工業技術研究院
Industrial Technology
Research Institute

# $CO_2$ Storage Assessment in Taiwan

IEAGHG/IETS Iron and Steel Industry
CCUS and Process Integration Workshop
Tokyo Tech Front, Tokyo Institute of Technology, Japan

**Chi-Wen Liao**
**Industrial Technology Research Institute**
**2013 NOV 6th**

# Industrial Technology Research Institute

## Recognition for Outstanding Technology Innovation

2012 - The Wall Street Journal's 2012 Technology Innovation Awards for SideLighter and aePLASMA
2012 - R&D 100 Awards for Lignoxy, TEMM, SideLighter, aePLASMA, Light&Light, and AWA-Camp
2012 - Aviation Week's A&D SIC Award for REDDER
2011 - The Wall Street Journal's 2011 Technology Innovation Awards for i2R e-Paper and Spray-IT
2011 - ITRI as Excellent Organization, Solar Industry Awards, UK for Solar Radome
2011 - R&D 100 Awards for i2R e-Paper and HyTAC
2011 - Silver Award, The Society for Information Display (SID) Display of the Year Awards (DYA) for ITRI Flexible Substrate for Displays
2010 - Overall Gold, The Wall Street Journal's 2010 Technology Innovation Awards for FlexLPD; Runner-up for MDPS (Micro-Deformable Piezoresistive Sensor Technology)
2010 - R&D 100 Awards for REDDER, i2/3DW, and FlexUFD
2009 - R&D 100 Awards for STOBA (self-terminated oligomers with hyper-branched architecture)
2009 - The Wall Street Journal's 2009 Technology Innovation Awards for FlexSpeaker
2009 - iF Design Award for Fluid Driven Lighting System
2009 - Red Dot Design Award for Flexio Radio
2008 - R&D 100 Awards for On-Chip AC LED Lighting Technology

**Electronics and Optoelectronics**
**Green Energy and Environmental Technologies**
**Information and Communications**
**Material, Chemical and Nanotechnology**
**Medical Device and Biomedical Technologies**
**Mechanical and Systems Technologies**

# Natural Resources Technology Div.

## Clean Coal Technology

- Calcium Looping $CO_2$ Capture
- Chemical Looping
- Coal and Bio-mass Gasification

## Geological Technology

- $CO_2$ Geological Storage
- Deep Geological Repository
- Advanced Geo-fluid Sampling

## Ocean Energy

- Wave Energy Harvesting / Conversion
- Point Source Wave Generator
- Structural and Mechanical Analysis
- Offshore Wind-farm Assessment and Planning
- Marine Weather Information System

## Geo-environmental Hazard

- Advanced Geophysical Investigation
- Geo-hazard Assessment and Alert System
- Land Subsidence Monitoring and Mitigation
- Laser-based System for Wind Speed Measurement

## Geothermal

- Resource Assessment
- Reservoir Engineering
- Geothermal Power Generation System
- Organic Rankine Cycle Power Generator
- Industrial Waste Heat Recovery

## Wind Energy

- Wind-farm Resource Assessment and Planning
- Wind Turbine System Integration
- Intelligent Control and Maintenance
- Transmission System Design and Analysis
- Large-scale Wind Turbine Control System

