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The impact of the heating mix on L- and H-mode DEMO plasmas

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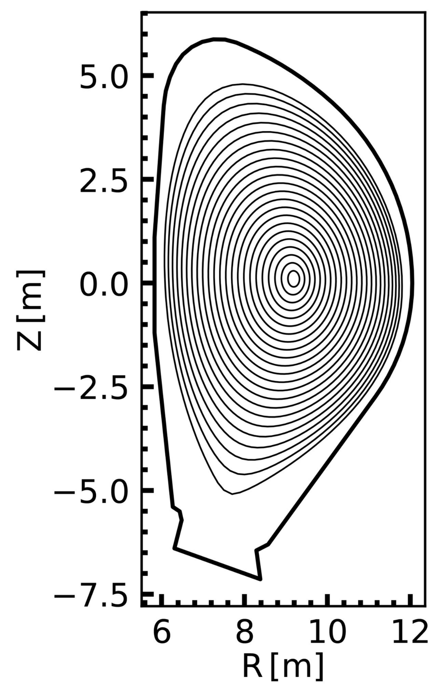
Abstract

- The precise heating mix for DEMO is still under consideration.
- An appropriate heating mix must fulfill all the plasma requirements: break down, ramp up, **L-H (or similar) transition, burn control**, NTM suppression, RI control and ramp-down.
- Integrated discharge modeling is a useful tool which can assist in the decision: capability to model the plasma response to a given heating mix.

Scope of the study and numerical workflow

The **ASTRA** code is used to assess the feasibility of the **L-H transition** and **fusion power production in H-mode**. The EU-DEMO 2018 baseline is used as a starting point. **Note** that this baseline, however, was not benchmarked to yield any particular value of fusion power under the assumptions introduced below, regardless of the heating scheme used.

Major radius, R	9 m
Separatrix Elongation, triangularity	1.77, 0.39
Plasma current, Ip	17.75 MA
Greenwald density (n_{GW})	7.2e19 m^3
On-axis field, B	5.85 T
Bulk heating hot-resonance ECRH frequency	160 GHz
Available auxiliary power for ramp-up / LH transition	130 MW
Target auxiliary power for flat-top	50 MW
He concentration	8 %



- **TGLF** and neoclassical analytical formulas (Galeev 1973; C. Angioni and Sauter 2000; C. Angioni 2001) are employed for the transport coefficients:

$$\chi_e = \chi_e^{\rm turb} + \chi_e^{\rm neo} \qquad D_e = D_e^{\rm neo}$$
$$\chi_i = \chi_i^{\rm turb} + \chi_i^{\rm neo} \qquad \vec{v}_e = \vec{v}_e^{\rm ware} + \vec{v}_e^{\rm turb}$$

$$P_e = P_e^{\rm Oh} + P_e^{\rm ECRH} + P_e^{\alpha} + P_{i^+\to e^-}^{\rm turb} - P_{\rm rad} - P_{e^-\to i^+}^{\rm clas.}$$
$$P_i = P_i^{\alpha} + P_{e^-\to i^+}^{\rm clas.} - P_{i^+\to e^-}^{\rm turb}$$
$$P_{\rm rad} = P_{\rm Brem.} + P_{\rm sync} + (P_{\rm Xe} \text{ or } P_{\rm W})$$

- The 2-point model is used for the separatrix temperature prediction in L and H-mode:

$$T_{\rm e,sep} = \left[T_{\rm t,e}^{\frac{7}{2}} + \frac{7}{2}\frac{q_{e,\parallel}\pi R_0 q_{\rm LCFS}}{\kappa_e}\right]^{\frac{2}{7}}$$

- The L-H transition is characterized by a critical ion heat flux crossing the LCFS, as found in ASDEX Upgrade and Alcator C-mod [M. Schmidtmayr, *Nucl. Fus* **58** (2018)]. This is compared to the L-H power threshold scaling [Y. R. Martin, JoP **123** (2008)]

$$Q_i^{\rm LH} = 0.0029\,\langle n_e\rangle^{1.05\pm0.1} B_{\phi,0}^{0.68\pm0.3} S^{0.93\pm0.2} \sim 44 \text{ MW for <ne> = 5e19 m}^{-3}$$

$$P^{\rm LH} = 0.0488\,\langle n_e\rangle^{0.717\pm0.035} B_{\phi,0}^{0.803\pm0.032} S^{0.941\pm0.019} \sim 111.8 \text{ MW for <ne> = 5e19 m}^{-3}$$

