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ASTRI

AUSTRALIAN SOLAR THERMAL RESEARCH INITIATIVE

Dynamic Model of a Continuous Hydrogen Production Plant Based on CeO_2 Thermochemical Cycle

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Introduction

ASTRI (Australian Solar Thermal Research Initiative)

Main goal: to deliver cost reductions and dispatchability improvements to CSP in Australia and to position Australia in CSP

Cost reduction base in 4 Nodes:

1. Heliostat Field and Receivers
2. Thermal Storage
3. Power Block
4. Adding Value

More than 120 researchers

Partners: Australian universities & institutes and international institutions

Funding partner

ARENA
Australian Government
Australian Renewable Energy Agency

Australian partners

CSIRO
Australian National University
Flinders University
QUT
The University of Adelaide
University of South Australia
The University of Queensland Australia

US collaborators

Sandia National Laboratories
Arizona State University
NREL National Renewable Energy Laboratory
University of Colorado Boulder

Europe collaborator

ETH Swiss Federal Institute of Technology Zurich

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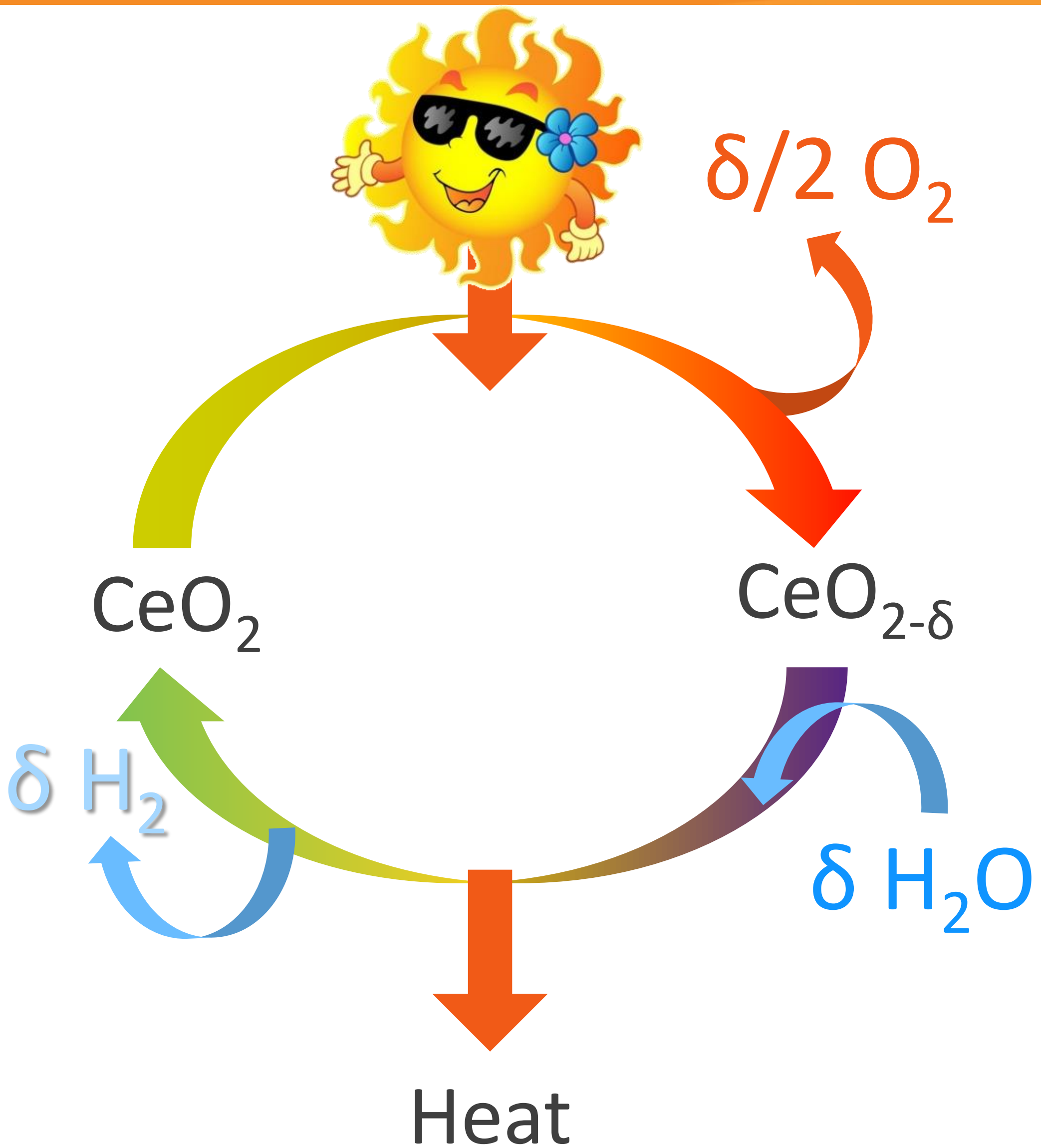
Overview Thermochemical Cycles



Features:

- ✓ Temperature ranges between 1300 and 1800 K
- ✓ Non stoichiometric thermal reduction
- ✓ Solar for sensible heat of solids and gases
- ✓ Heat recovery requirements from solids species

Drawbacks:

- HT → Heat losses (re-radiation and conduction)
- Materials requirement (building reactors)
- Thermal-shock resistance
- Efficient heat recovery from solids
- Reactor design

