Smart control of hydrogen-based multi-energy systems

SESAAU25
Copenhagen, Denmark

Including annotations and remarks in highlighted boxes

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Motivation

- Current decarbonization strategies rely mostly on
  - increased sector coupling
  - the integration of various volatile energy carriers

- **Challenges**
  - Energy systems become more interconnected
  - Energy carriers (heat, electricity, hydrogen, …) should be used in the most synergetic way

Increasing complexity and range of energy carriers requires **a flexible and efficient control of all components**

Renewable energy system of the future (AI-generated)

Requirements for smart control of energy systems

optimal operation
(efficiency, CO_2 emissions, …)

→ **optimization-based**
ensures optimal operation of the system
by targeted utilization of the different technologies

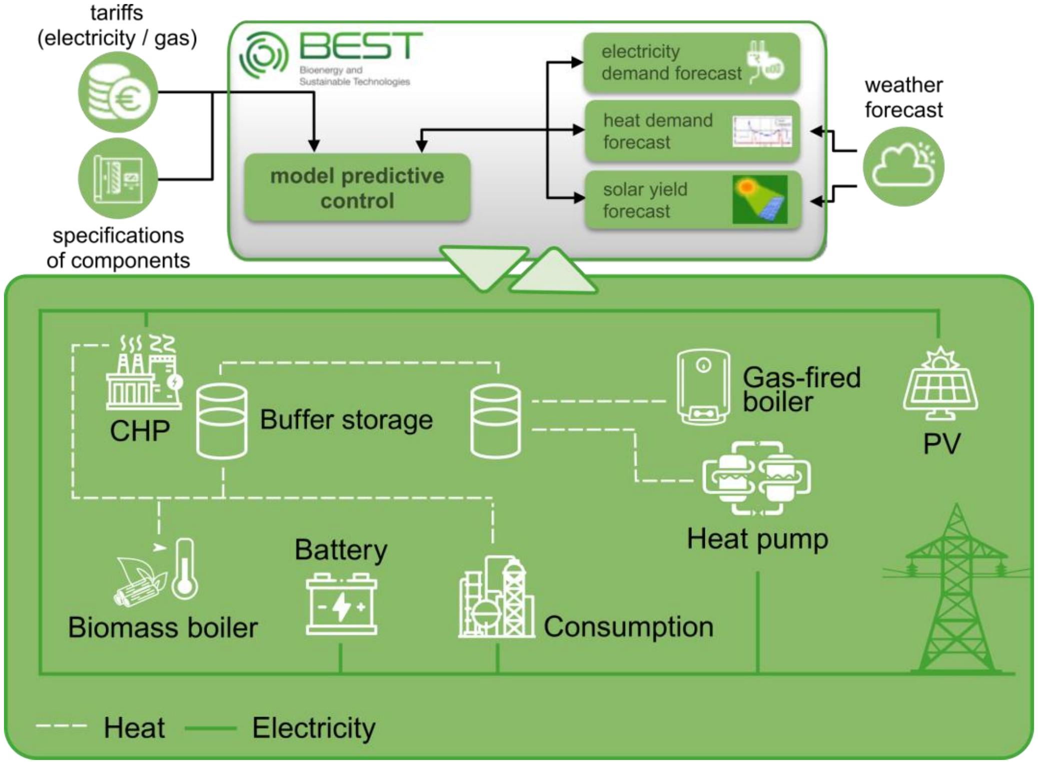
volatility
of production and consumption

→ **predictive**
integration of weather and price forecasts
calculation of forecasts for yields and consumptions

variation range
of the configurations

→ **modular**
automatic (re)formulation of the optimization problem
based on the specifications of the components

