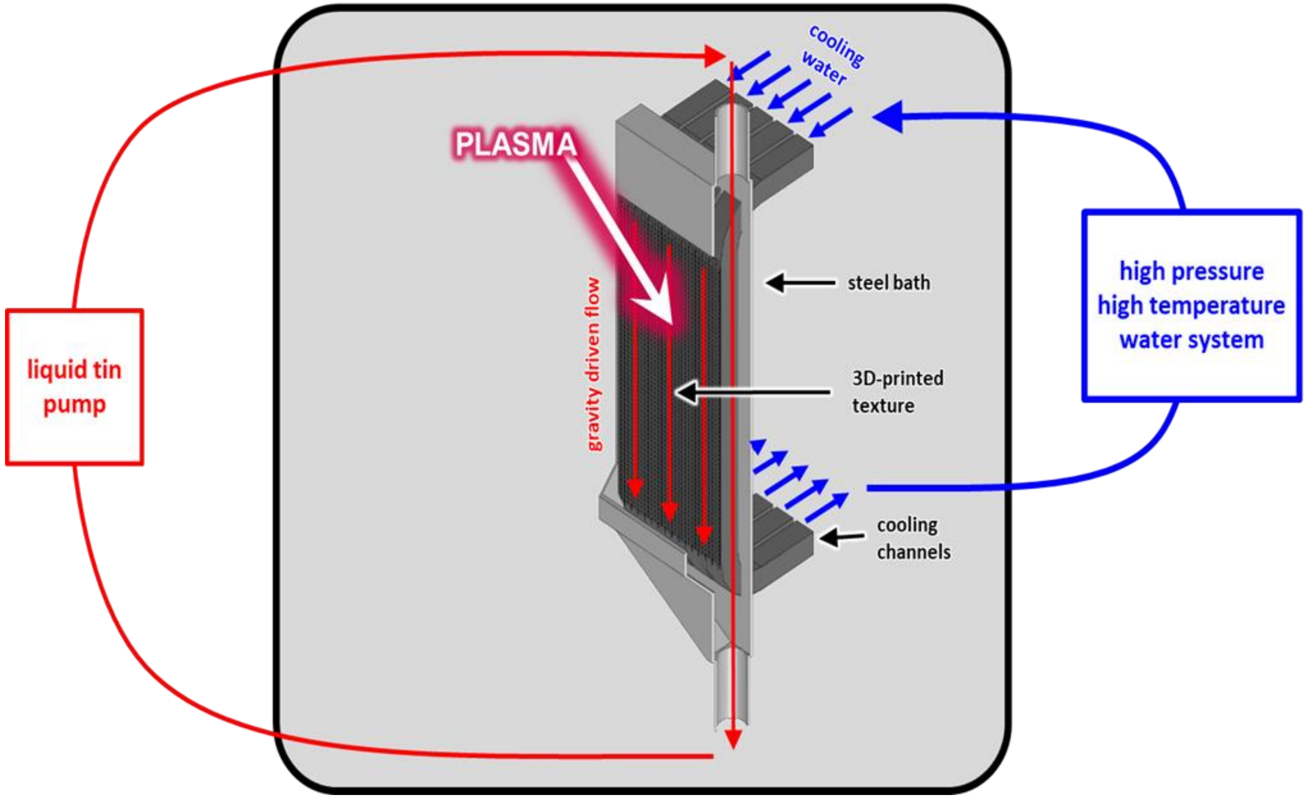
Fusion rectors will produce more heat and neutrons and operate continuously

Significant challenges when using water cooled tungsten wall components in fusion reactors

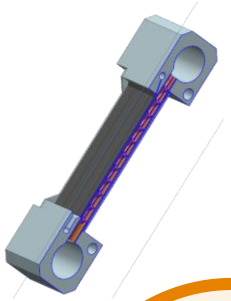
- Erosion lifetime
- Vulnerable to cracking
- Irreversible damage (melting)
- Neutron damage

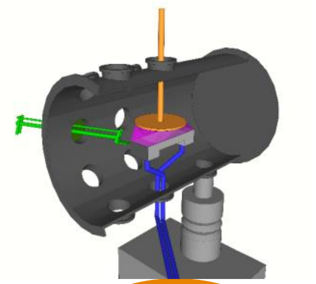
Liquid metal walls have significant potential to avoid/mitigate these issues

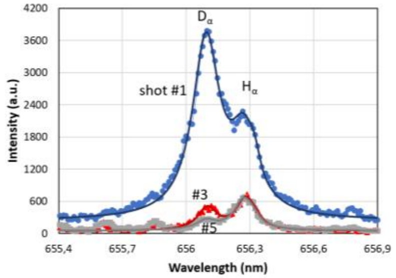
- Self healing
- No cracking
- Already molten, vapour shielding
- Neutrons only affect substrate, not liquid metals



LiMeS-lab: an integrated laboratory for the development of Liquid Metal Shield technologies for fusion reactors