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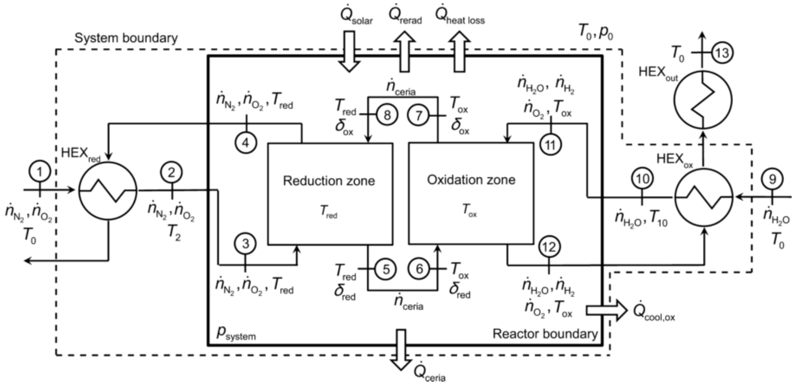
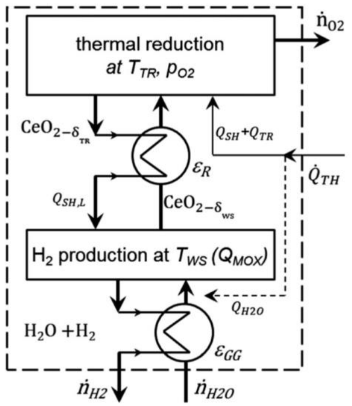
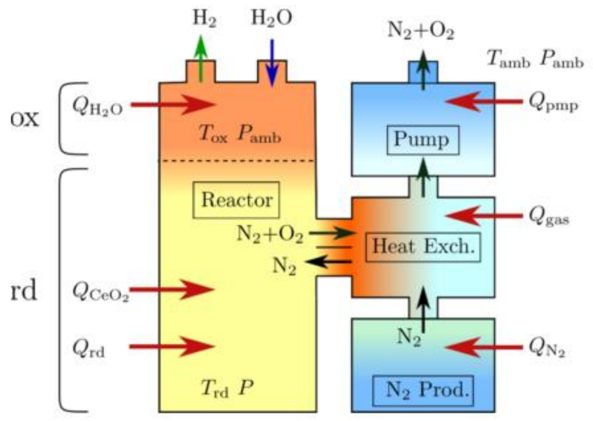
Literature Review



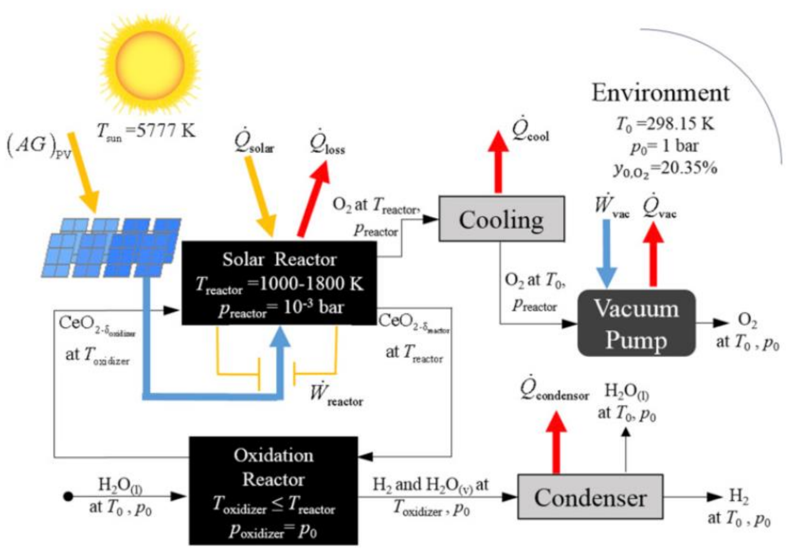
Bader et al. 2013



Ermanoski et al. 2014



Bulfin et al. 2015



Schieber et al. 2017

Bader et al. 2016. Thermodynamic Analysis of Isothermal Redox Cycling of Ceria for Solar Fuel Production. Energy & Fuels, 27, 9, 5533-5544

Ermanoski et al. 2014. Efficiency maximization in solar-thermochemical fuel production: challenging the concept of isothermal water splitting. PCCP 16, 18, 8418-8427

Bulfin et al. 2015. Thermodynamics of CeO_2 Thermochemical Fuel Production. 29, 2 1001–1009

Schieber et al. 2017. H_2O splitting via a two-step solar thermoelectrolytic cycle based on non-stoichiometric ceria redox reactions: Thermodynamic analysis. IJHE, 42, 30, 18785-18793

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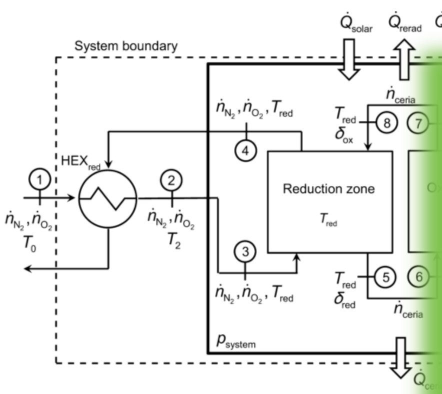
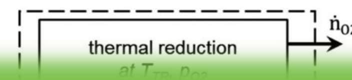
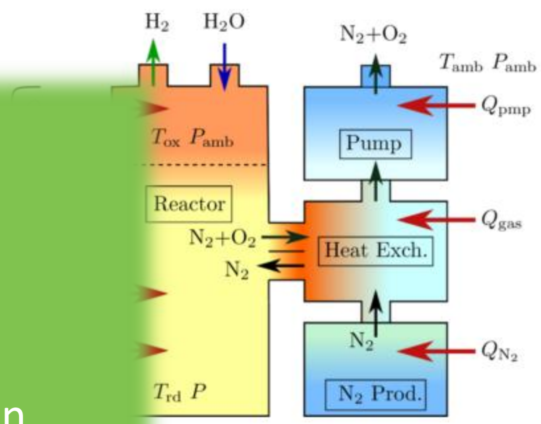
Literature Review



Bader et al. 2[...]





