# Transitioning $CO_2$-EOR Field to Dedicated $CO_2$ Storage: Risk Considerations and Quantifications

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*Presenter: Guoxiang "Gavin" Liu*
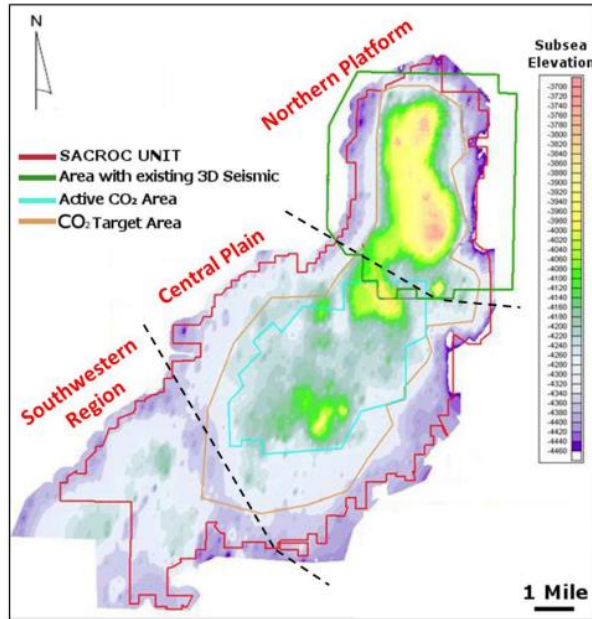*General Engineer, National Energy Technology Laboratory*
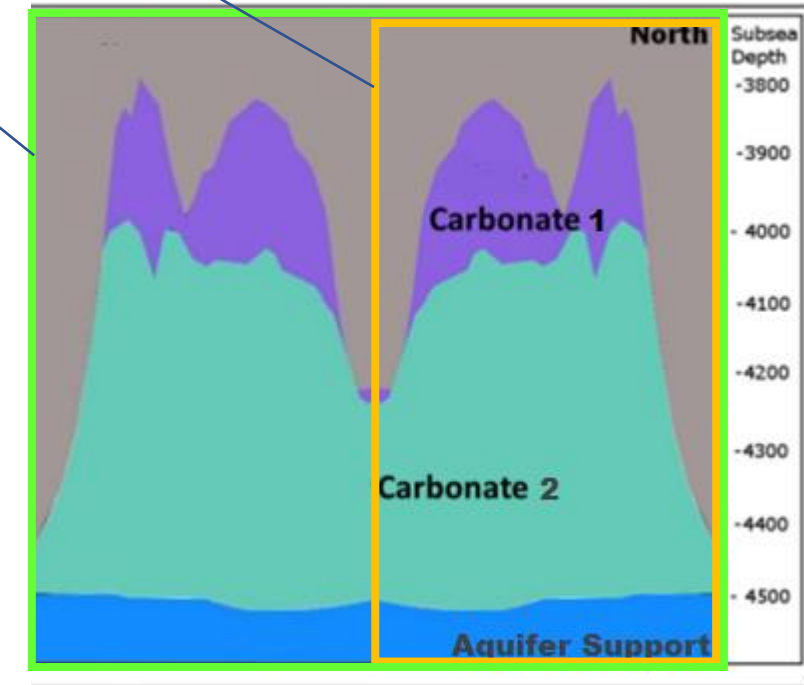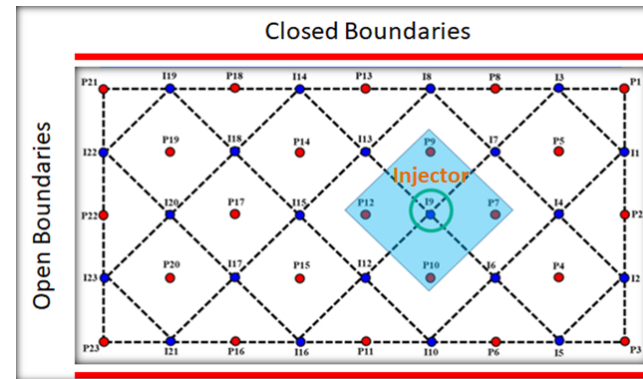
# Disclaimer

# Challenges, Motivation, and Objectives

➢ When is the transition considered?

➢ What are the factors to be considered regarding to risk assessment?

❑ Develop a conceptual & numerical simulation workflow that enables risk assessment of the transition of existing $CO_2$-EOR injection wells to dedicated $CO_2$ storage.

❑ Conduct numerical simulation of a realistic and practical $CO_2$-EOR field site transitioning.

❑ Explore influence of scenario responses reservoir that can support stakeholder decision makings for the objective regarding to risk assessments and priorities.
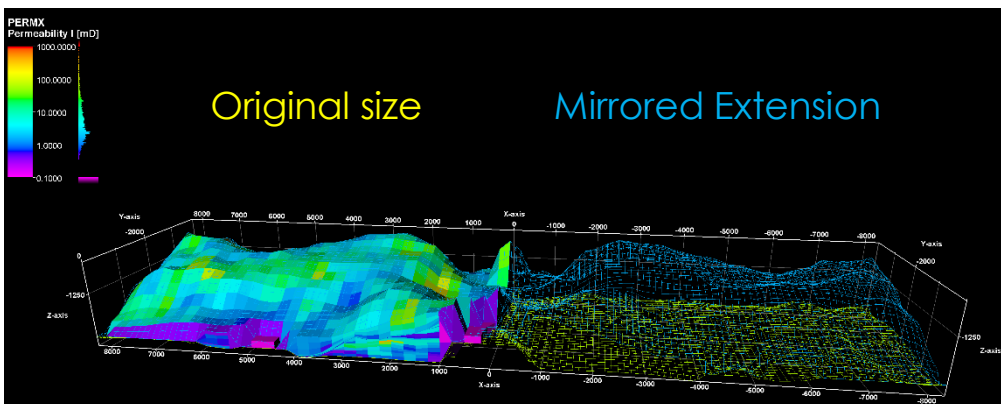
# Case Study Selection and Model Generalization



General lithologic Setting of reference geology and structure

https://repositories.lib.utexas.edu/bitstreams/a5cf187f-170c-4267-907c-790a8087e480/download

# Scenario Design

To assess the potential risk and impacts of the transition, a total of seven scenarios are designed as:

- Dedicated $CO_2$ storage AoR comparison to BAU and baseline (Cases 1, 2, 3)

- AoR impacts by **depletion levels, initial pressure** under or above MMP, (Cases 4 and 7)

- AoR impacts by **reservoir fluids**, hydrocarbon or saline, (Cases 4 and 6)

- AoR impacts by **model domain size and boundary conditions** (Cases 3, 4, 5, 6),

| No. | Simulation Focus | Model Size | Depletion Level (Initial Pressure) | Reservoir Fluids | Operations | Boundary Conditions |
|-----|------------------|------------|-----------------------------------|------------------|------------|---------------------|
| Case 1 | Baseline for Comparison | Original | N/A | Hydrocarbon | No injection after EOR | One side open |
| Case 2 | Business as Usual (BAU) | Original | N/A | Hydrocarbon | Continuous EOR | One side open |
| Case 3 | Dedicated Storage | Original | Under MMP | Hydrocarbon | Dedicated $CO_2$ storage | One side open |
| Case 4 | Dedicated Storage | Extension | Under MMP | Hydrocarbon | Dedicated $CO_2$ storage | Extended\closed |
| Case 5 | Dedicated Storage | Original | N/A | Saline Aquifer | Dedicated $CO_2$ storage | One side open |
| Case 6 | Dedicated Storage | Extension | N/A | Saline Aquifer | Dedicated $CO_2$ storage | Extended\closed |
| Case 7 | Dedicated Storage | Extension | Above MMP | Hydrocarbon | Dedicated $CO_2$ storage | Extended\closed |

Liu, G., Mehana, M, Dilmore, R., Strazisar, B., Lackey, G., Morgan, D., & Cunha, L. (2024, March 11). Risk Considerations of Transitioning CO2-EOR Field [Presentation]. CCUS 2024, Houston, Texas.

# Total Stored CO$_2$ over 30 Years

- The figure shows the net storage of CO$_2$ in the reservoir for 7 cases.

- Case 1 is the base line to compare with others, and it has no injection/production over the dedication CO$_2$ storage period.

- Case 2 exhibits the highest storage capacity, as multiple wells operate (22 injectors and 23 producers) in the EOR process. Other dedicated CO$_2$ storage cases (Cases 2, 3, 4, 7) are also higher, because fluids are **miscible and compressible** more than Cases 5 and 6 in saline reservoirs.

- Case 6 shows low carbon storage capacity, as the extension is small domain size (compared to the **aquifer boundary condition** in Case 5).

- Case 7 is a hydrocarbon reservoir but with high initial pressure, above MMP and exhibits moderate storage overall in the plots.
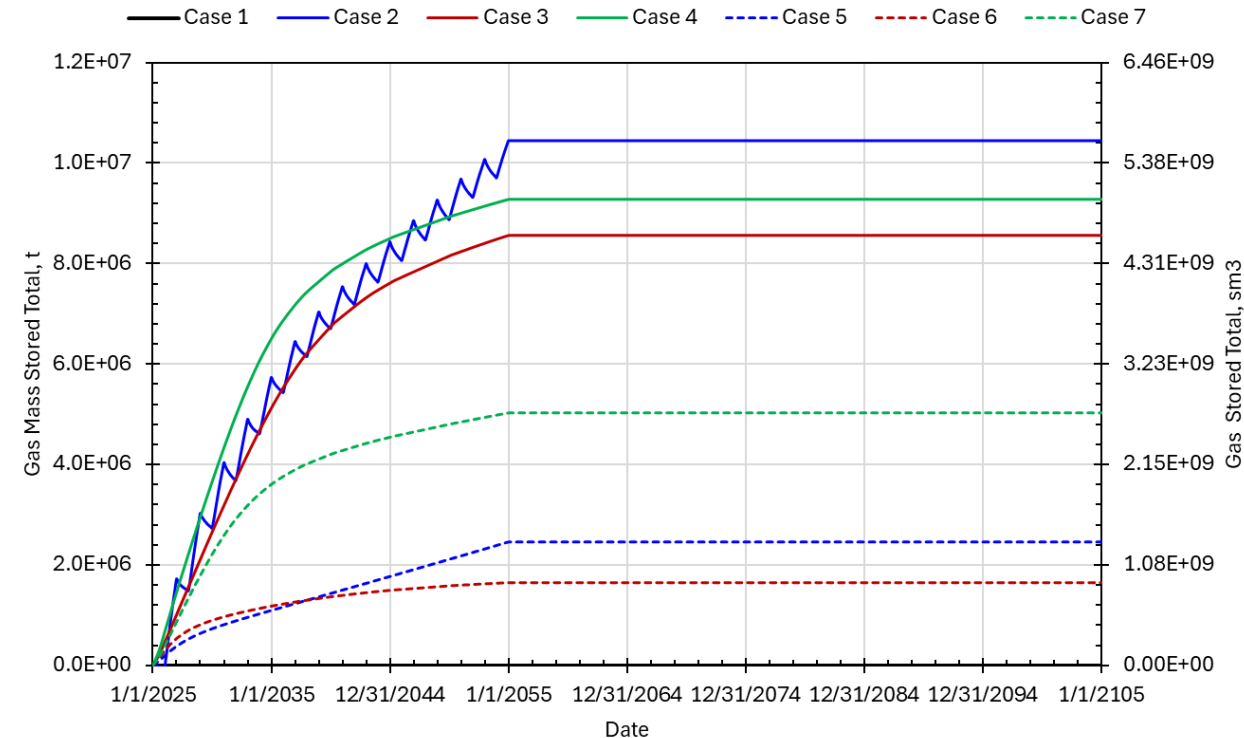
# Union AoR Summary

**Initial Condition**

- **Union AoR:**
  - ❑ Pressure front based on critical pressure (Nicot, 2009) **cutoff, 176 bar, 2553 psi** (in red polygon)

