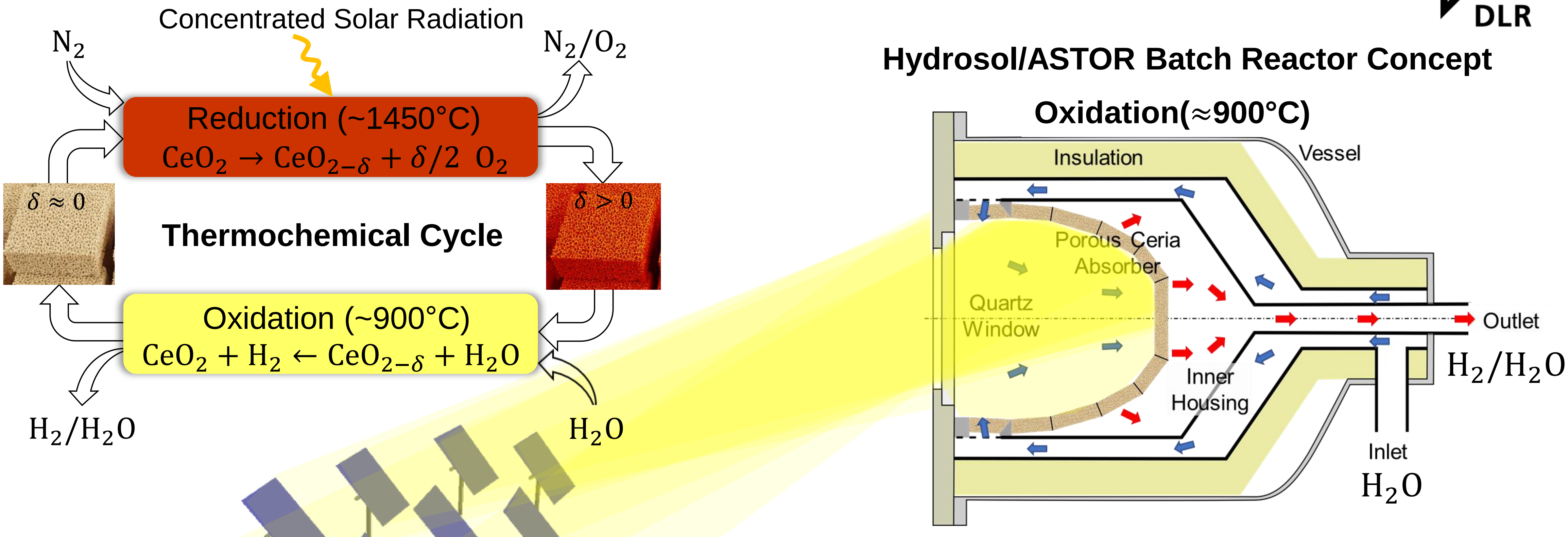
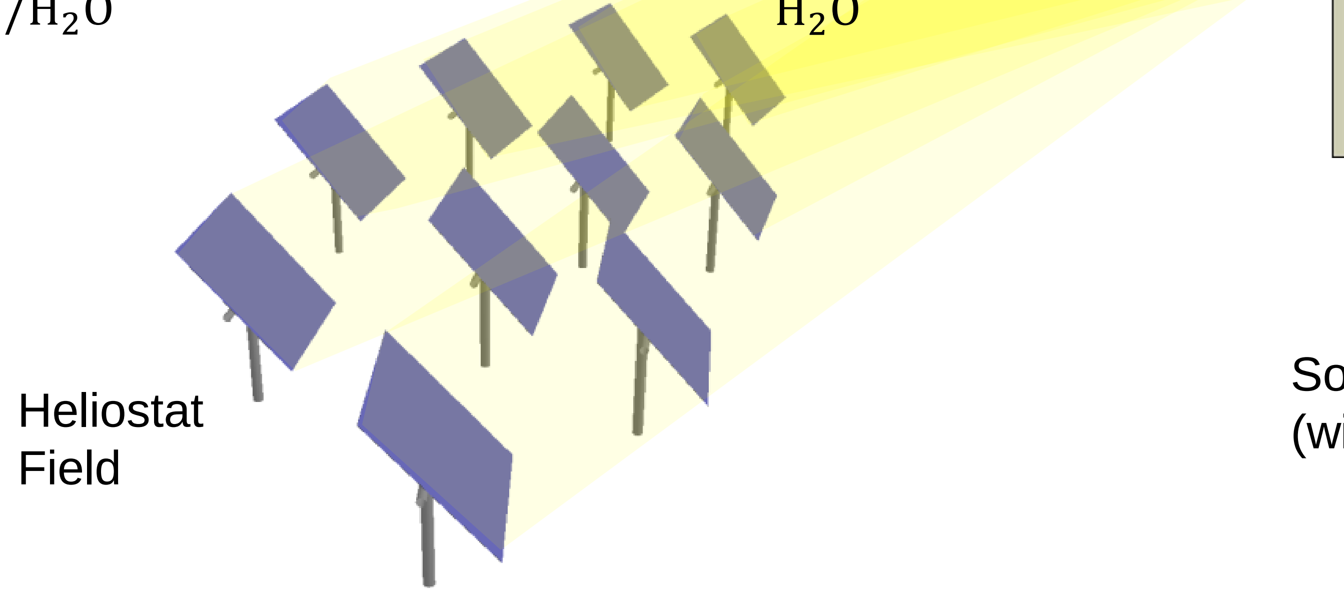
Control of Solar Thermochemical Fuel Production Processes