[...]lfin et al. 2015

Considerations:

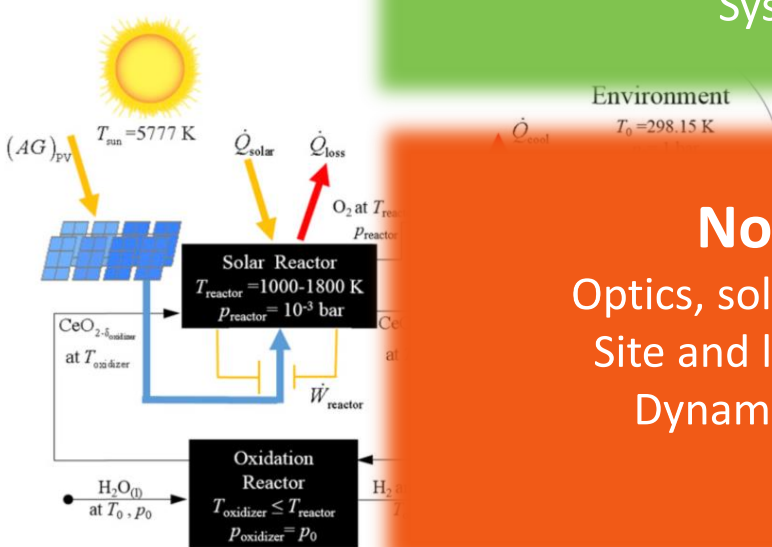
Steady State Operation

Effect of ΔT

Effect of O_2 and H_2 separation

Radiation, conduction and convection losses

System efficiency



Schieber et al. 2017

Bader et al. 2016. Thermodynamic Analysis of Isothermal Redox Cycling of Ceria for [...]uels, 27, 9, 5533-5544

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[...]ermochemical Fuel Production. 29, 2

[...] solar thermoelectrolytic cycle based [...]hermodynamic analysis. IJHE, 42, 30, [...]3

Not included:

Optics, solar field configuration

Site and location of the plant

Dynamics (DNI variation)

Controls

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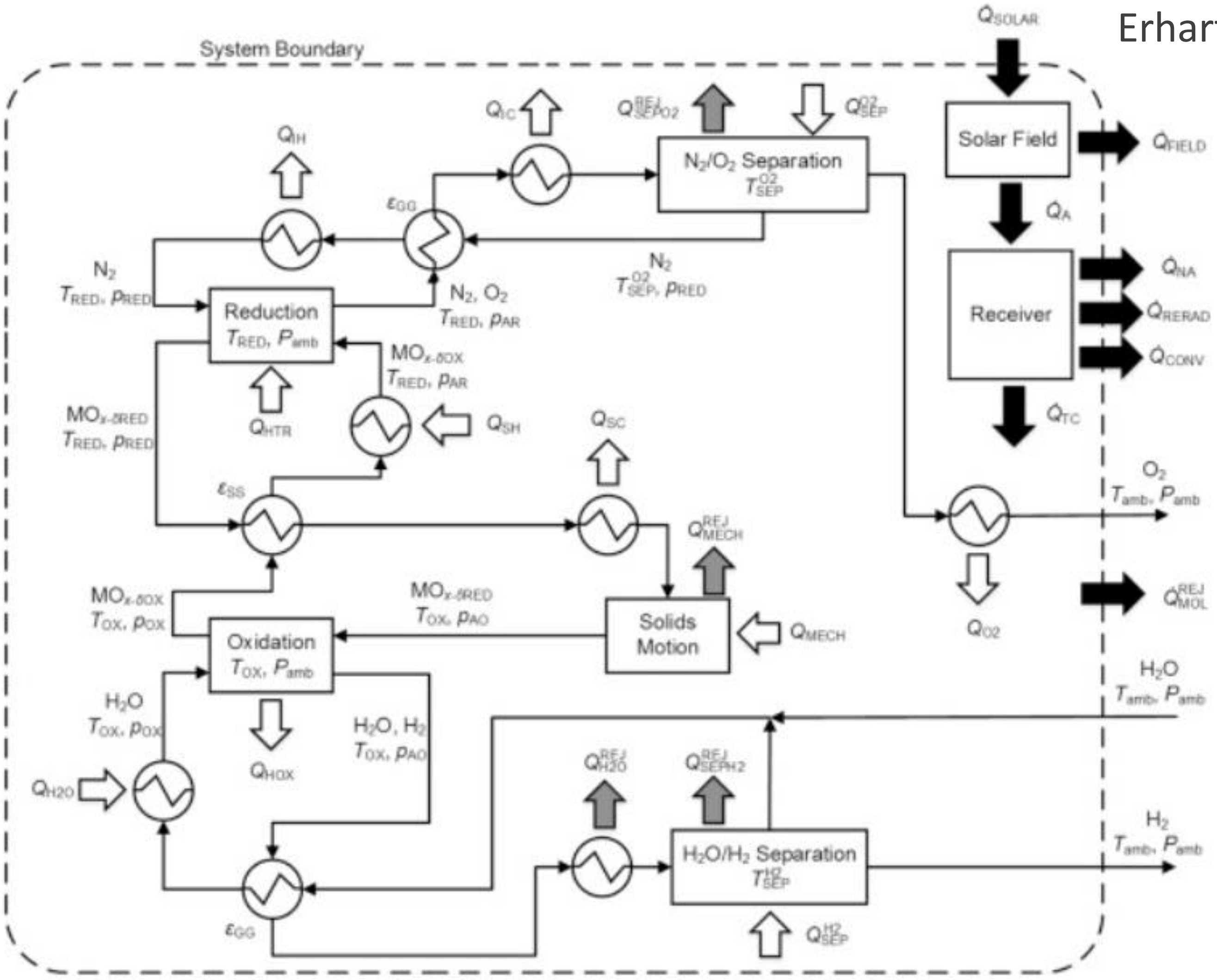
Literature Review

Erhart et al. 2016



Erhart et al. 2016 System efficiency for two-step metal oxide solar thermochemical hydrogen production – Part 1: Thermodynamic model and impact of oxidation kinetics. IJHE, 44, 46, 19881–19893 https://doi.org/10.1016/j.ijhydene.2016.07.109