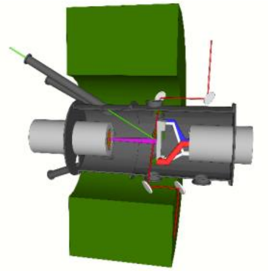
Design and manufacture mock-up

3D printing on to mock-up

Wetting liquid metal

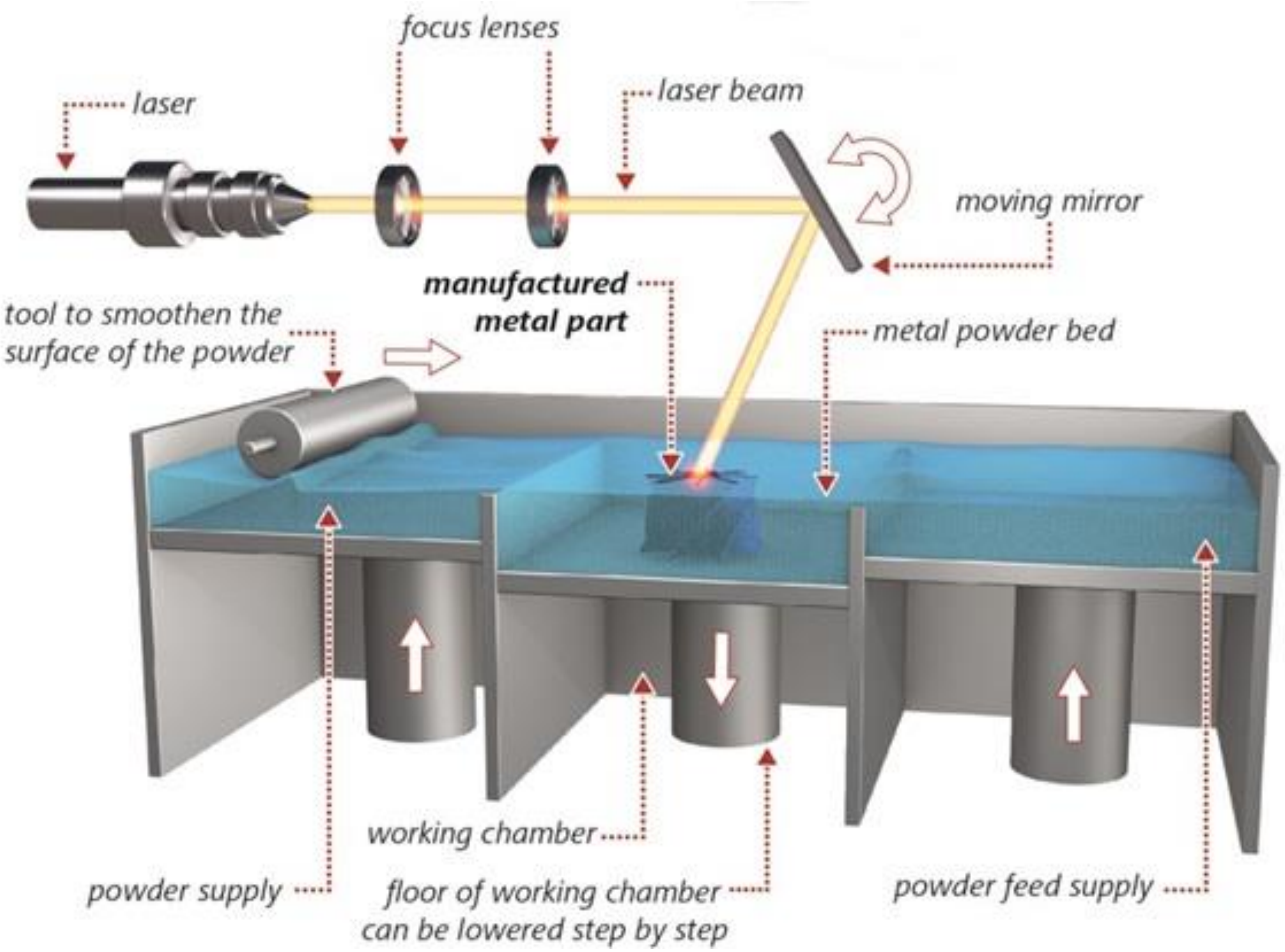
Experiments linear plasma device

Post-mortem analysis



Use Selective Laser Melting to produce high quality 3D printed structures to contain liquid metal

- Priorities:
  - High density W
  - Small feature size (<100 um)
  - Good strength/toughness
- Upgrade foci:
  - Powder bed temperature
    - → reduce thermal gradients
  - Oxygen content
    - → reduce porosity
  - Laser power density/spot size
    - → reduce feature size



empa.ch

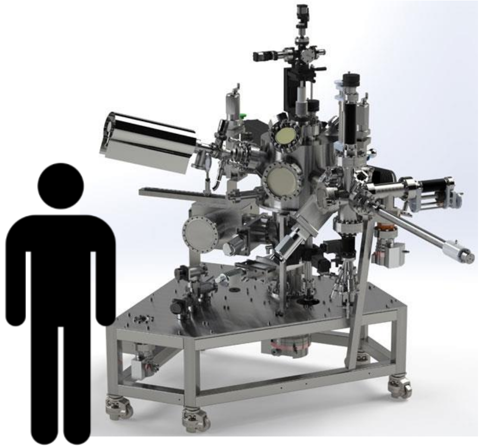
Pulsed Laser Deposition Lab for Energy Research (PLD4Energy)

DIFFER | UNIVERSITY OF TWENTE. | TU/e Technische Universiteit Eindhoven University of Technology | RATIO computer aided systems engineering

university of groningen | TU Delft | Universiteit Leiden | Universiteit Utrecht | TNO innovation for life

- Ample in situ characterization
- Well-controlled deposition of transition metal oxides up to 10 cm in diameter