- The pedestal top pressure model is based on a DEMO **EPED** scaling [M. Siccinio *Nucl. Fusion* **58** (2018)]

$$p_{e,\rm ped} = 1.516\times10^{20} R^{-0.38}\delta^{0.83} I_p^{1.25}\kappa^{0.62}\beta_N^{0.43} \qquad T_{e,ped} = T_{i,ped}$$

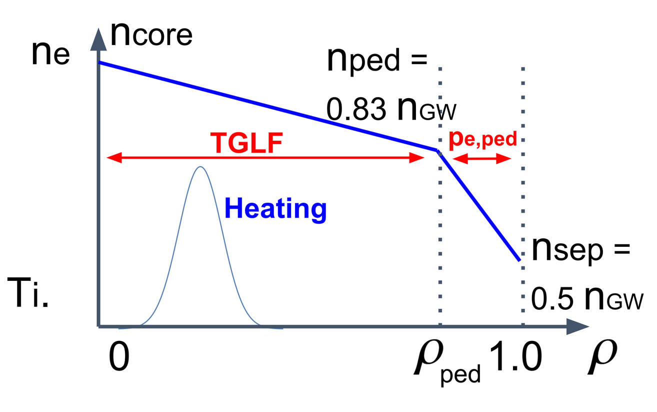
$$\Delta_{\rm ped} = 0.076\sqrt{\beta_{\rm p,ped}}$$

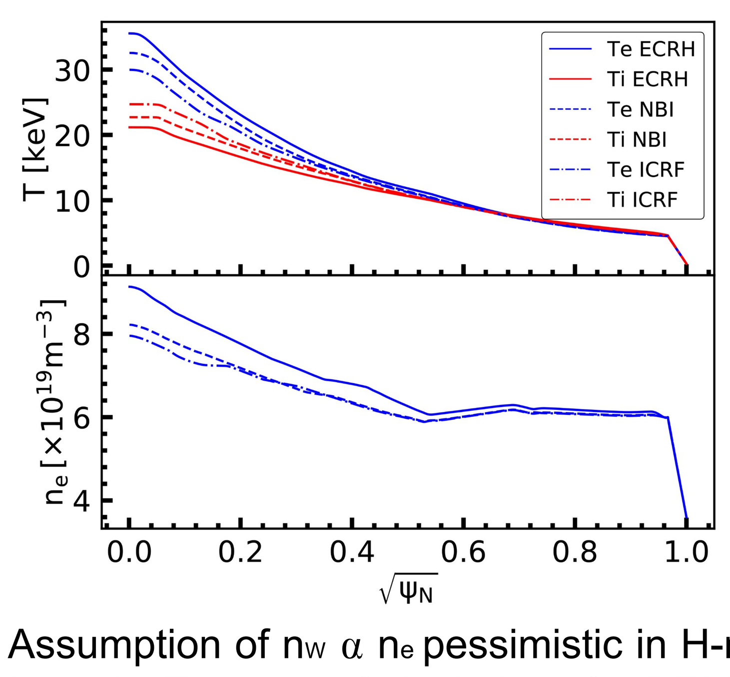
The pedestal width is chosen limited by KBM, where the DIII-D pedestal factor was used.

