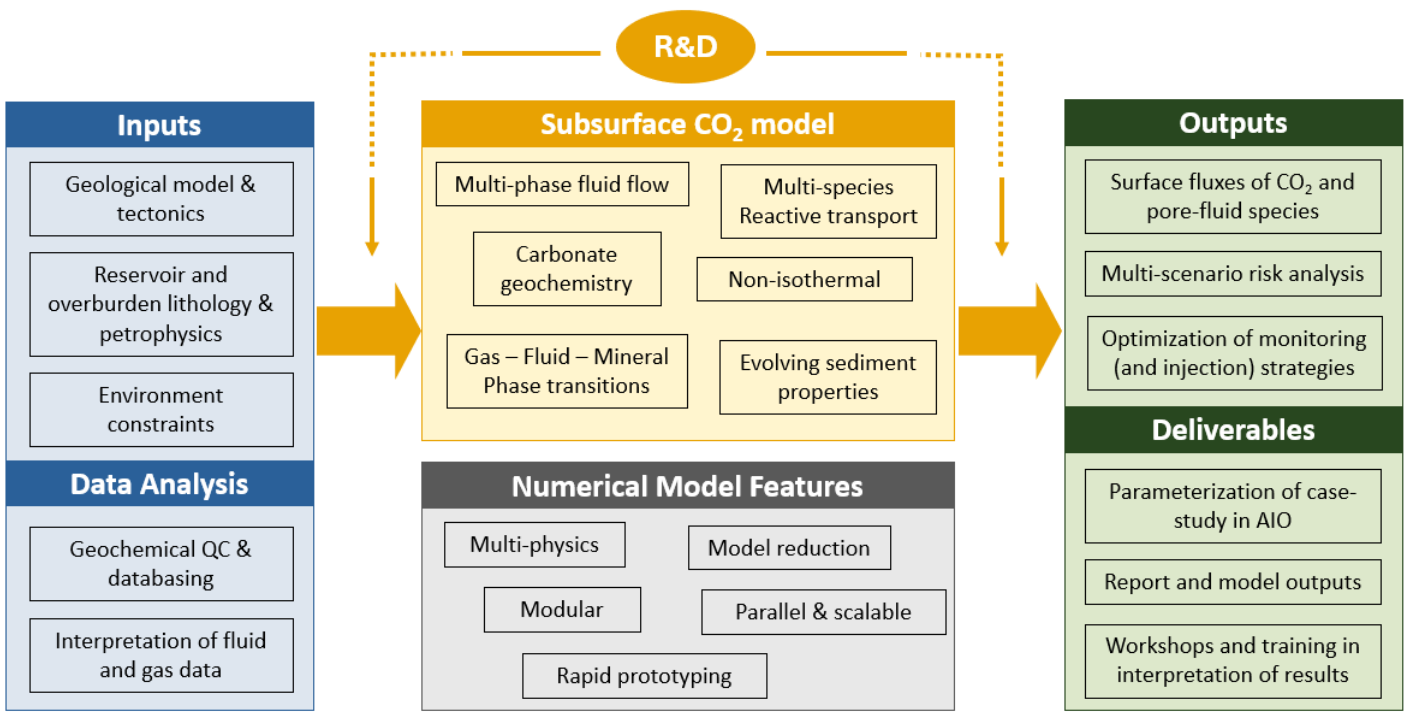
CO2MIG:
A Novel Multi-Physics CO_2 Migration modeling Workflow



An Industry-Focussed R&D Project for the Geological Storage of CO_2

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R&D PROJECT MOTIVATION

Bridging the gap between reservoir modeling and surface seepage to optimize injection and monitoring strategies associated with the geological storage of CO_2.

