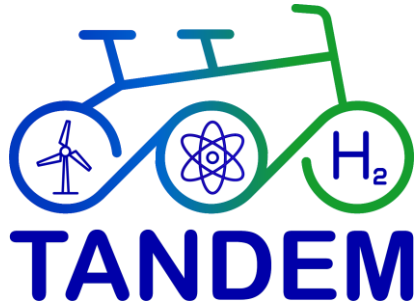
# *Hybrid Energy System* modeling

## The Modelica TANDEM Library

*G. Simonini, EDF R&D, 11th October 2024*



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# EU decarbonization & the TANDEM project [1]

Future energy needs:

- Heat
  - Corresponds to 50% of EU energy needs
  - Strongly dependent on fossils
  - Decentralized
- Hydrogen
- Flexible Production

→ **SMR producing both electricity & heat**

**TANDEM main objective**:

→ **To facilitate the integration of SMR into *Hybrid Energy Systems* (HES)** to support the European energy transition:

- → By developing methodologies and tools
- → By addressing safety issues and assessing the feasibility of an efficient integration

Focus on PWR (deployment in EU by the 2030s), with perspectives for AMR (by 2050).

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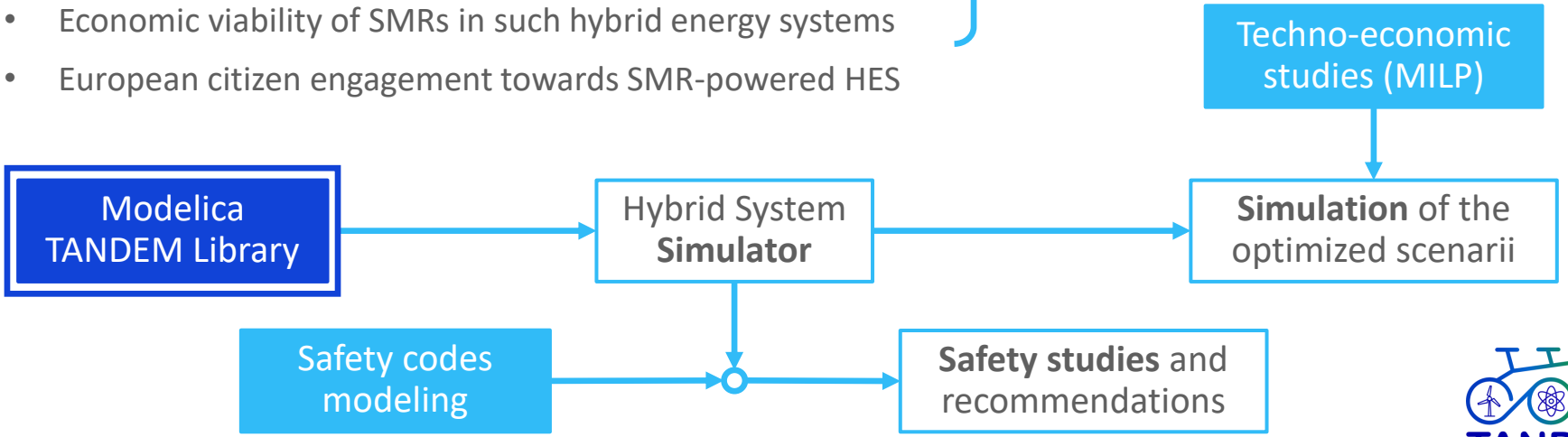
# Modeling for SMR the integration

**Key factors** for a successful integration:

- Extension of the current safety approach to nuclear HES
- Operationality (flexibility) of energy production within hybrid energy systems
- Economic viability of SMRs in such hybrid energy systems
- European citizen engagement towards SMR-powered HES