Single chamber PLD system



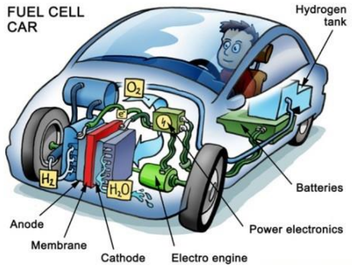
+

PLD cluster line

Photovoltaics

https://news.mit.edu

Fuel Cells

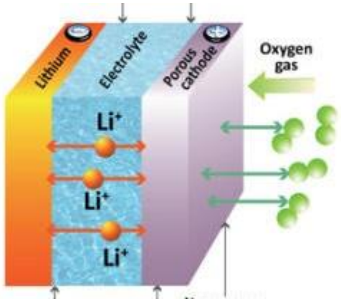


www.imageproduction.nl

Electrolysers

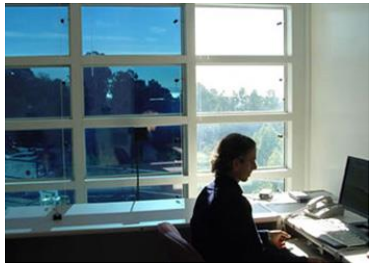
www.wikipedia.com

Batteries



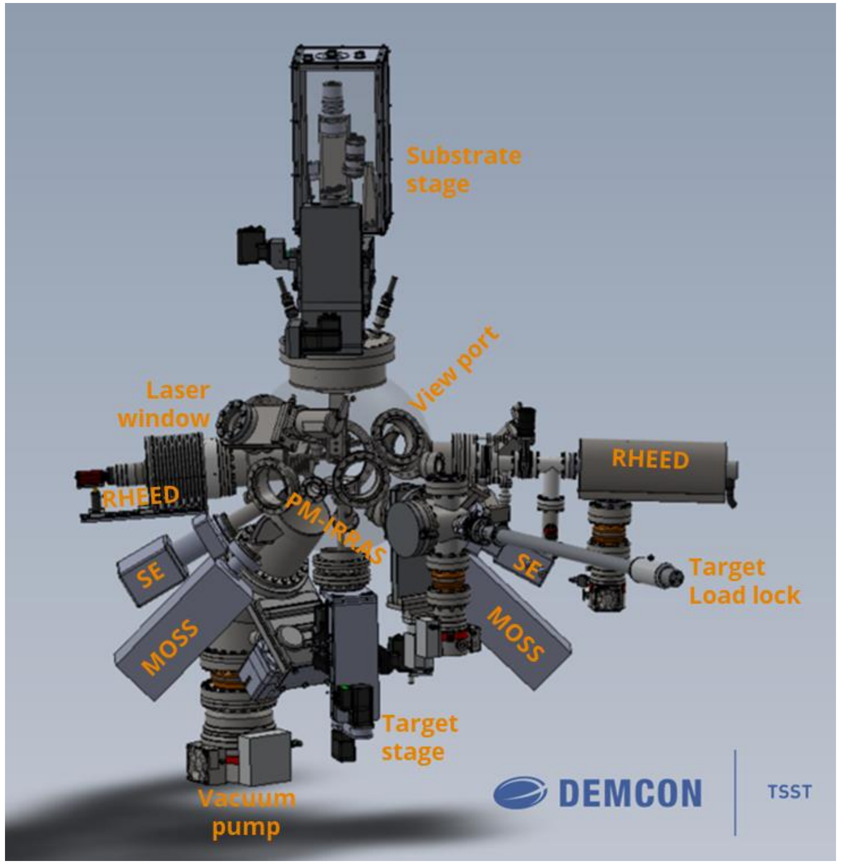
Argonne National Laboratory

Electrochromic windows

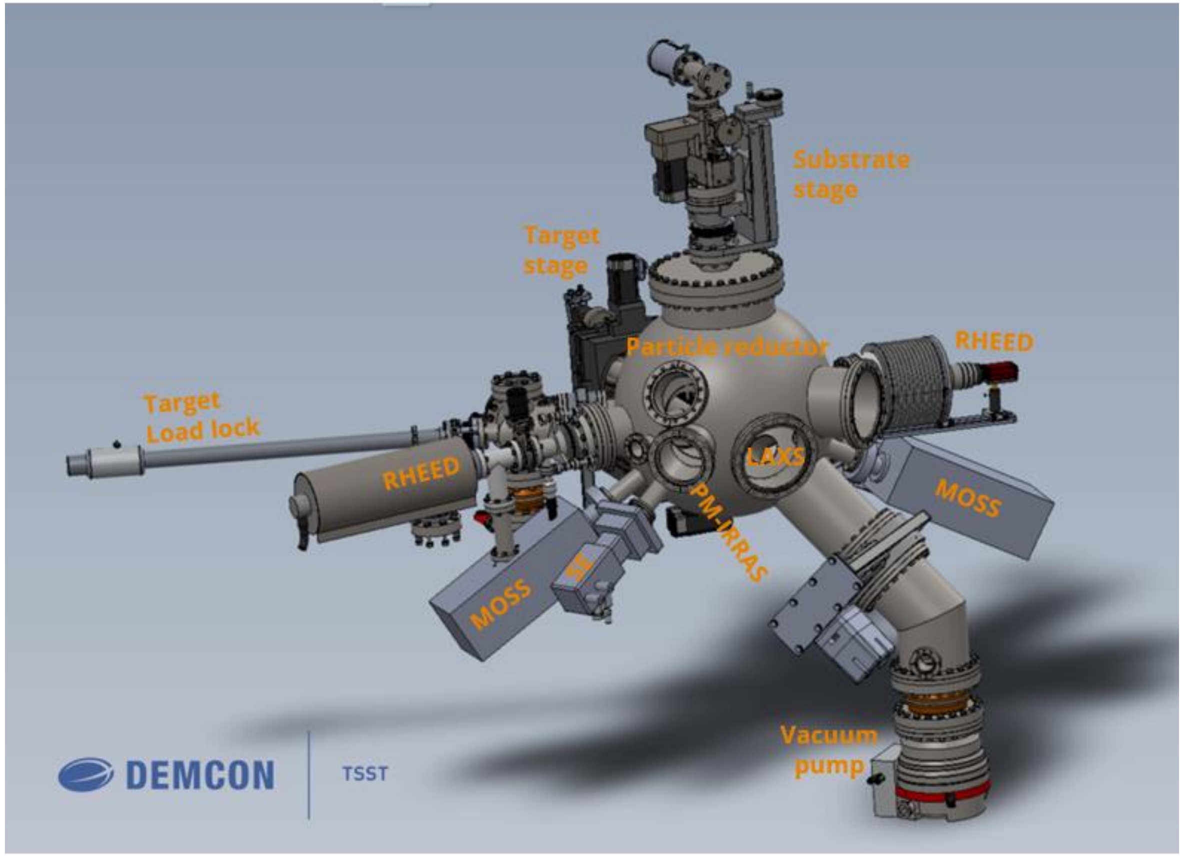


www.greengeek.ca

Pulsed Laser Deposition Lab for Energy Research (PLD4Energy)