  - ❑ $CO_2$ plume in contour maps

- Map view of the layer with most of $CO_2$ spread

- Initial Conditions:
  - ❑ Used as starting point for each of cases to track down the union AoR changes over the injection period and post-injection period
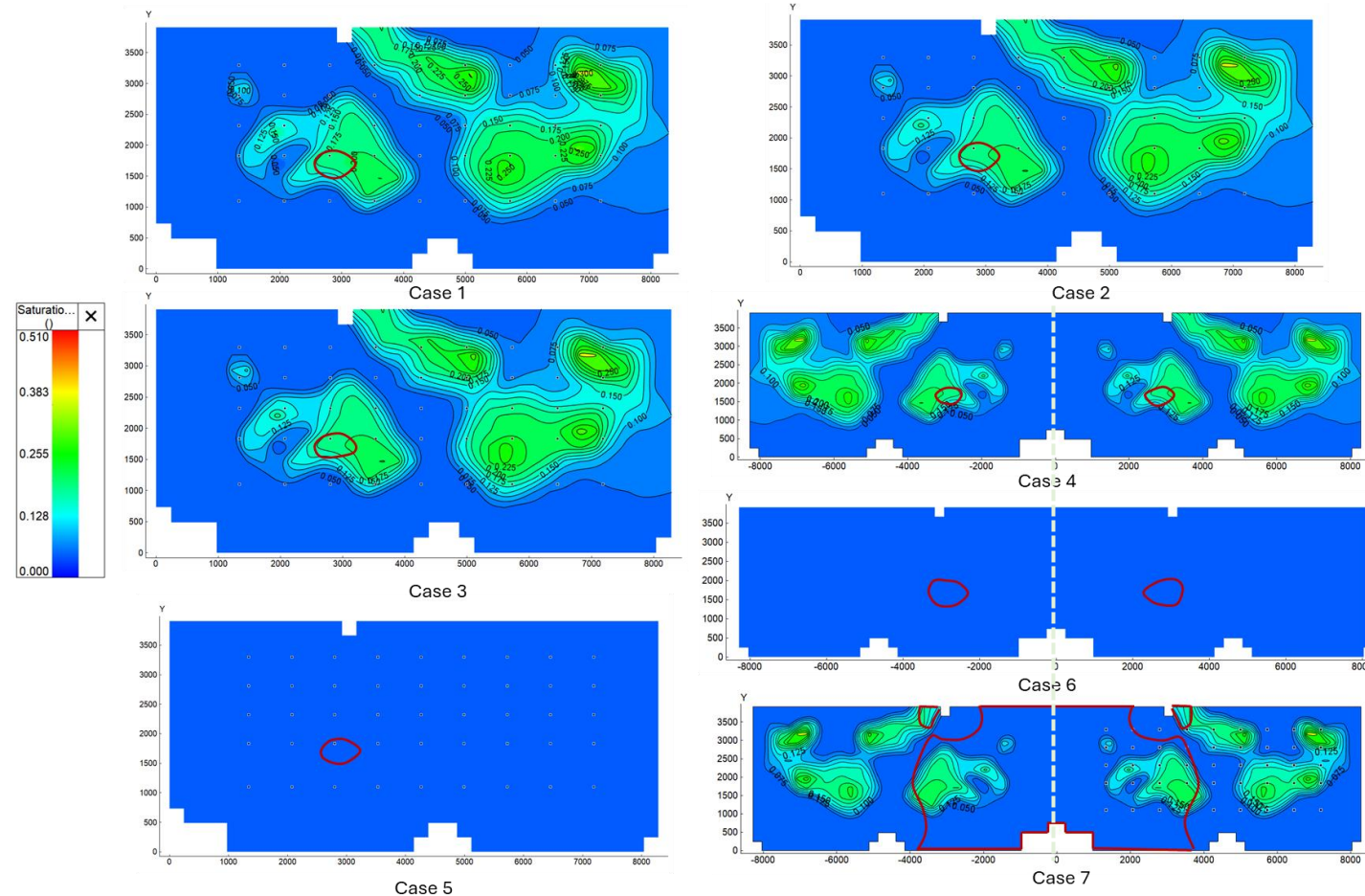
Pressure perturbations from geologic carbon sequestration: Area-of-review boundaries and borehole leakage driving forces

# Union AoR Summary (cont.)

- **Case 1**: pressure dissipates and the gas plume shows small reduction, as there is no fluid injection and gas dissolves. The pressure does not reach critical pressure.

- **Case 2**: pressure increases as EOR continues due to unbalanced source-sink later of the operations.

- **Case 3**: overall temporary pressure dissipation because the dedicated $CO_2$ storage injection in one well only.

- **Case 4**: pressure starts to increase on injection side.

- The pressure in **Cases 5 and 6** increases quickly in saline reservoir condition, although, in one well only, $CO_2$ injection happens

- **Case 7**: pressure starts to dissipate in the reservoir, but there are increases on the injection side. The increase is higher than Case 4 because of above MMP (Case 4, under MMP)

**After 5 Years Injection**
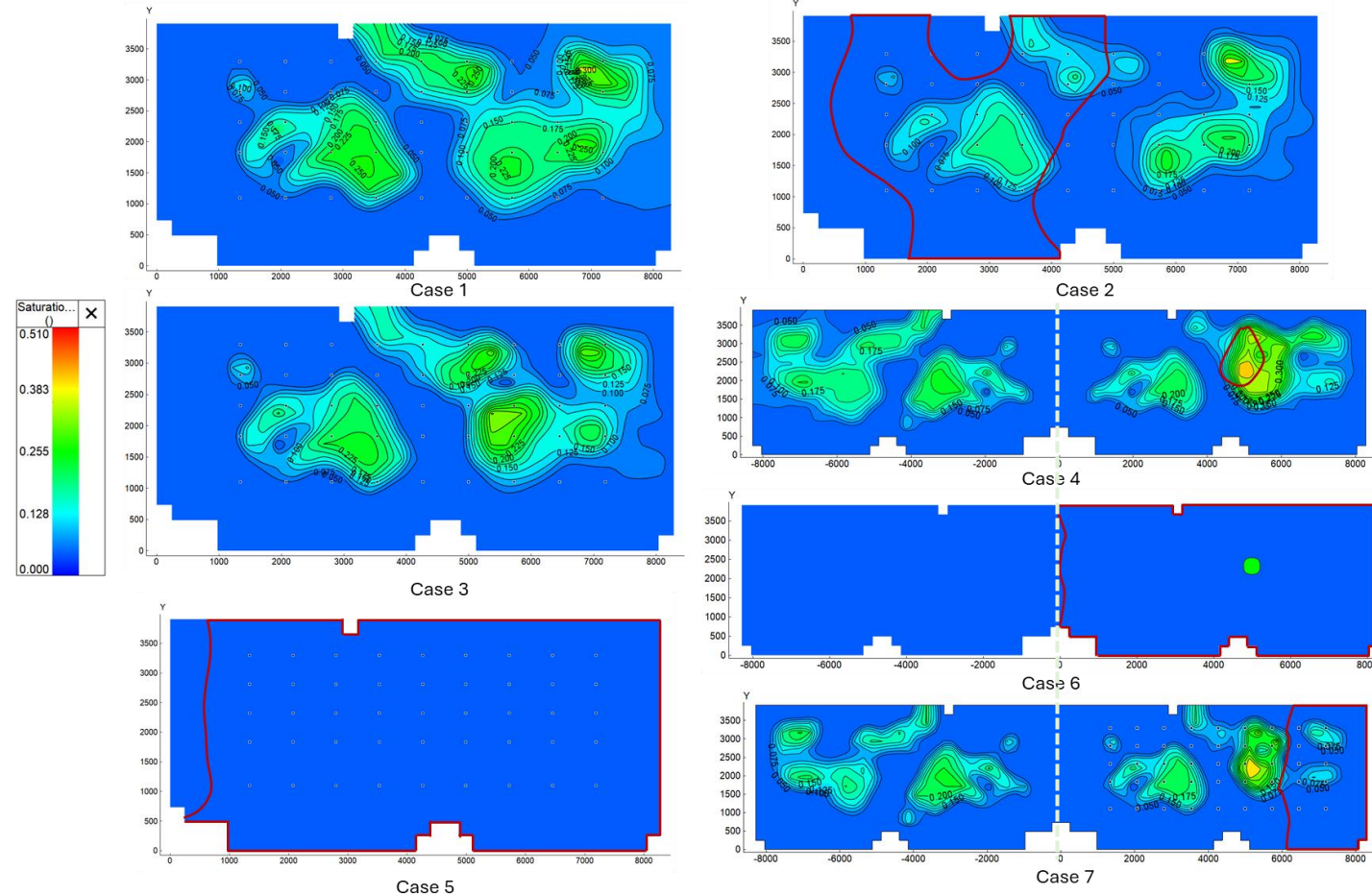
# Union AoR Summary (cont.)

- **Case 1**: continuation of pressure dissipation, and small reduction in gas plume.

- **Case 2**: pressure increases, and gas plume expands, as EOR continues, again due to unbalanced source-sink later of the operations.

- **Case 3**: pressure shows increases, and gas plume shows higher saturations. The high pressures (above 176 bars) cover about 15% of the reservoir domain.

- **Case 4**: Both pressure and plume spreading seem faster in Case 4 than Case 3 due to model domain size and boundary condition difference.

- **Case 5**: high pressures cover almost the full reservoir in saline reservoir condition. Moreover, the observation in **Case 6** is even more obvious, again, due to the model domain size and boundary condition difference.

- **Case 7**: Pressure extension in this case even exceeds the original reservoir size majorly because of higher initial pressure (depletion level is above MMP), compared to Case 4. However, the extension is still less than saline condition in Case 6 obviously.

**After 10 Years Injection**
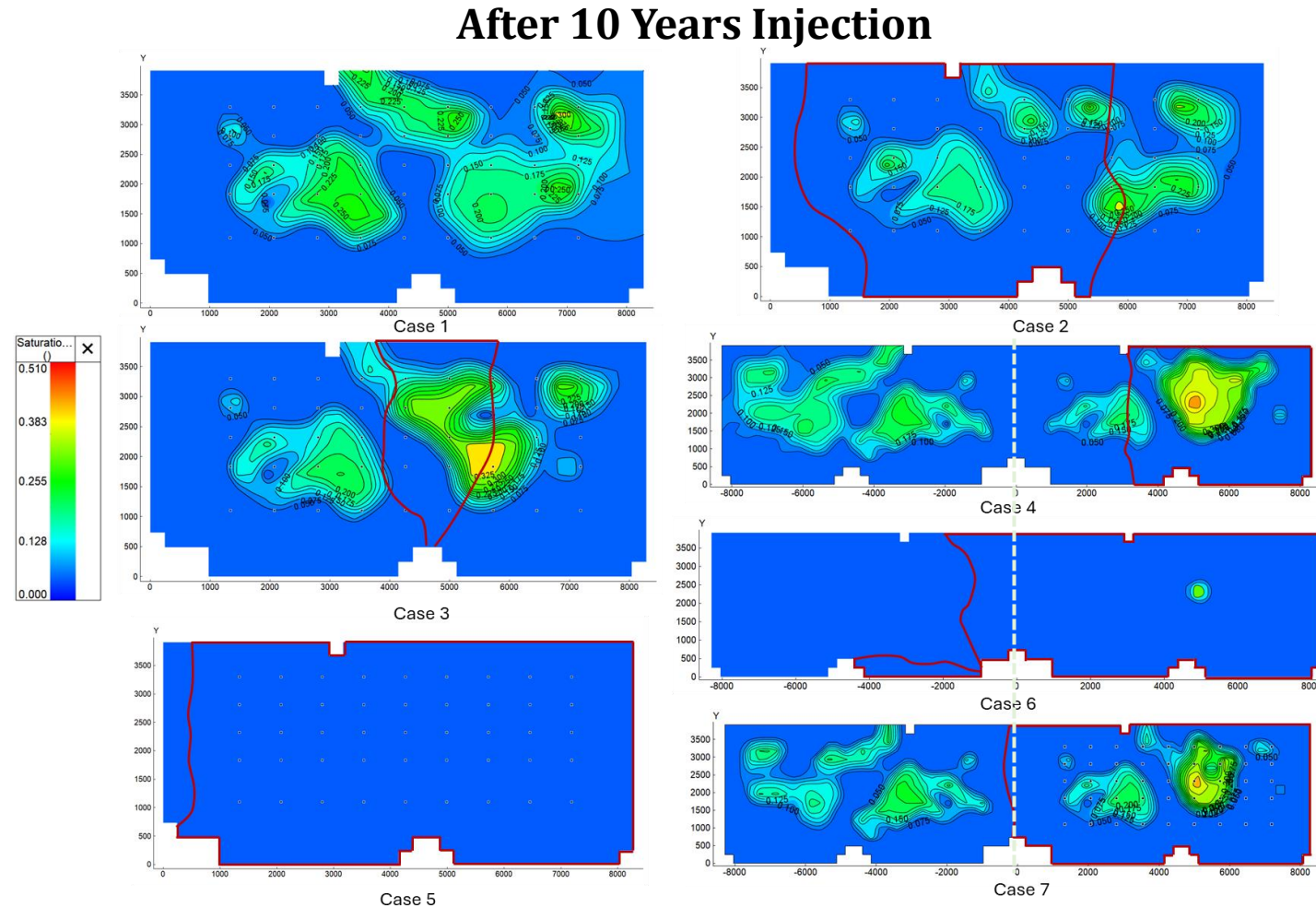
# Union AoR Summary (cont.)

- **Case 1**: no much surprise

- **Case 2**: Both pressure and plume keep increasing and expanding.