→ **Modeling**

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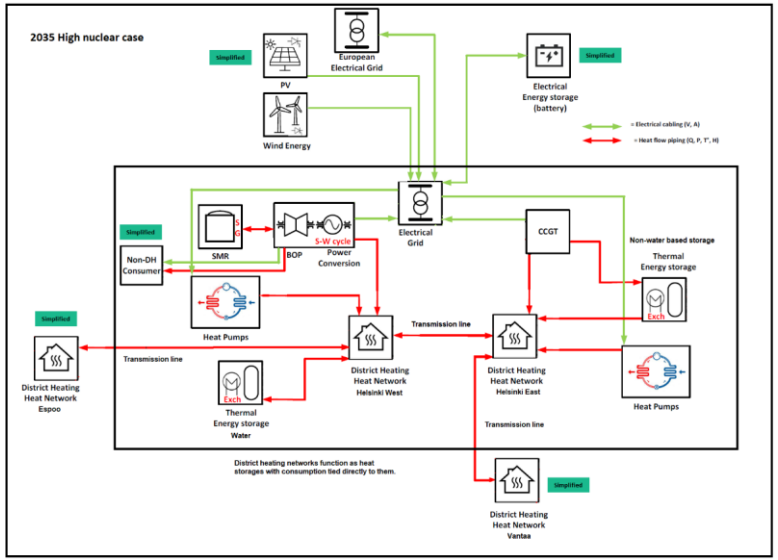
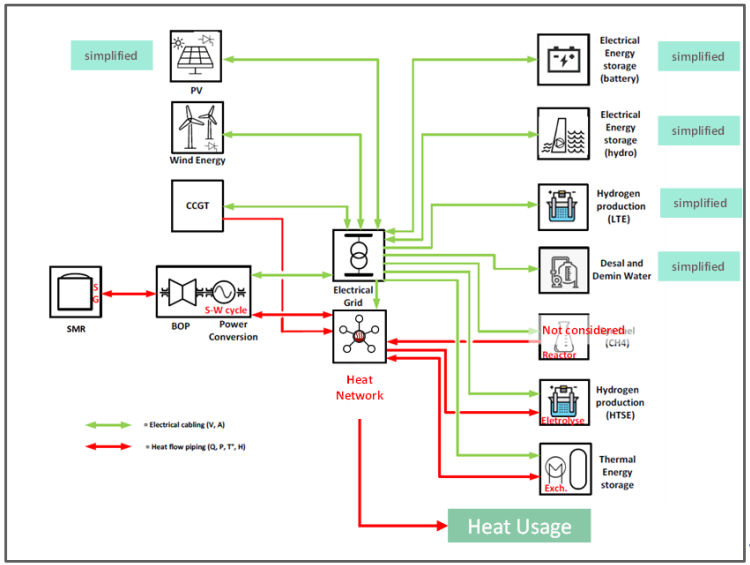
# The 2 HES configurations for TANDEM

## District Heating




## Energy Hub




*Images from K. VARRI et al. "Description of selected study cases for safety, techno-economic analysis and optimization" D1.4, 2023. http://tandemproject.eu/*



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# The Modelica TANDEM Library [2][3]

https://gitlab.pam-retd.fr/tandem/tandem

1. SMR
   a. NSSS
   b. CI-BOP
2. Electrical Grid
3. District Heating
4. Storage
   a. Thermal
   b. Electrical *Simplified*
5. RES *Simplified*
6. Desalination *Simplified*
7. H2
   a. Low Temperature *Simplified*
   b. High Temperature

*Developed by:*

POLITECNICO MILANO 1863, EDF, CEA, TRACTEBEL ENGIE

*EDF contributors:*

- *Y. Hammadi*
- *S. Hocine-Rastic*
- *V. Ferrara*
- *G. Simonini*

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# Supporting Libraries

- **ThermoSysPro** & **ThermoPower**



Thermohydraulics (& control) modeling:
power plants, heat storages, district heating…

