Theoretical modelling of non-hydrogenic plasma wall interaction experiments in ASDEX Upgrade and the GyM linear device

C.Tuccari[a], G. Alberti[a], F. Mombelli[a], L.Bana[a], D.Dellasega[a,b], A. Uccello[b], M. Pedroni[b], A. Cremona[b], F.Cani[b], J. Romazanov[c], A. Kirschner[c], A. Hakola[d], M. Passoni[a,b], The GyM team, The ASDEX Upgrade team and the EUROfusion tokamak exploitation team

[a] Dipartimento di Energia, Politecnico di Milano, Via Ponzio 34/3, 20133 Milan, Italy
[b] Istituto per la Scienza e Tecnologia dei Plasmi, ISTP-CNR, Via R. Cozzi 53, 20125 Milan, Italy
[c] Forschungszentrum Jülich GmbH, Jülich, Germany
[d] 4VTT Technical Research Centre of Finland, VTT Espoo, Finland

*Author email: carlo.tuccari@polimi.it

MoD-PMI 2025, 26-28th May, IAEA Headquarters, Vienna

Motivations and aims

Motivations

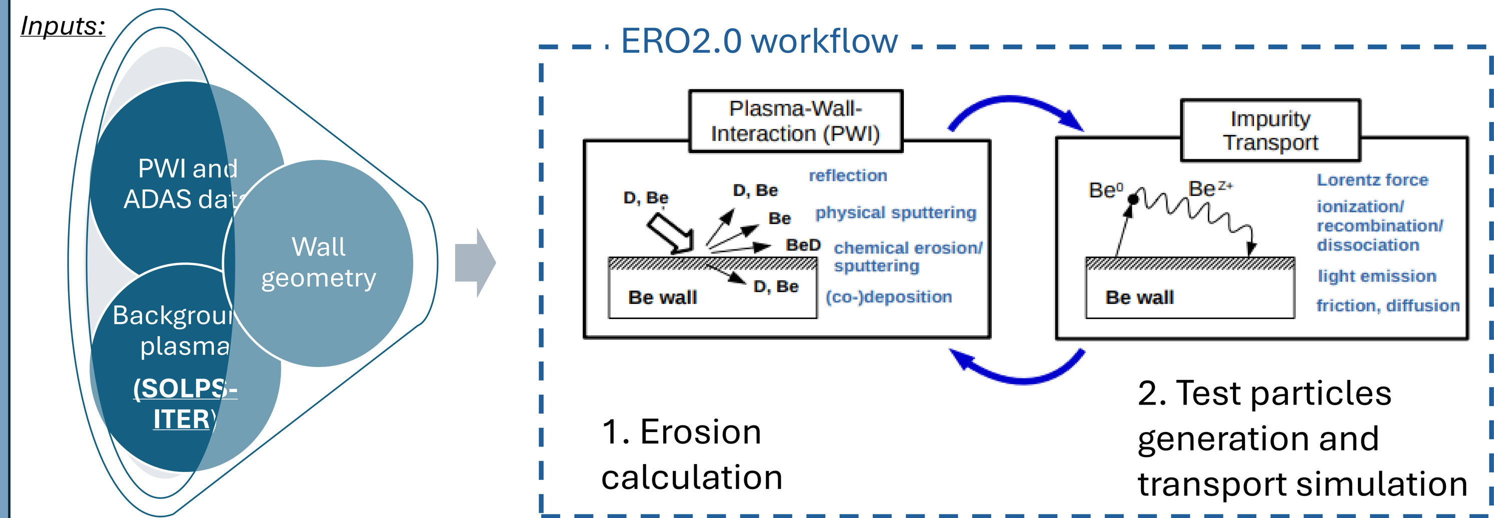
- Heavier non-hydrogenic plasma species, e.g. helium (He) ash, argon (Ar) seeding, may influence plasma-wall interaction (PWI)
- Linear plasma devices (LPDs) are used to perform dedicated PWI experiments in a controlled environment, to complement the more complex tokamak experiments
- Modelling PWI processes allows a deeper understanding of these phenomena and offers support for experiment interpretation
- Global SOLPS-ITER [1] and ERO2.0 [2] coupling allows self-consistent simulation of erosion and impurity transport processes, both in tokamaks and in linear devices [3]