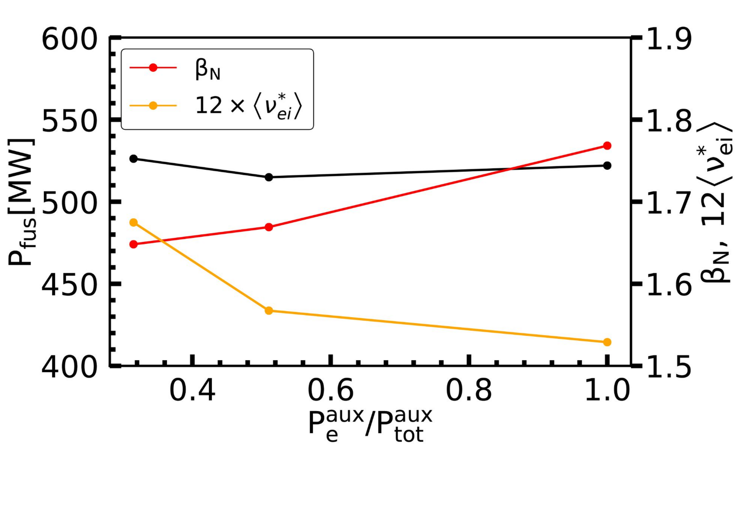
Impact of the heating mix on H-mode flat-top plasmas

A scan of the electron to ion heating fraction was performed for three cases: 100% electron heating (ECRH-like), 50-50% electron to ion heating (NBI-like) and 30-70% ratio (ICRF-like). A W concentration of 40 ppm was used for the impurity level as homothetic to n_e. Heating was modeled with a Gaussian function.

- Pure e-heating leads to larger T_e/T_i, but also to larger β_N (through higher T_e).
- Density peaking increases n_e as electron heating fraction becomes dominant.
- Fusion power thus remains constant despite smaller T_i.



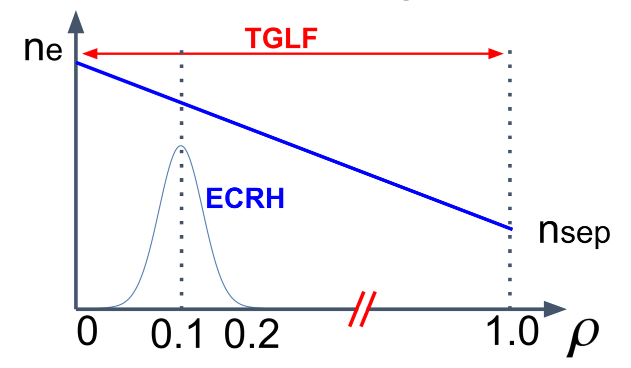




- Assumption of n_W α n_e pessimistic in H-mode due to temperature screening (C. Angioni, Impurity Transport Calculations for DEMO, EUROfusion final report (2015)).
- However, low fusion power motivates a revision of the DEMO 2018 baseline scenario, in line with previously published studies [F. Palermo et al (2019) *Nucl. Fusion* **59**]