- **Case 3**: pressure continues to increase, and high pressure covers large AoR.

- **Case 4**: Pressure outline covers almost the original reservoir portion with high gas concentration. In the extension segment, the gas plume shows small reduction as gas dissolves. The pressure AoR in case 4 is larger than Case 3, due to the larger $CO_2$ injection.

- **Cases 5 and 6**: high pressures cover almost the full reservoir in saline reservoir condition. It requires strategy for pressure management such as introducing brine extraction

- **Case 7**: The pressure, above MMP of depletion in this case shows more extension than in Case 4, under MMP. However, the plume seems different.

**After 15 Years Injection**
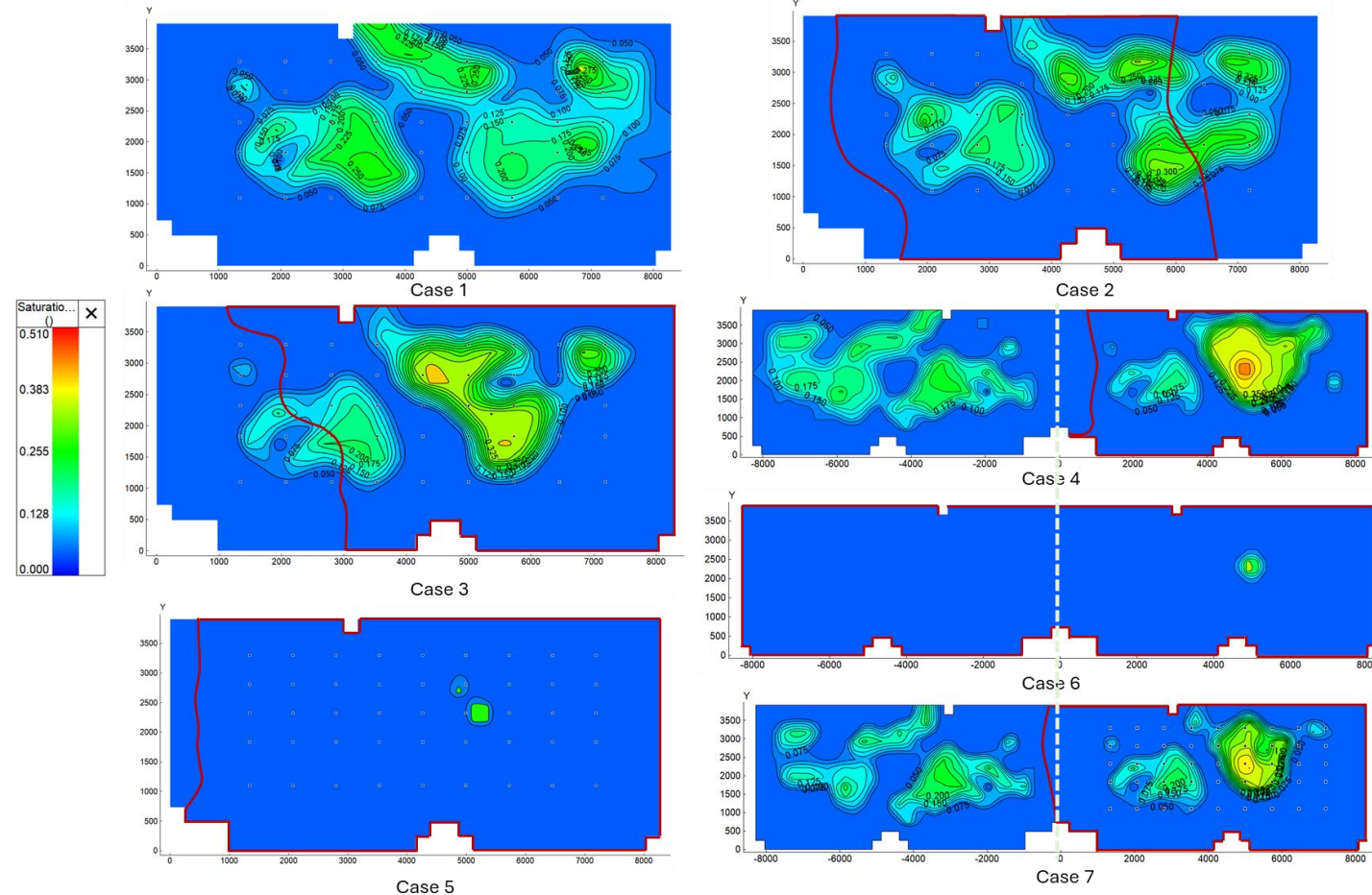
# Union AoR Summary (cont.)

- **Case 1**: continuous dissipation as expected.

- **Case 2**: both pressure and plume keep increasing and expanding

- **Case 3**: pressure continues to increase, and high pressure covers large AoR

- **Case 4**: high pressures covers the original reservoir segment, and the gas plume continues to expand.

- **Cases 5 and 6**: plumes in saline reservoir due to dedicated $CO_2$ storage are relatively more manageable by comparing to the cases in hydrocarbon reservoir condition. Case 5, due to the open boundary condition on the left side, the plume seems to migrate more toward the open boundary side compared to Case 6 of a close domain.

- **Case 7**: no much surprise

### After 30 Years Injection
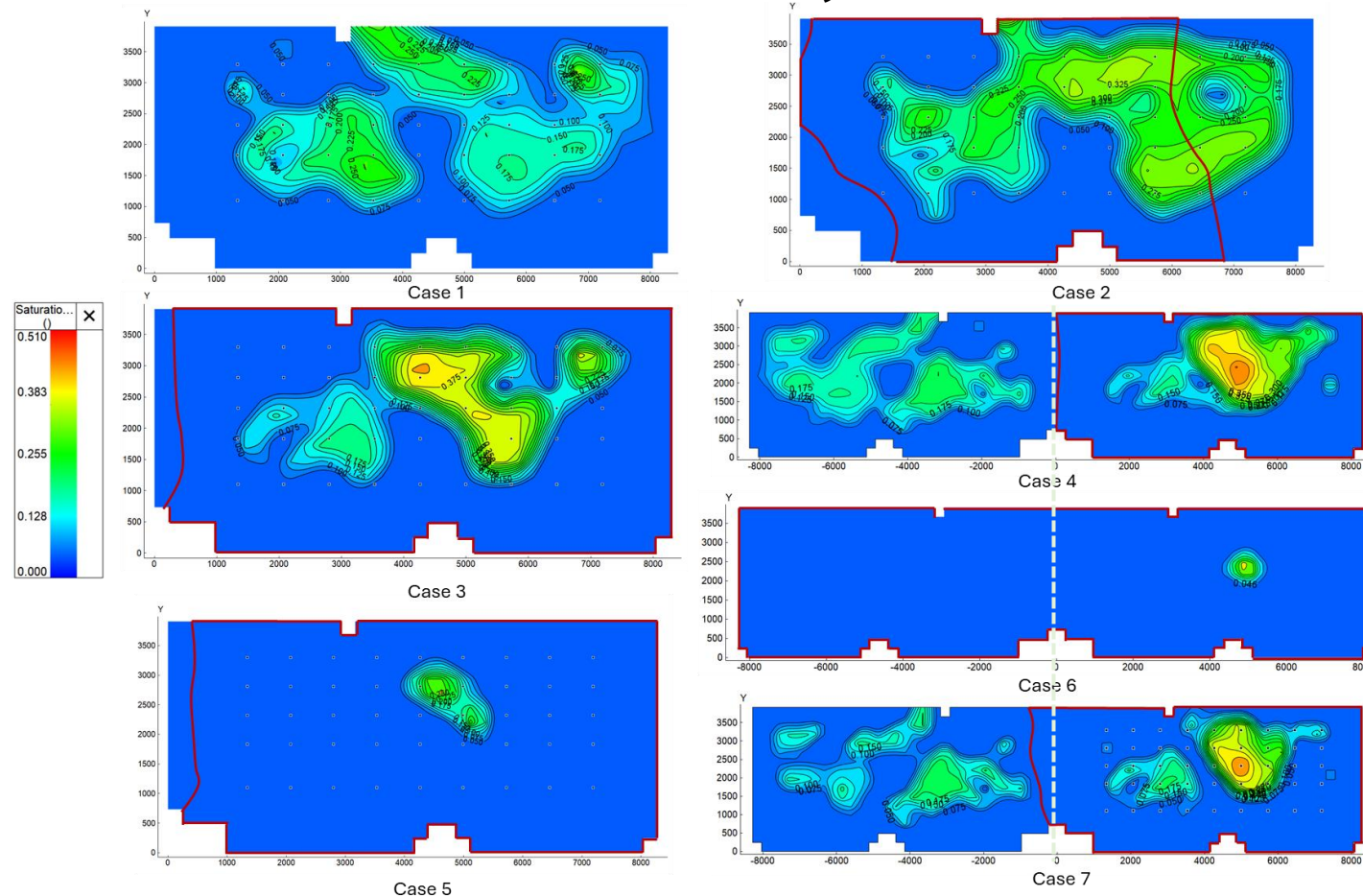
# Union AoR Summary (cont.)

- **Case 1**: continuous dissipation as expected.

- **Case 2**: pressure rebalancing and reshaping without production.

- **Case 3**: $CO_2$ injection stopped. However, the pressure increases due to aquifer support.

- **Case 4**: high pressures are decreasing as injection stops over post-injection period. However, the aquifer provides pressure support in Case 3.

- In **Case 6,** pressure AoR covers the entire reservoir domain. However, in **Case 5**, the open boundaries help dissipate pressure. It can be observed for plume as well, much wider spreading than Case 6 because of the boundary condition again.

- **Case 7**: the pressure dissipates but continues to be higher than the critical value and impacts the significant potion of the reservoir.

