Geomechanical simulation of CO_2 leakage and cap rock remediation

Presenter

Runar Nygaard

Assistant professor

Project members

PI

Dr. Runar Nygaard

Dr. Baojun Bai

Dr. Andreas Eckert

Graduate students

Imowo Akpan, MS, Amin Amirlatifi, PhD, Aaron Blue, MS

Olarewaju Tiamiyu, PhD, NN, PhD

City Utilities of Springfield

CUS team led by Gary Pendergrass

DOE project manager

William O'Dowd

Outline

- Technical background on CO_2 sequestration and identification of the problem
- Objective of project "*Simulation of CO_2 leakage and cap rock remediation*"
- Shallow sequestration in the Lamotte sandstone as a field case
- Project timeframe, specific task and members

Outline

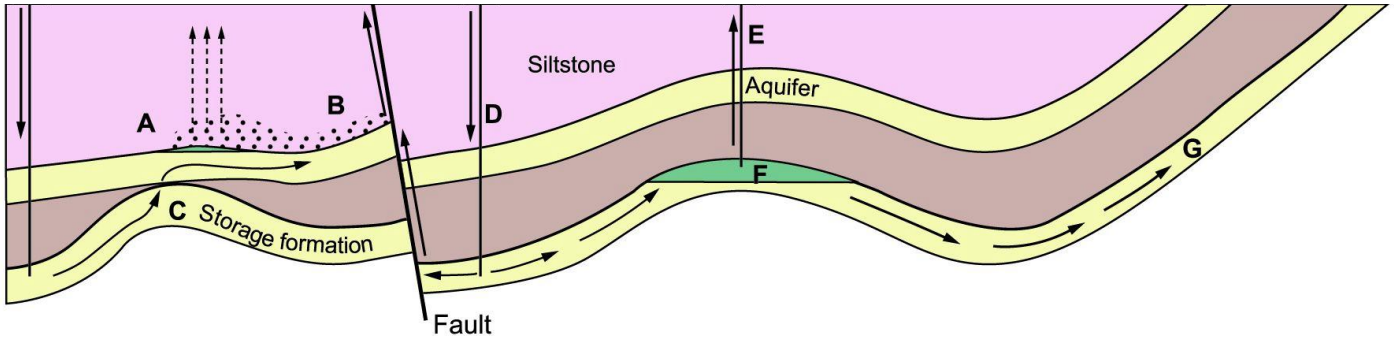
- Technical background on CO_2 sequestration and identification of problem

- Objective of project "*Simulation of CO_2 leakage and cap rock remediation*"

- Shallow sequestration in the Lamotte sandstone as a field case

- Project timeframe, specific task, members and cost

Identified leakage mechanisms



Matrix

- Capillary entry pressure
- Seal permeability
- Pressure seals
- High permeability zones

Structural

- Flow on faults
- Flow on fractures
- Flow on hydraulic fractures
- Flow between permeable zones due to juxtapositions
- Fractured shales

Geomechanics

- Hydraulic fracturing
- Creation of shear fractures
- Earth quake release

Figure: IPCC

Slip tendency analysis

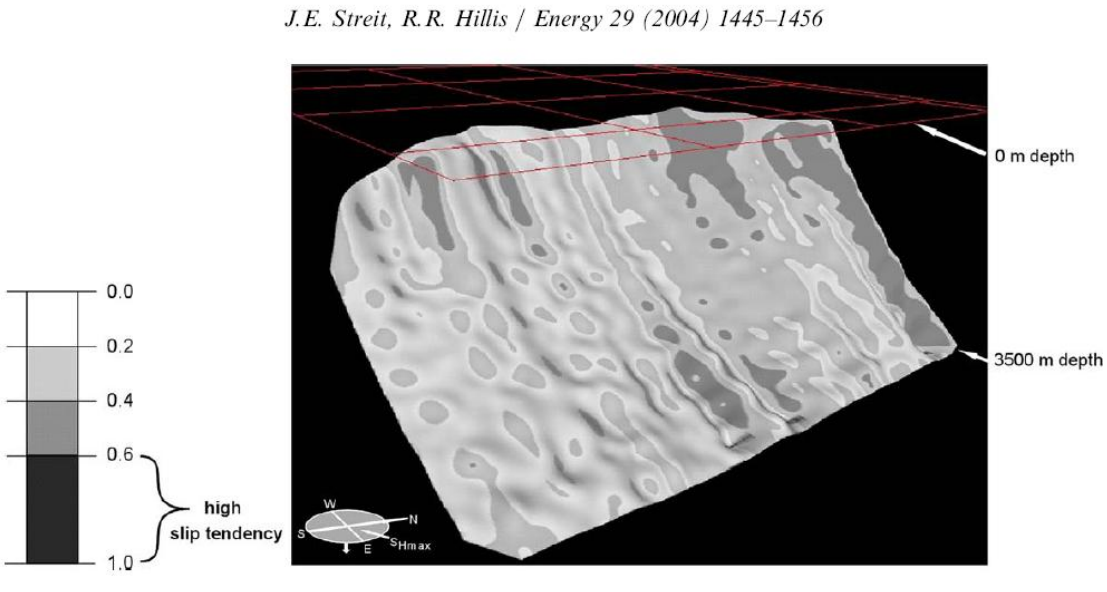
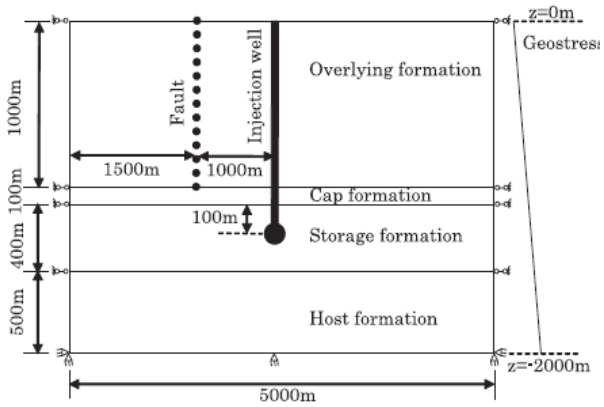


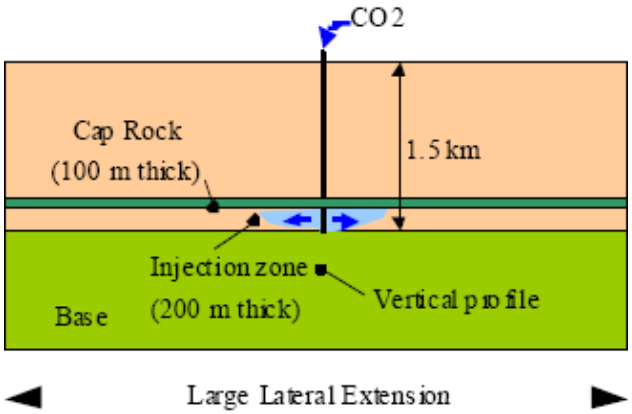
Fig. 3. Slip tendency on a fault surface.

- Requires good information on pre-existing fractures.
- No occurrence of new fractures.