Smart control of multi-energy systems



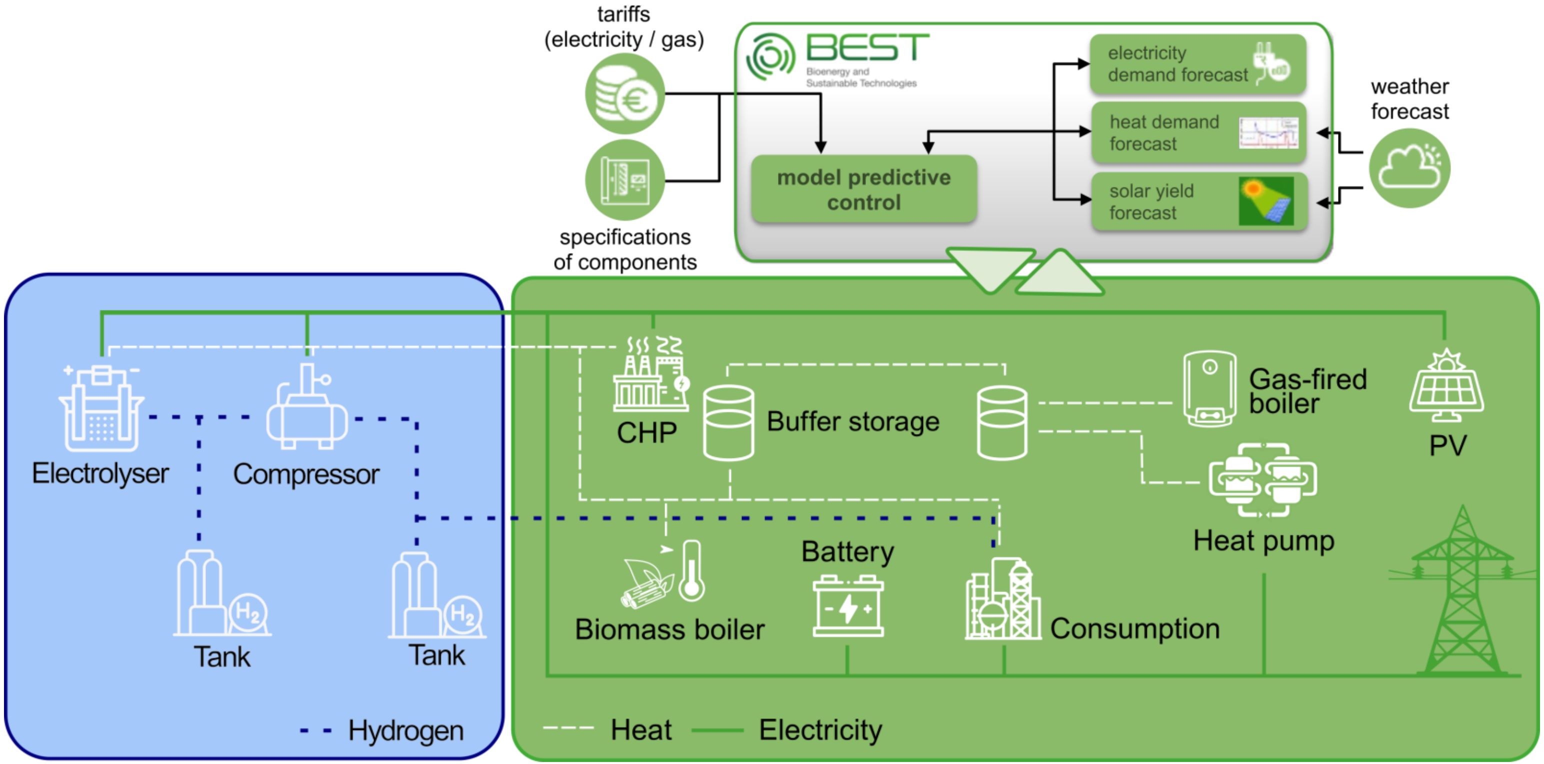
Addressing all requirements:

A **modular** framework based on a **model-predictive** controller

Such a framework for a supervisory controller considering electricity and heat as an energy carrier has been developed. See references.

[1] **Moser, Andreas et.al**. (**2020**).
DOI: 10.1016/j.apenergy.2019.114342.
[2] **Muschick, Daniel et.al**. (**2022**).
DOI: 10.1016/j.apenergy.2022.118890.

Smart control of hydrogen-based multi-energy systems



In this talk we will consider an extension of such a framework with hydrogen components.