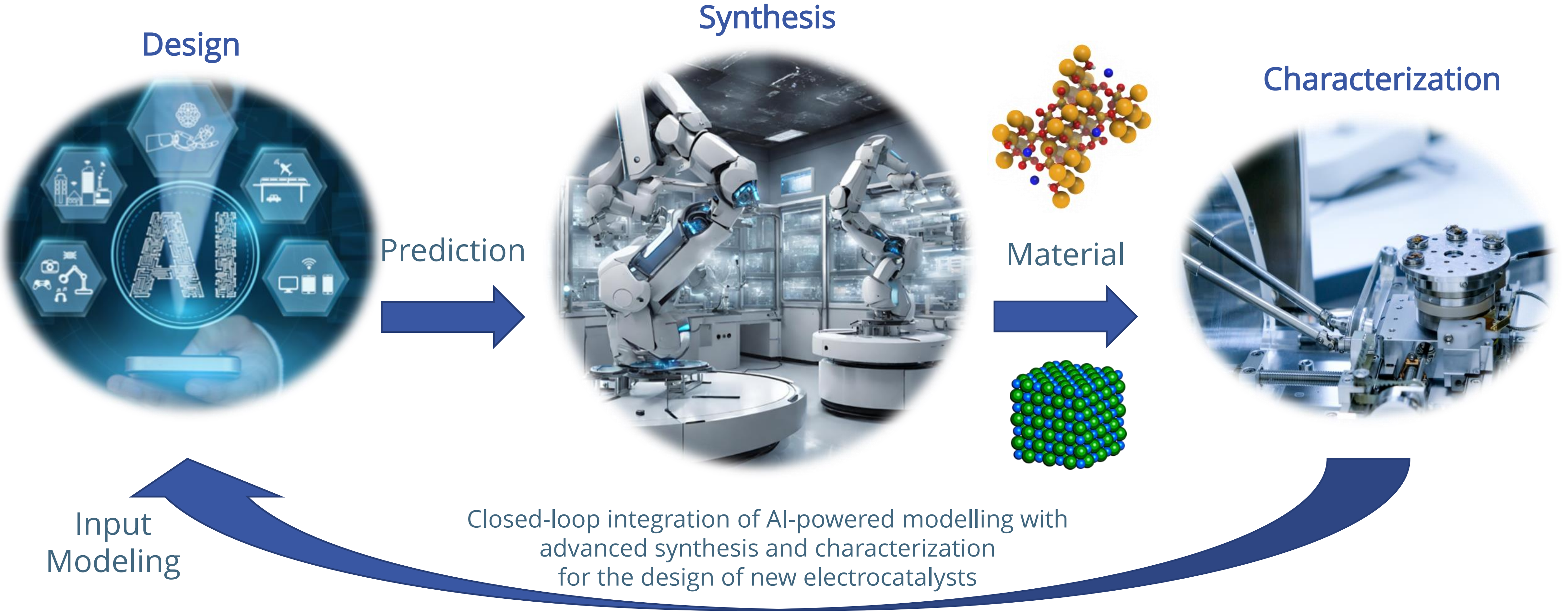


Small area



Large area

Self-driving lab



Design

Prediction

Synthesis

Material

Characterization

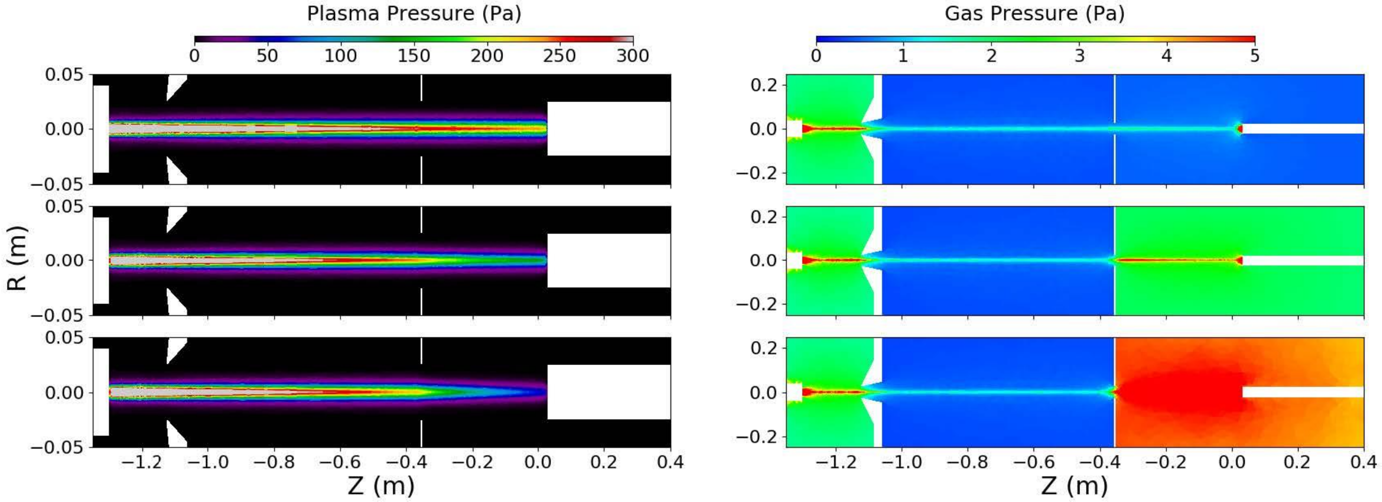
Input
Modeling

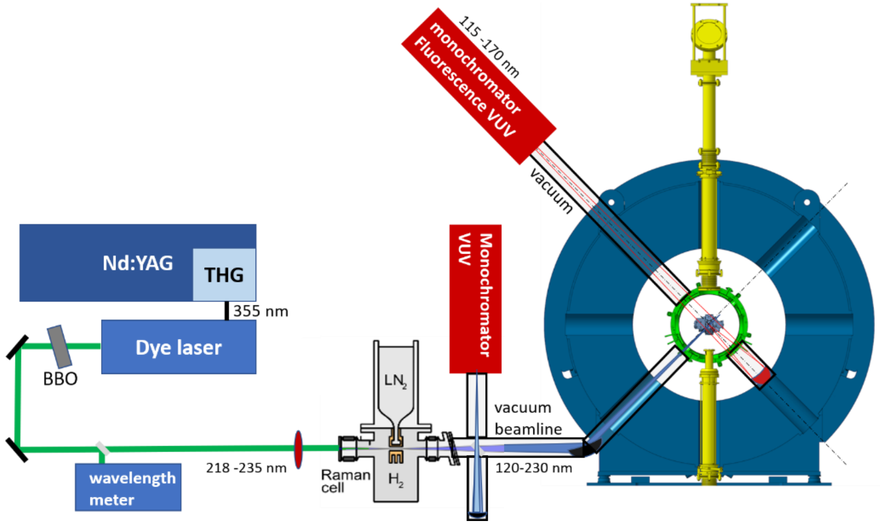
Closed-loop integration of AI-powered modelling with
advanced synthesis and characterization
for the design of new electrocatalysts