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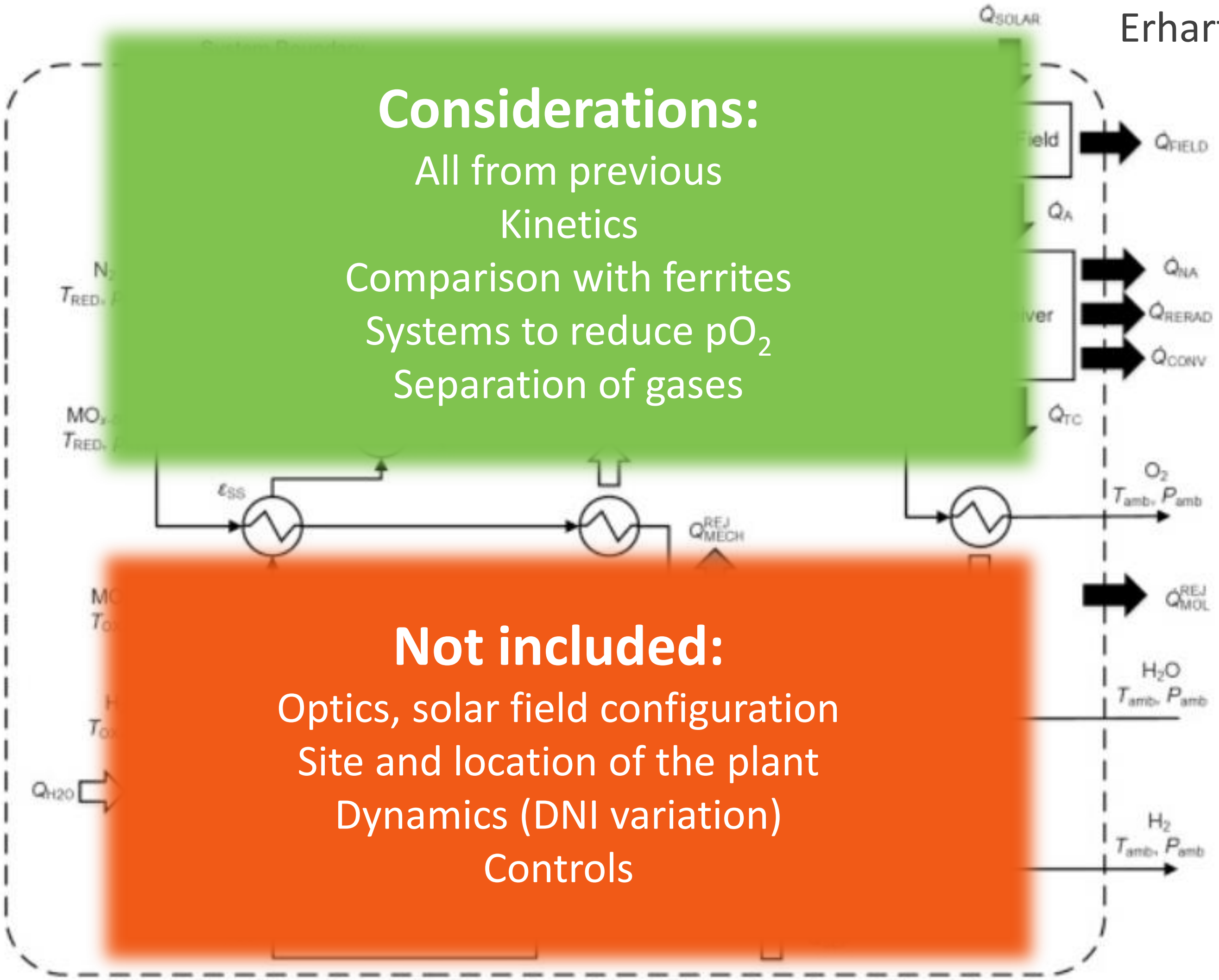

Considerations:

All from previous

Kinetics

Comparison with ferrites

Systems to reduce pO_2

Separation of gases

Not included:

Optics, solar field configuration

Site and location of the plant

Dynamics (DNI variation)

Controls

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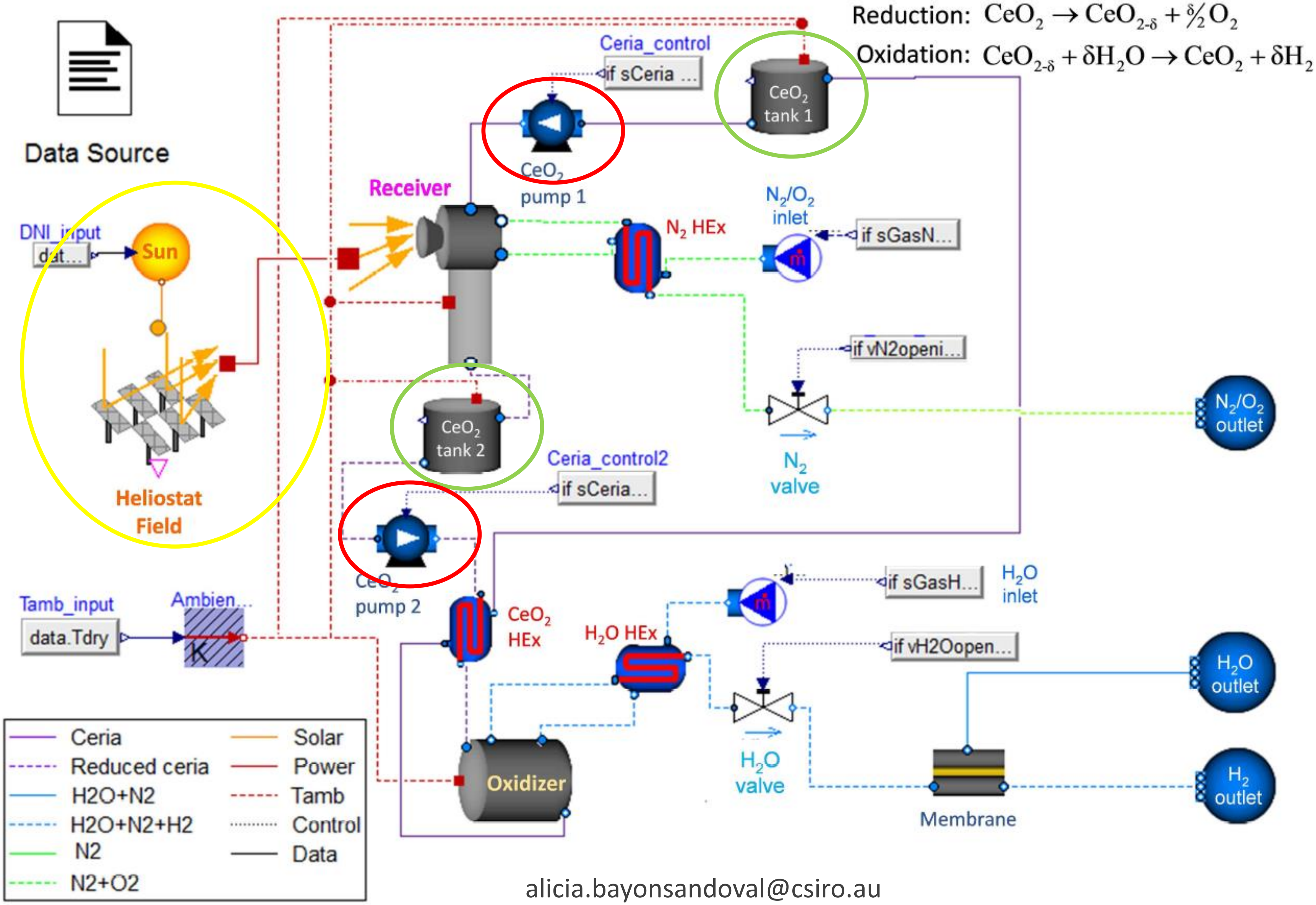
System Description: what is new?