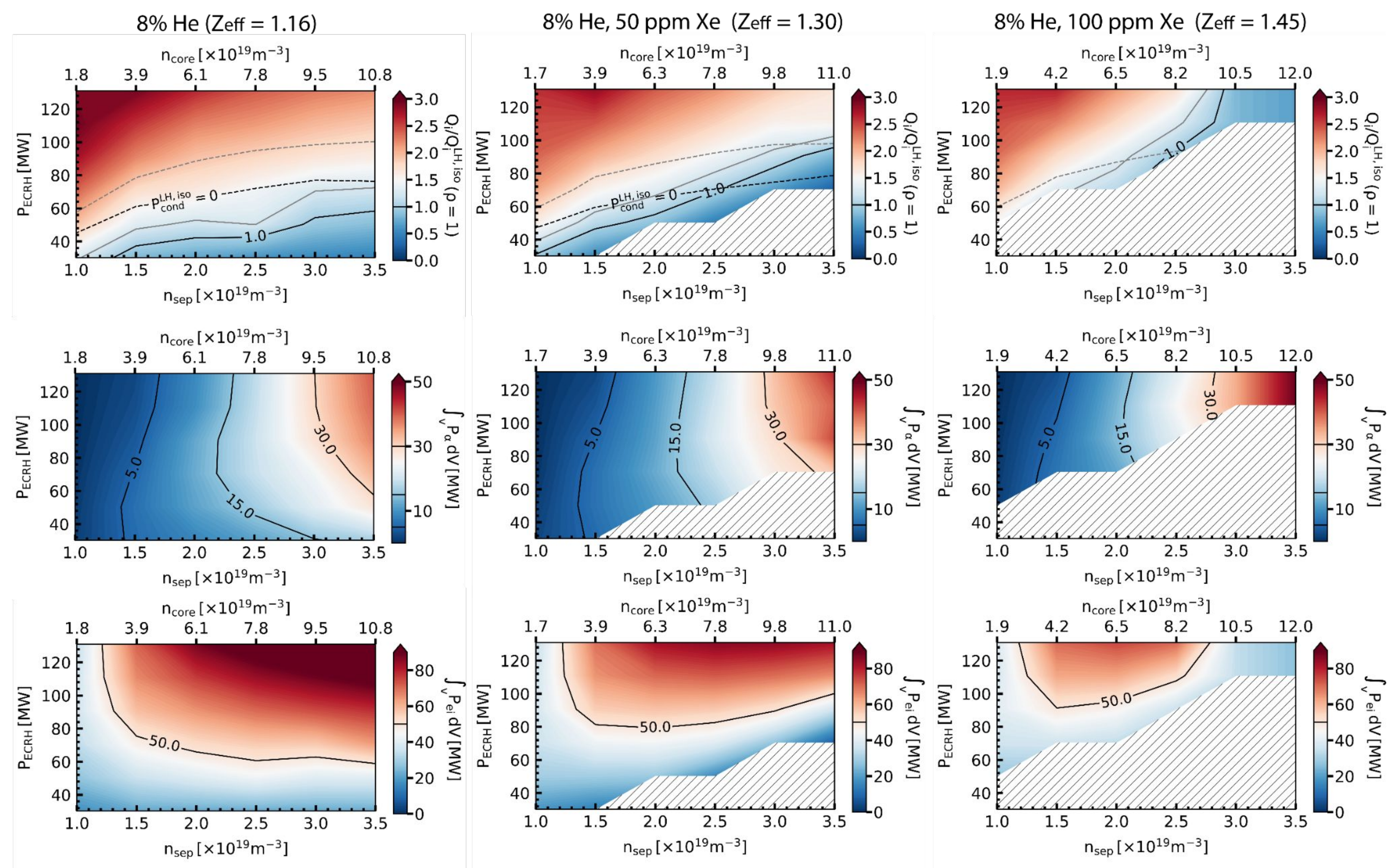
Accessibility to the L-H transition in pure electron-heated plasmas

The impurity seeded H-mode is seen as one of the best candidates for a high-confinement scenario in DEMO. Thus, it is essential to investigate the feasibility of the L-H transition. Because ion heating eases such transition (through either direct ion heat flux or increased alpha heating), the L-H transition has been investigated in this work for pure electron-heated plasmas.