Section C
Additional slides

Sensors for exhaust and performance control

- Detachment physics and model validation
- Diagnostic of plasma neutral interaction in the divertor
- Modelling and validation of atomic/molecular plasma interactions
- Coming soon: active spectroscopy for atomic and vibrationally resolved molecular Hydrogen



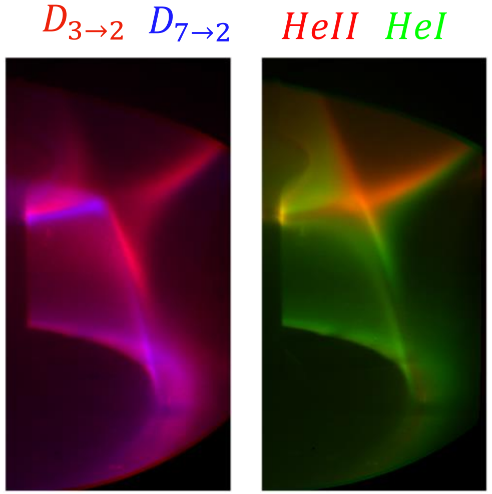


Sensors for exhaust and performance control

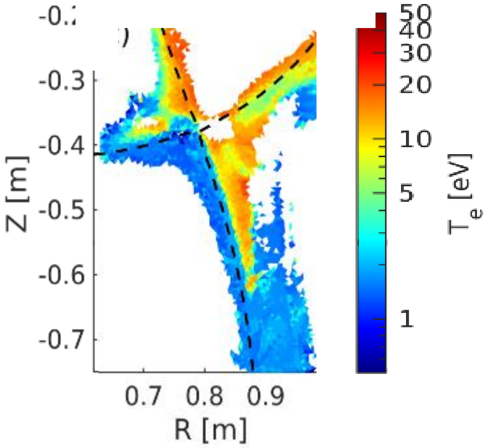
- Diagnostic of plasma neutral interaction in the divertor
- Multi-Spectral Imaging diagnostics (MANTIS): TCV, MAST-U
- Detachment physics