Aims

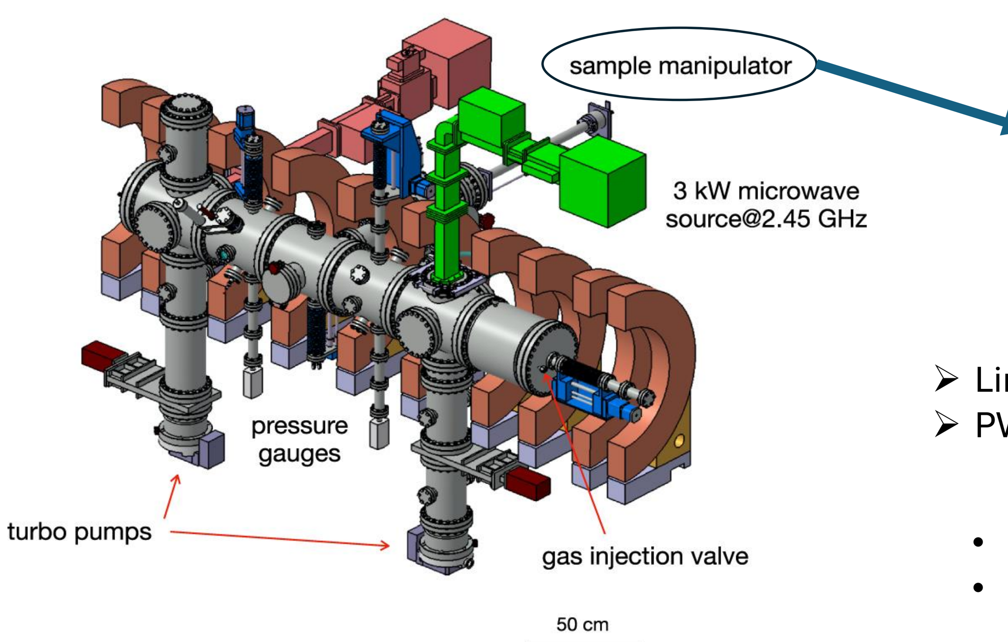
- Present an overview of erosion modelling activities with non-hydrogenic plasmas in different environments
- Design an erosion and migration experiment in the GyM linear device [4] and validate ERO2.0 simulations with experimental results
- Model outer divertor erosion in ASDEX Upgrade H-mode He plasma discharges [5]

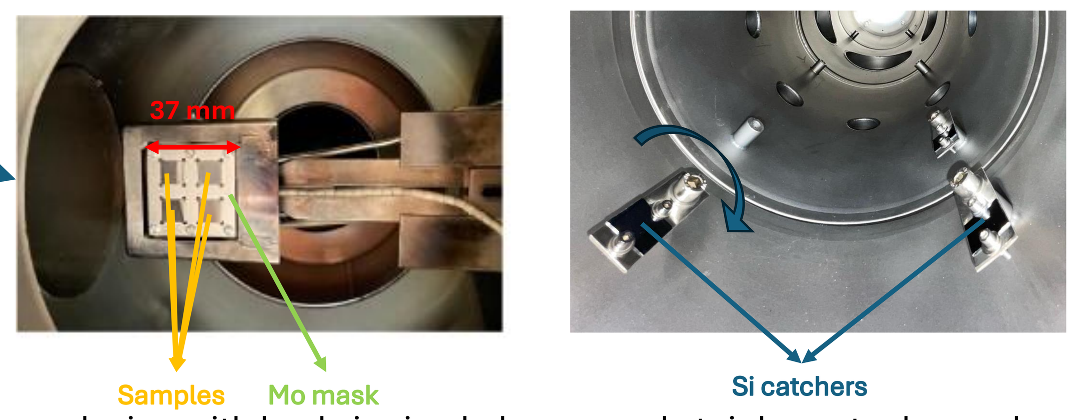
ERO2.0 code

- 3D Monte Carlo code for erosion and impurity migration simulation
- Global and self-consistent description in whole machine volume
- Test particles approximation: traced impurities do not influence background plasma parameters



The GyM linear device





- Linear device with lowly ionized plasma and stainless steel vessel
- PWI experiments with ion fluxes ~ CX neutrals on ITER first wall