25th Cologne Solar Colloquium | 22 June 2022

Dr.-Ing. Johannes Grobbel, DLR Institute of Future Fuels, Jülich

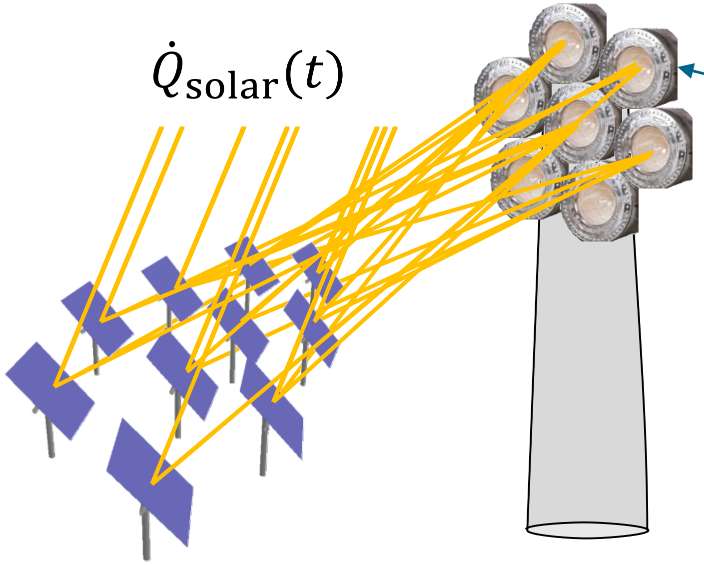
Thermochemical Redox Cycle for Hydrogen Generation



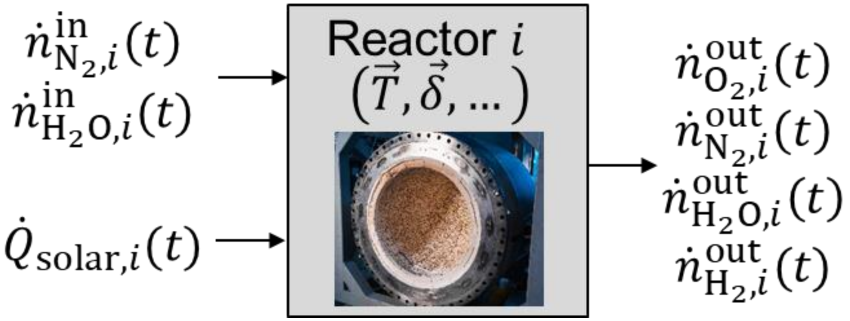


Solar Batch Reactor (window removed)

Scaled Plant with Multiple Reactors



Receiver with
N Reactors i:



Overall Hydrogen Production: $$n_{\mathrm{H_2}} = \int_{(1\ \mathrm{day})} \sum_{i}^{N} \dot{n}^{\mathrm{out}}_{\mathrm{H_2},i}(t)\,\mathrm{d}t$$

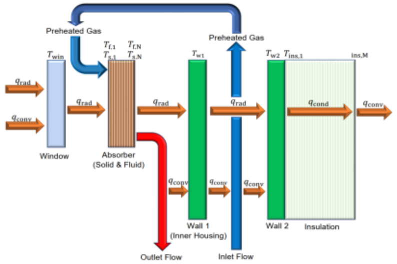
750 kW Hydrosol Plant (3 reactors)

Control Tasks:
- maximize overall hydrogen production
- safe operation within the material limits of the reactors

Manipulated Variables:
- irradiation to each reactor $\dot{Q}_{\mathrm{solar},i}(t)$ by setting the heliostat aim points
- the inlet gas flows of each reactor (having only limited temperature control capability)

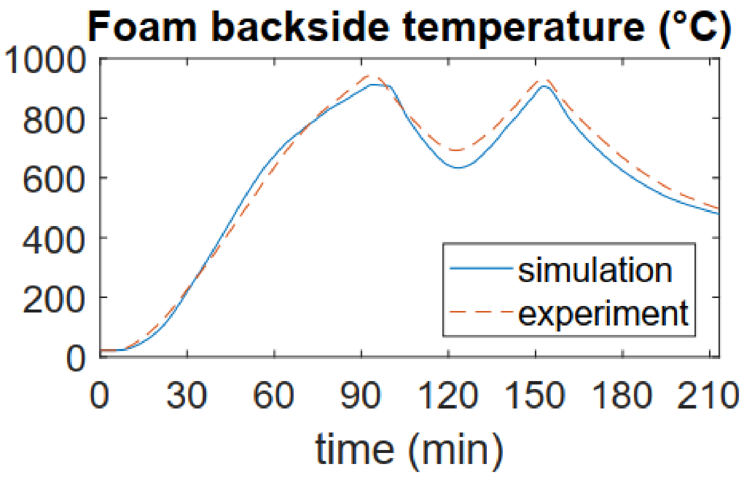
First Approach: Cascade Control in Project H2Loop