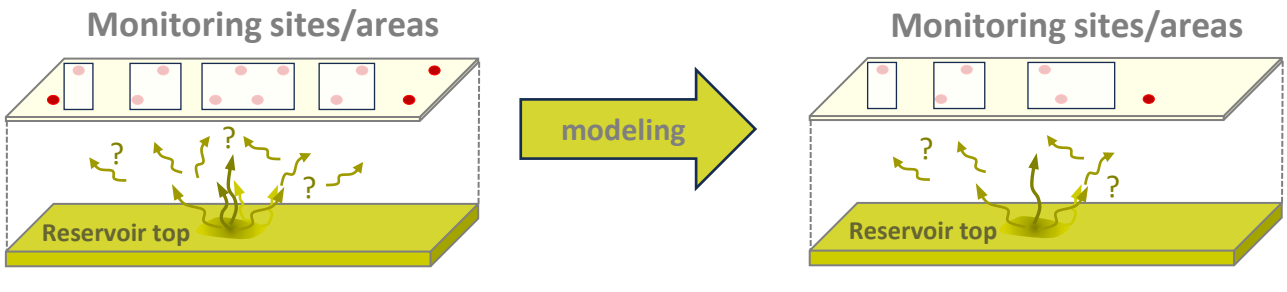
Currently, CO_2 migration monitoring tools used in Carbon Capture and Storage (CCS) focus on imaging the evolution of injected CO_2 fluids in the reservoirs and/or in monitoring boreholes, and on measuring surface seepage. The lack of reliable and cost-effective methods to forecast potential seep locations strongly increase surface monitorization costs because un-necessary surveys are needed in compensation.

In contrast, the migration of CO_2 plumes in the overburden between a potentially leaking reservoir and the surface has so far been largely overlooked. This is partially due to the complexity of the problem and the associated uncertainties.

We believe that modeling the key processes controlling the migration of CO_2 in the sediment overburden can improve significantly our ability to predict the location, intensity and evolution of potential emissions through time. A modeling workflow integrating a large range of parameters can be a powerful means of testing alternative scenarios for injection and CO_2 plume migration, thus reducing monitorization costs and efforts.

Modeling of complex systems has been successfully applied in the O&G industry for decades and has led to the optimization of seismic surveying and drilling strategies, which have orders of magnitude higher costs than modeling. We propose applying the same principles and mindset to the geological storage of CO_2 using state-of-the-art modeling techniques.