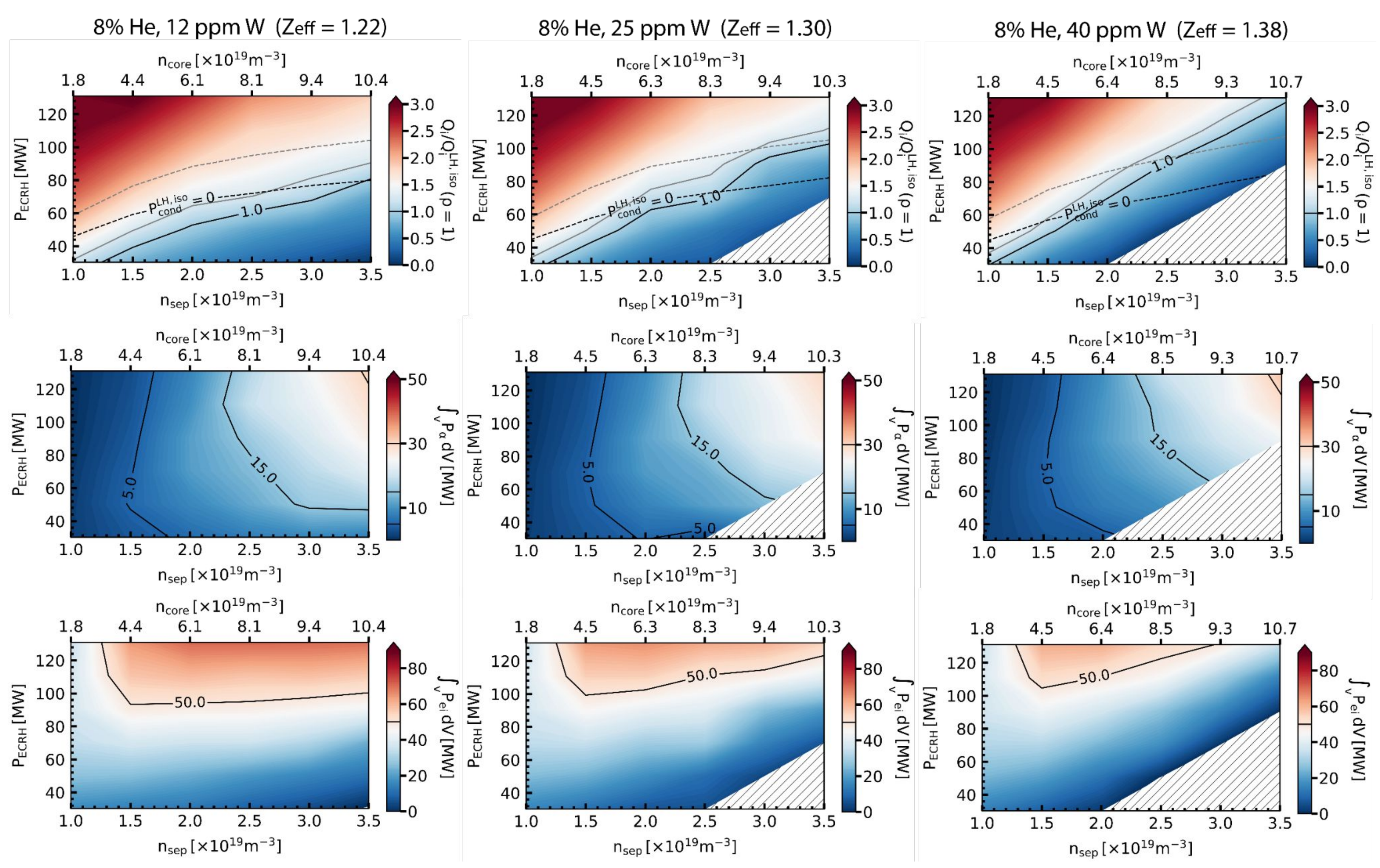
- Scan of separatrix n_e.
- Scan of Xe and W concentration homothetic to n_e.
- Scan of ECRH power.
- ECRH power as a bulk-only Gaussian heating.

Xenon scan: Xe could be added to control the heat flux if not detrimental for the L-H transition.



- Because the alpha heating contribution remains overall small, even at high-density, low-density scenarios improve the L-H transition accessibility.
- The addition of Xe increases P_{ECRH} requirement with no clear heat flux advantage.

Tungsten scan: DEMO FW will be constructed of W-coated Eurofer. Divertor targets of W monoblock (or similar). During the ramp-up, plasma will be in a limiter phase, allowing W influx (F. Maviglia, *Nuclear Materials and Energy* **26** (2021)).



- L-H transition is achieved in pure electron-heated plasmas at any density up to 40 ppm W. Higher W concentrations are possible the lower the plasma Greenwald density fraction is.
- Beam heating profile: damping location and width were also scanned (not shown). We find a very small effect on the presented results.

Conclusions

- L- and H-mode plasmas were studied for the DEMO2018 baseline scenario. The feasibility of the L-H transition was assessed with pure e-heating, while a heating mix scan was performed for H-mode plasmas.
- The L-H transition is seen feasible for pure electron heated L-mode plasmas for a parameter space bounded by the impurity concentration and available heating power.
- The electron to ion heating ratio was scanned in flat-top H-mode plasmas. Larger e-heating fraction leads to larger T_e/T_i, but also larger density peaking. In turn, the net effect is a constant fusion power. The latter is smaller than the necessary 2 GW foreseen for DEMO, which calls for further attention to both the verification of the transport models used as well as the scenario development for DEMO.

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