[1] **Moser, Andreas et.al**. (**2020**).
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Modelling H_2 components for smart control

Main hydrogen components

H_2 Tank   Compressor   Electrolyser   Fuel Cell

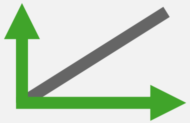
Considerations for hydrogen

The main problem when integration hydrogen components lead to the following question.

- Non-linear density-pressure relation
- Pressurized flow dynamics

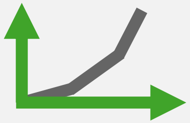
Simple (MILP) formulation or non-linear models?

→ Investigating different approaches for calculating: $p = f(m)$



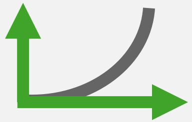
Linear

Ideal gas law



Linearized (PWA)

Empiric data approximated by piecewise affine function (PWA)



Non-Linear

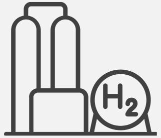
Physics-based: Redlich-Kwong Eq.

Modelling H_2 components for smart control

Input | **Model considerations** | **Output**

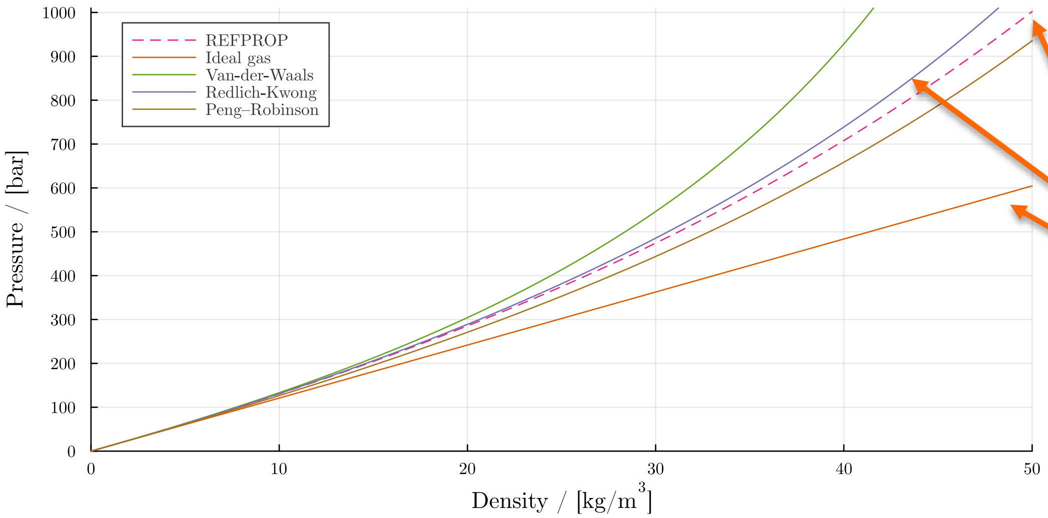
Mass flow ⇒

Passive component



State variables:
Mass (Integrator model)
Pressure (non-linear)

⇒ Mass flow



The hydrogen tank needs to consider the non-linear density-pressure relation. Possible approaches are shown here:

- Real reference data
- Non-linear equations
- Ideal gas law

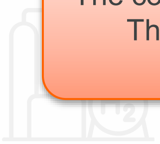
[1] **van der Roest, Els et.al**. (**2023**). DOI: 10.1016/j.ijhydene.2023.03.374.

Modelling H_2 components for smart control

Input | **Model considerations** | **Output**

Mass flow

Passive

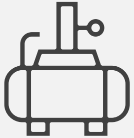


The compressor has a non-linear behaviour when increasing the pressure of the gas.
The mass-flow is here a function of the electricity input and the pressure rise.
This is described by the compressor map.