- **Buildings**


Buildings (& supporting systems) modeling:
→ electrical grid

- **CEA_Energy_Process_Library**

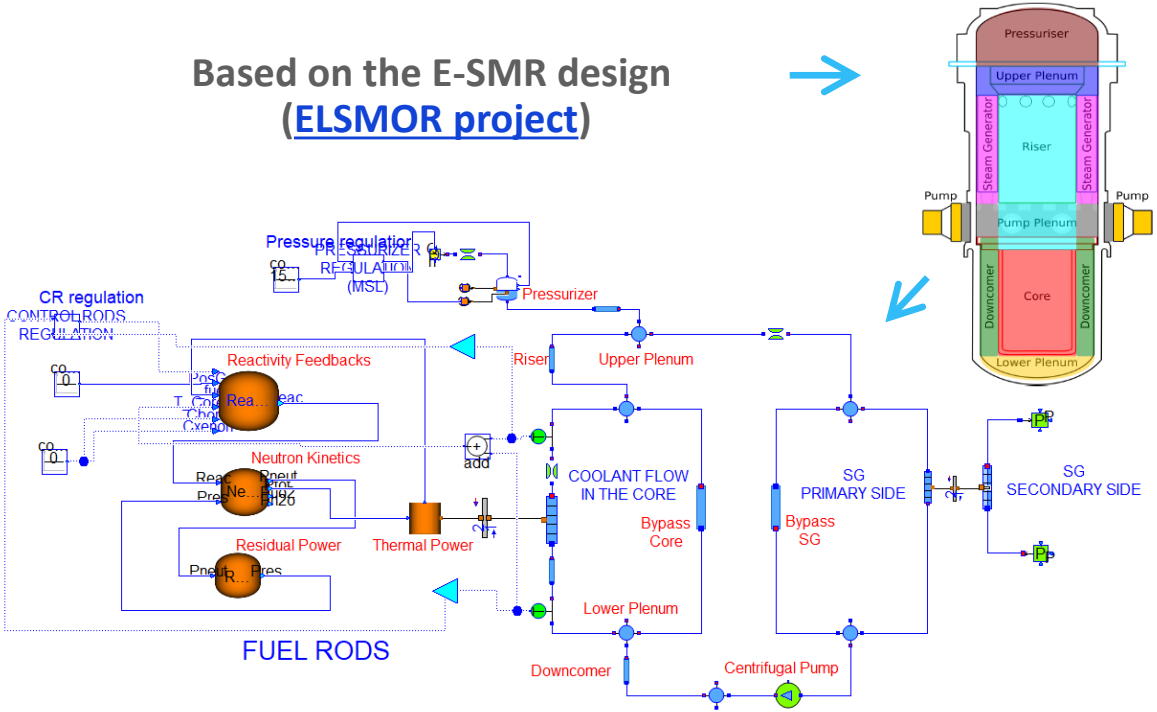

Energy processes & associated media:
hydrolysis, fuel cells…

- **WindPowerPlant**


Models injecting variable electrical power to the grid

# Nuclear Steam Supply System: the TSP model

**Based on the E-SMR design (ELSMOR project)**







*Courtesy of V. Ferrara [4]*

Key features:

- Nuclear point-kinetics
- Temperature control by rod movements
- Pressure control in the pressurizer
- Several Interfaces to the secondary cycle (fluid or heat)

A “twin” model developed with ThermoPower by Polimi

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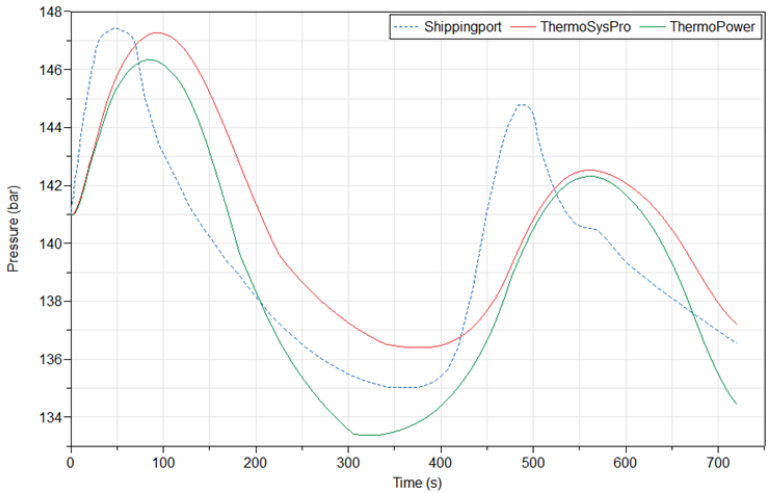
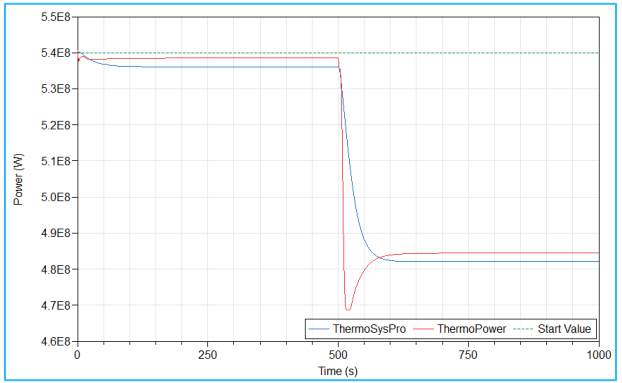
# Nuclear Steam Supply System: benchmarks