Optimization of surface monitoring strategies with modeling workflow



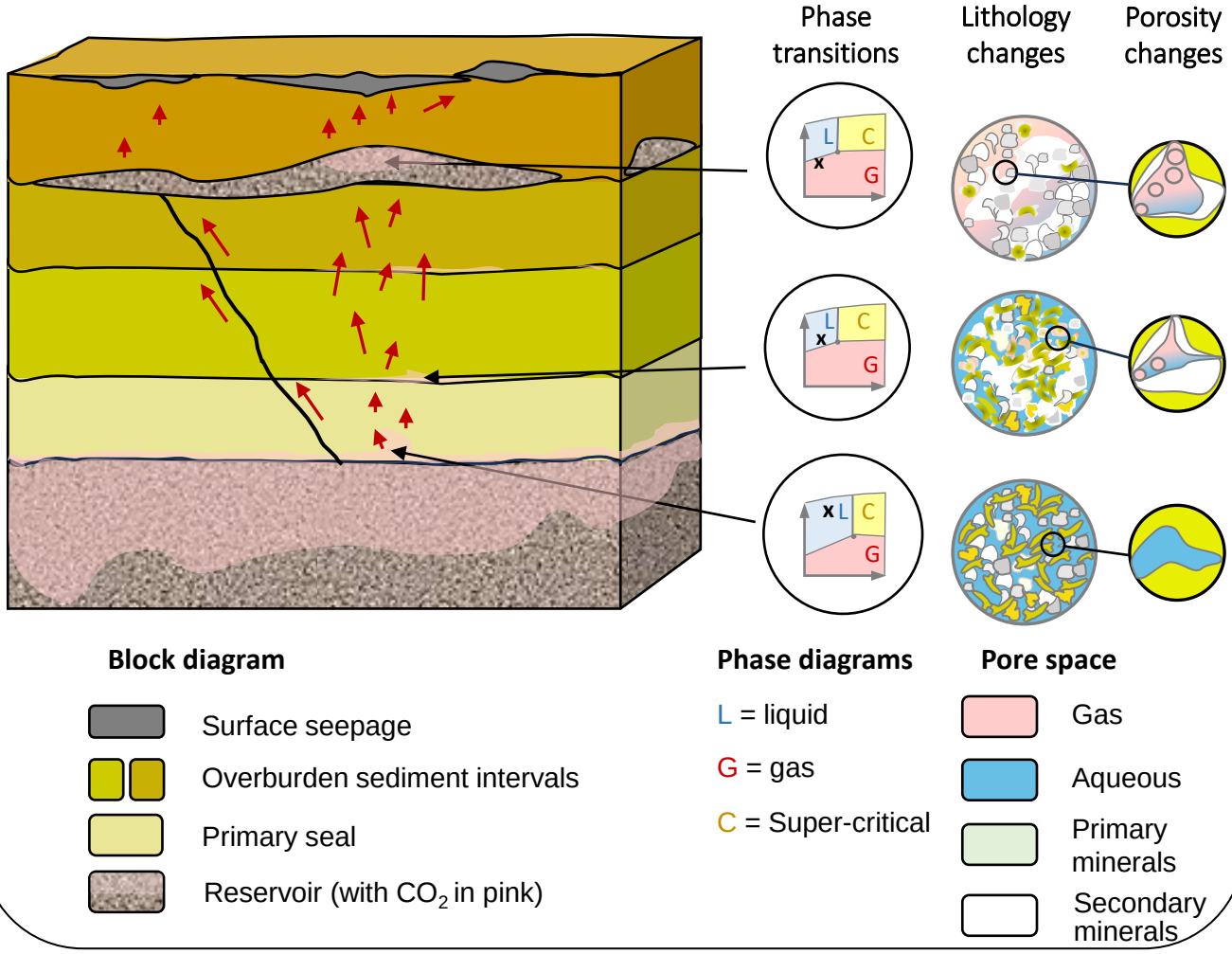
Our multi-disciplinary team proposes to develop a migration modeling workflow using a sophisticated numerical model recently produced in academia to model subsurface dynamic fluid flow and which is being adapted for the CCS industry. The model development will be tailored for the AOI of the project partners, allowing for the detailed investigation of leakage risk factors in the selected case scenarios. We are strongly encouraged by the demonstrated ability of the modeling software produced by our academic collaborators to resolve complex phase transitions in an evolving sedimentary environment.

CO_2 MIGRATION modeling POTENTIAL

The proposed workflow will model the 4-D migration of CO_2 plumes and analyze the risks of surface leakage. The enhanced plume transport simulation is based on the integration of a large range of parameters, which interactions control the evolution of the plumes in the overburden in space and time. The capacities of the modeling workflow will include:

- Predicting the multi-directional phase transitions in the plume;
- Producing fluid flow field evaluations (in operational settings) and predictions (at planning and pilot stages).
- Mapping the multi-phase migration of leaked CO_2 in different lithological and structural settings.
- Testing the model sensitivity to variations in model parameterization and for alternative scenarios.
- Supporting the identification of the risks, magnitude and timing of potential surface emissions.

Simplified scheme illustrating how interrelated physical & chemical parameters modulate the evolution of CO_2 plumes



MULTI-PHYSICS MODEL FOR PREDICTING FLUID PHASES

The new modeling approach is supported by a software developed in academia to model subsurface reactive dynamic fluid flow in a multi-physics framework.

The numerical model was produced to simulate gas hydrates dynamics, involving intricate gas-liquid-solid phase changes (Gupta et al., 2020, 2022, 2023) and recently adapted to model CO_2 fluxes in subsurface sediments.