Mass flow

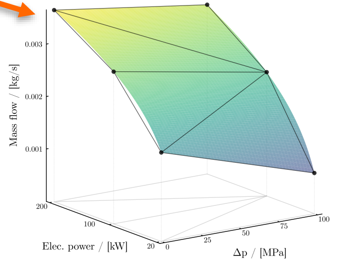
Electricity

Active component



Compressor map (non-linear)
Linear approximation via
Piecewise affine surfaces

Mass flow



Mass flow
OR
Electricity

Active components

Constant pressure
No non-linearity
Efficiency curve

Electricity
OR
Mass flow

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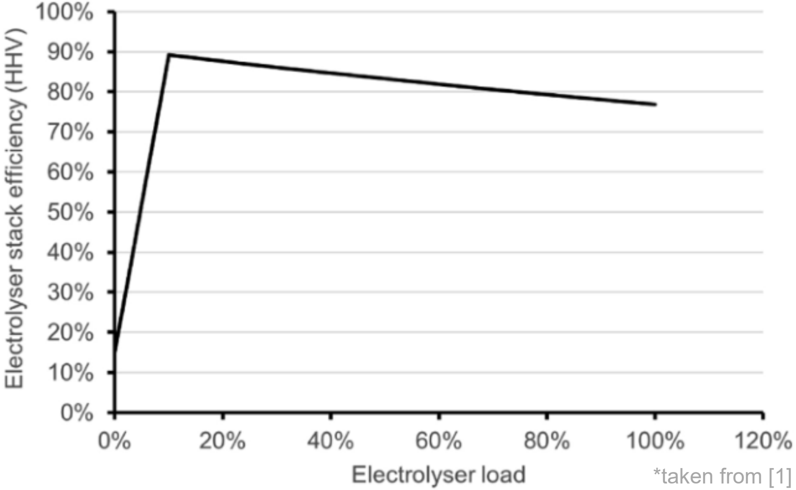
Modelling H_2 components for smart control

Input

Model considerations

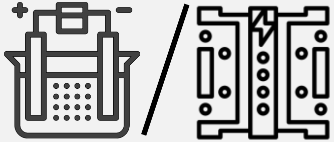
Output



Electrolyser and fuel cell are similar components transforming electricity to hydrogen or vice versa with some efficiency.

Mass flow
OR
Electricity

Active components



Constant pressure
No non-linearity
Efficiency curve

Electricity
OR
Mass flow

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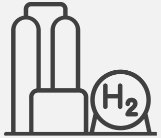
Modelling H_2 components for smart control

Input | **Model considerations** | **Output**

Mass flow →

Passive component



State variables:
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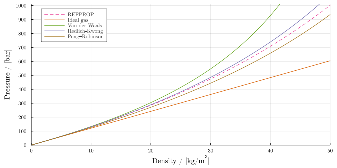
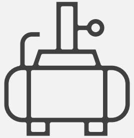
Pressure (non-linear)

→ Mass flow



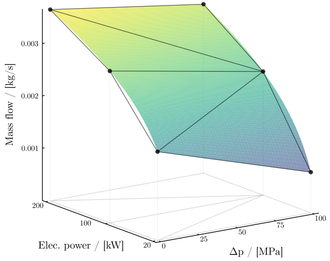
Mass flow →
Electricity →

Active component



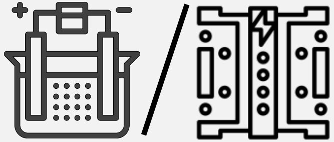
Compressor map (non-linear)
Linear approximation via
Piecewise affine surfaces