1. Pressurizer modeling vs. experimental data (Shippingport):
   → Take into account the thermal stratification

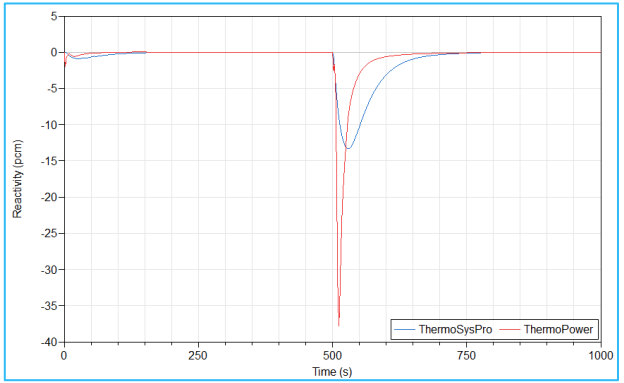



2. Models responses to typical power transients:
   →Different behavior depending on the control logic
   (“P on rod speed” vs “PI on reactivity”)

Power




Reactivity

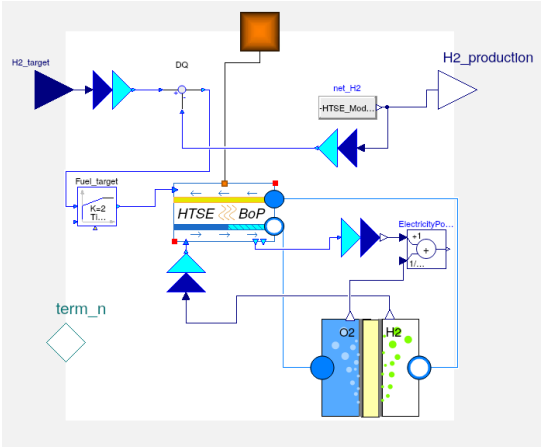


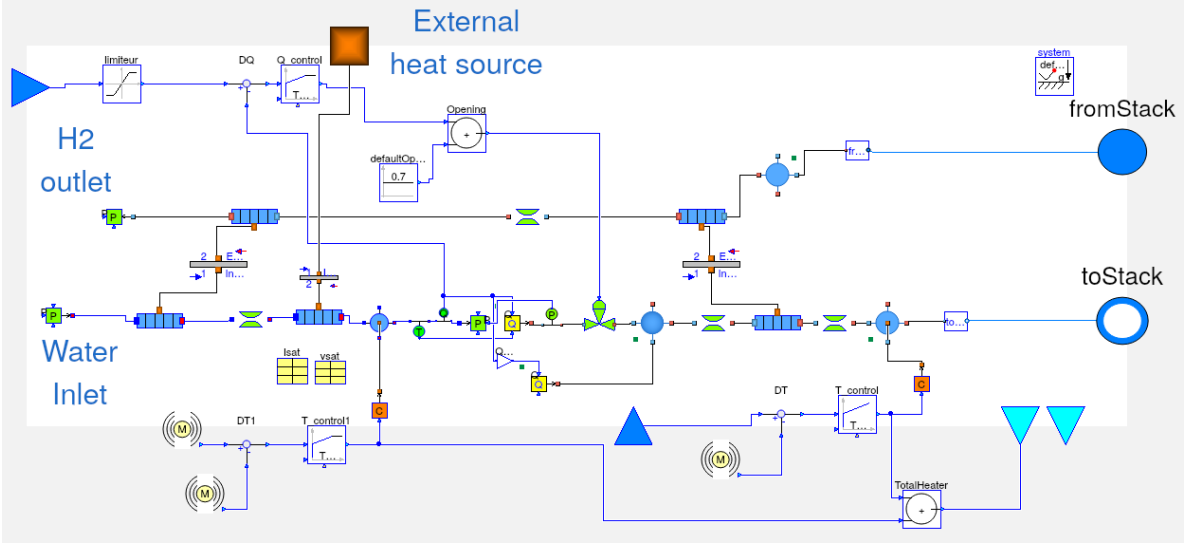
# High Temperature Steam Electrolyser: model