The software is modular and highly versatile, allowing it to incorporate numerous processes that affect phase transitions within the migrating fluids. Key processes include:

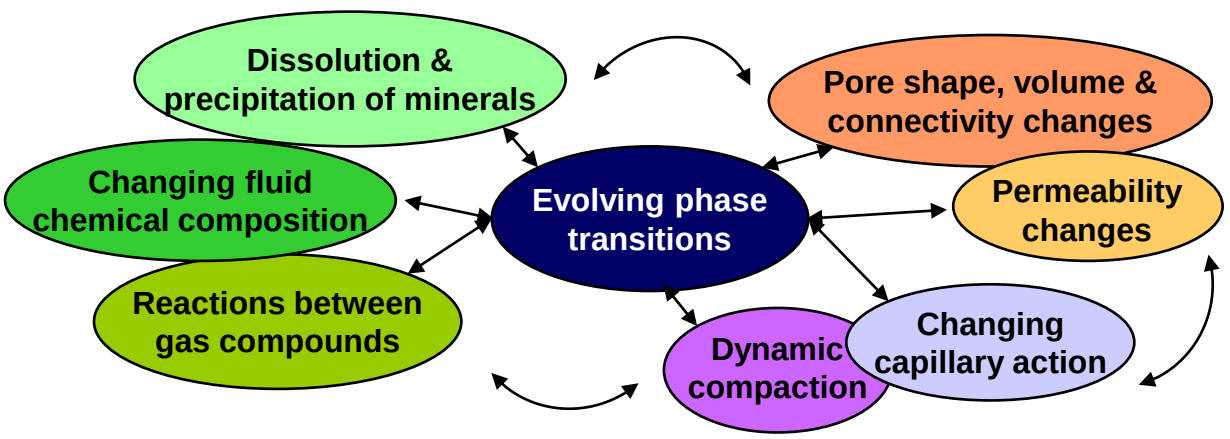
- **Chemical changes of the porewater composition** - The addition of CO_2 in pore fluids leads to chemical reactions between (1) solutes in water; (2) solutes and matrix minerals; and (3) aqueous solution and gas phase components (e.g., gaseous CO_2, methane). The number of reactions integrated in the reaction networks is practically unlimited, i.e., the complexity of chemical processes modeled can be user-defined.

- **Dissolution and precipitation of minerals** - Solutes-mineral reactions cause the dissolution of primary minerals and the precipitation of secondary minerals. These result in modifications of pore shape and volume, therefore impacting on permeability and plume migration.

- **Dynamic Pressure-Temperature-Composition (P-T-X) conditions** - The P-T-X conditions are transformed constantly in all parts of the developing CO_2 plume. The model computes P-T-X variations resulting from physical-chemical changes, which are themselves induced by the migration of the fluids, enabling an enhanced accuracy of plume migration predictions.

- **Changing capillarity action** due to P-T-X and porosity transformation acting on the migration paths and rates are included in the model.