B field	0.13 T	Ion flux	10^{21} ions m^{-2} s^{-1}
Working pressure	10^{-3} Pa	Ion fluence	10^{25} ions m^{-2} (~7h)
Electron density	$<10^{17}$ m^{-3}	Diameter	0.25 m
Electron temperature	<15 eV	Length	2.1 m
Ion temperature	0.1 eV	Working gases	H_2, D_2, N_2, **He**, **Ar**, mixtures

Sample-holder

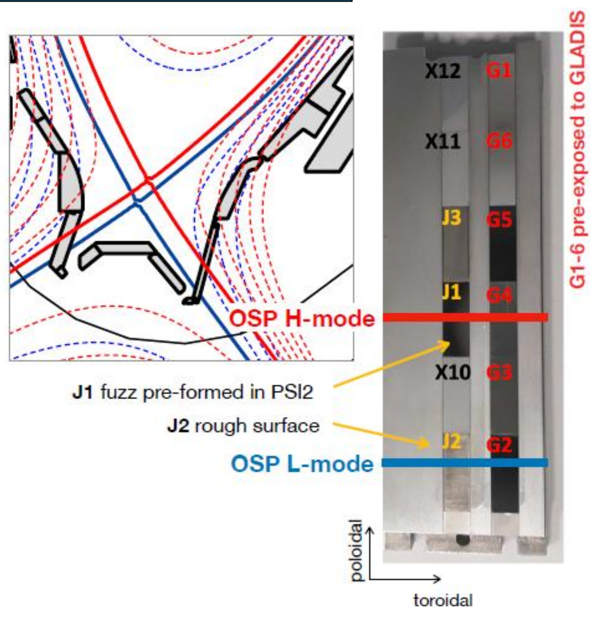
- Used to expose samples
- Negatively Biased to tune ion impact energy
- Typical exposed material: fusion relevant W (1x1 cm^2) mounted in a Mo frame. Other configurations are possible, i.e. different samples material or larger sample without mask (~ 3x4 cm^2)

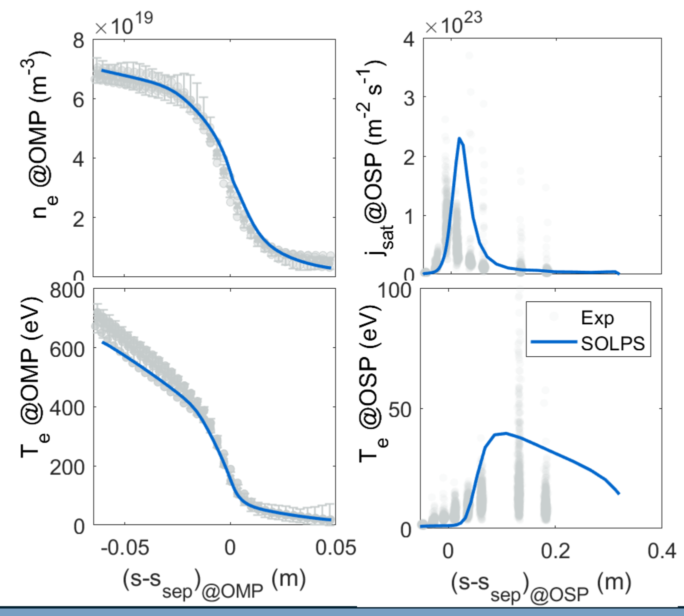
Catchers

- Introduced for modelling validation purposes
- Installed in proximity of lateral wall, able to rotate around the screw
- Aimed at providing measurable deposition layers from sputtered impurities

ASDEX Upgrade He campaign

- 2022 **He plasma** campaign aimed at observing fuzz formation on W divertor tiles
- 14 consecutive discharges: 8 **H-mode** and 6 L-mode
- H-mode and L-mode strike points separated by few centimeters to distinguish divertor regions
- **150-250 nm erosion** after 3.4×10^{24} m^{-2} fluence observed on polished W samples near the H-mode OSP [5]