**After 50 years of post-injection**
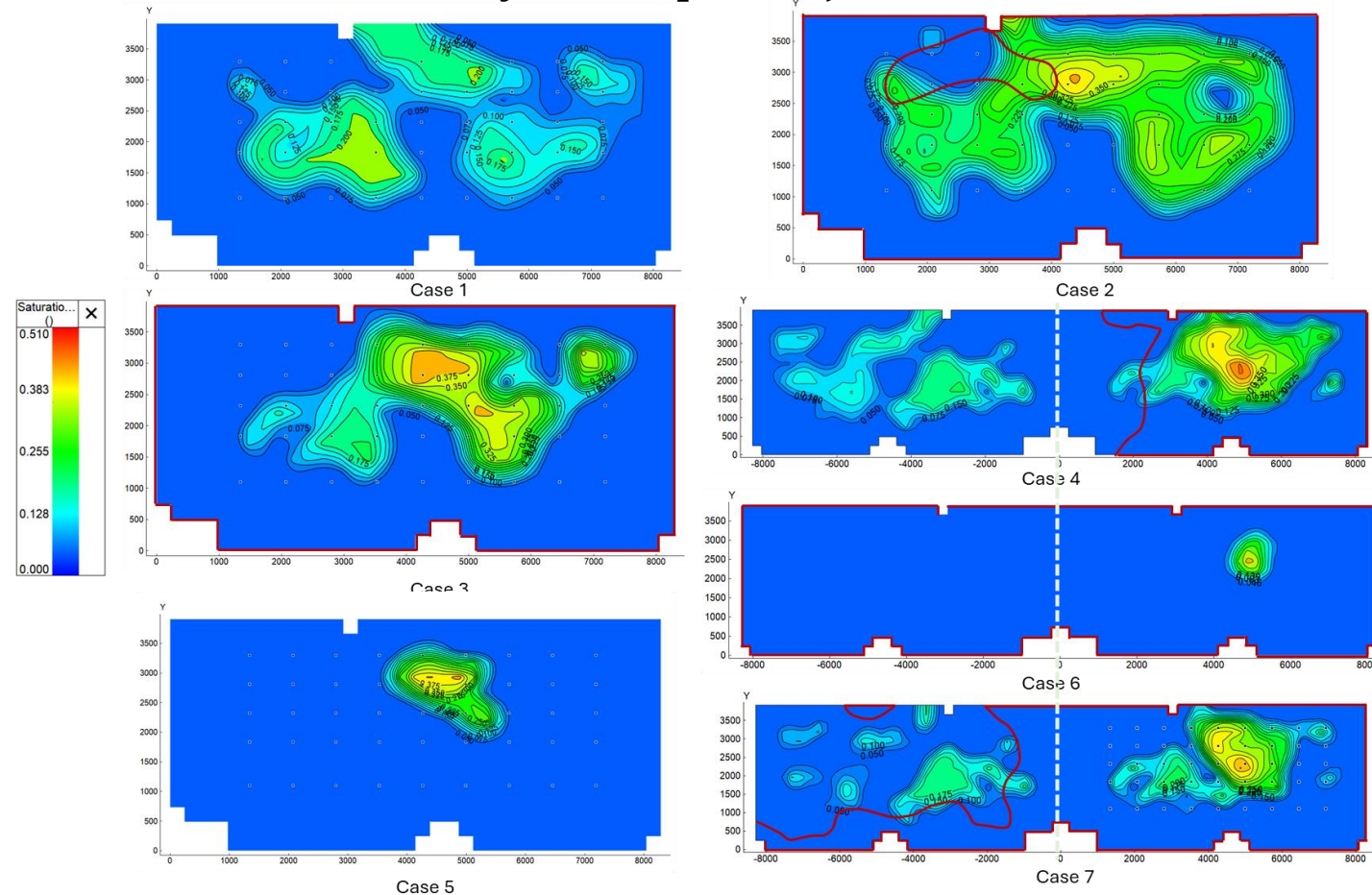
# Quick Summary

| No. | Simulation Focus | Model Size | Depletion Level (Initial Pressure) | Reservoir Fluids | Operations | Boundary Conditions | Union AoR (plume) | Union AoR (Pressure) | Notes for Risk Considerations |
|---|---|---|---|---|---|---|---|---|---|
| Case 1 | Baseline for Comparison | Original | N/A | Hydrocarbon | No injection after EOR | One side open | **Baseline 33.5%** | **Baseline 0%** | Even without $CO_2$ injection in dedication period, the plume is still about 33.5% of the coverage from EOR for monitoring and risk assessment |
| Case 2 | Business as Usual | Original | N/A | Hydrocarbon | Continuous EOR | One side open | **36.5%** | **81%** | Overall, there is not much big spreading, but more $CO_2$ concentrated in the existing plume area. More injection/production still makes plume bigger due to unbalanced source-sink operations |
| Case 3 | Dedicated Storage | Original | Under MMP | Hydrocarbon | Dedicated $CO_2$ storage | One side open | **30.5%** | **100%** | One dedicated $CO_2$ injection well may not necessarily spread larger plume size overall but with more concentrated $CO_2$ within existing plume area |
| Case 4 | Dedicated Storage | Extension | Under MMP | Hydrocarbon | Dedicated $CO_2$ storage | Extended/closed | **33.5%** | **41.5%** | Extended model domain size added up more plume for monitoring and risk assessment than the original domain |
| Case 5 | Dedicated Storage | Original | N/A | Saline Aquifer | Dedicated $CO_2$ storage | One side open | **5%** | **0%** | Open boundary condition with aquifer support shows much rapid reservoir pressure build-up in the beginning but slow down later. The monitoring/risk assessment area for plume is slight big than Case 6 but much less than hydrocarbon reservoir cases |
| Case 6 | Dedicated Storage | Extension | N/A | Saline Aquifer | Dedicated $CO_2$ storage | Extended/closed | **1.5%** | **100%** | Extended model shows more pressure build-up and less $CO_2$ storage due to the close system than Case 5 |
| Case 7 | Dedicated Storage | Extension | Above MMP | Hydrocarbon | Dedicated $CO_2$ storage | Extended/closed | **29.5%** | **71%** | With initial pressure above MMP (depletion level), the plume size is relatively small comparing to the other cases under MMP |

# Remarks and On-Goings

**Risk Considerations and Priorities:**

- Depletion level/initial condition (pressure, saturation) plays primary impact of the union AoR and risk assessment

- Model domain from sink-source balanced EOR may not be enough for dedicated sink-based $CO_2$ storage requirements, especially, pressure front extensively transit to domain edges, where applied numerical boundary condition assumptions may not represent the dynamic response regarding to risk consideration

- Due to existing $CO_2$ from EOR stage, $CO_2$ plume AoR in hydrocarbon reservoir is much bigger than saline reservoir condition. However, the peak pressure is lower than the saline cases even the average reservoir pressure is higher.

**On-Going and Further Work:**

- Prepare a journal manuscript with more quantitative analysis

- More sensitivity analysis among of the risk consideration and priorities are still on-going

- New idea of the monitoring design and cost/economics assessment have been proposed for the following study

- Optimal solution of EOR and storage and/or using as proxy each other for mission priorities

# Questions??



Original size      Mirrored Extension

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# Backups

# 2D and 3D Model Visualization

Original size reservoir model (left) and extended model (right)
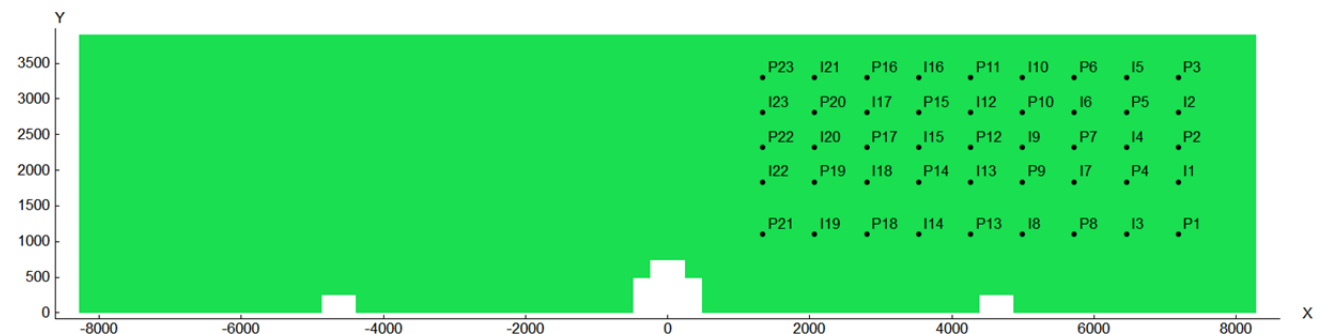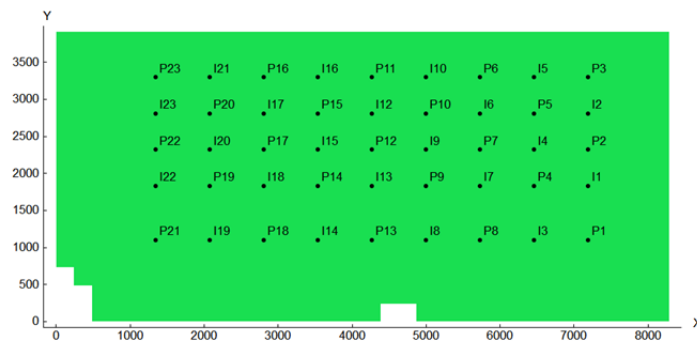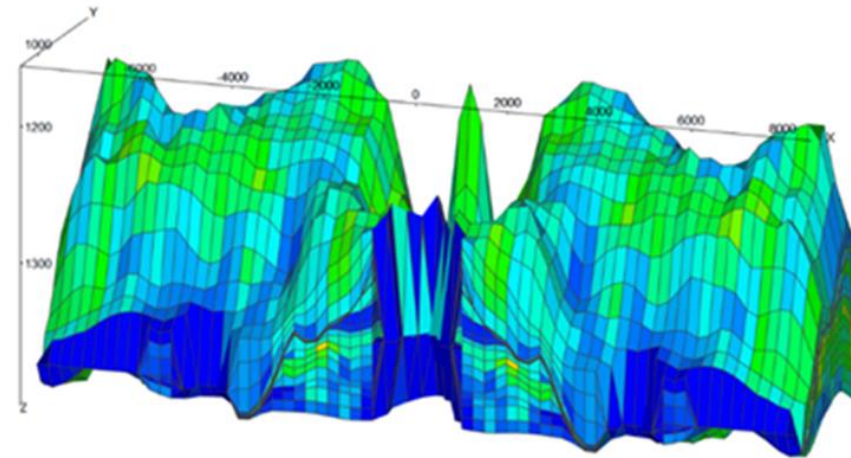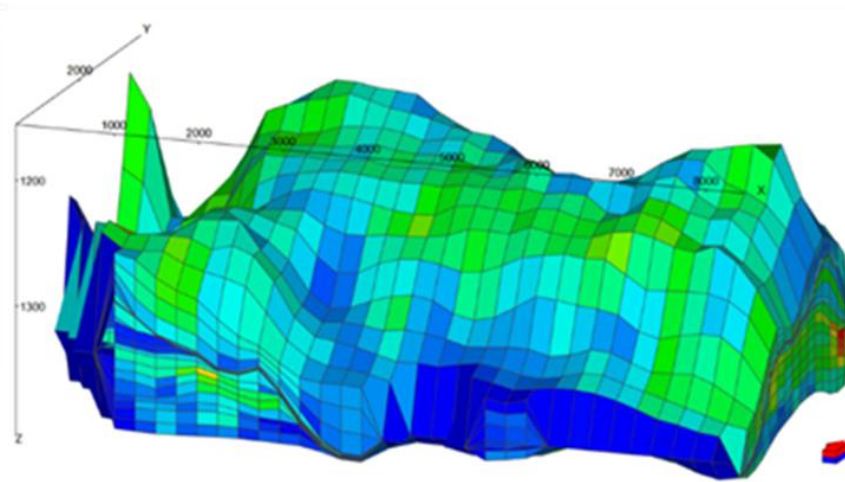
# BAU Case (Case 2)

## Production (liquid, and gas) and injection (water, and $CO_2$) profile

- The injection-production profile of **Case 2** shows that the reservoir produces (2.4E7 sm3) slightly more liquid than the water injection (2.33E7 sm3).

- However, the gas curves, shows a significant difference between the $CO_2$ injection (1.17E10 sm3) and gas production (0.7E10 sm3), leading to a positive net injection.

- This explains the AoR increases over time on pressure maps.
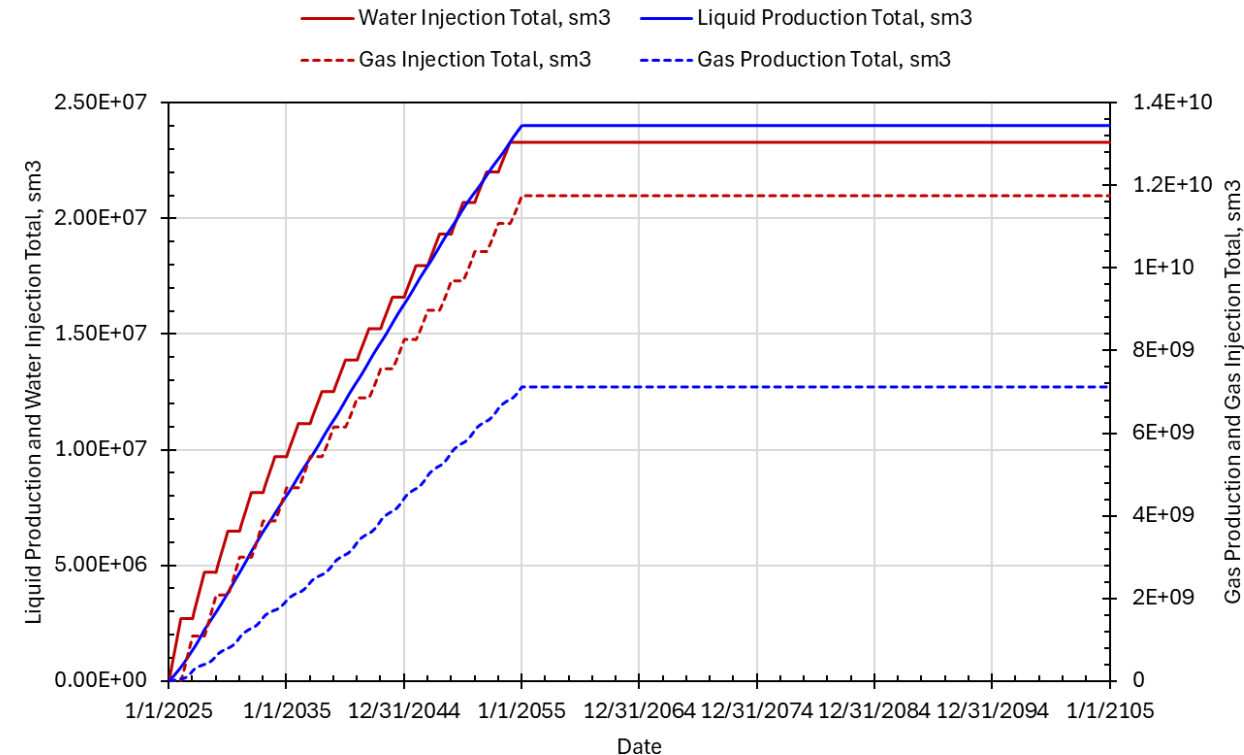
# Average Reservoir Pressure Profiles

- The figure shows the development of average reservoir pressure over time. **Case 1**, where there is no injection/production, tends to have a stable pressure.