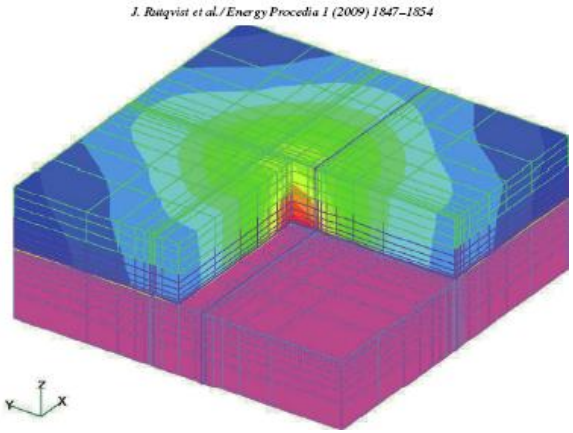
Geomechanical Modeling of seal leakage



Li et al., 2006

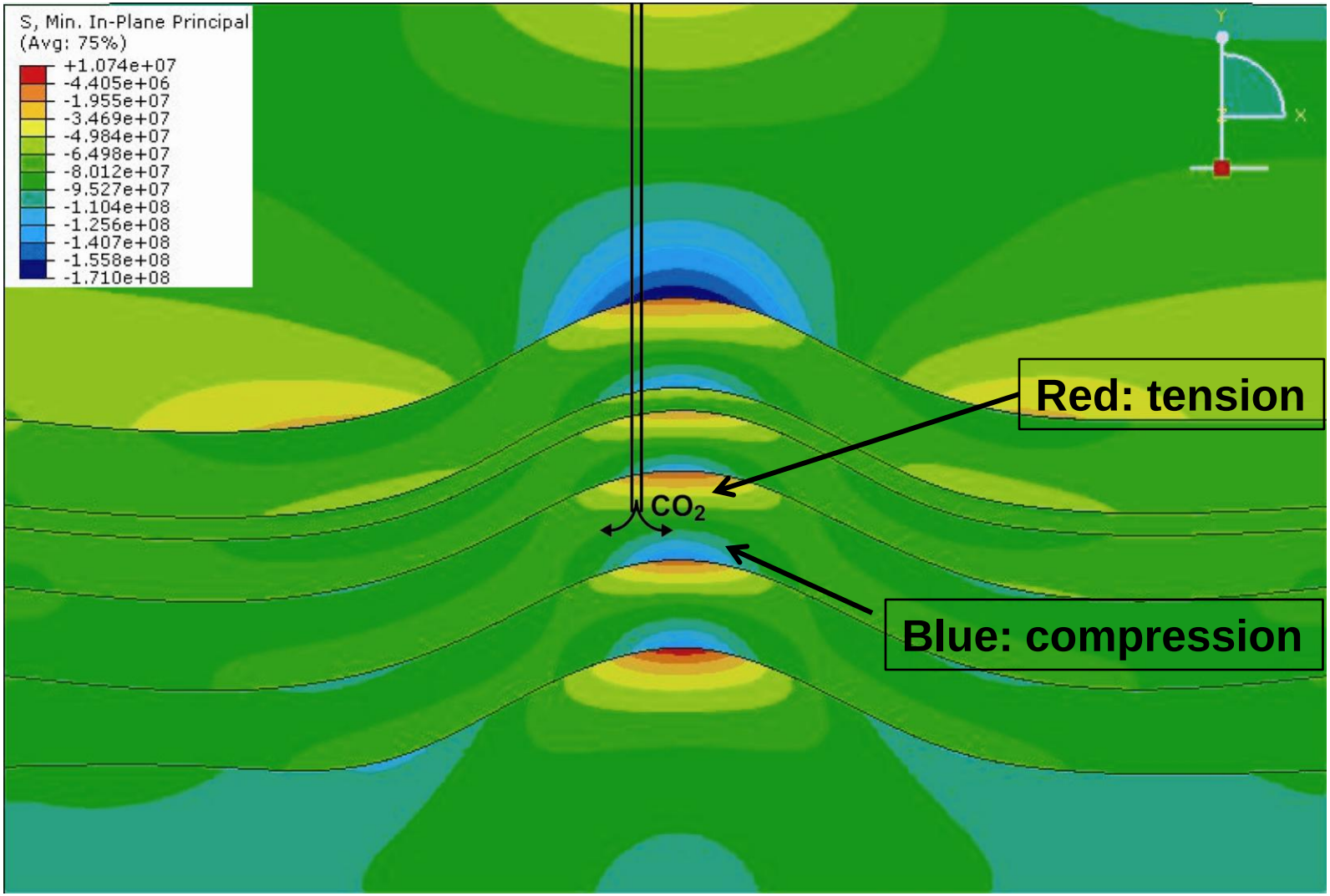


Rutqvist et al., 2008



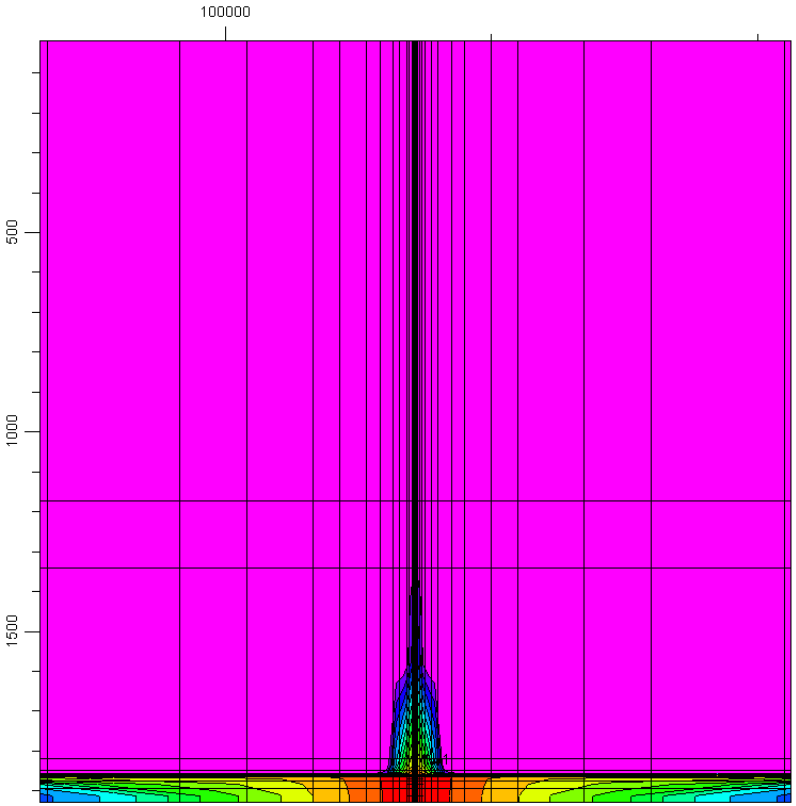
Rutqvist et al., 2009

Geometric influence on σ_1

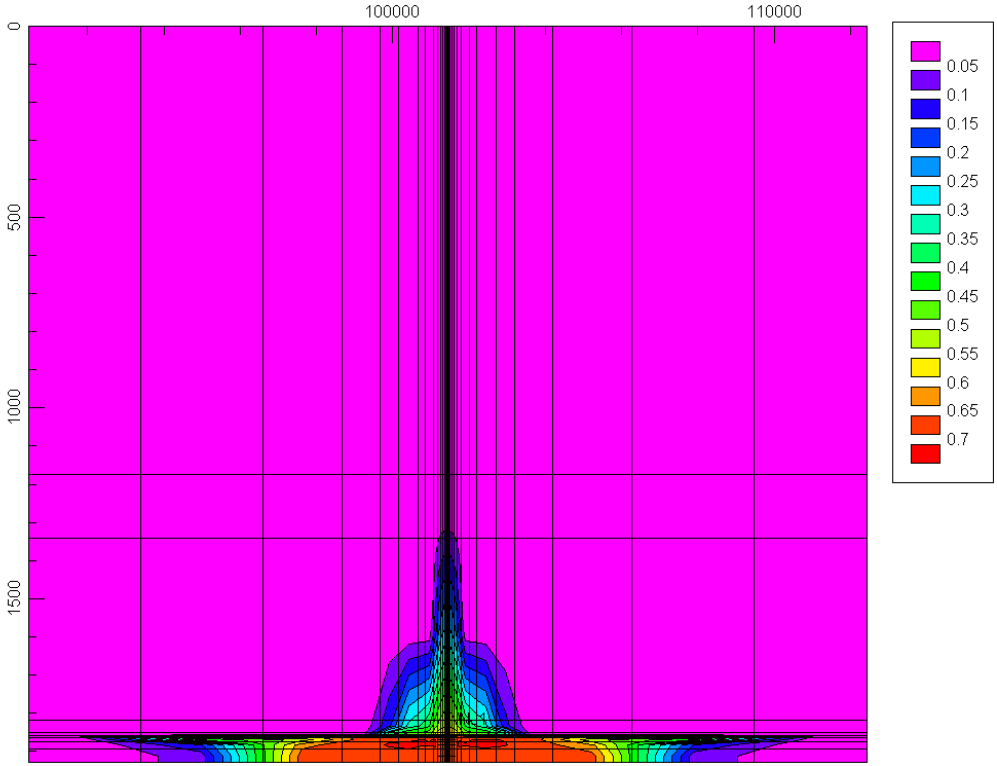


Modeling thermal effects

Gas saturation at 2 Mt/year allowing fracture propagation