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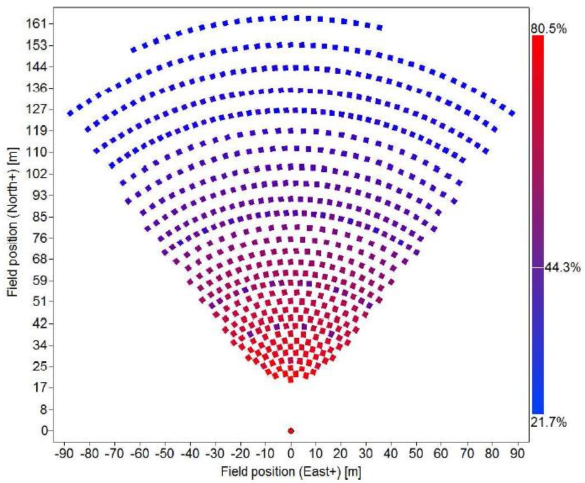
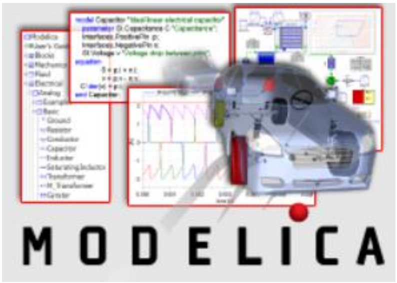
Modelling Methodology

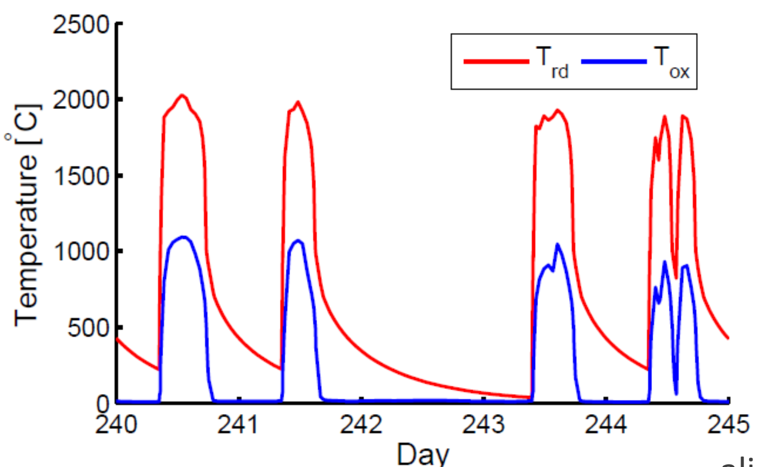
de la Calle & Bayon 2017 – Annual Performance of a Thermochemical Hydrogen Production Plant Based on CeO_2 Redox Cycle. 12th International Modelica Conference, Prague, Czech Republic.
https://www.modelica.org/events/modelica2017/proceedings/html/submissions/ecp17132857_DelacalleBayon.pdf

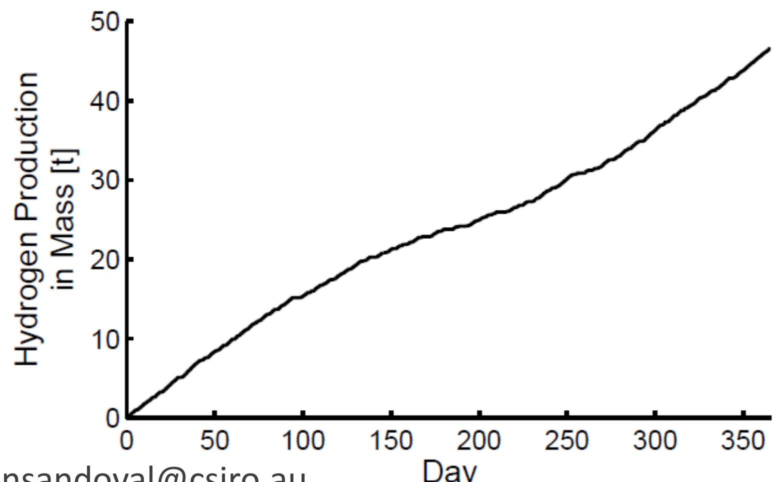


Modelica Language:

- Object oriented
- Flexible & adaptable
- Simulate physical systems
- Transient simulations & controls