→ Mass flow



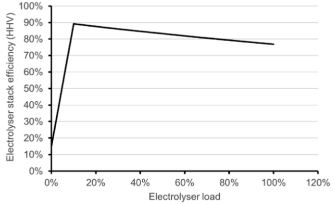
Mass flow
OR
Electricity →

Active components



Constant pressure
No non-linearity
Efficiency curve

→ Electricity
OR
Mass flow



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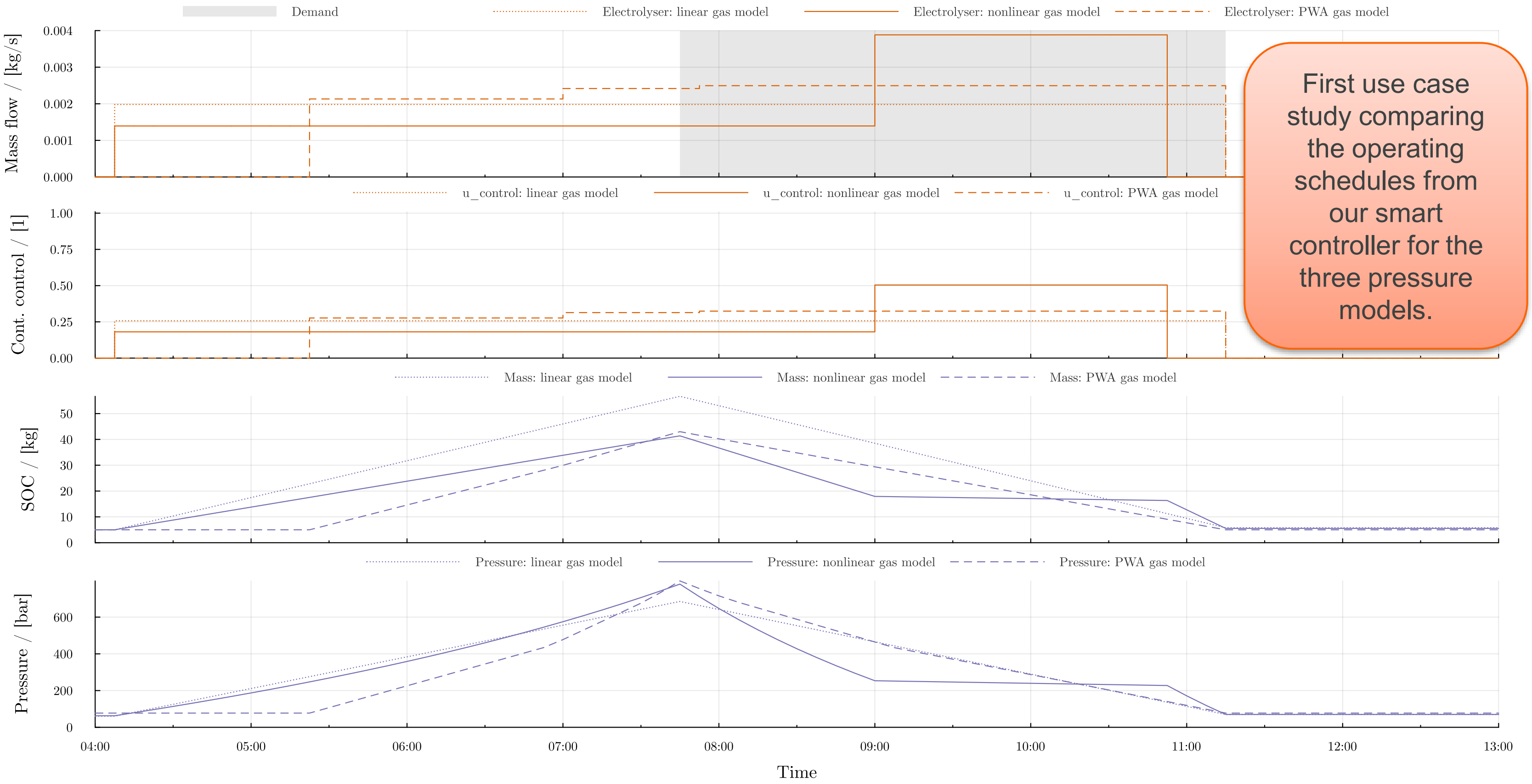
Use case A: pressure model comparison