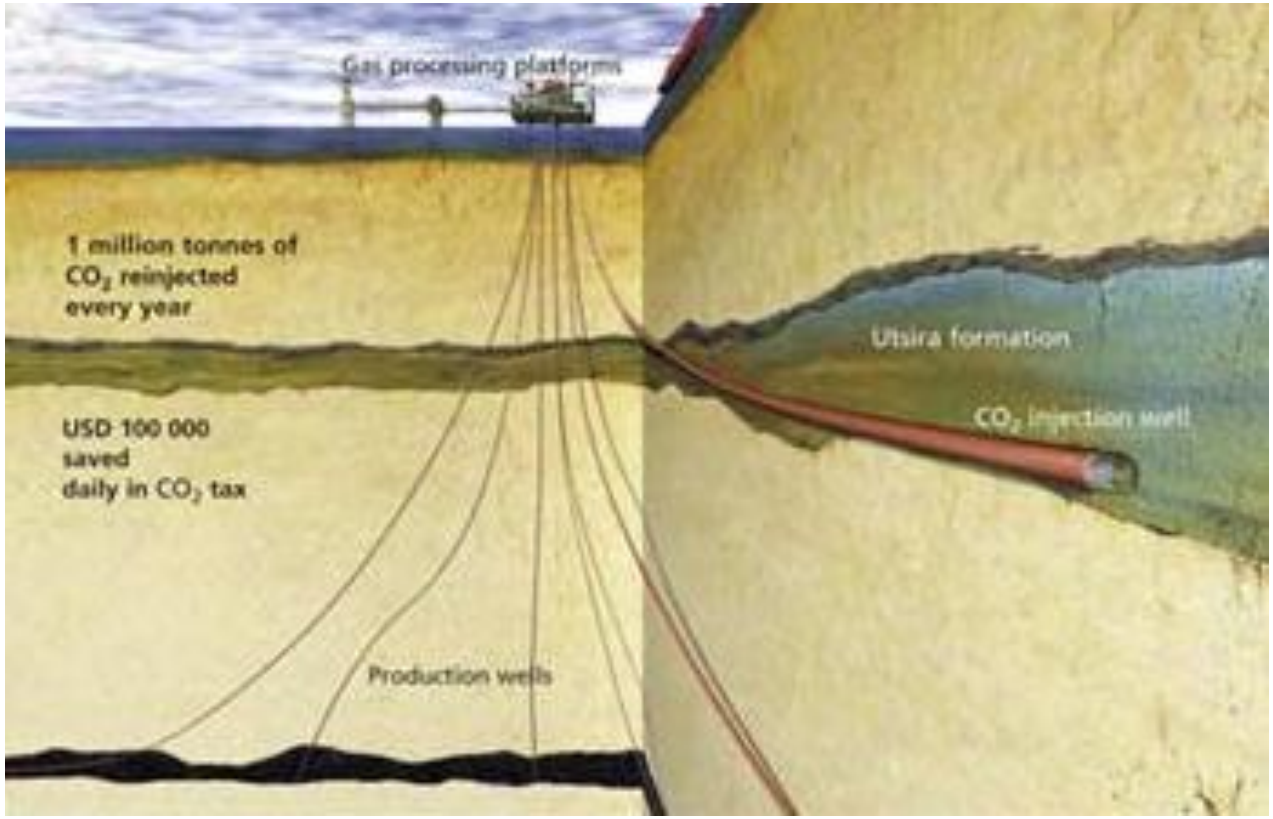


Gas saturation at 2 Mt/year allowing fracture propagation and thermal cooling



Source: WASP final report, www.ucalgary.ca/wasp

Sleipner case study



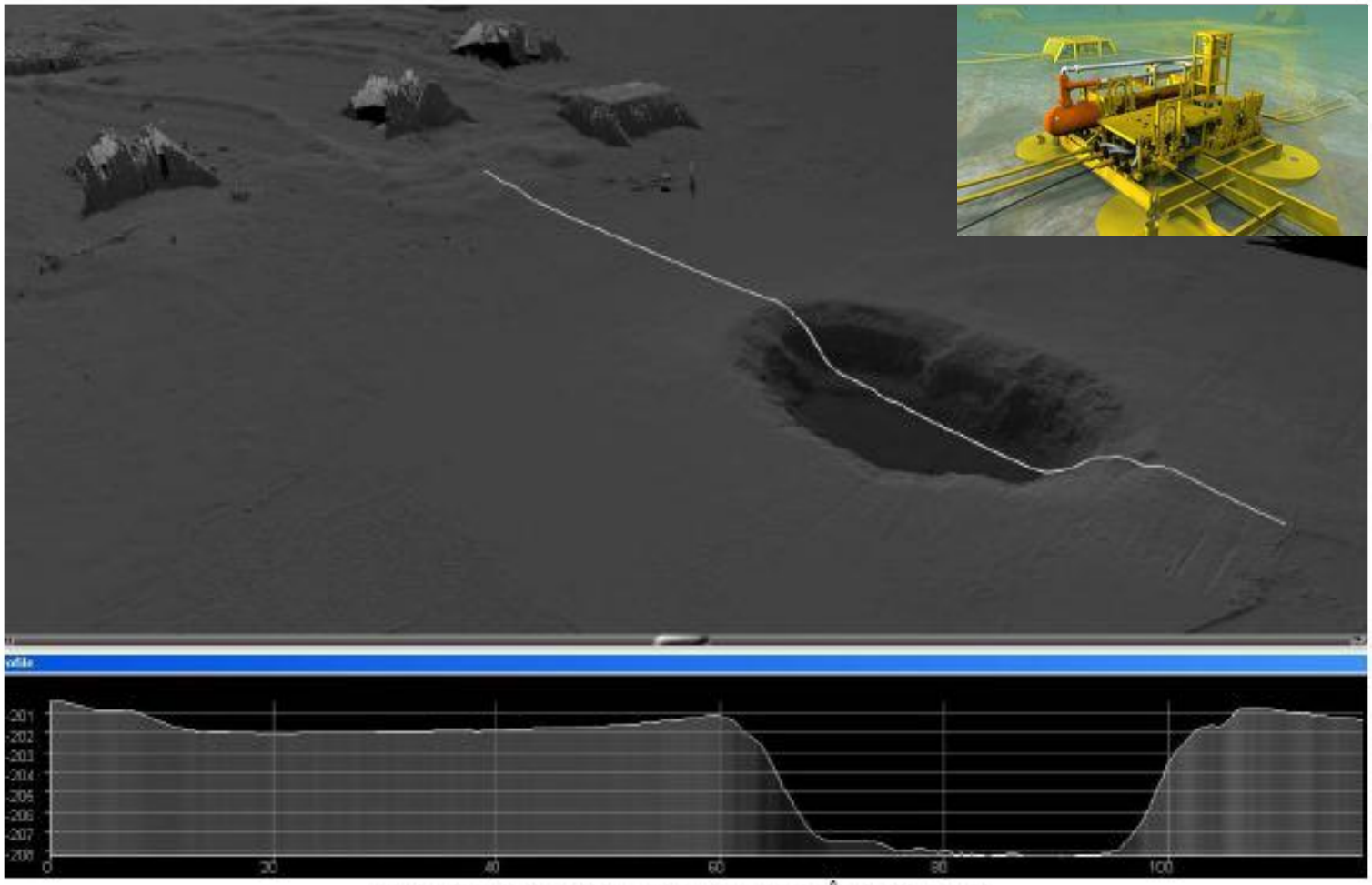
Figures: Statoil

Subsurface leakage through fracture caused by water injection on Tordis

(Utsira formation same as on Sleipner)