**HTSE**: - electrolysis @ high temperature (~750 °C),
- pre-heating and steam (“fuel”) production by “nuclear steam”.

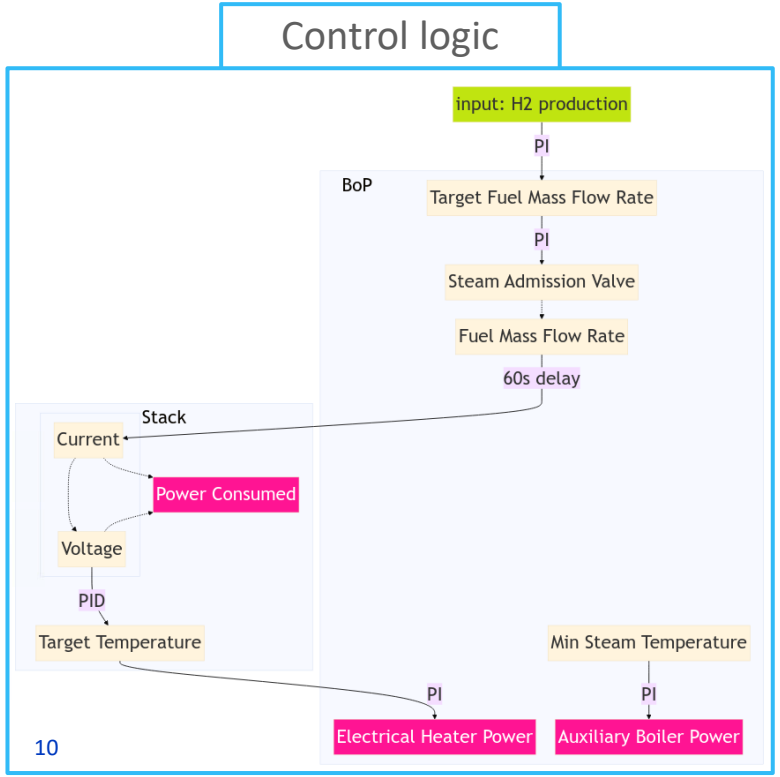
Model codeveloped with the CEA:

- CEA for the electrolyser stack
- EDF for the BoP



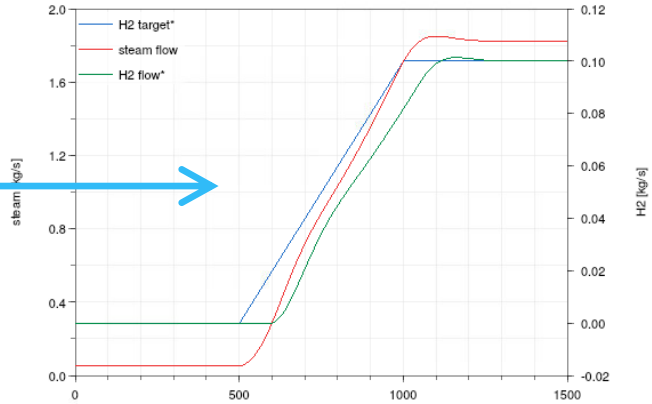
# High Temperature Steam Electrolyser: example

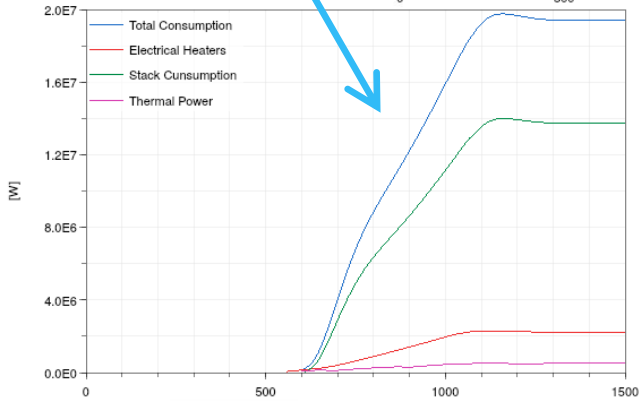



Example of start-up transient: simultaneous increase of:

- H2 target
- Thermal power input

Plant efficiency still to be optimized (power ratio, heat recover design…)

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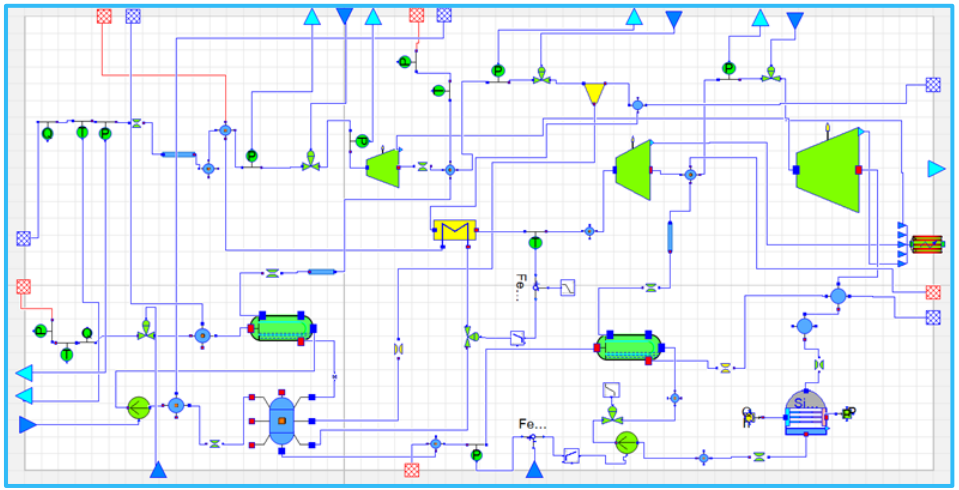
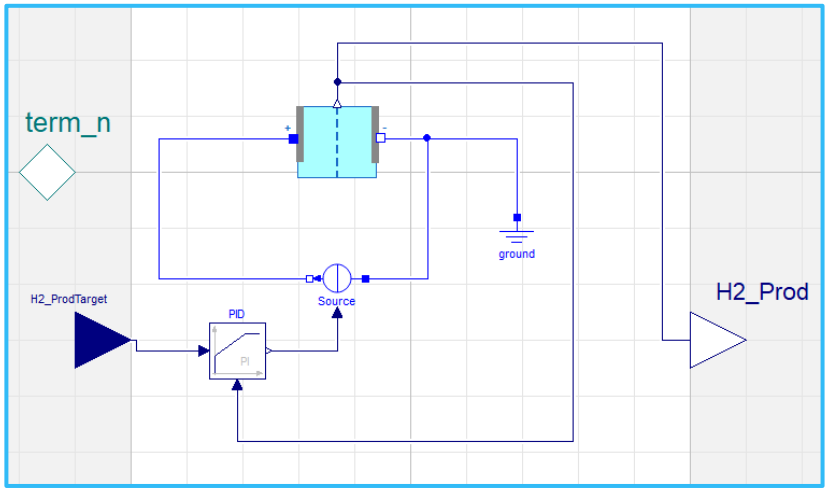
# Other ThermoSysPro models for TANDEM

**Conventional-Island BoP** developed by the CEA



**Light Temperature Electrolyser**



# Developments Driven by TANDEM

**Improvements (under) development** :

- Nuclear core modeling → new “public” components for ThermoSysPro
- Pressurizer modeling → thermal stratification
- Water compressibility → thermal dilatation only, reduced overload
- New fluids and mixes → $H_2O + H_2 + \ldots$
- Hydrogen electrolyser models → LTE: Proton Exchange Membrane

# Usages of the library

**Customizable HES simulator** by assembling the available bricks...
→ or even new bricks of your own ! (depending on your need)

**HES operation studies**:

- Heat load transients (daily, seasonal…)
- Response to electrical grid needs (flexibility)
- Analyses of
  - Architecture design
  - Operation strategies
  - Control logic

Optimization :
Clevery (MILP),
genetic algorithms…

**HES accident scenarii**:

- Provide realistic boundary conditions
  → solicitation on the reactor
- Allow preliminary studies