MANTIS diagnostic

Camera images



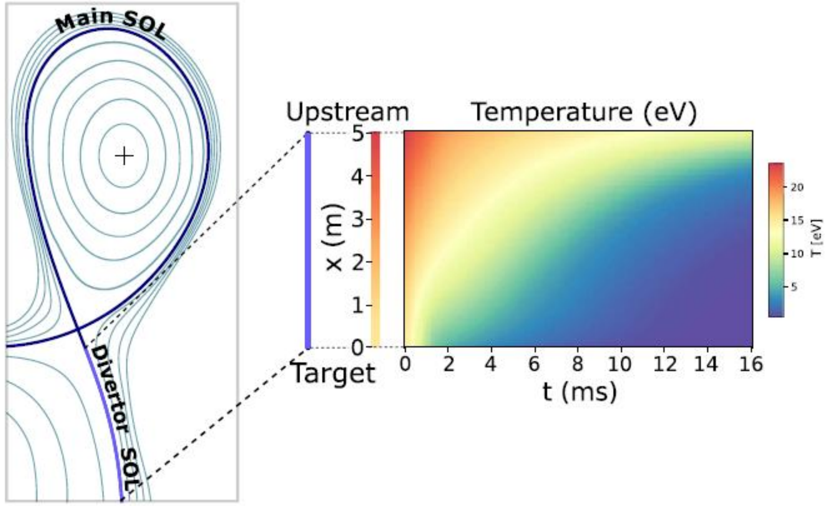
Derived temperature



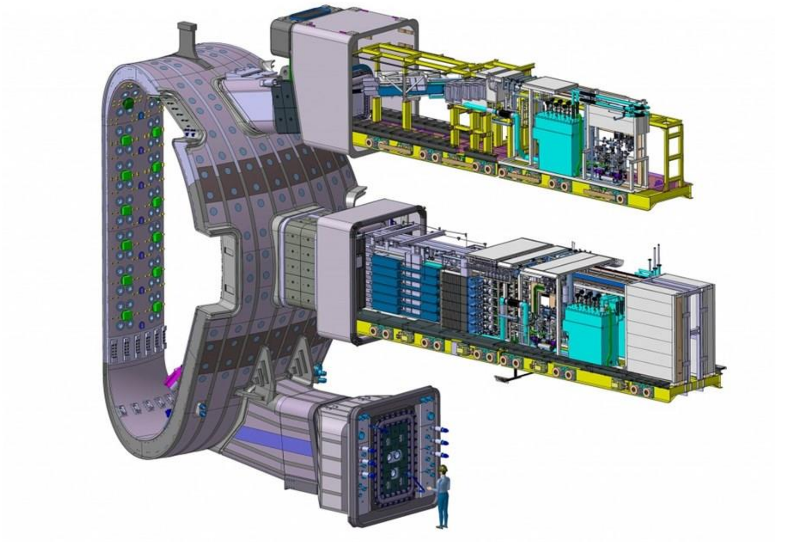
Exhaust and performance control

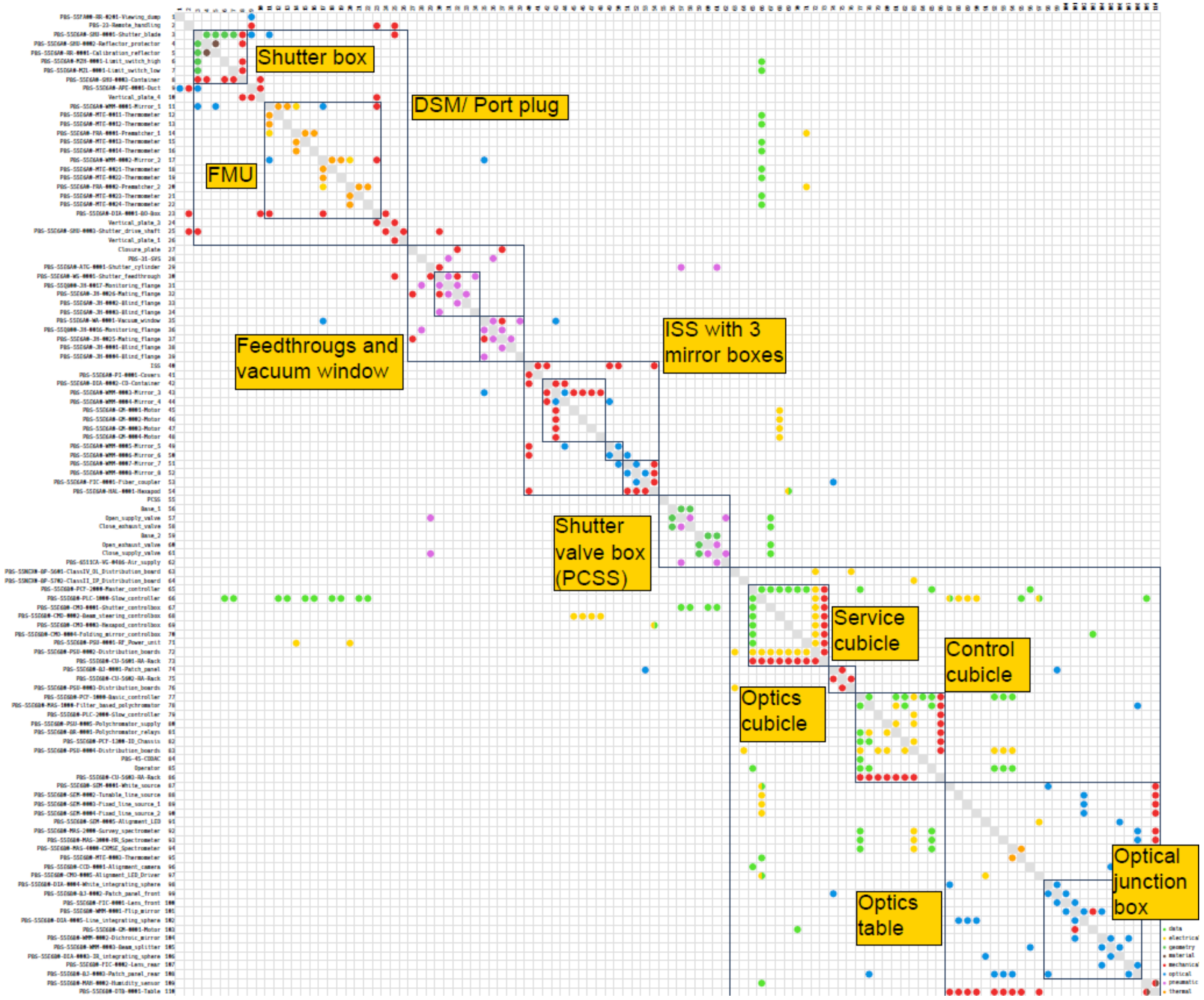
- System Identification and control of divertor dynamics
- Development and validation of reduced models of divertor dynamics

x-point radiator control on ASDEX-U with DIFFER controller



Systems Engineering example: ITER VRVS diagnostic





T. Beernaert et al., *To be submitted*

Applied to ITER diagnostics

- VSRS diagnostic as case study
- DSM shows dependency patterns in complex system architecture

➔ Tool to manage and organize complex systems

Electrochemical membrane reactors for energy storage

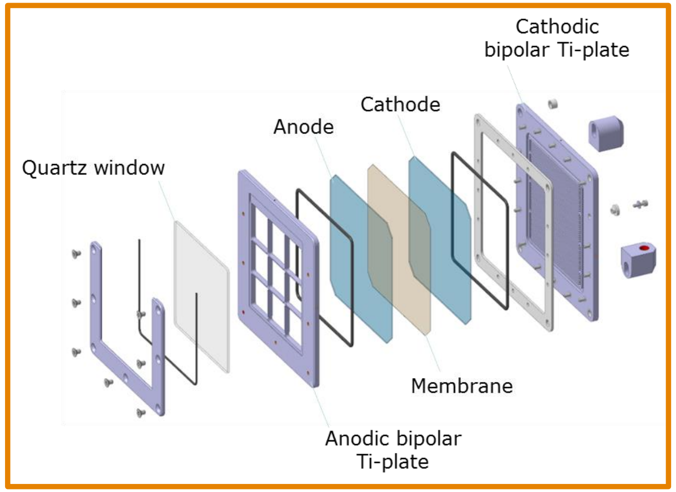
- Chemical lab for material development
    - (Nanostructured) electrode, (thin) electrolytes and membrane electrode assemblies

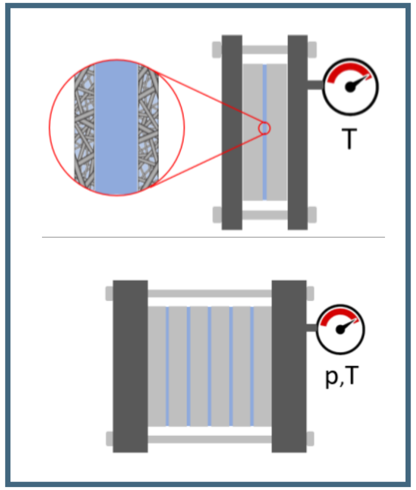
- Electrochemical systems
    - Conventional: Anion Exchange Membrane (AEM) electrolysers; Proton Exchange Membrane (PEM) electrolysers; Solid Oxide Electrolyte Cells (SOEC)
    - Novel/Hybrid: light driven; plasma enabled