Length:
30-40 m

Depth:
Ca. 7 m



Bilde 4.2: Utstrekning av gropen på havbunnen

Source: Statoil, FMC

Mitigation main problem addressed

- Currently there is no method to stop reservoir leakage except depleting the injection formation
- With thousands of sequestration projects do we expect no cap-rocks to leak?
- If leakage occur what should we then do?

No guarantee against CO_2 leakage.

CO_2 sequestration should solve Norway's climate budget. But when water can leak is it safe to store CO_2 in the subsurface?

Source: Aftenbladet.no

Outline

- Technical background on CO_2 sequestration and identification of problem

- Objective of project "*Simulation of CO_2 leakage and cap rock remediation*"

- Shallow sequestration in the Lamotte sandstone as a field case

- Project timeframe, specific task, members and cost

Project objective

The main objective for this project is to ***simulate cap rock leakage* and *simulate the success of remediation of leakage paths*** through the cap rock for a shallow CO_2 injection site through coupled reservoir and geomechanical modeling. The specific objectives is:

i. develop a detailed 3D shared earth model, to use as a consistent data set for coupled reservoir and mechanical simulations.

ii. develop the methods to perform ***coupled 3D reservoir and multi scale geomechanical simulations*** and conduct simulations on a detailed shared earth model for the City Utilities of Springfield CO_2 sequestration demonstration site.

iii. develop ***fracture leakage remediation methods*** for sealing fractures and faults if a leak through the cap rock occurs and develop modeling capabilities for evaluating success of fracture remediation.

Outline

- Technical background on CO_2 sequestration and identification of problem

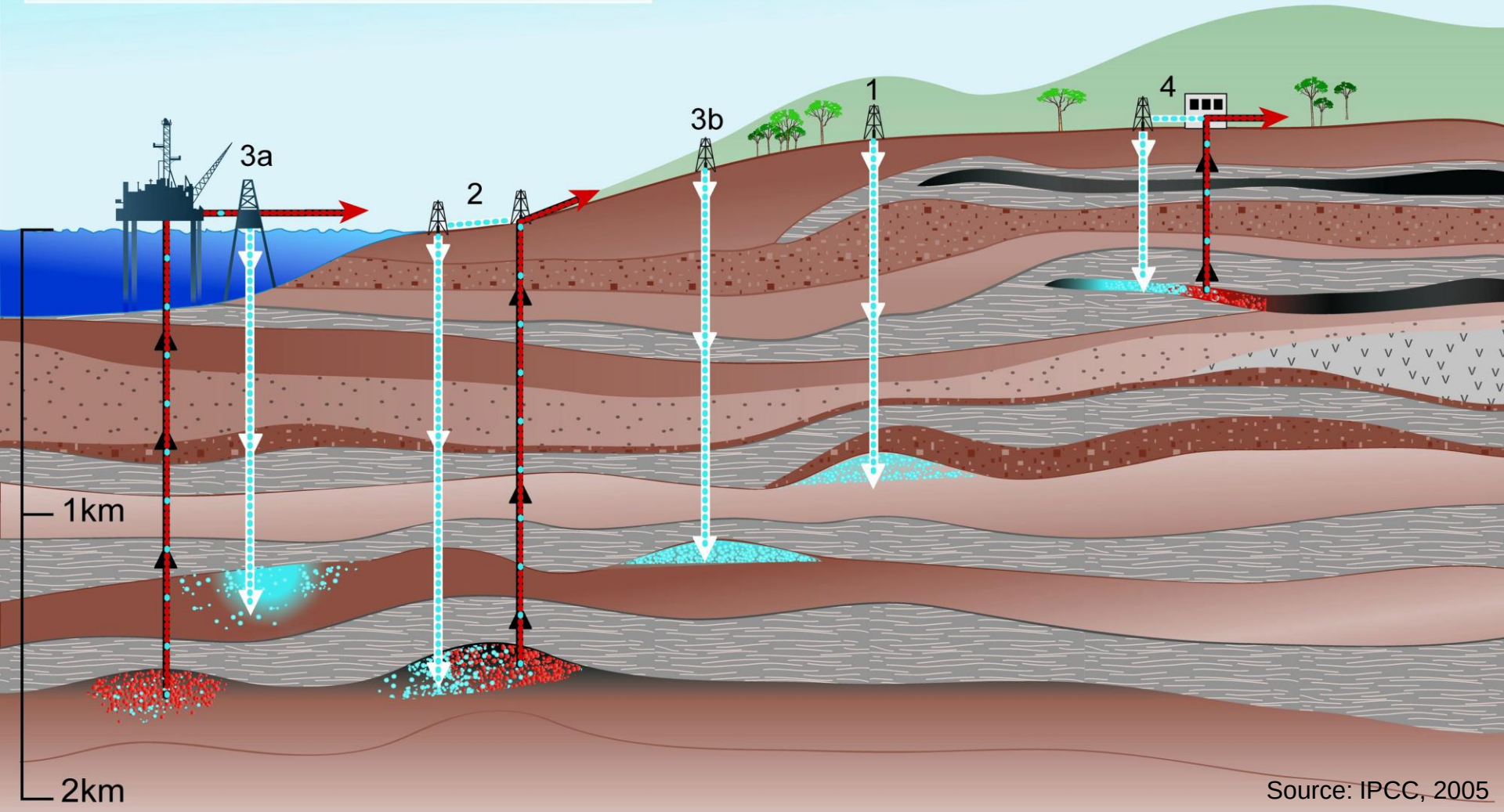
- Objective of project "*Simulation of CO_2 leakage and cap rock remediation*"