- The pressure curve of **Case 6** (extended saline) is the highest pressure, due to its faster reservoir pressure build-up.

- **Cases 2 and 4** shows moderate average reservoir pressures (below 176 bars). Case 2 production from multiple wells and Case 4 hydrocarbon extension help with the pressure dissipation.
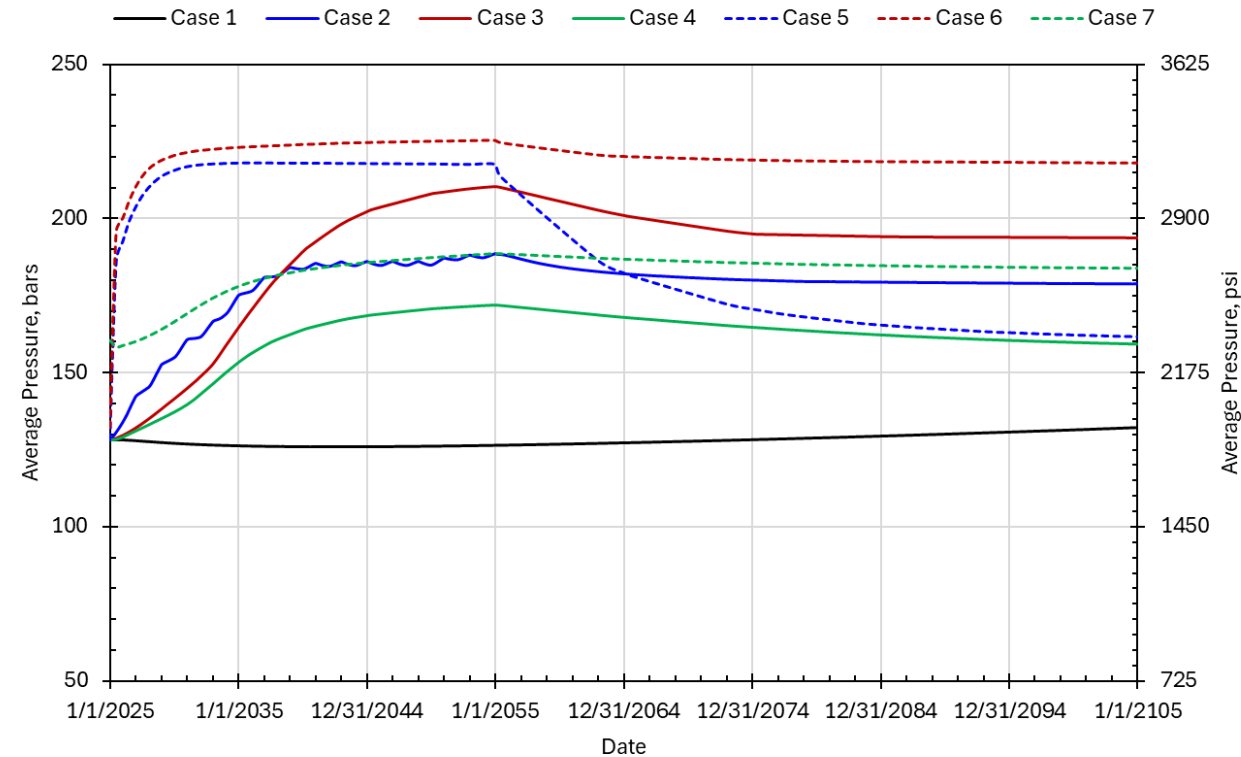
# Pressure Histogram:
*Initial conditions*


Case 1


Case 2

- The histograms show identical pressure distributions as the cases are initialized similarly, expect for **Case 7**. The critical pressure value (176 bars) is shown in green dash line in Case 1 which is same for **Cases 2 to 6**.

- **Case 7** is above MMP which is higher initial pressure with more histogram bars.
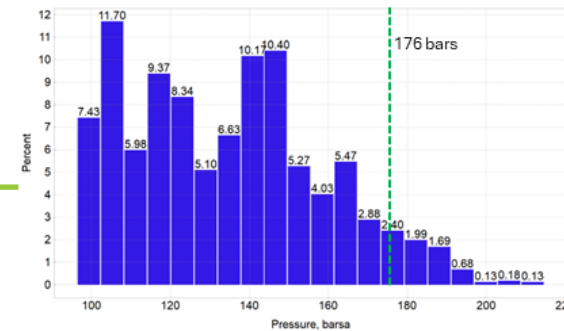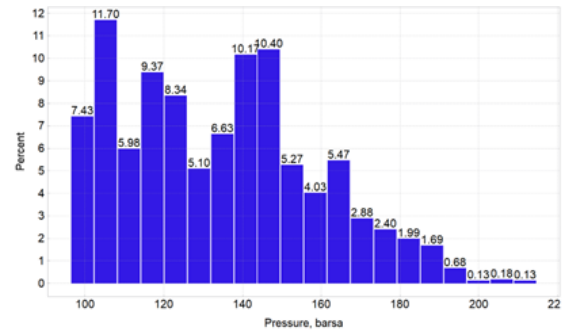

Case 3
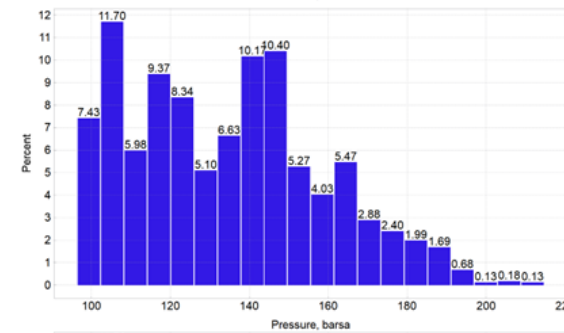

Case 4


Case 5


Case 6
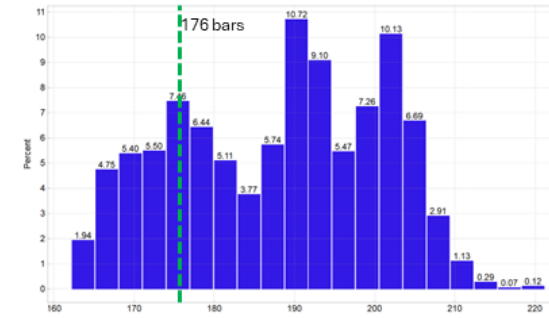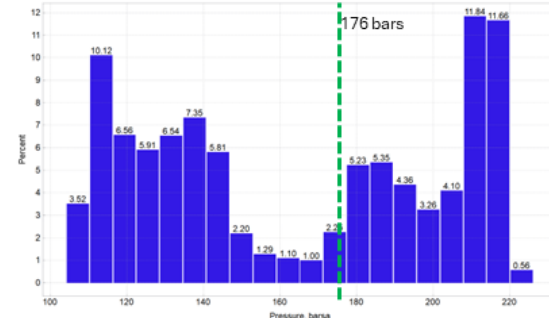

Case 7

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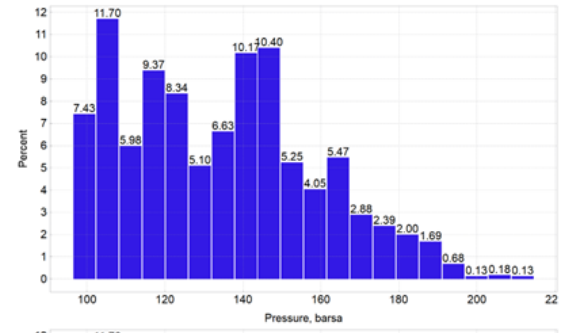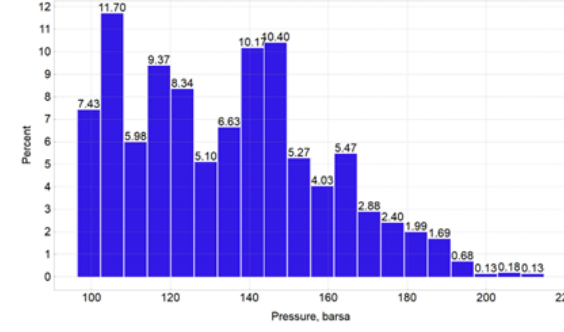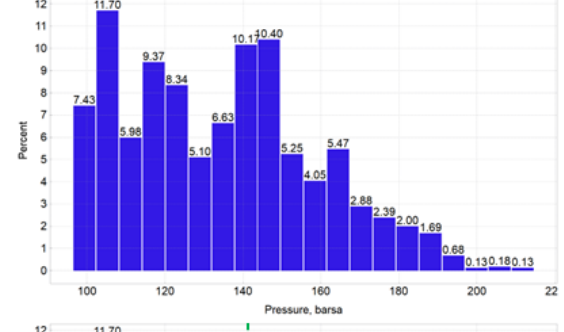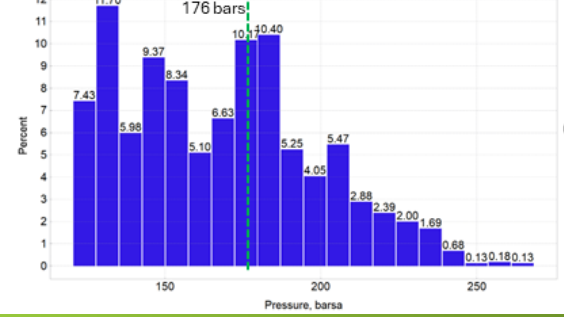
# Gas saturation histogram:
*Initial conditions*

- The histograms show identical initial gas saturation in **Cases 1-4**.

- **Cases 5 and 6** are saline reservoir, where reservoir is initially saturated with water.

- Although **Case 7** has the same initial component composition as Cases 1-4, the gas saturation shows a different distribution , due to the high initial pressure value (>MMP). The increases in initial pressure bring gas into solutions and reduce free gas.
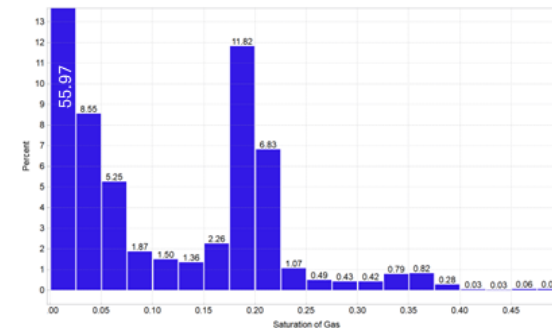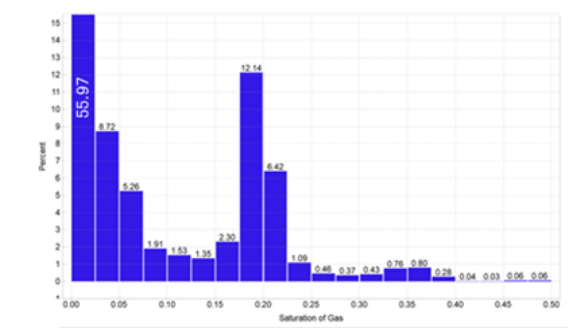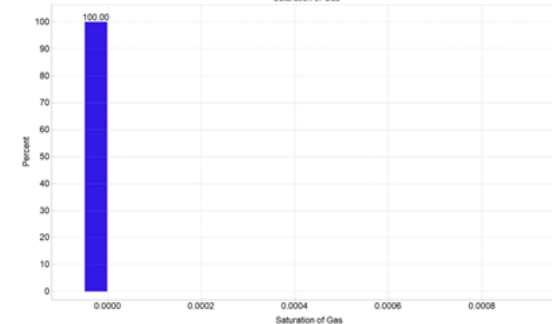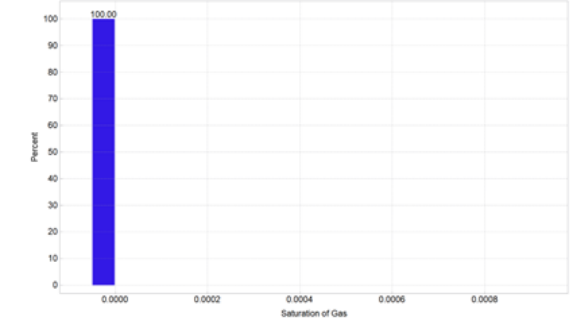
# Pressure Histogram:
## *After 5 years injection*

- All pressures of **Case 1** drop below the critical value.

- **Cases 3 and 4** shows close pressure distribution that is aligned with the cases similar injection and average pressure profiles. The two cases show similar pressure development in early time, as $CO_2$ is injected into hydrocarbon reservoir portion of identical conditions.

# Gas Saturation Histogram:
## *After 5 years injection*

- Plume is re-equilibrium in **Case 1** (bas case) showing reduction in high saturation bars.

