Chair of Renewable and Sustainable Energy Systems
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Modeling magnetic confinement fusion power plants in future energy systems

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Background

- Problem? Global rise of electricity and energy demand, energy dependency
- Solution contributor? Controlled nuclear fusion as local energy source
- Long-term potential of nuclear fusion in energy systems? Examination of optimal future pathways

Study Objective

- Description of tokamak and stellarator type fusion power plants in energy systems
- Systematic analysis of respective scenario options
- Modeling and implementation of nuclear fusion power plants in energy system optimization tools urbs and evrys for analysis of their optimal expansion and operational planning in Europe and the ASEAN region

Operational Characterization of 1 GW_{el} Fusion Power Plants

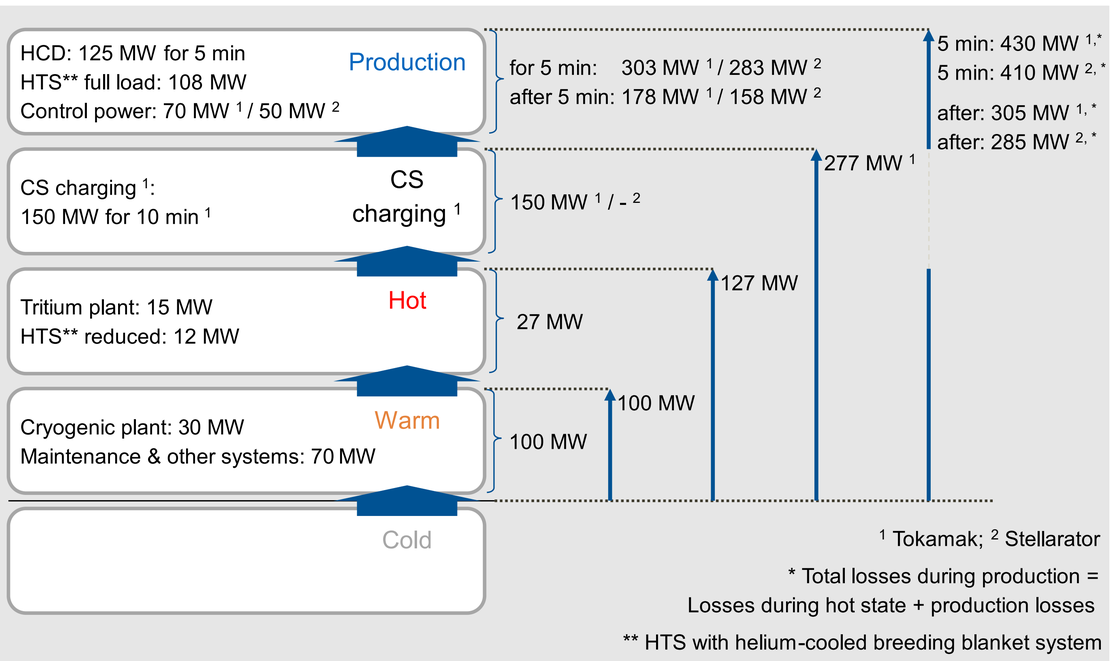


Figure 1: Power requirements of identified operating states [1]