- Shallow sequestration in the Lamotte sandstone as a field case

- Project timeframe, specific task, members and cost

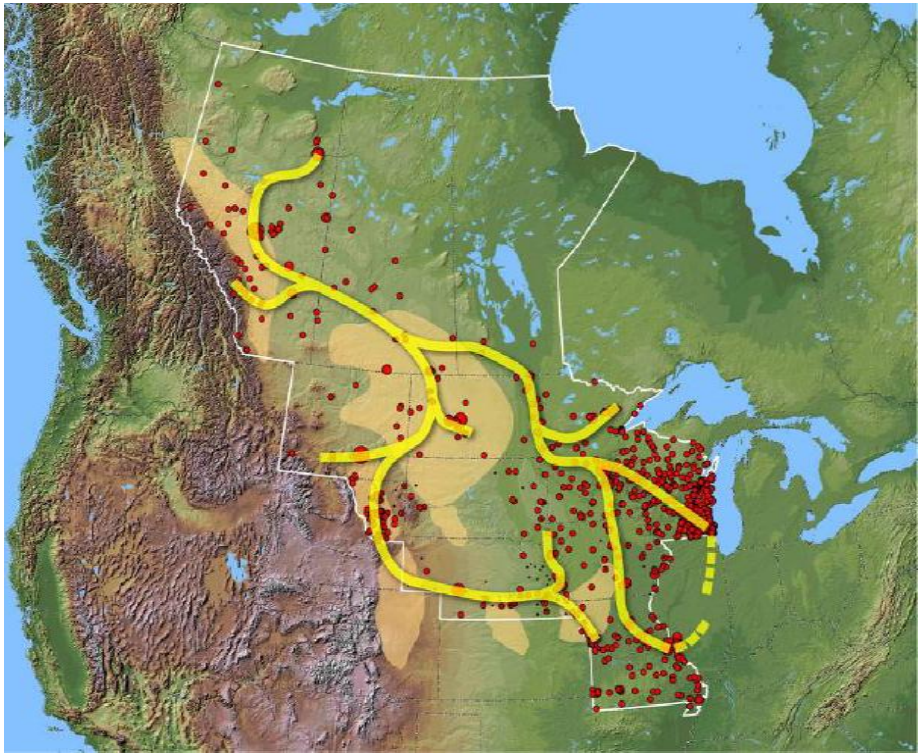
Overview of Geological Storage Options

1 Depleted oil and gas reservoirs
2 Use of CO_2 in enhanced oil and gas recovery
3 Deep saline formations — (a) offshore (b) onshore
4 Use of CO_2 in enhanced coal bed methane recovery



Source: IPCC, 2005

Why shallow sequestration in the Lamotte sandstone?



Source, PCOR

Outline

- Technical background on CO_2 sequestration and identification of problem
- Objective of project "*Simulation of CO_2 leakage and cap rock remediation*"
- Shallow sequestration in the Lamotte sandstone as a field case
- Project timeframe, specific task, members and cost

Scope of work statement

Develop a coupled 3D geomechanical and reservoir modeling approach to simulate the possibility of leakage of CO_2 through the cap rock and further to simulate remediation technologies for sealing faults.

A detailed shared earth model to conduct a more geologically correct explicit coupled reservoir and geomechanical simulation to capture the effect increased pore pressure and reduced temperature has on the stability of the cap rock.

This approach will give a much higher reliability of the location where the leakage in the cap rock may occur.

The project scope further includes the development methods to remediate leakage of CO_2 by sealing of leaking faults or fracture.

Different options of fracture sealing materials for leaking fractures will be tested in the laboratory which will further incorporated in the geomechanical simulations.

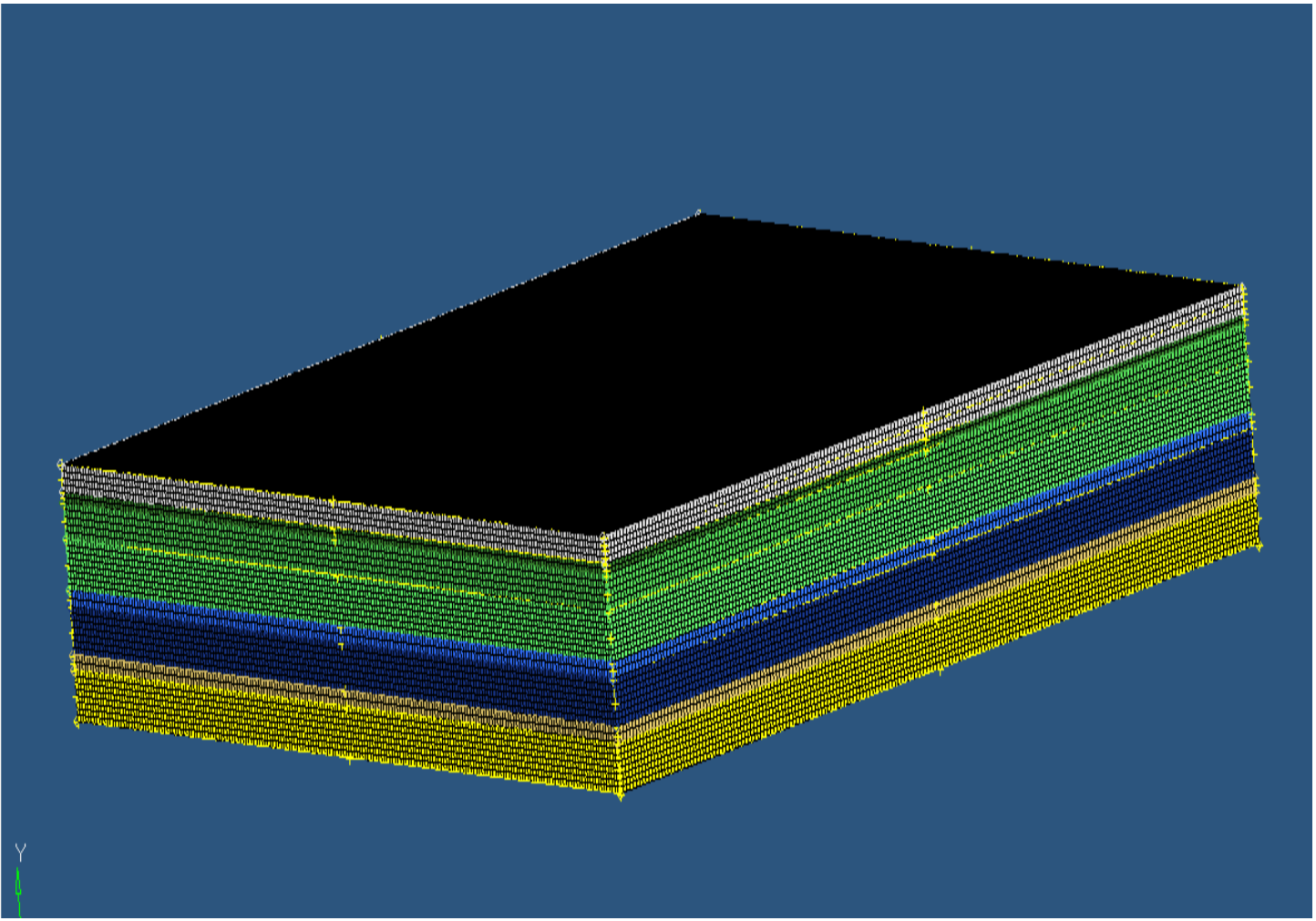
Project Gant chart

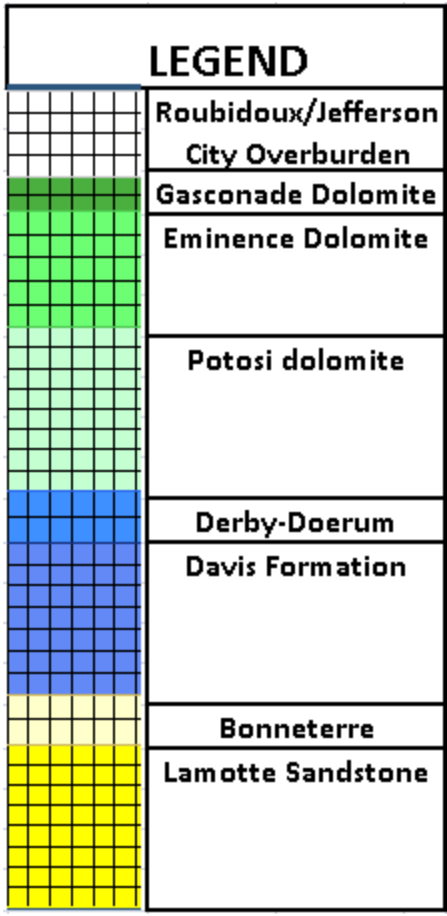
TECHNICAL TASKS	FY2010				FY2011				FY2012			
	12/31	03/31	06/31	09/31	12/31	03/31	06/31	09/31	12/31	03/31	06/31	09/30
1.0 Project Management, Planning, and Reporting												
2.0 Development of a shared earth model												
2.1 Geological and petrophysical model												
2.2 Geomechanical characterization												
2.3 Rock mechanical testing												
3.0 Model development												
3.1 D Finite element (FE) model construction												
3.2 Calibration of the 3D FE model to the in situ state of stress												
3.3 Static reservoir modeling												
Task 4.0 Coupled modeling												
4.1 Coupling of res. and geomech. model												
4.2 Coupled modeling reservoir model												
4.3 Coupled modeling – geomech. model												
4.4 Res. and geomech. results analysis												
5.0 Experiments of fracture remediation												
5.1 Design of fracture filling materials												
5.2 Fracture filling shear apparatus test												
5.3 –Fracture filling triaxial test												
6.0 Numerical verification of fracture remediation												