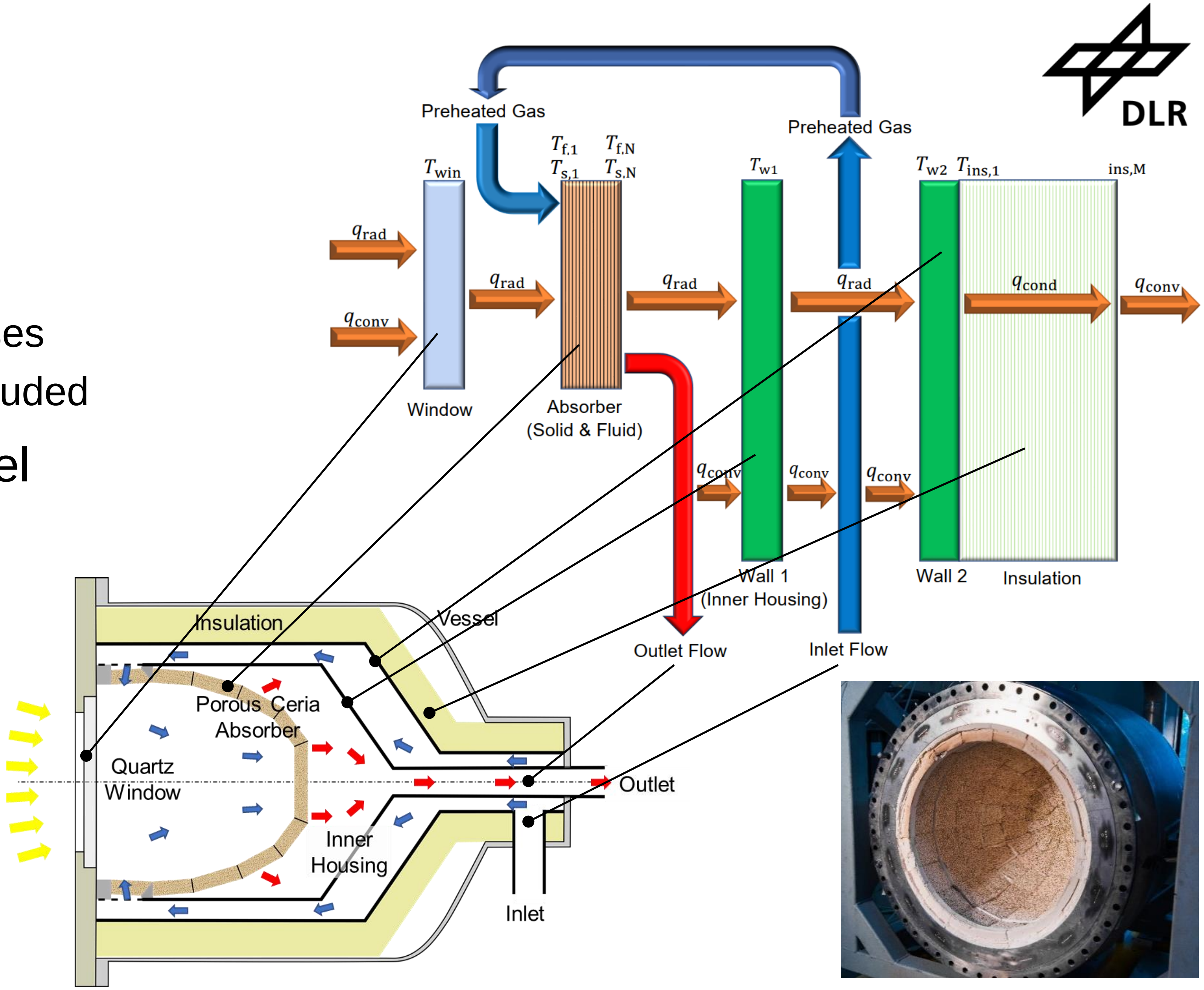
Physical Reactor Model



Reactor Model

- Absorber:
  - 1-D finite volume method
  - Coupled fluid & solid phases
  - Reduction & oxidation included
- Spectral view factor model
- Gas preheating included
- Validated



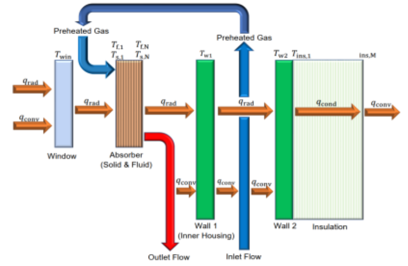


[1] Grobbel et al., AIP Conference Proceedings 2445, 130004 (2022); https://doi.org/10.1063/5.0085738

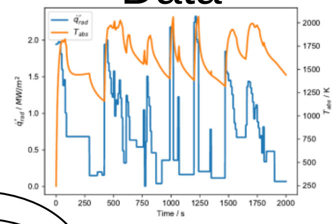
First Approach: Cascade Control in Project H2Loop