Fusion Power Plant Modeling in Energy Systems

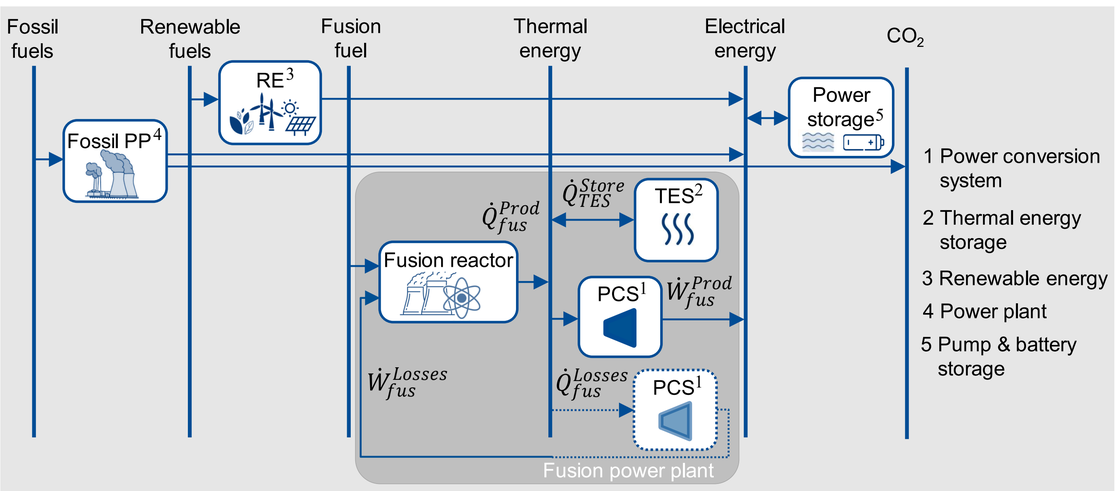


Figure 2: Integration of fusion power plants in energy systems

urbs [2]

- Linear optimization model for expansion and operational planning
- Model language: Python (+ Pyomo)

$\boldsymbol{Q_{fus}^{Pulse-Start,l}}$: Energy losses for pulse-start [1]

$\boldsymbol{Q_{fus}^{Prod}}$: Thermal energy production of the fusion reactor

$\boldsymbol{Q_{fus}^{Prod,l}}$: Energy losses during production

$\boldsymbol{Q_{fus}^{Cont,l}}$: Continuous losses to maintain the hot (production-ready) state

- Tokamak/Stellarator [2] -

evrys [3,4]

- Mixed integer linear optimization model for operational planning
- Model language: GAMS/Python

- Tokamak -

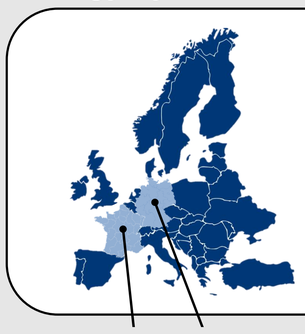
- Stellarator -

[1] Assumption: Pulse-start losses distributed over the production pulse (*left*); Pulse-start only at the beginning of production pulse with time resolution of 1h (*right*)
[2] Identical implementation of fusion reactors; different power requirements due to tokamaks pulsed operation

Figure 3: Fusion in the energy system optimization framework urbs and evrys

Operational Planning in European Power System

Energy system



- Europe in year 2050
- 268 model nodes
- Temporal resolution: 1h
- Installed fusion capacity: 50GW_{el} (France/ Germany)
- Installed capacities are predetermined
- Optimization method: Mixed integer linear
- Investigation objective: Operational planning of fusion in a largely decarbonized energy system

Fusion operation (Reference scenario)