H_2-output & -demand

Control schedule

H_2 mass stored

H_2 pressure



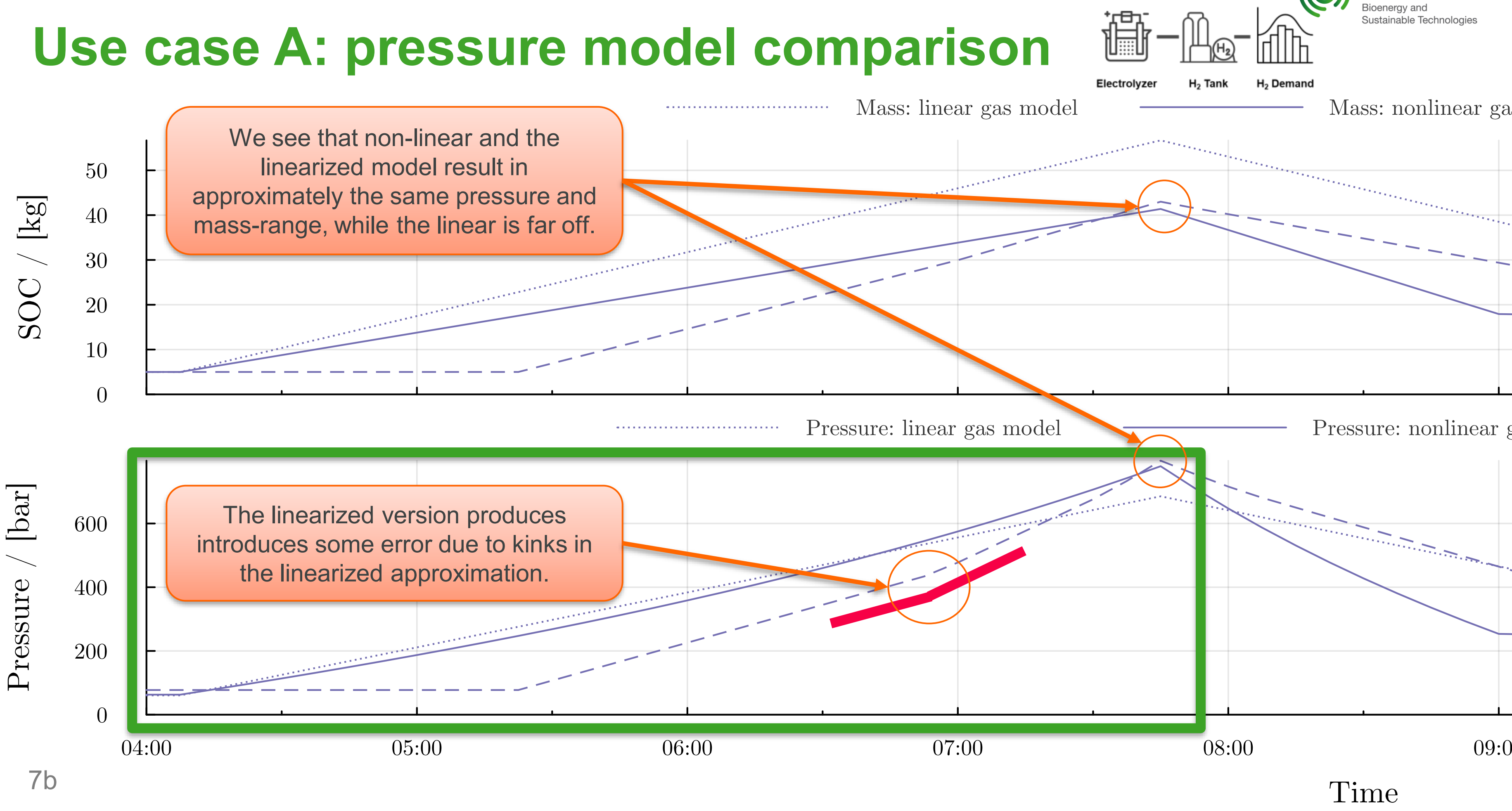
First use case study comparing the operating schedules from our smart controller for the three pressure models.

Electrolyzer
H_2 Tank
H_2 Demand

Use case A: pressure model comparison

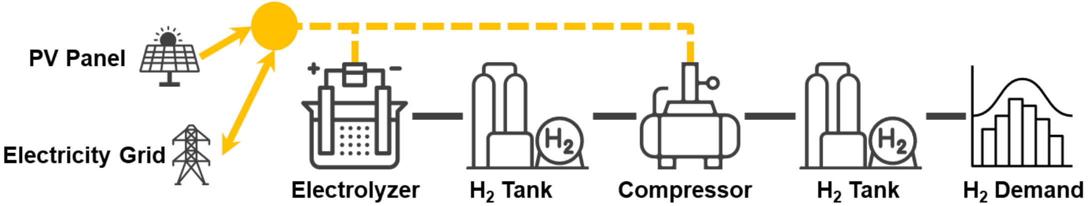
We see that non-linear and the linearized model result in approximately the same pressure and mass-range, while the linear is far off.