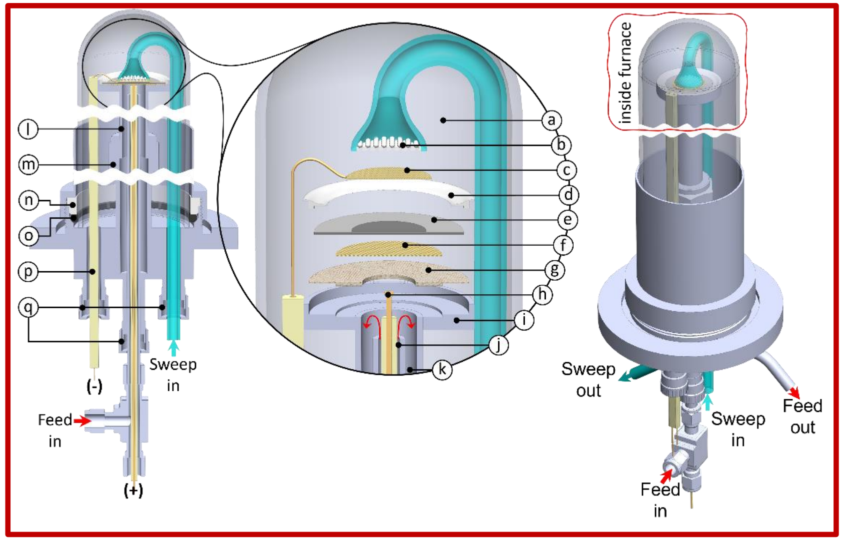
Electrochemical membrane reactors for energy storage

Multiple testing facilities

- Photoelectrochemical setups (x3)
  - Lab scale cells: 1-5 cm^2 active area
  - Prototype: 100 cm^2 active area
- AEM/PEM setups (x4)
  - Lab scale single cells: 1-10 cm^2 active area
  - Short stack: 250 cm^2 active area
  - Operating T: 20-80^{o}C
- SOE setups (x3)
  - Lab scale single cells; Active area: 1-10 cm^2
  - Short stack: 500 cm^2
  - Operating T: 400-900^{o}C

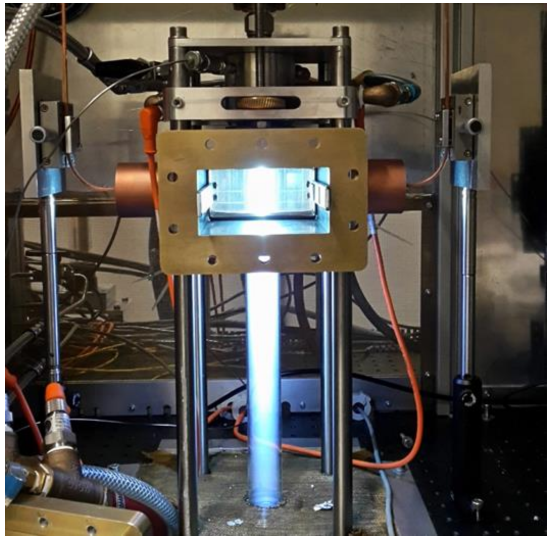






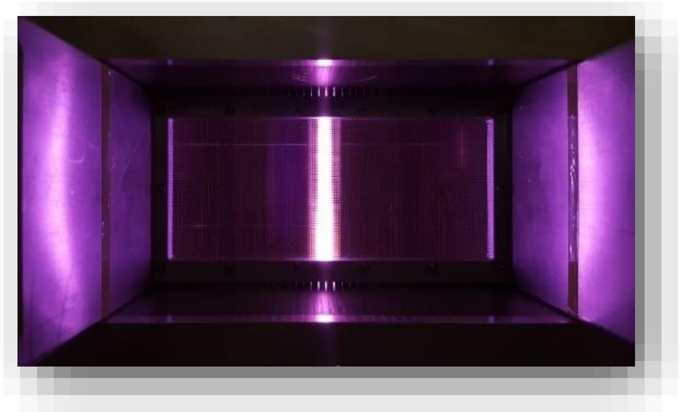
Plasma facilities for molecular conversion