Data-Driven Reactor Model

Physical Reactor Model

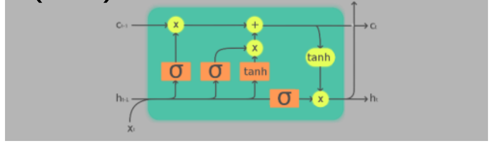


Data

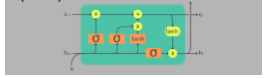


Training

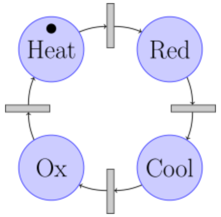
(fast) LSTM reactor model



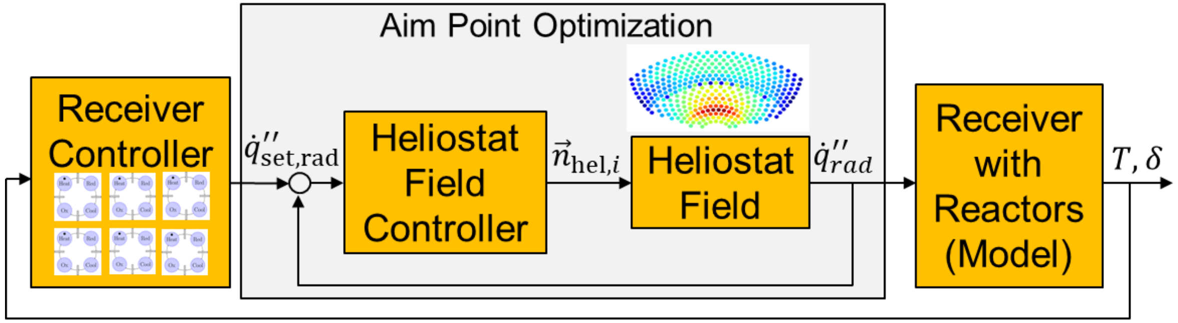
Trained LSTM



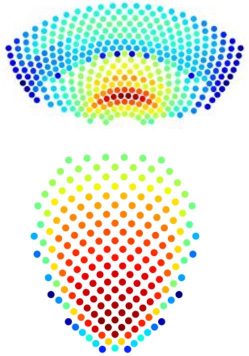
Hybrid Automaton

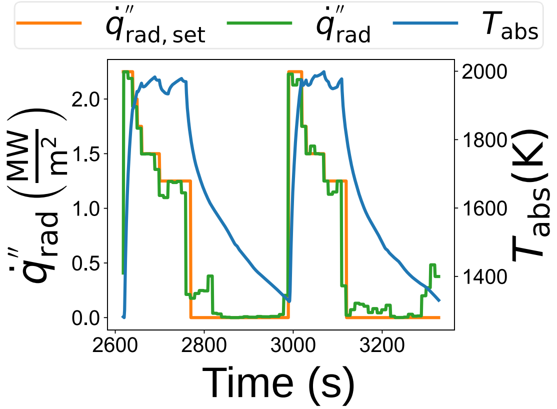


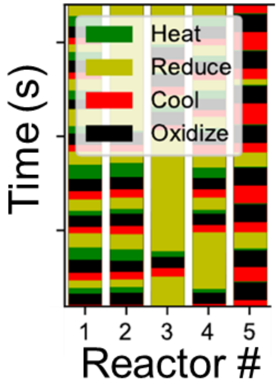
Cascade Control



Optimized Operation



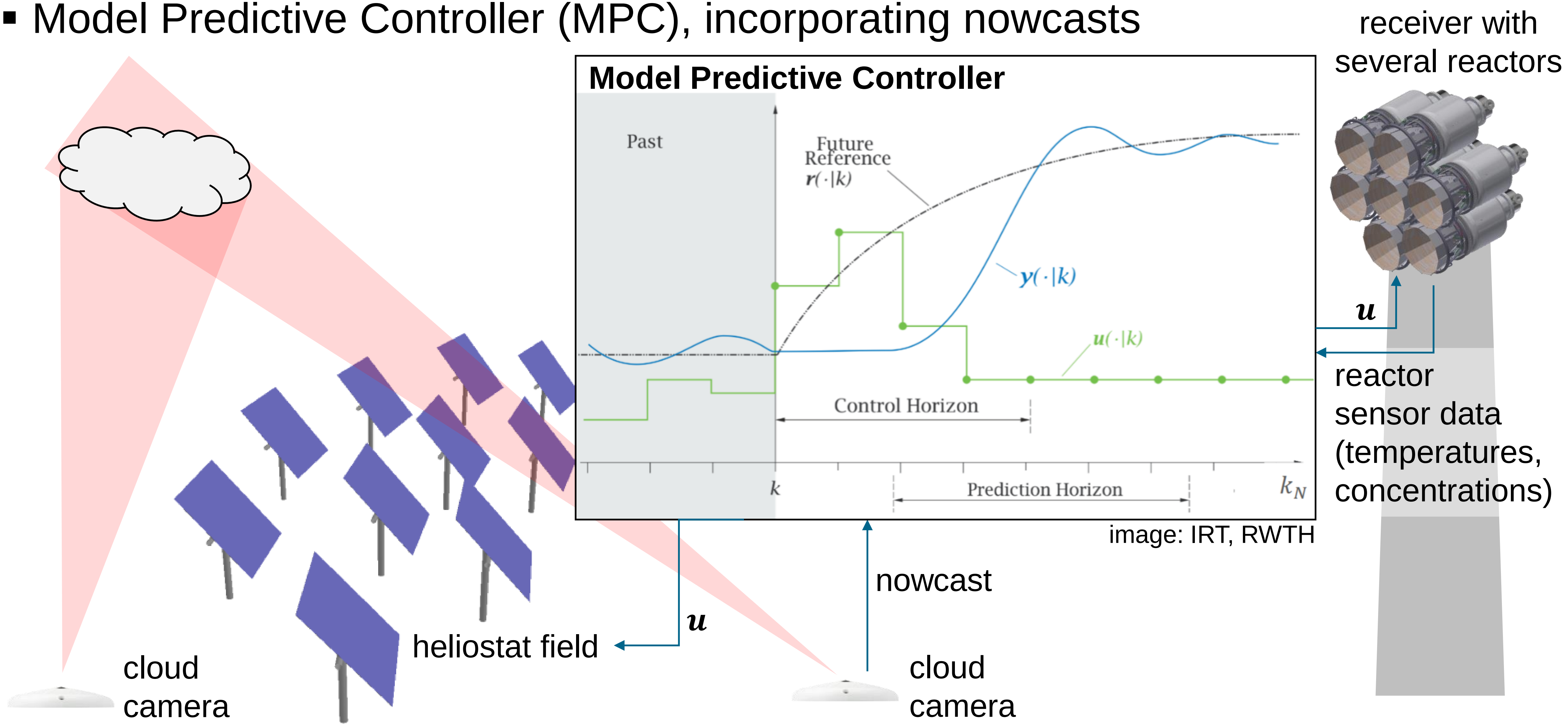




Oberkirsch et al., submitted to Solar Energy (in review)

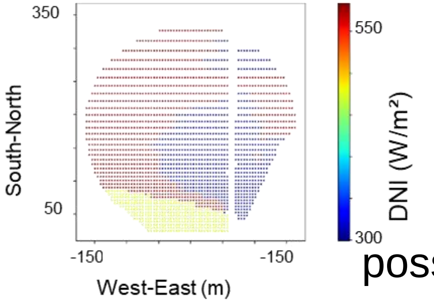
Project SolarFuelNow: MPC with DNI Nowcasting

- Model Predictive Controller (MPC), incorporating nowcasts