Task 2.1 1D Geological model

Period	Lithology	Formation Name	Group	Rock Type	Max Thickness(ft)	Hydro-Stratigraphy	Bottom contact (ft)	Top contact (ft)	Porosity(%)	K range(mD)	AVG. UCS (Mpa)
Lower Ordovician		Jefferson City	Ozark	Cherty/Drusy Dolomite	930	Aquifer	+370	+1300			
		Roubidoux									
		Gasconade									
Upper Cambrian		Eminence									
		Potosi									
		Derby Doerun	St Francois Confining Unit	Shaly Dolomite	120	Aquitard	+250	+370	0.50-6.23	$3.988\text{-}9.00*10^{-6}$	257
		Davis		Dolomite shale	355	Aquitard	+105	+250	4.57-17.47	$1.43E\text{-}03\text{-}7.00*10^{-6}$	283
		Bonneterre	St Francois	Dolomite/Limestone	155	Aquifer	-220	+105	5.6	0.126	106
		Lamotte		Sandstone & Conglomorate	~1800	Aquifer	-600	-220	10.6	17.596	129
Precambrian Rocks			Basement Confining Unit	Granitic,Basic and Felsitic Extrusives	>220	Aquitard	<-600	<-600			

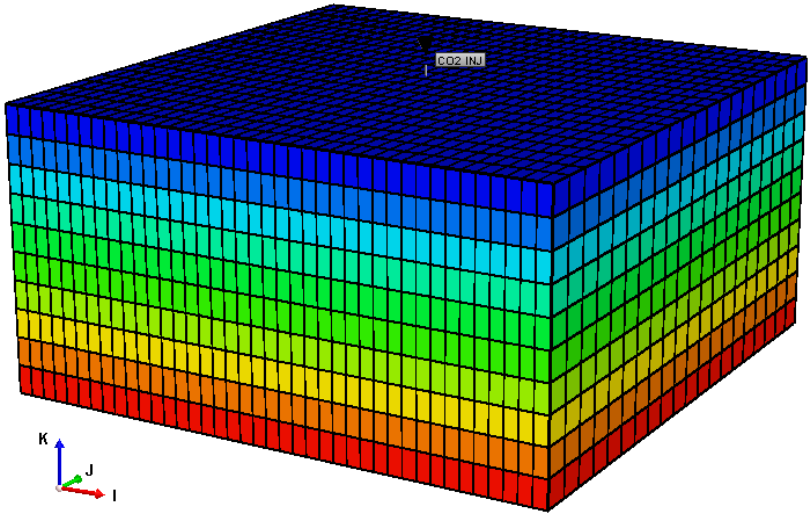
Task 3.1 1D FE-model

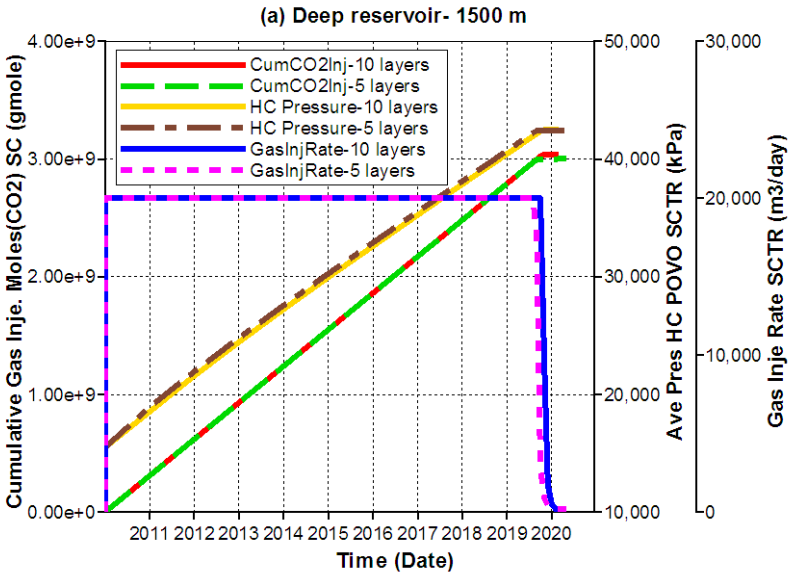


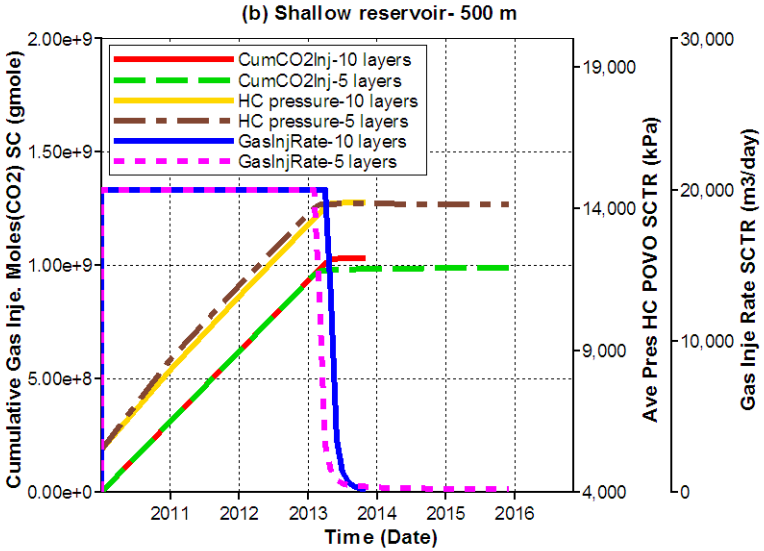


Task 3.3 Static reservoir modeling

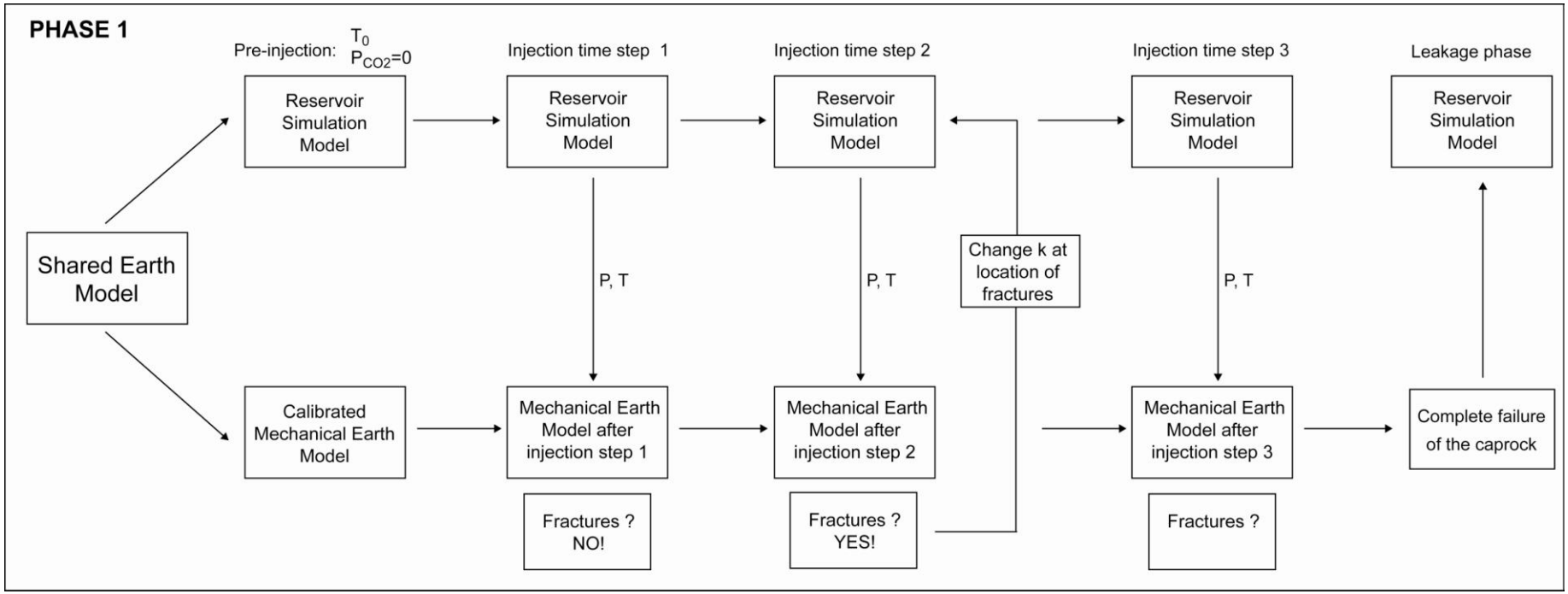
Grid model of reservoir



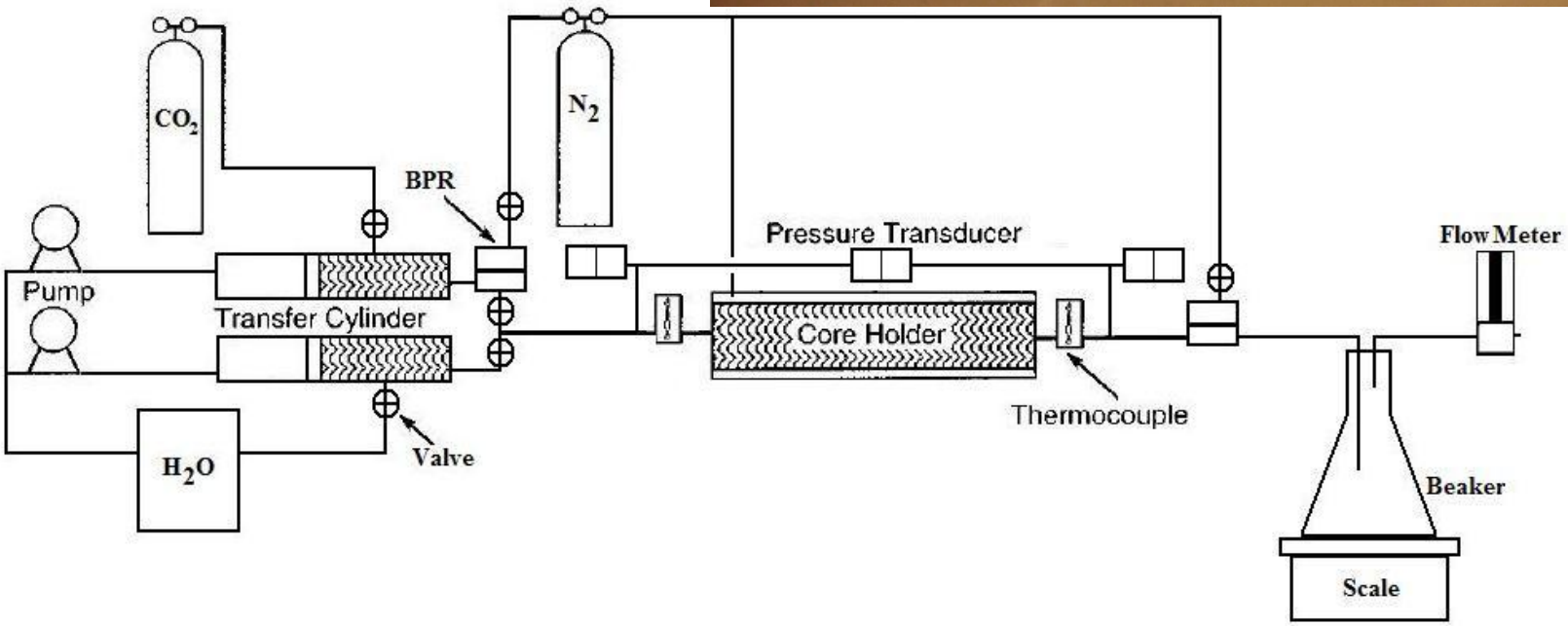




Task 4.1 –Explicit coupling of reservoir and geomechanical model

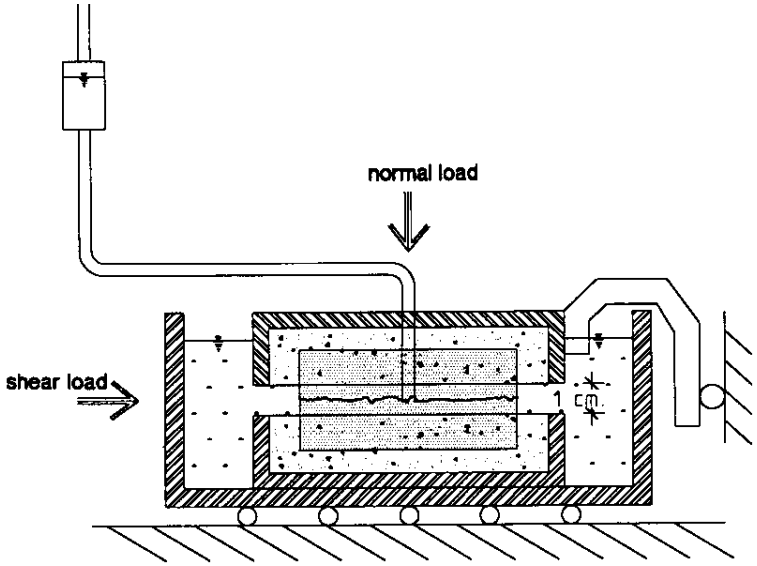


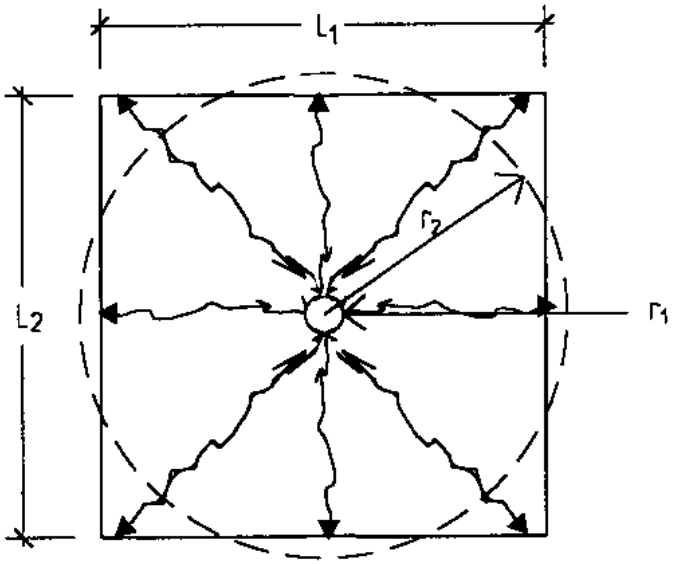
Task 5 Design and selection of fracture filling materials, cement grouts, polymers.