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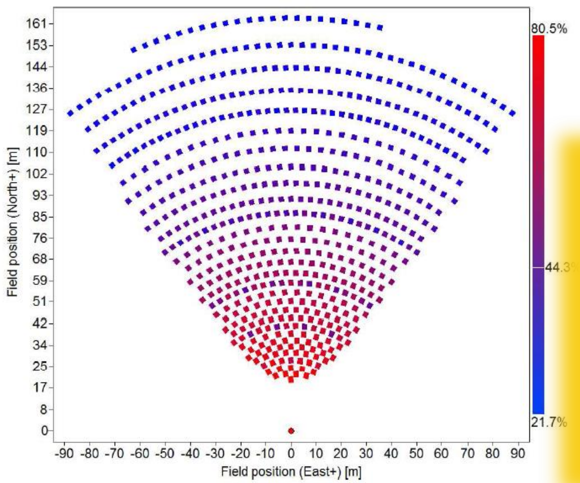
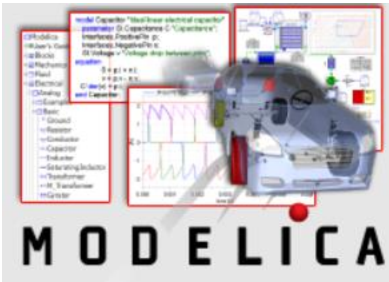


Modelica Language:

tems

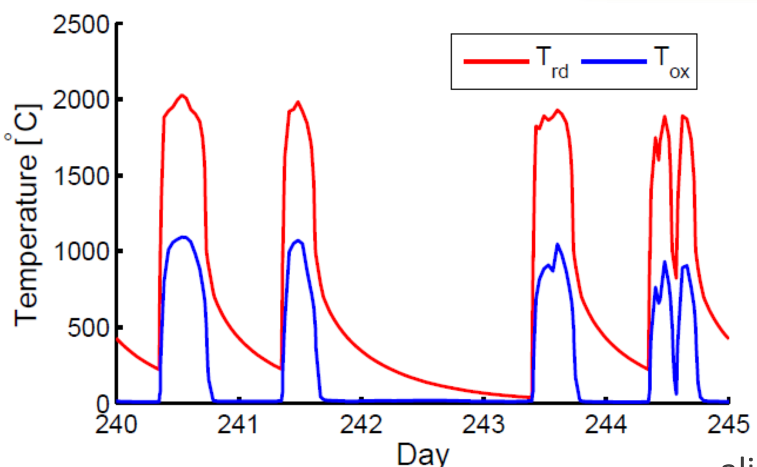
s & controls

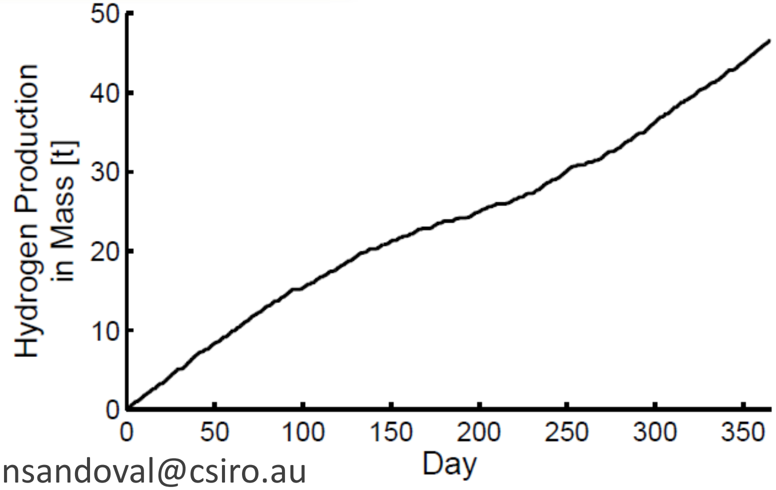


New Models

Membrane

Seasonal Controls





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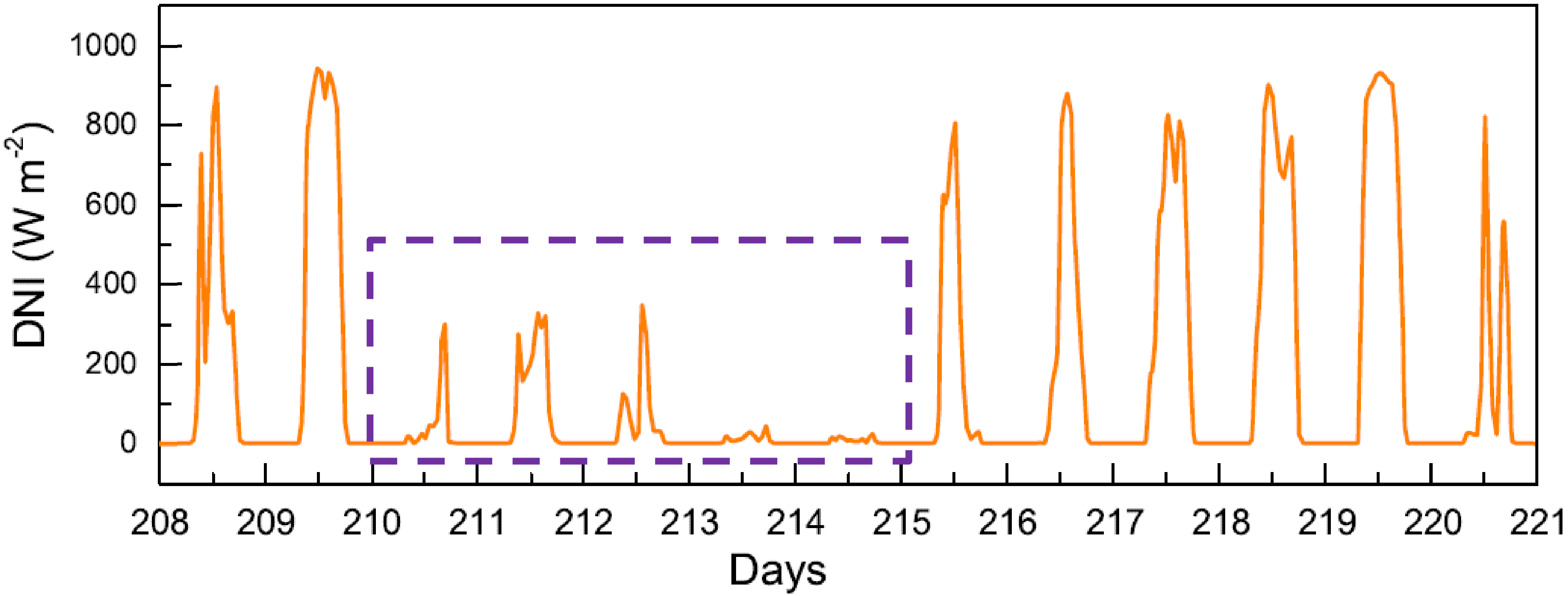
Results and discussion: DNI Geralton, WA