- **Case 2** shows increases in zero-saturation bar, as WAG injection causes increases in pressure and gas dissolves in liquid.

- **Cases 3 and 4** show similar histogram shape. However, zero-gas saturation, in Case 3, is higher due to the case higher pressure development and lower $CO_2$ cumulative injection.

- **Cases 5 and 6** show small portion of plume, less than 2% of reservoir domain particularly.
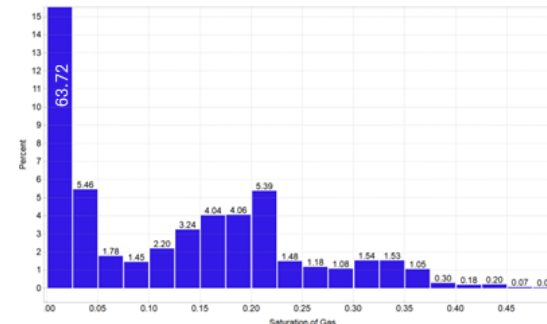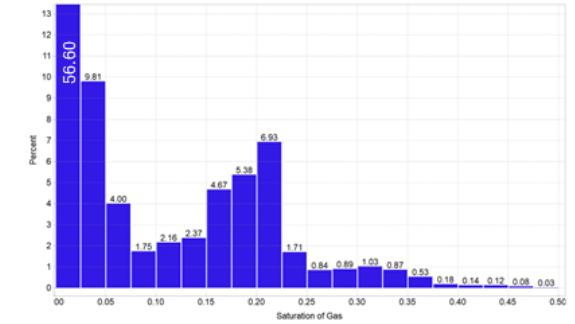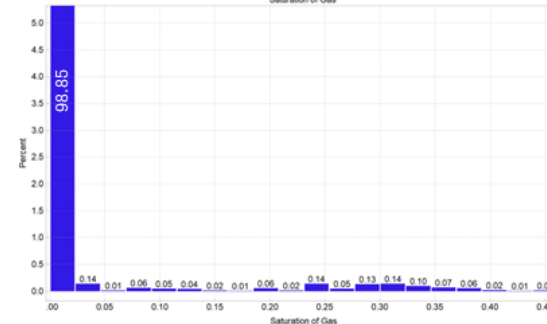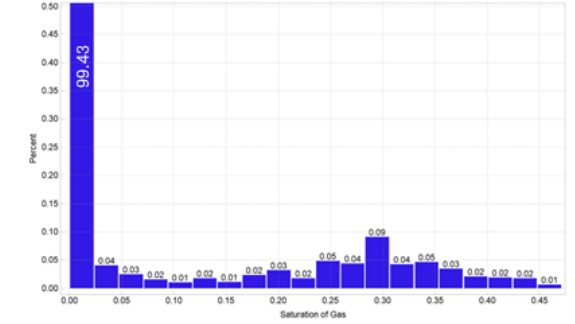
# Pressure Histogram:
## *After 10 years post injection*



- **Case 1** remains below 176 bars.

- **Case 3 and 4** (dedicated injection in hydrocarbon reservoir) start to show different distribution. Case 3 pressure distribution shows large concentration around 160-165 bars (around the aquifer pressure).

- Significant portions of reservoir domain in **Case 5 and 6** (saline reservoir) are dominant by high pressures
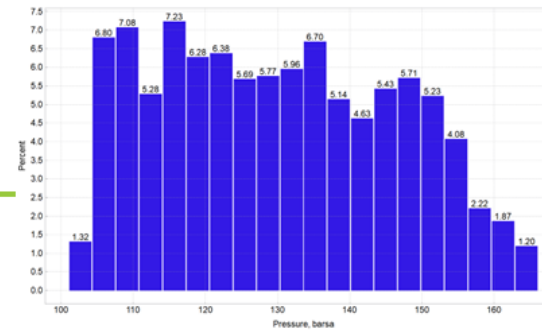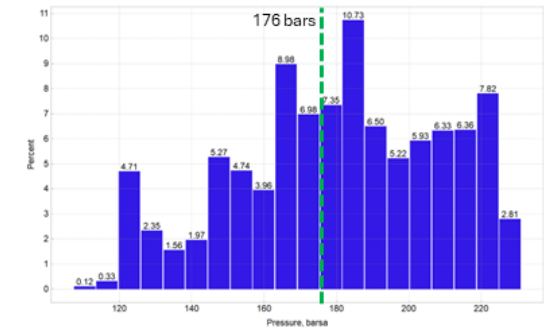
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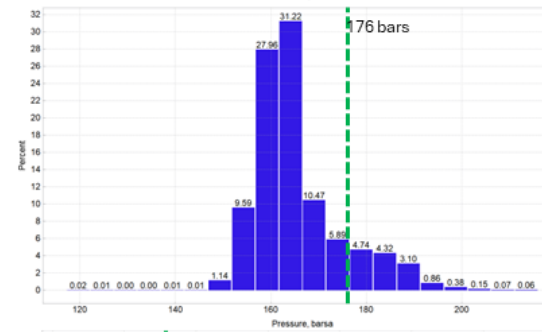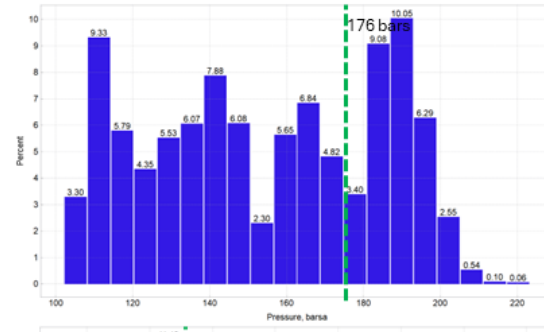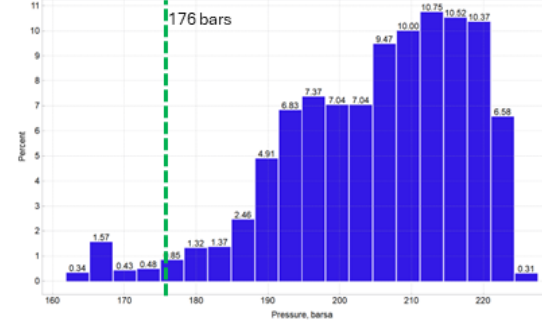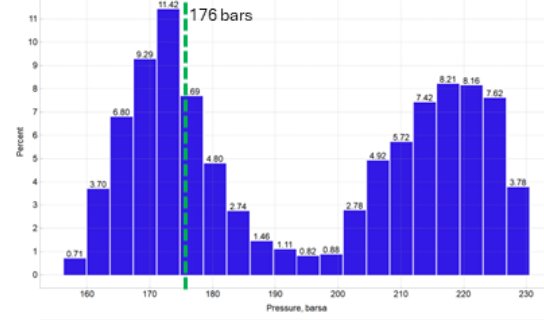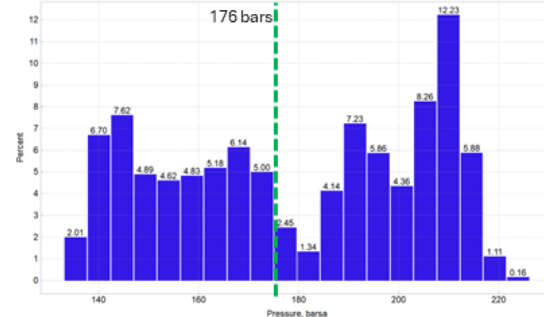
# Gas Saturation Histogram:
*After 10 years post injection*

- **Case 1** minimum changes over the re-equilibrium

- Further EOR operations in **Case 2** introduces pressure increases above MMP and much miscible phenomenon happened

- Overall, $CO_2$ plume in **Cases 5 and 6** increases slow but the pressure build-up is much quick

- **Case 7** also shows very small percentage change regarding to plume
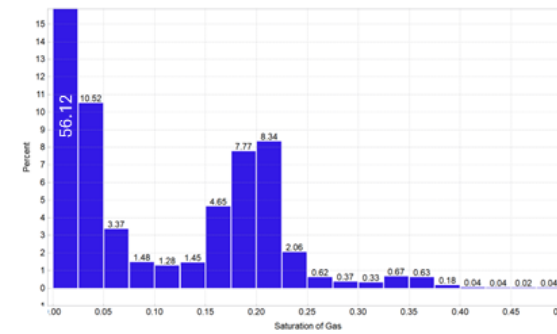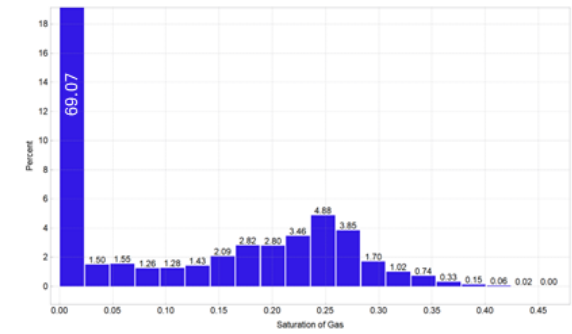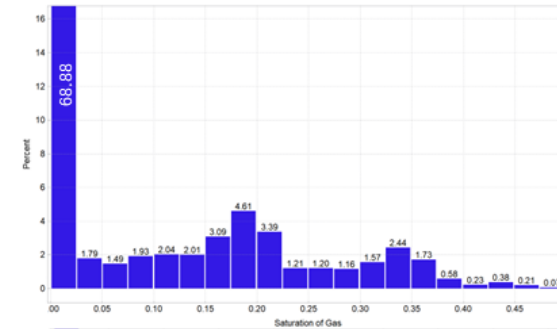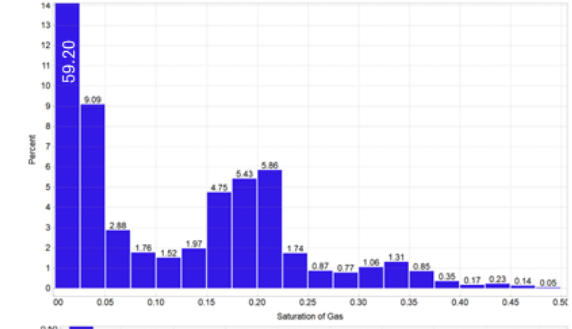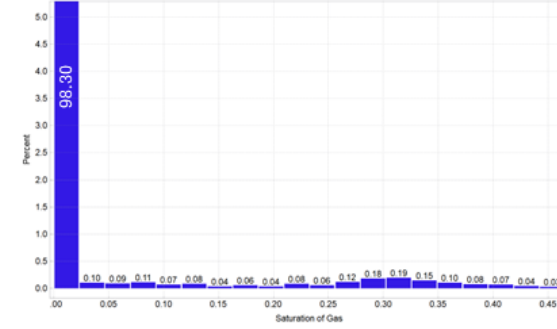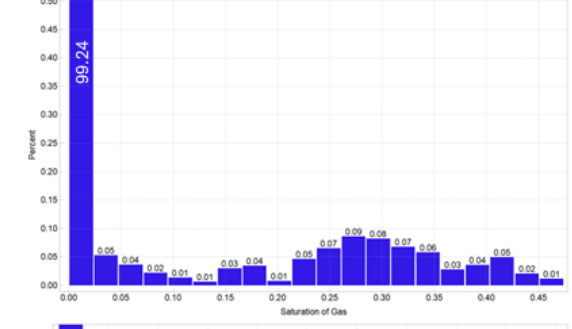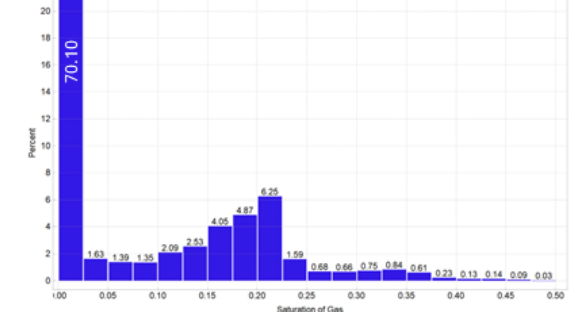
# Pressure Histogram:
## *After 15 years of injection*

- **Case 1** continues to be below the critical pressure

- **Cases 2 and 4** are of moderate pressure distribution, due to the multiple production wells of Case 2, and the high $CO_2$ solubility and compressibility in Case 4 hydrocarbon extension.