The linearized version produces introduces some error due to kinks in the linearized approximation.

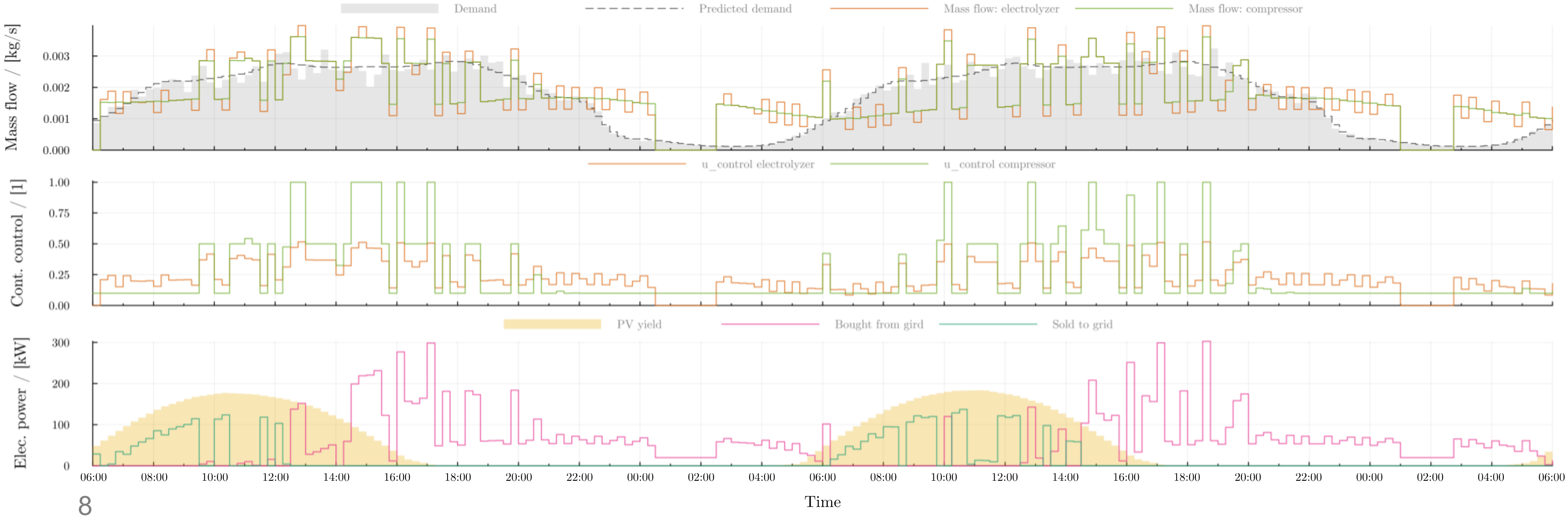


Use case B: Full system & compressor model

More involved use case also considering electricity from volatile sources.