DNI varies all over the year



Days without or partial irradiance → control strategy

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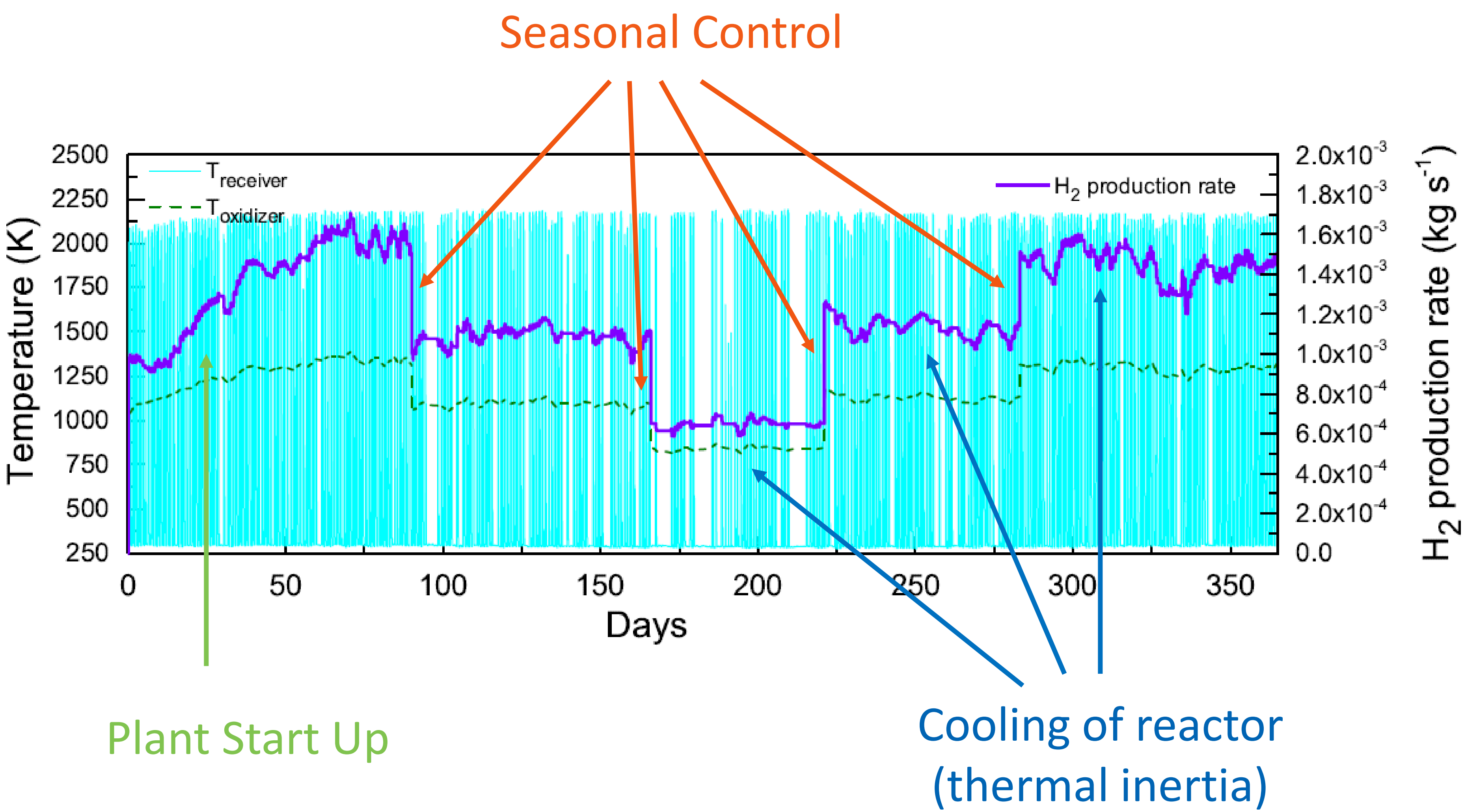
Results and discussion: hydrogen production