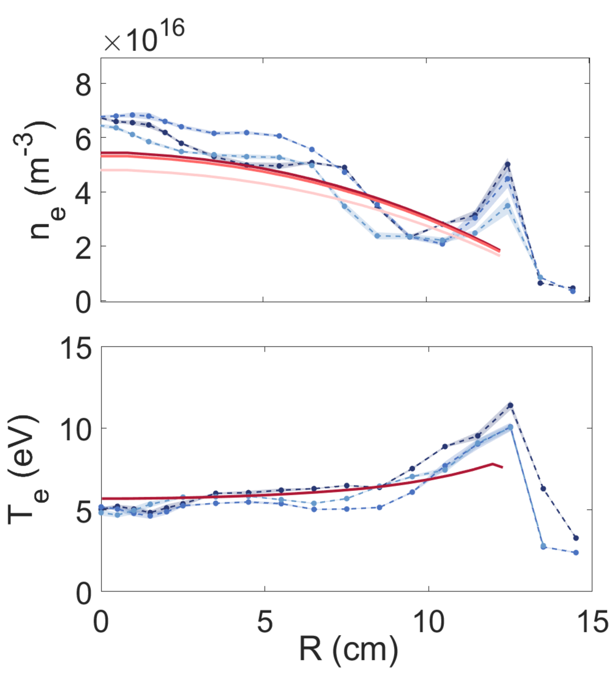


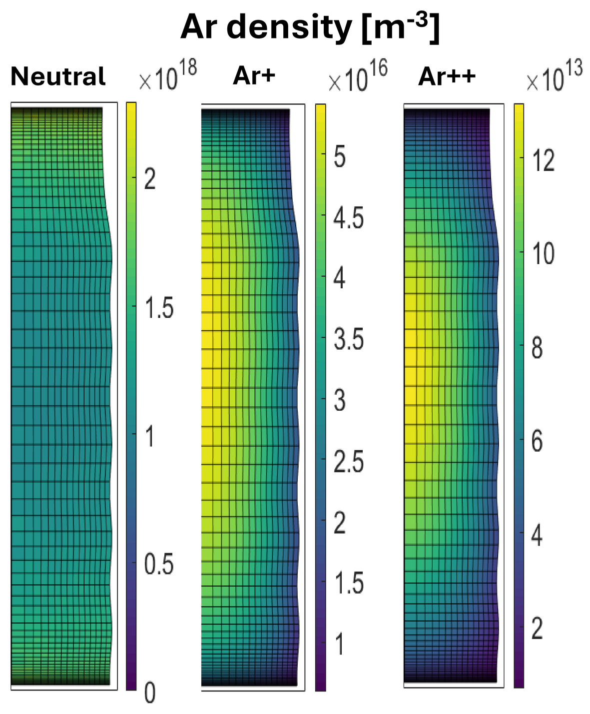
Background plasma to simulate inter-ELM phase of H-mode discharges produced with SOLPS-ITER.
Benchmarked with Langmuir probes measurements at outer midplane (OMP) and outer strike point (OSP)

Experiment design and ERO2.0 validation in GyM

Argon plasma

Ar background plasma from **SOLPS-ITER,** matching experimental radial profile of plasma parameters, measured with **Langmuir probes** at 3 axial locations



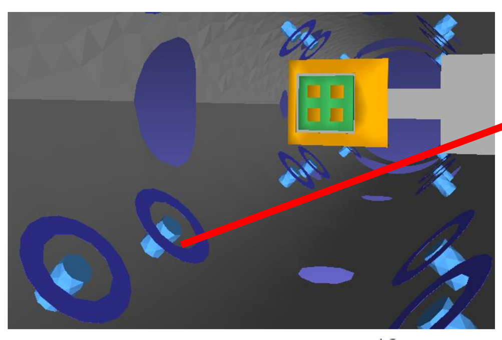


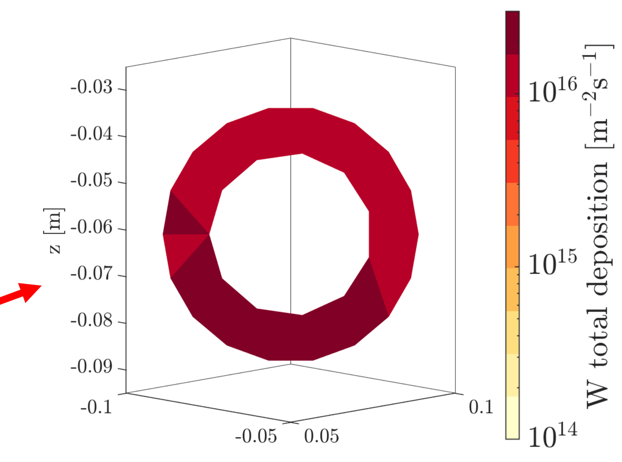
Ar plasma mostly neutral
Ar^+ is the dominant ionization stage, 3 orders of magnitude higher density than Ar^{2+} and other charge states