CATHARE, ATHLET…
but also, potentially, neutron
or thermo-mechanical codes



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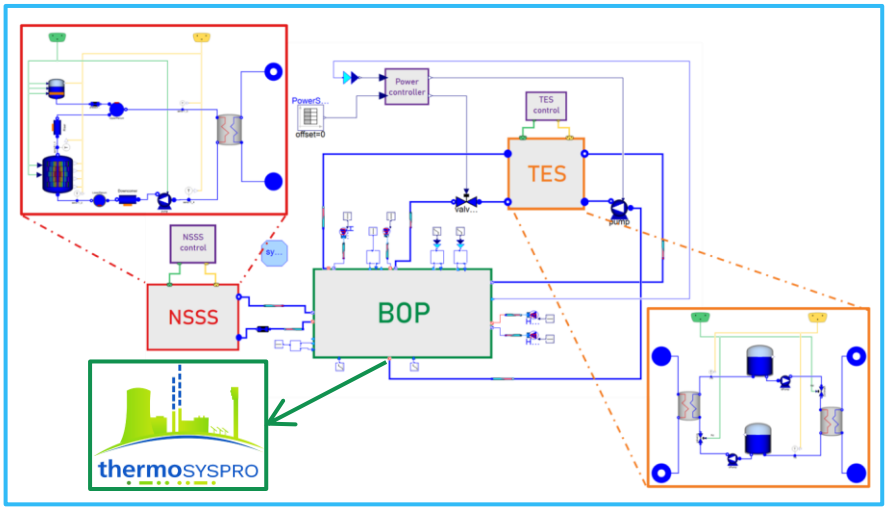
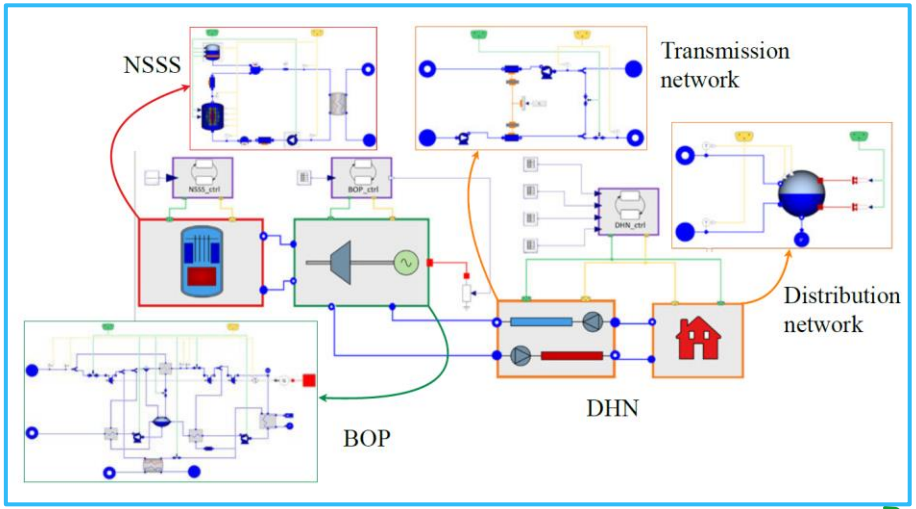
# Examples of techno-economic studies

## Thermal storage valorization for plant flexibility




*Courtesy of G. Masotti [5]*

## SMR for district heating




*Courtesy of G. Masotti [6]*



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# Conclusions

- **Modelica library** with the bricks to build a **customizable HES simulator**: SMR, heat storage, renewables, hydrolysers, district heating…
- Based on, among other libraries, **ThermoSysPro**
- The library enables:
  - Normal operation tecno-economic studies
  - More “realistic” safety studies (through coupling with safety codes)

- The project was also motivating framework to push some **ThermoSysPro developments**: benchmark, new usages…

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# Bibliography


1. C. Vaglio-Gaudard et al. « The TANDEM Euratom Project: Context, Objectives and Workplan ». Nuclear Engineering and Technology 56, n° 3 (mars 2024): 993-1001. https://doi.org/10.1016/j.net.2023.12.015.
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5. G. Masotti et al. “Simulation of flexible small modular reactor operation with a thermal energy storage system”, IAEA SMR conference, Wien, Austria, 2024.
6. G. Masotti et al. “Dynamic Modelling and Optimisation of a Small Modular Reactor for Electricity Production and District Heating in the Helsinki Region”. ICAPP, Las Vegas, NV, 2024.

# TANDEM Partners


















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