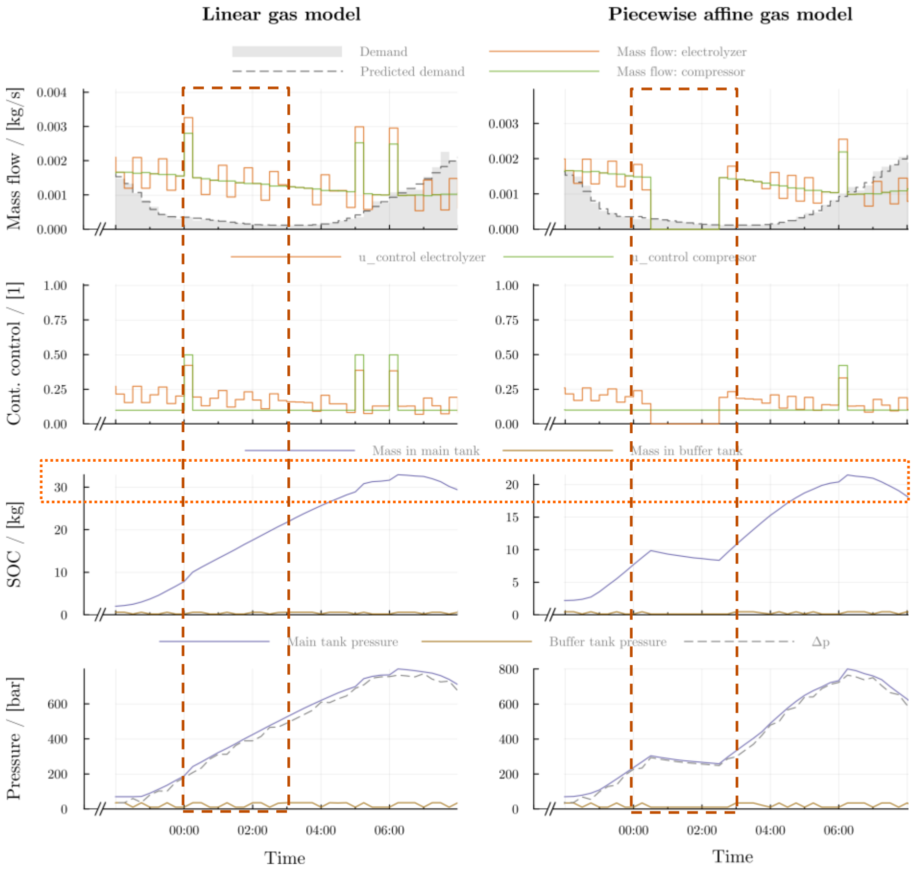
PWA model



Use case B: Full system & compressor model

- Problems of linear approach
  - Overestimating mass and underestimating pressure → dangerous in real life
  - Increased energy demand due to higher H_2 production
  - Demand at fixed pressure level cannot be modelled reliably

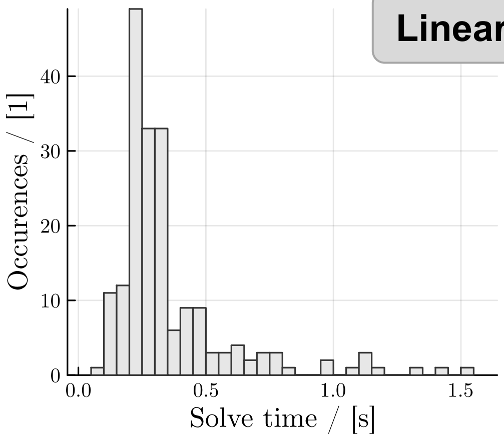
Linear approach has multiple shortcomings



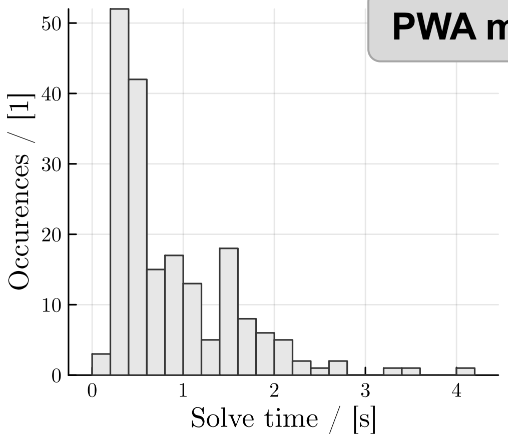
Run time analysis

Pressure model	Solve Time (Use Case A)	Solve Time (Use Case B)
Linear	(0.03 ± 0.01) s	(0.36 ± 0.24) s
PWA	(0.08 ± 0.01) s	(0.88 ± 0.68) s
Non-linear	(152 ± 22) s	no solution in reasonable time

Linear model



PWA model



Conclusion and outlook

Key messages

New challenges in sector-coupled energy systems require **smart control strategies**

Hydrogen is part of this game, but **non-linear dynamics** requires careful consideration

Hydrogen aspects

Mass flow model is suitable for smart control

Linear: severely underestimates pressure

Non-linear: too slow for real application

Linearized: provide fast and reliable results

Next steps

Including **temperature dependency** for control of **waste-heat utilization**

Real-life **implementation** and application for co-simulation with real plant

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