SolarFuelNow: System Overview

- Nowcasts with probability information
- DNI predicted for next 20 minutes



- Acts as OPC UA Server
- Collects, distributes and stores data
- monitors variables and ensures safe operation

- aim point optimization
- heliostat field control

WobaS → STRAL → possible reactor irradiations → Programmable Logic Controller (PLC) → set fluxes to reactors → STRAL

STRAL ↔ HeliOS → Heliostat Field

PLC → safety defocus → Heliostat Field

Solar Reactors → sensor data → PLC; PLC → actuator set points → Solar Reactors

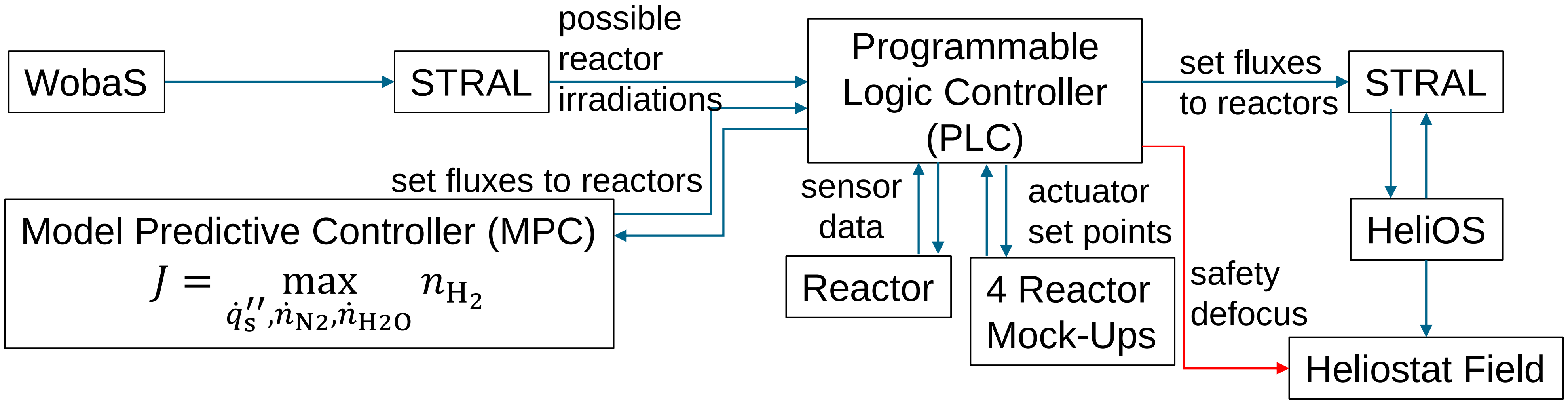
PLC ↔ sets fluxes and gases for reactors ↔ Model Predictive Controller (MPC)