- **Cases 5 and 6** are almost totally dominated by high pressure

- **Case 7** is a hydrocarbon case, but of high initial pressure. Big portions of reservoir domain start to exceed high pressures (higher than 176 bars)
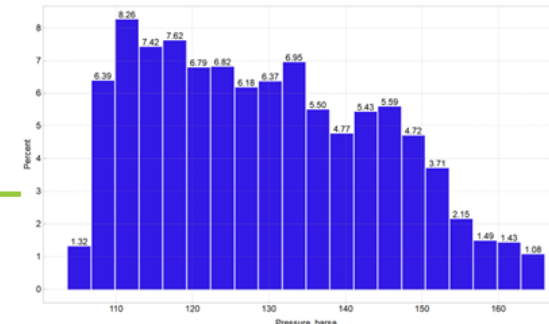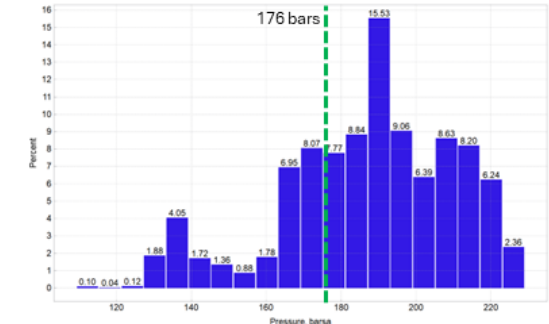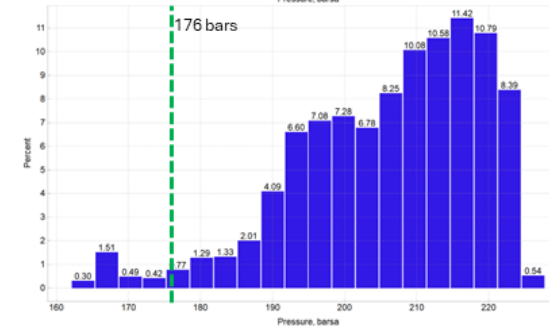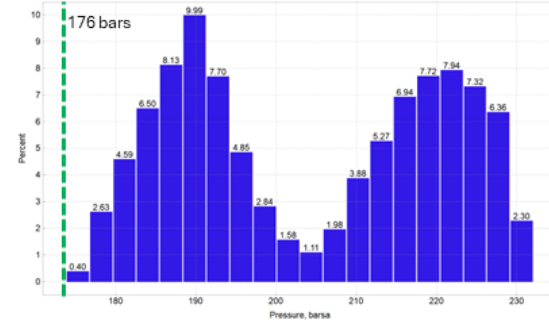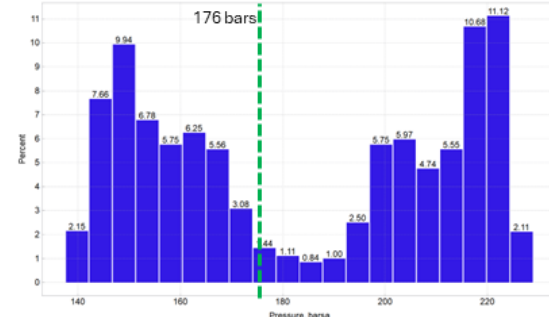
# Gas Saturation Histogram:

*After 15 years injection*

- **Case 1** exhibits more spreading but the saturation self within the plume is reducing

- Plume in **Case 2** starts to expands and cover larger reservoir domain due to unbalanced source-sink operations again

- Plume size is contained in **Cases 5 and 6**, less than 3% of reservoir domain, due to fast pressure build-up
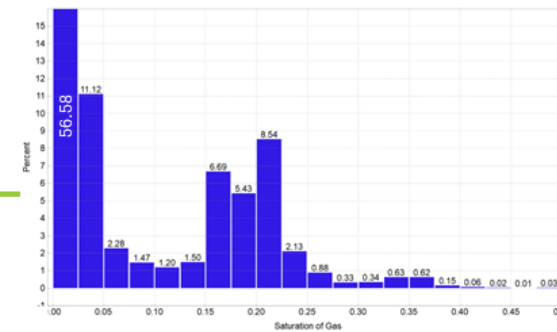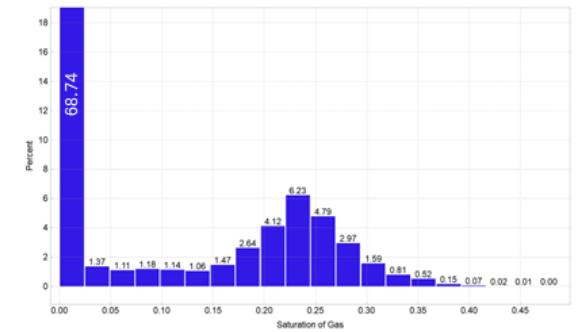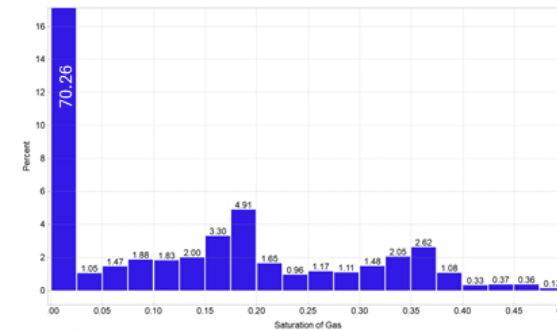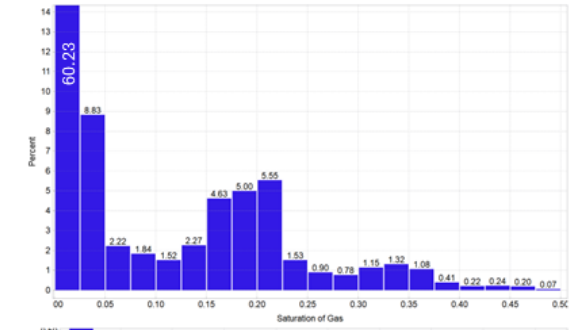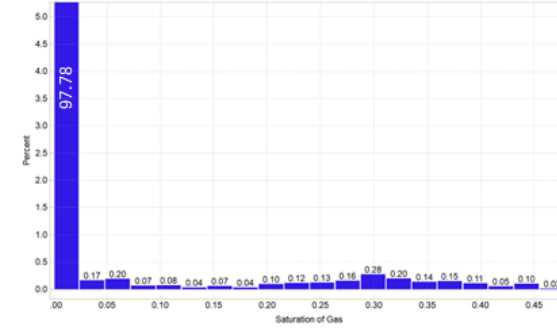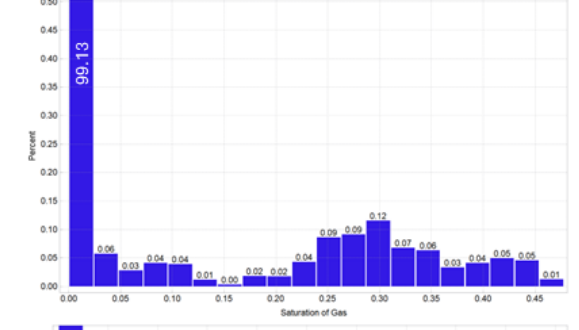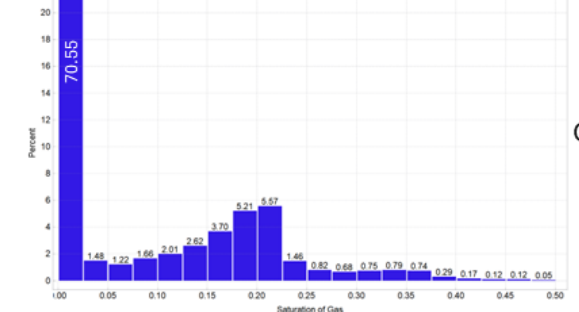
# Pressure Histogram:
*After 30 years of injection*



- All pressures in **Case 6** quickly exceed 176 bars, due to injection into saline reservoir without fluids miscible feature. It is worth noting that saline reservoir requires pressure management to provide high storage capacity.

- High pressures affect **Cases 2, 3, 4, 5, and 7** partly, due to injection operations. Rapid pressure increases in **Cases 3 and 5**, along with Case 2, are observed, noting that these three cases are of aquifer open boundaries.
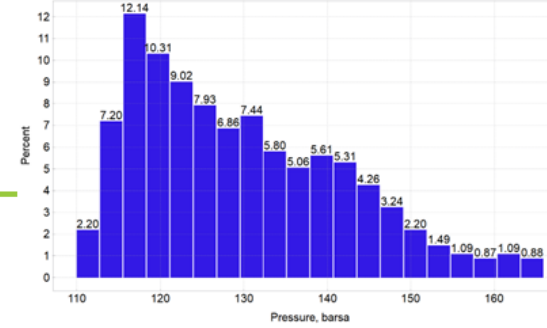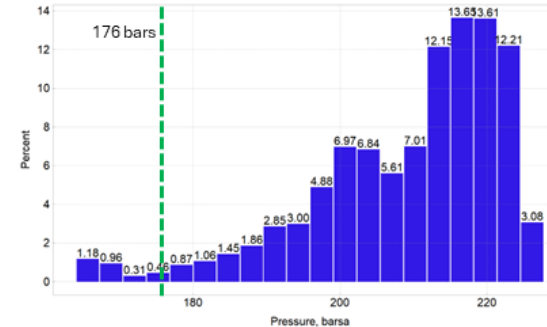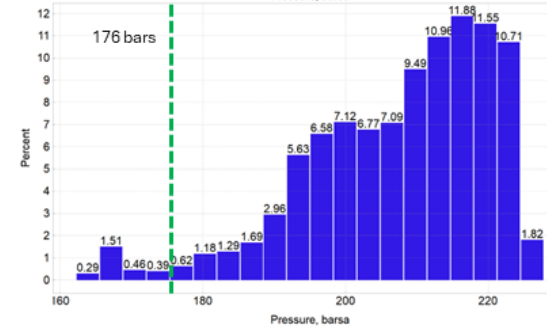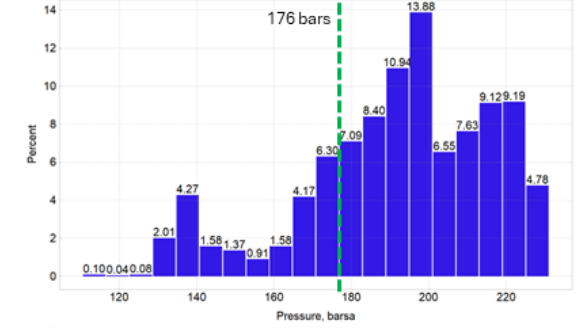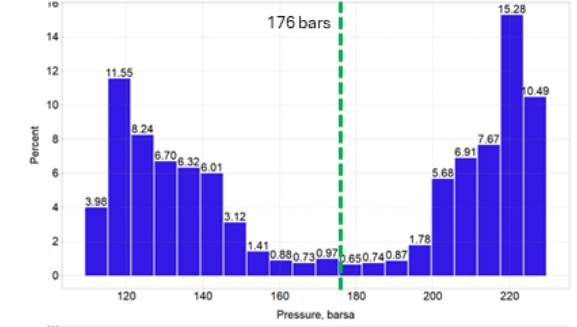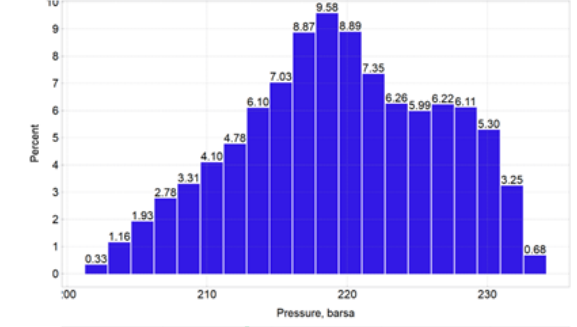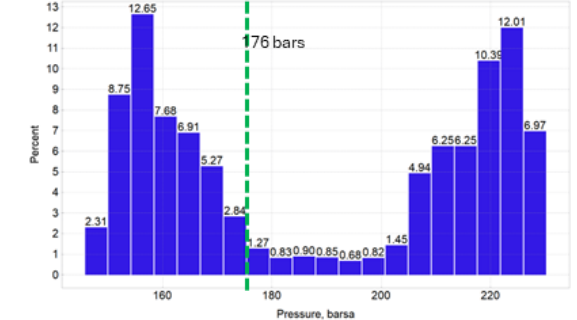
# Gas Saturation Histogram:
*After 30 years injection*