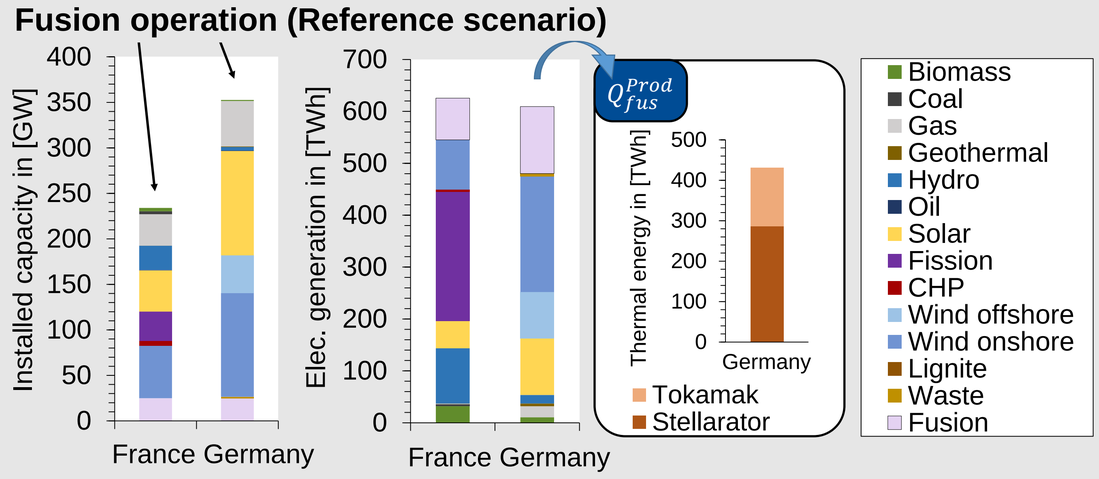


Figure 4: Installed capacity (*left*) and electricity generation (*right*) in Europe 2050

Expansion Planning in the ASEAN Region

Energy system

- ASEAN region in year 2050
- 10 model nodes
- Temporal resolution: 1h
- Expansion of installed capacities part of optimization
- Optimization method: Linear
- Investigation objective: Expansion planning of fusion in a region with high population and demand density as well as new technological developments

Fusion expansion (Reference scenario)

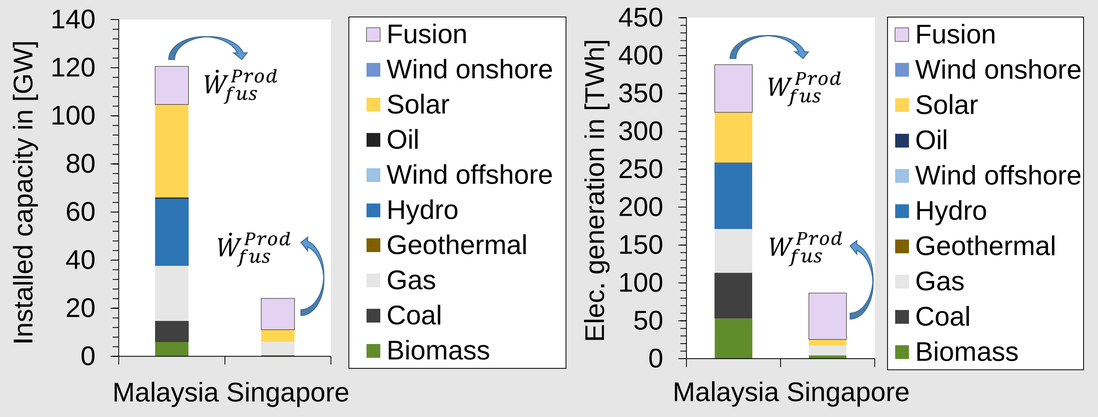


Figure 5: Installed capacity (*left*) and electricity generation (*right*) in ASEAN region 2050

Conclusion

- Three operational states of fusion power plants are modeled in energy systems based on their operational characterization. Stellarator and tokamak types are distinguished.
- First results regarding the modeling of the European energy system indicate that fusion will be used in Europe under the assumption that investments in fusion power plants have been taken and that they are part of the energy system.
- Fusion power could be a suitable extension of energy systems in regions with high population and demand density and new technological developments, like ASEAN region.

References

[1] A. Kerekeš, L. Breuning, A. von Müller, J. Gawlick, F. Warmer, S. Fietz, S. Kembleton, W. Hering, H. Zohm, T. Hamacher, Operational characterization of tokamak and stellarator type fusion power plants from an energy system perspective. Fusion Engineering and Design (2022). https://doi.org/10.1016/j.fusengdes.2023.113496.
[2] J. Dorfner, K. Schönleber, M. Dorfner, S. Candas, L. Odersky, T. Zipperle et al. urbs: A linear optimisation model for distributed energy systems 2019. https://doi.org/10.5281/zenodo.3265960.
[3] M. Huber, Flexibility in Power Systems - Requirements, Modeling, and Evaluation. Dissertation, 2016.
[4] M. Silbernagel, A Polyhedral Analysis of Start-up Process Models in Unit Commitment Problems. Dissertation, 2016.