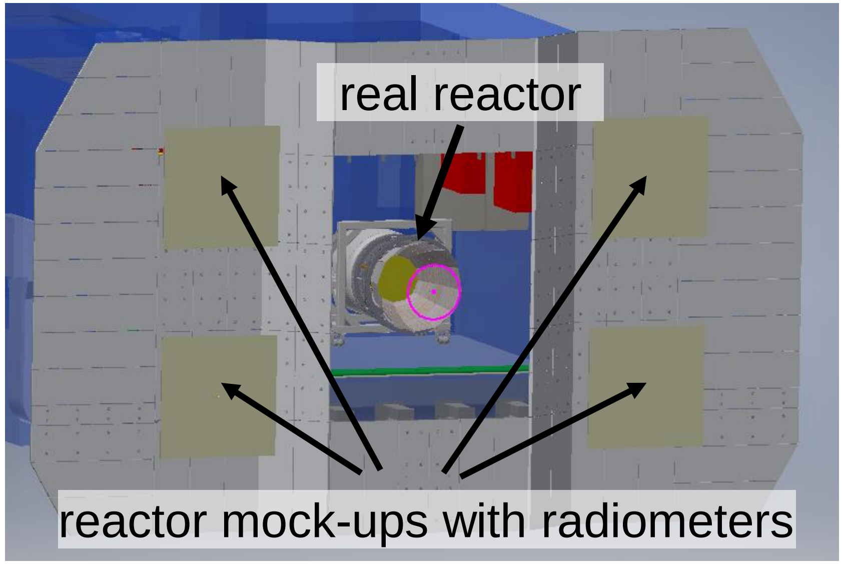
Model Predictive Controller (MPC)

$$J = \max_{\dot{q}_S'', \dot{n}_{N2}, \dot{n}_{H2O}} n_{H_2}$$

- has access to all system data from PLC
- uses physical model of reactor in state space form
- plans which reactors will be operated in the next 15-20 minutes
- decides when to start the reduction or oxidation cycle in each reactor

Outlook: Demonstration of MPC at Solar Tower Jülich





- demonstration with one real reactor and four mock-ups in 2023
- mock-ups have the same inputs and outputs as a real reactor
- mock-up state will be calculated by detailed model, fed with measured flux densities

Summary

- Solar chemical processes have special characteristics

  → requirements for control differ from the ones for CSP plants

- Two control approaches for thermochemical batch reactors were presented:
  - Cascade control using hybrid automata with a data-driven reactor model (LSTM)
    - allows flexible cycle durations and captures interdependency between reactors through coupling with heliostat field control
    - control behavior strongly dependent on switching criteria of hybrid automata
    - assumes constant DNI
  - Model predictive control
    - expected to be more versatile
    - incorporating probabilistic nowcasting information
    - in development, will be tested at Solar Tower Jülich in 2023
- The automatization of solar chemical processes becomes more important as the processes make their way from the lab to the field and are realized in larger scale

Acknowledgements

DLR

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Autor: Johannes Grobbel

Institute: DLR Institut für Future Fuels