- Gas plume continues spreading for all cases
- The key point is much on reservoir responses of pressure build-up and constraint that impact on injection, as well as the MMP, boundary condition, and solubility
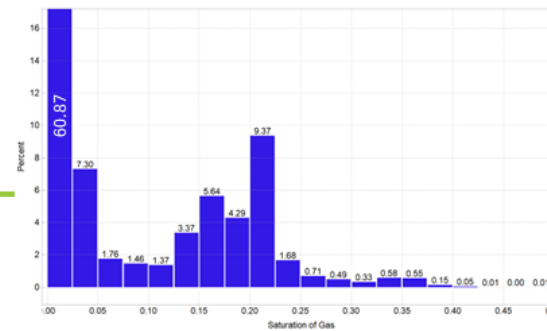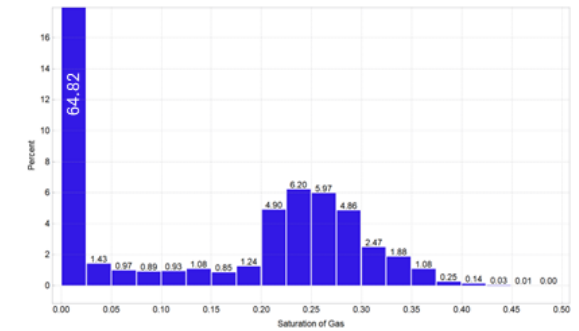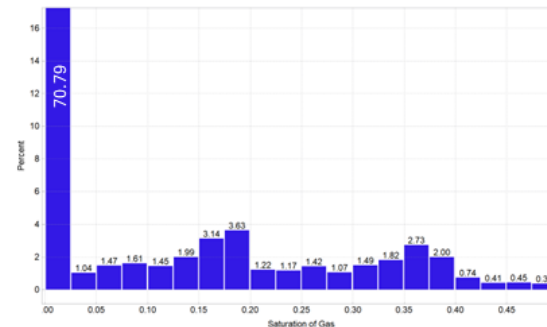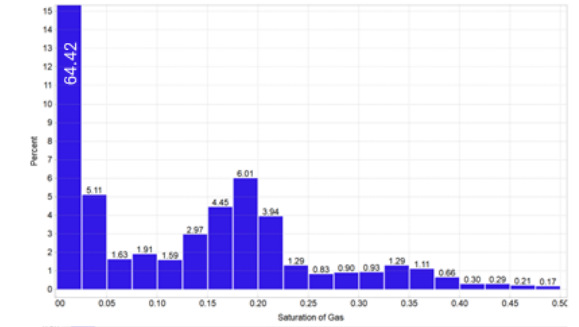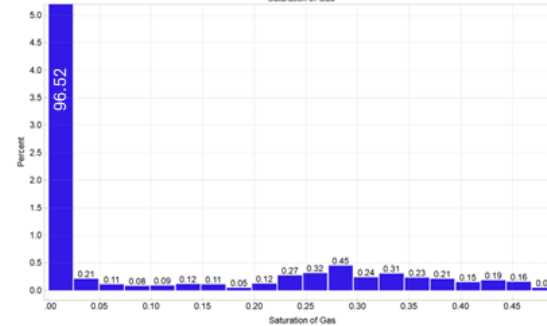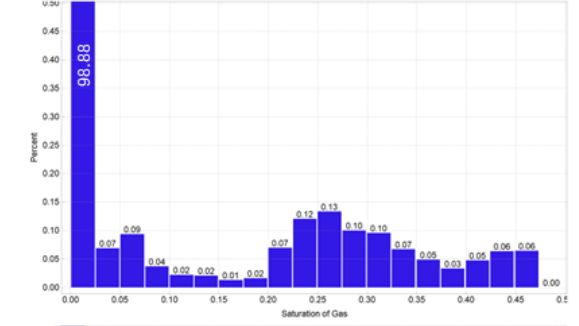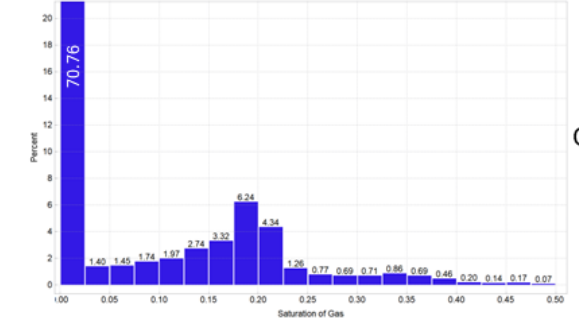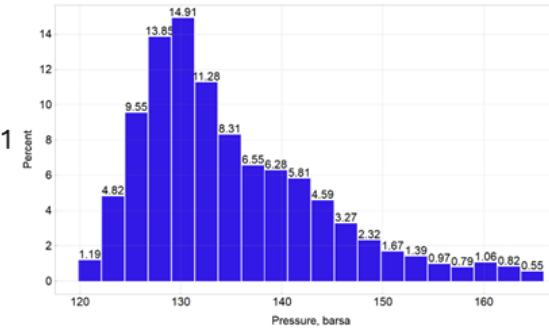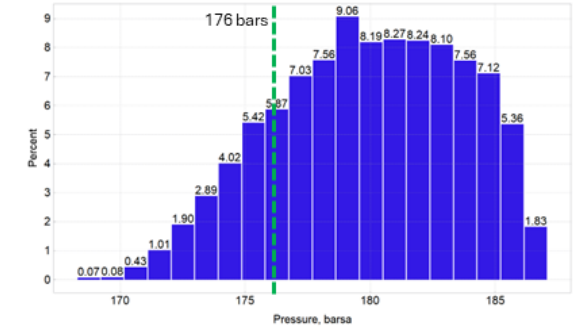
# Pressure Histogram:
*After 50 years post-injection*

- Overall, the pressure migration is significantly different for the cases with open boundary conditions such as **Cases 3 and 4**. Saline reservoir condition cases also show it equilibrium changes in Case 3 and 5.

- Generally, pressure in cases such as 5 and 7 with domain extended model, close boundary condition are higher except Case 4 due to under MMP.

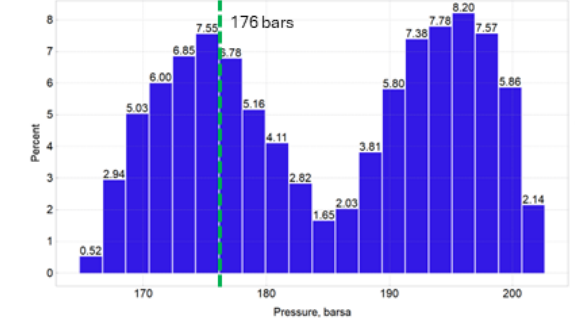- The further comparison about under and above MMP are much clear between **Case 4 and 7**.
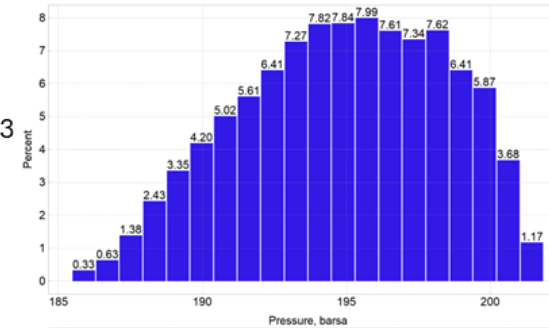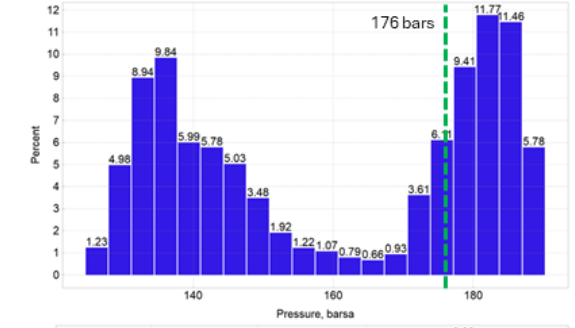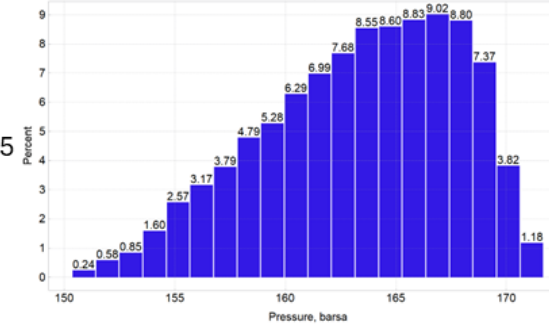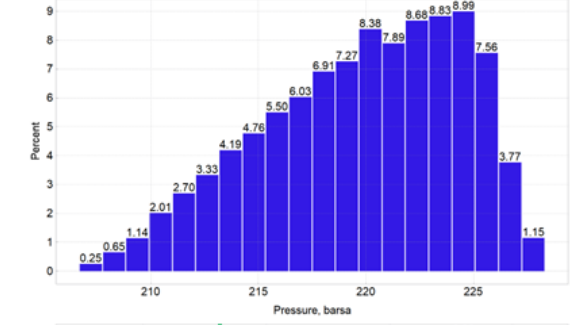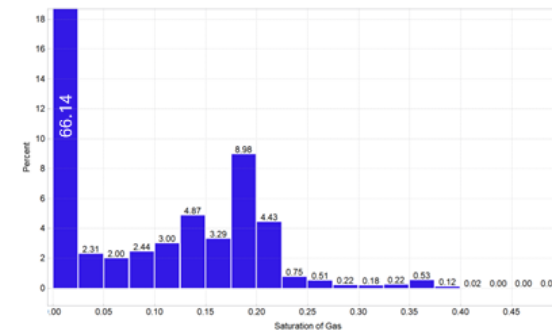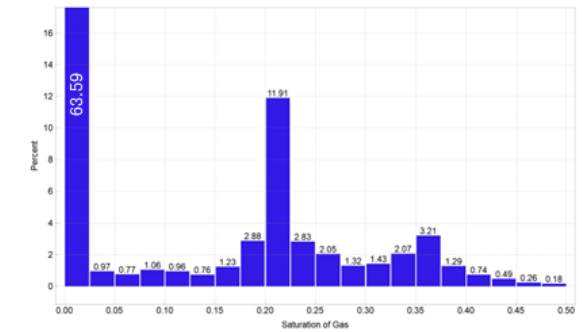
# Gas Saturation Histogram:
*After 50 years post-injection*

- In **Case 1**, zero gas saturations increase to cover 66.14% of the reservoir domain.

- The gas plume expand in **Case 2** to covers 36.5% of the reservoir domain. Around 63.5% of the reservoir domain has no free gas (initial conditions: zero saturation bar is 56%).

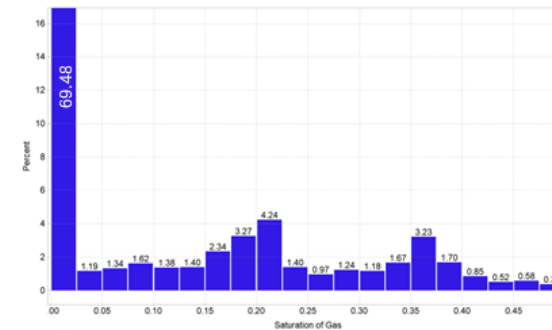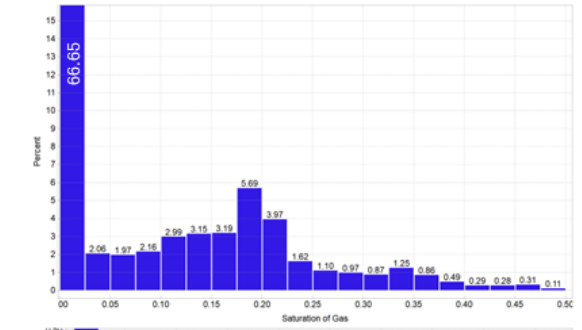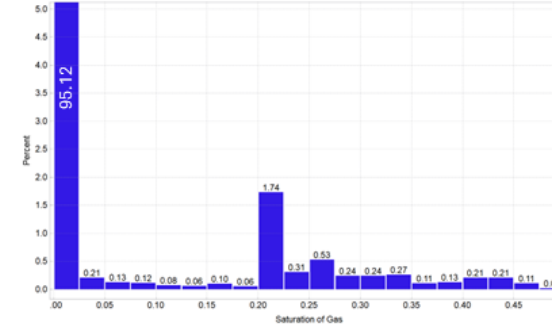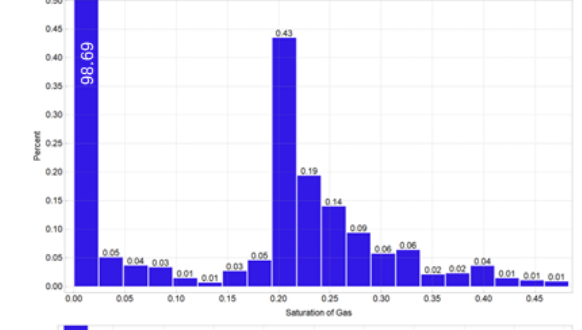- Reduction in gas plume size in **Cases 3 and 4**, where 69.5% and 66.65% of the reservoir domains have no free gas, respectively.