Task 5.2 –Fracture filling test in shear apparatus

Modified direct shear flow test





Source: Gutierrez, Oino, Nygaard, 2000

Task 5.3 –Fracture filling test in triaxial cell at elevated stresses

Triaxial test with existing fractures

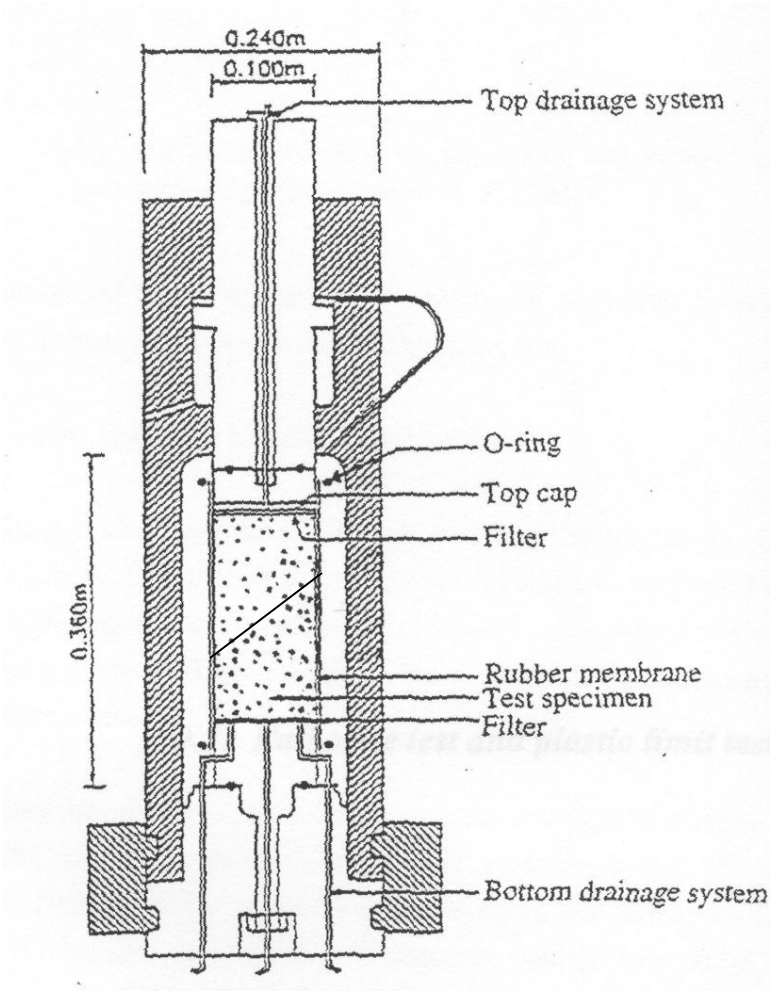
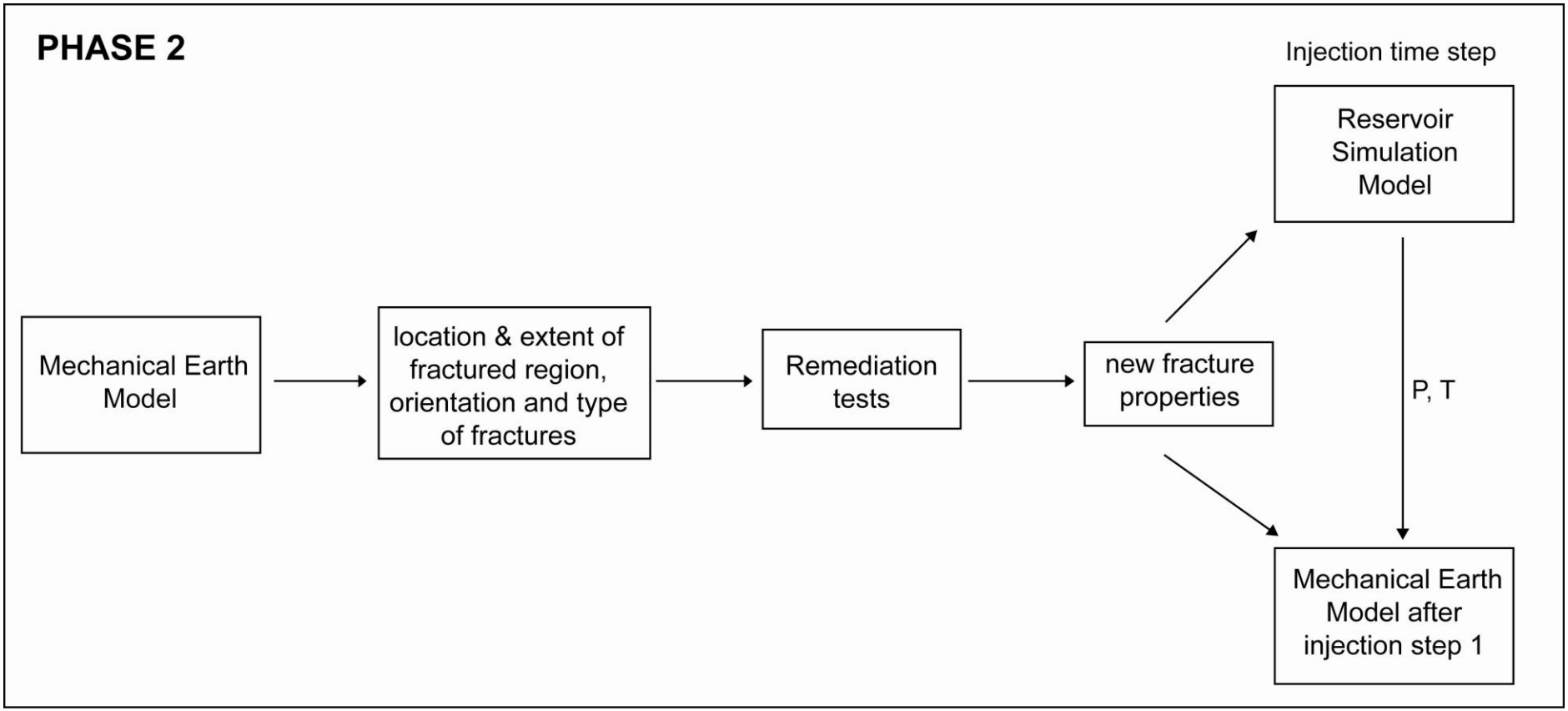


Figure: NGI

Task 6.0 – Numerical verification of fracture remediation



Project impact and benefits

- Develop new numerical simulation methods to identify rates and location where leakage can occur
- Develop new materials to seal of fracture leakage in cap rocks
- Developed materials will be beneficial for wellbore remediation

Summary

OBJECTIVE

- Locate CO_2 leakage from subsurface injection
- Simulate cap rock leakage probability and rates
- Develop fracture leakage remediation methods for sealing fractures and faults

TECHNICAL APPROACH

- Create a shared mechanical earth model of City Utilities of Springfield shallow CO2 sequestration demonstration site
- Perform coupled 3D reservoir and multi scale geomechanical modeling of leakage risk and rates
- Develop fracture leakage remediation methods for sealing fractures and faults

IMPACTS

- Develop new numerical simulation methods to identify rates and location where leakage can occur
- Develop new materials to seal of fracture leakage in cap rocks
- Developed materials will be beneficial for wellbore remediation