Experiment design

ERO2.0 simulations to determine:

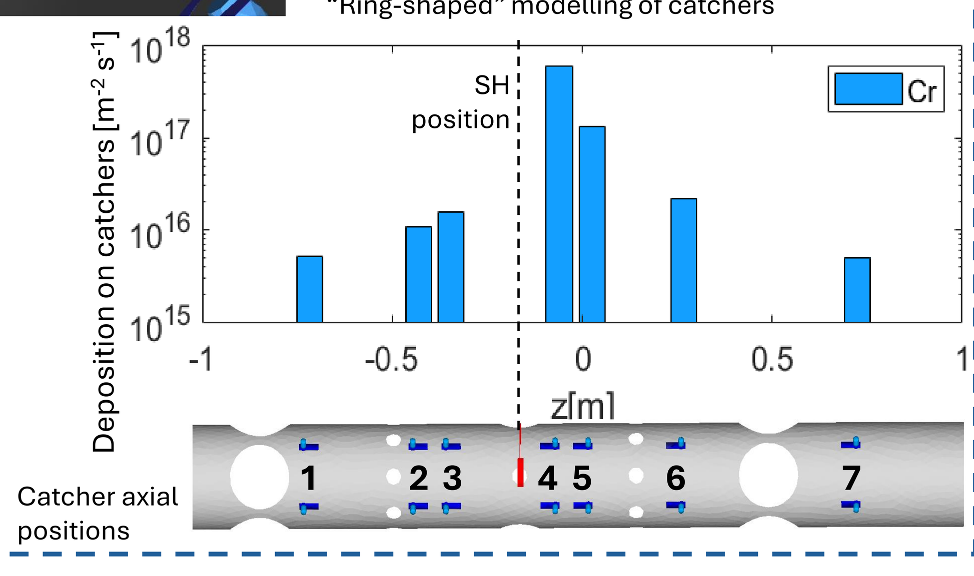
- Catcher location and orientation
- Material and size of samples to be exposed





"Ring-shaped" modelling of catchers

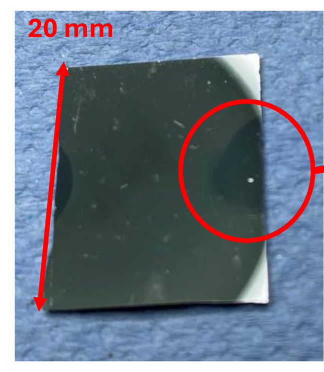
- Highest deposition found closer to SH, with catchers pointing towards it
- Large Cr sample chosen because of its higher erosion rate, hence higher deposition rate on catchers



Experimental results

- Cr coatings deposited on Si, exposed at 70 V
- Total 3 um thickness eroded

~30 nm deposited layer and ~70 ug mass gain expected on catchers according to ERO2.0 predictions



Catcher in axial position 4

Visible Cr deposition on catchers, with bare Si on shadowed surface regions

Measured mass gain: ~50 ug
Comparable with ERO2.0 predicitions

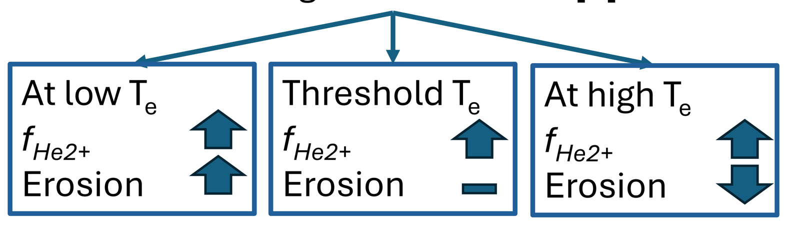
First EDX analysis confirms superficial Cr content, to be further investigated with other techniques to estimate layer thickness