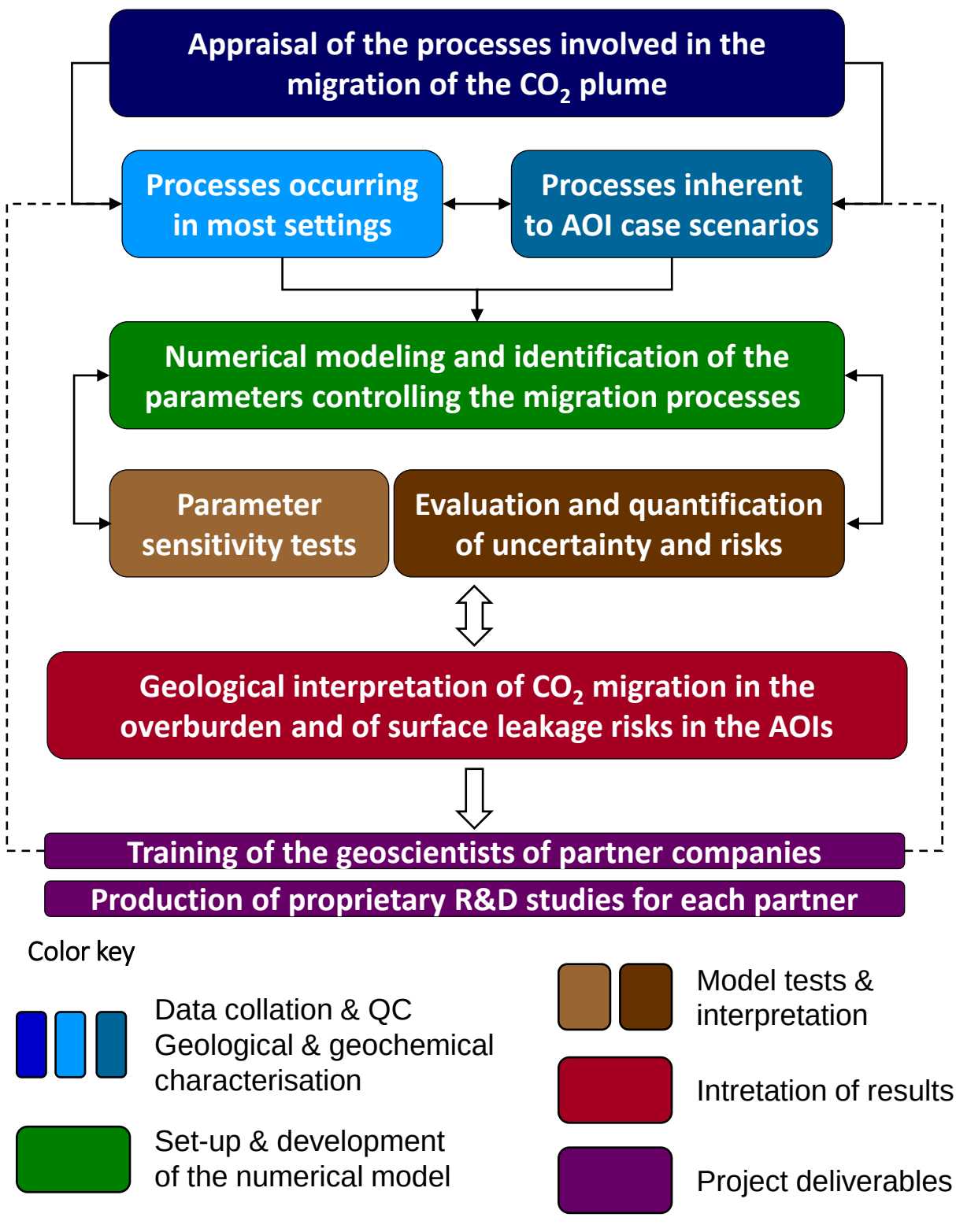
Interrelated processes controlling complex phase transitions



The R&D project is structured in a succession of stages involving:

- Analysis and interpretation of a broad range of geological and geochemical data including the structural, tectonic and petrophysical context and the geochemistry of aqueous, gas & minerals phases.
- modeling of the plume evolution and prediction of the sub-surface migration and surface leakage scenarios.
- Sensitivity analysis and evaluation/quantification of the uncertainty and risks associated with the different case scenarios specific to the AOIs.

Overview of the structure of the migration modeling workflow project



THE R&D PROJECT TEAM

The multi-disciplinary project team encompasses experts from the fields of geology, geochemistry, modeling and statistical modeling (brief presentation below).

Dr Tiago Cunha is is a geologist, marine geophysicist and modeller with over 20 years of experience in Basin and Petroleum Systems modeling (BPSM).
Tiago holds a Ph.D. in gravimetry modeling of continental margins from the University of Oxford (UK), followed by 5+ years of academic research in basin modeling. He has been working as a BPSM for the O&G industry for over 12 years.

Dr Marianne Nuzzo is a geologist and organic geochemist with over 20 years of experience in gas and petroleum geochemistry.
Marianne holds a Ph.D. in gas seep biogeochemistry from the University of Bristol (UK), followed by 6 years of academic research in marine seeps gas geochemistry. She has been working as a gas and petroleum geochemist for the Oil & Gas (O&G) industry since 2013.

Dr Dan Cornford is a mathematician with 21 years of academic research in statistical modeling.
Dan holds a Ph.D. in spatial statistics and climatology from the University of Birmingham (UK). After 20 years of academic research in statistical modeling, AI and computer sciences, he joinined IGI where he has been leading software development activities for 12+ years, now heading statistical modeling & AI research projects.

The IGI Team will interact with our two academic consultants: Dr Shubhangi Gupta, who produced the software, and Dr Ewa Burwicz-Galerne, who tested initial versions, to adapt the model and advise on its usage according to the specificities of the AOIs.

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