CO_2 plasmolysis: studying the high-rate decomposition of CO_2 into CO and O_2



INIT-SF

1.5 kW/2.45 GHz, 30 slm, 50 - 1000 mbar



PROTO-SF

6 kW/913 MHz, 120 slm, 50 - 1000 mbar

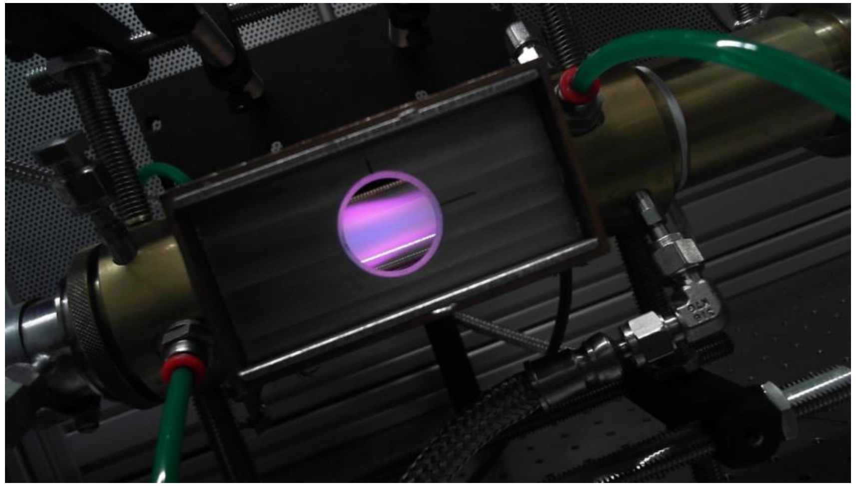
KEROGREEN

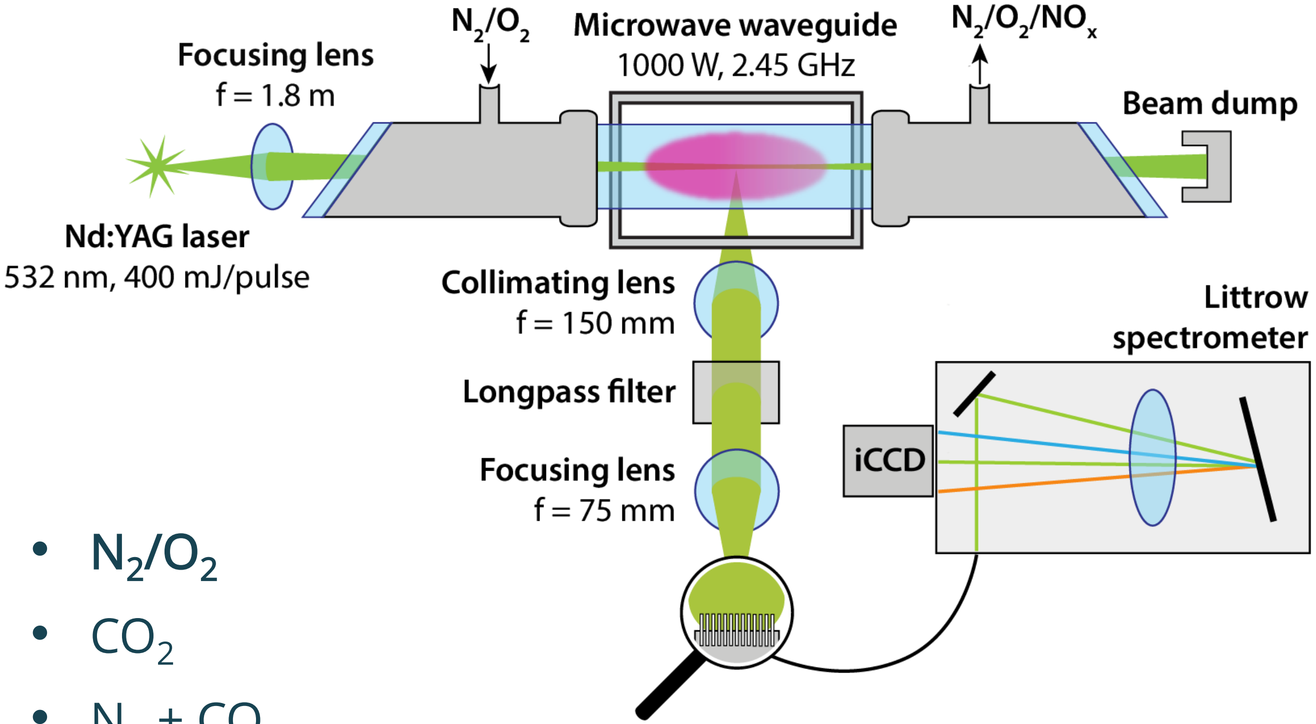
6 kW/913 MHz, 120 slm, 100 - 200 mbar

Fully integrated concept reactor for production of kerosene from CO_2, H_2O & renewable electricity

Plasma facilities for molecular conversion

- Laser spectroscopic methods (Thomson, rotational and vibrational Raman) for operando plasma and molecular characterization
- Output gas analysis: Fourier-transform infrared spectroscopy (FTIR)





- N_2/O_2
- CO_2
- $N_2 + CO_2$
- $CH_4 + CO_2$

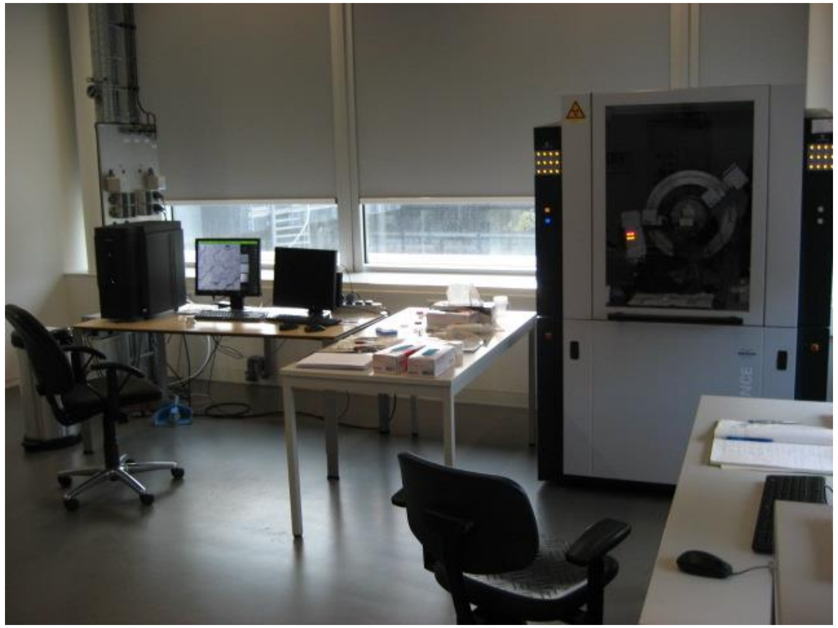
NEXT-SF

1.5 kW/2.45 GHz, 30 slm, 50 - 1000 mbar

Materials Characterization Lab

Cluster the general-purpose materials characterization tools in one location

- Atomic force microscope (AFM)
- Fourier transform infrared spectroscopy (FTIR)
- Scanning electron microscopy (SEM) with energy dispersive x-ray analysis (EDX)
- Sputter coater for SEM
- Spectroscopic ellipsometry
- Ultraviolet–visible spectroscopy (UV-VIS)
- X-ray diffractometer (XRD)
- Dielectric measurement setup
- Transmission electron microscopy (TEM) (other location)



SEM/EDX and XRD

Our facilities are open to external researchers and industry

Hans van Eck

DIFFER