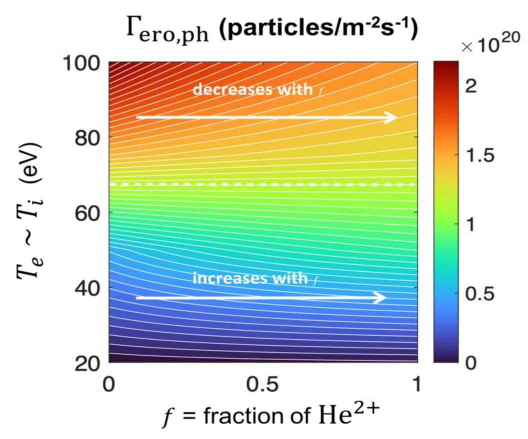
Element	Atomic %
C	11.27
O	3.44
Si	69.38
Cr	15.90

ASDEX Upgrade erosion modelling

- Near 50%/50% He^+/He^{2+} at the strike point
- Mostly He^{2+} farther in the SOL (see Fabio Mombelli et al. poster)

Influence of He^+/He^{2+} ratio on erosion given a fixed Jsat [6]

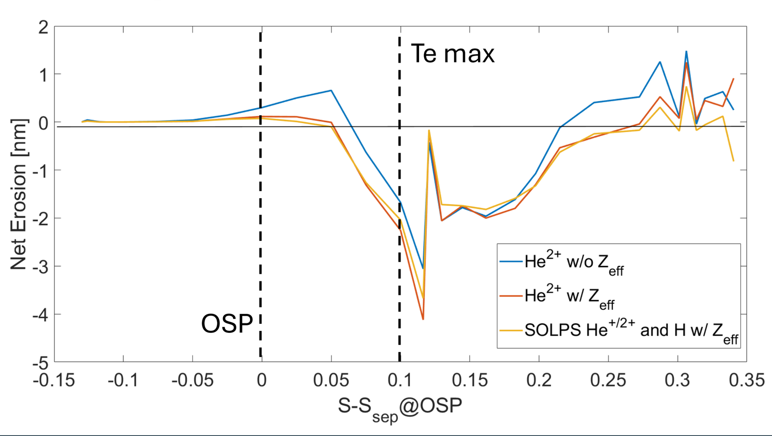




ERO2.0 results

Outer divertor erosion in inter-ELM phase estimated for different He ions modelling:

- Full He^{2+} plasma
- Full He^{2+} ion fluxes at divertor with Z_{eff} distribution in the volume
- SOLPS-ITER distribution of ion fluxes with Z_{eff} in the volume



- Net erosion peak observed in proximity of max T_e
- Z_{eff} distribution affects impurity transport, slightly increasing erosion
- Real fluxes distribution has minor influence on erosion, i.e. assuming a full He^{2+} flux is a good approximation. Possibly because T_e is close to threshold value

Conclusions and perspectives

Conclusions

- PWI experiments with non-hydrogenic plasmas were modelled through SOLPS-ITER and ERO2.0, highlighting the different role of higher charge states in a linear device and in a tokamak

GyM

- Large Cr samples and catcher installation near the SH were chosen through preliminary ERO2.0 modelling
- First experimental measures in good agreement with ERO2.0 predictions

ASDEX Upgrade

- He H-mode discharges successfully modelled with SOLPS-ITER
- Estimated OD erosion in inter-ELM phase and studied the influence of ion flux charge state composition

Perspectives

GyM

- Further analysis on deposited layers to determine thickness and refine the comparison with ERO2.0 modelling
- Future use of catchers as backup diagnostics in GyM PWI experiments

ASDEX Upgrade

- Investigate the impact of foreign light impurities on erosion
- Develop a strategy to model intra-ELM erosion and improve the comparison with experimental erosion measures

References

[1] X. Bonnin, et al, Plasma Fusion Res. 11, 1403102 (2016)
[2] J. Romazanov, et al., Phys. Scripta 2017.T170, 014018 (2017)
[3] F. Mombelli, et al., Nucl. Fusion 65, 026023 (2025)
[4] A. Uccello, et al. Front. Phys. 11, 1108175 (2023)
[5] M. Rasinski, et al., Nucl. Mat. Energy 37, 101539. (2023)
[6] Manuscript submitted to Nuclear Fusion

This work has been carried out within the framework of the EUROfusion Consortium (WP-PWIE), partially funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200—EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them. Part of this work is funded by Eni S.p.A, in the framework of the Contract N. 4400010490.