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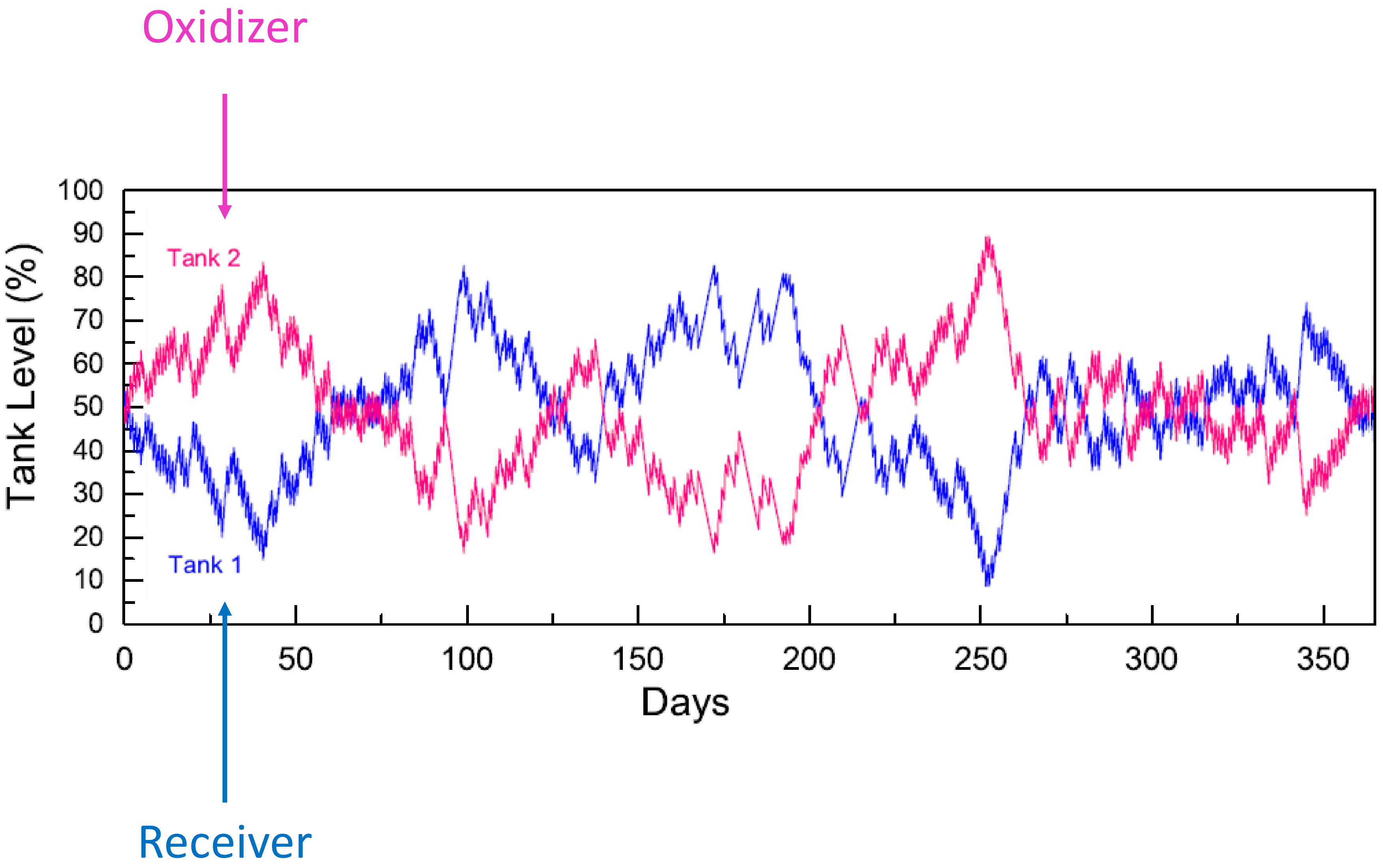
Results and discussion: seasonal control



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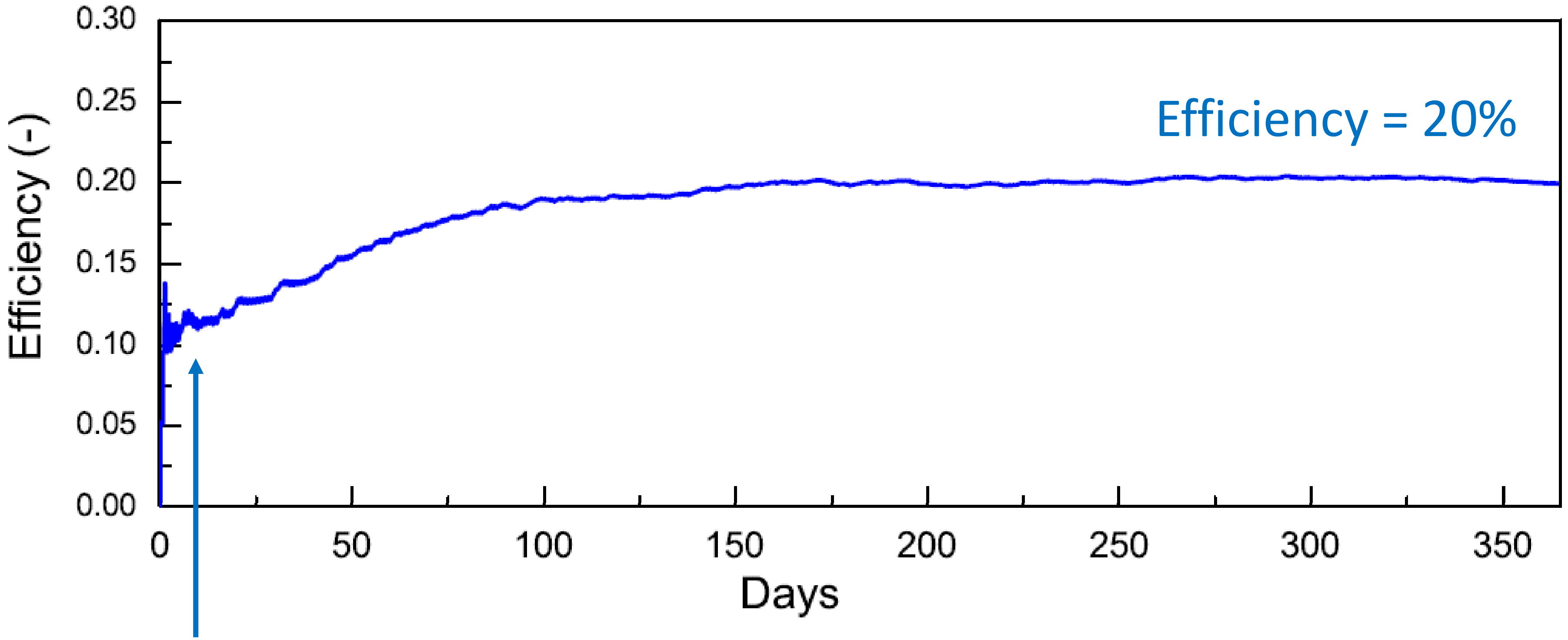
Results and discussion: annual efficiency



Start-up effect

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Conclusions & Future work

- System dynamics of a 1 MW_{th} plant are described and implemented in Modelica
- Continuous H_2 production was obtained by a seasonal control strategy over the CeO_2 particles
- Efficiency of 20% was obtained
- Further models of N_2 purification, vaccum and steam production are required to calculate the efficiency considering these parasitic losses
- Looking for collaboration in dynamic modelling and model validation with experimental demonstration

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Thank you

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Funding partner

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CSIRO

QUT

The University of Queensland Australia

Australian National University

Flinders University

The University of Adelaide

University of South Australia

US collaborators

Sandia National Laboratories

ASU Arizona State University

NREL National Renewable Energy Laboratory