# Co-contributors

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- Keni Zhang, Cai Li
  (Beijing Normal University)
- J.J. Ou, J.D. Chen, R.F. Shen
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- Shin-Tai Hu, Ta-Lin Chen, Chenners Chen-Hui Fan, Ch-Chung Tseng
  (CPC Corporation)
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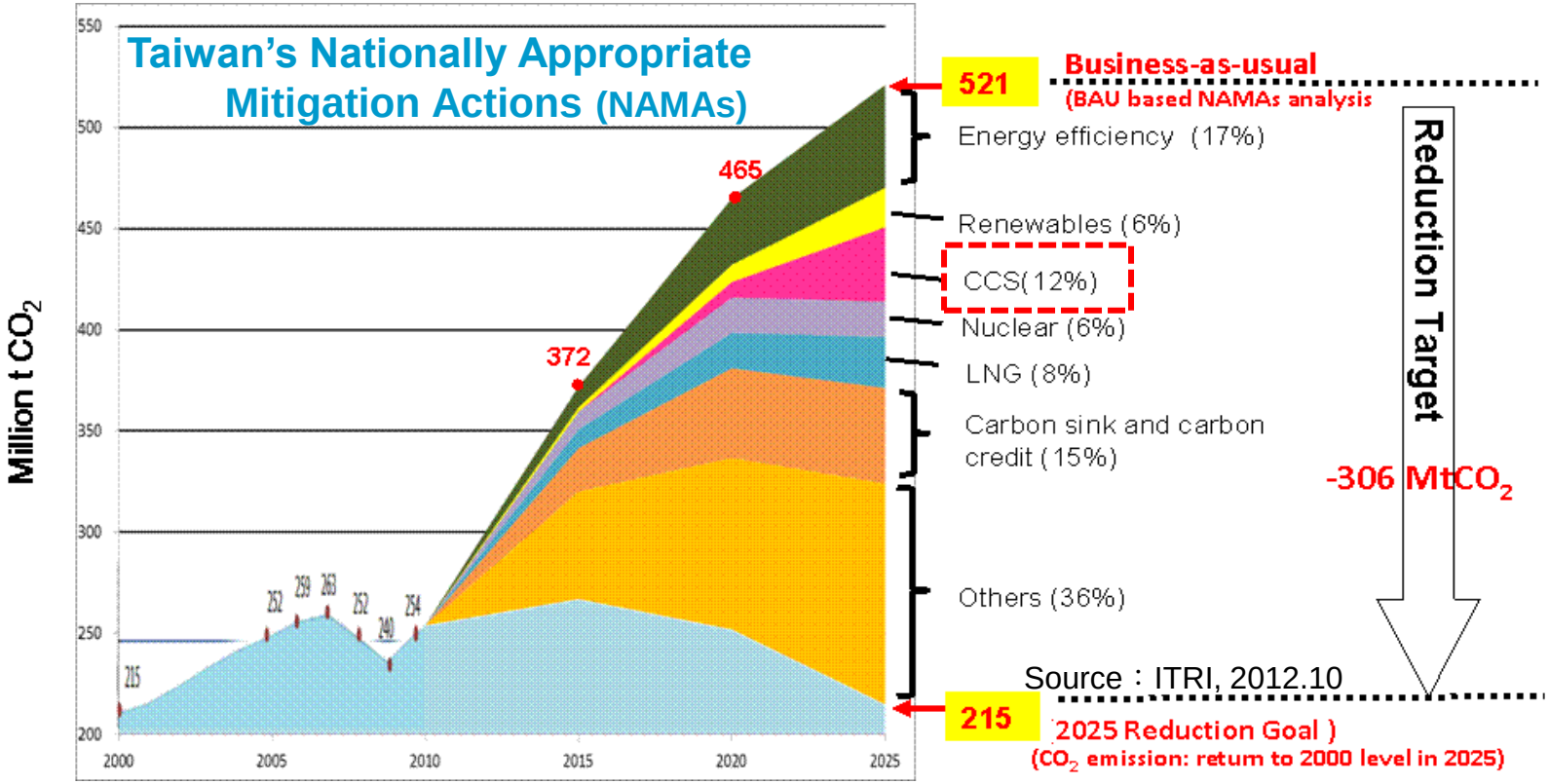
# Outline

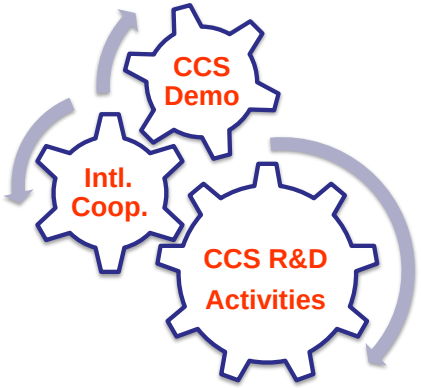
- Background
- $CO_2$ Storage Assessment in Taiwan
- CCS Pilot Projects
- Natural and Industrial Analogue
- Conclusion

# Taiwan's Challenges

- > 98% of energy supply rely on imports
- Energy Bill (% of GDP): 3.8%(2001) → 13.6%(2012)
- Emit approximately 270Mt $CO_2$ in 2010, ~0.89% of global $CO_2$ emission, ranked 20nd globally (IEA)
- CCS will contribute 12% $CO_2$ emission reduction, about 36.7 million tons $CO_2$ per year in 2025 according to proposed NAMAs



# National Energy Project - CCS




**Technology Development**
- $CO_2$ Capture
- Injection/Storage
- Monitoring
- Simulations
- Risk Assessment

經濟部能源局 Bureau of Energy
ITRI Industrial Technology Research Institute

**Technology Demonstration**
- $CO_2$ Capture
- Oil/Gas Structures
- Saline Aquifers

ITRI Industrial Technology Research Institute
CHINASTEEL
台灣中油股份有限公司 CPC Corporation, Taiwan
Taiwan Power Company

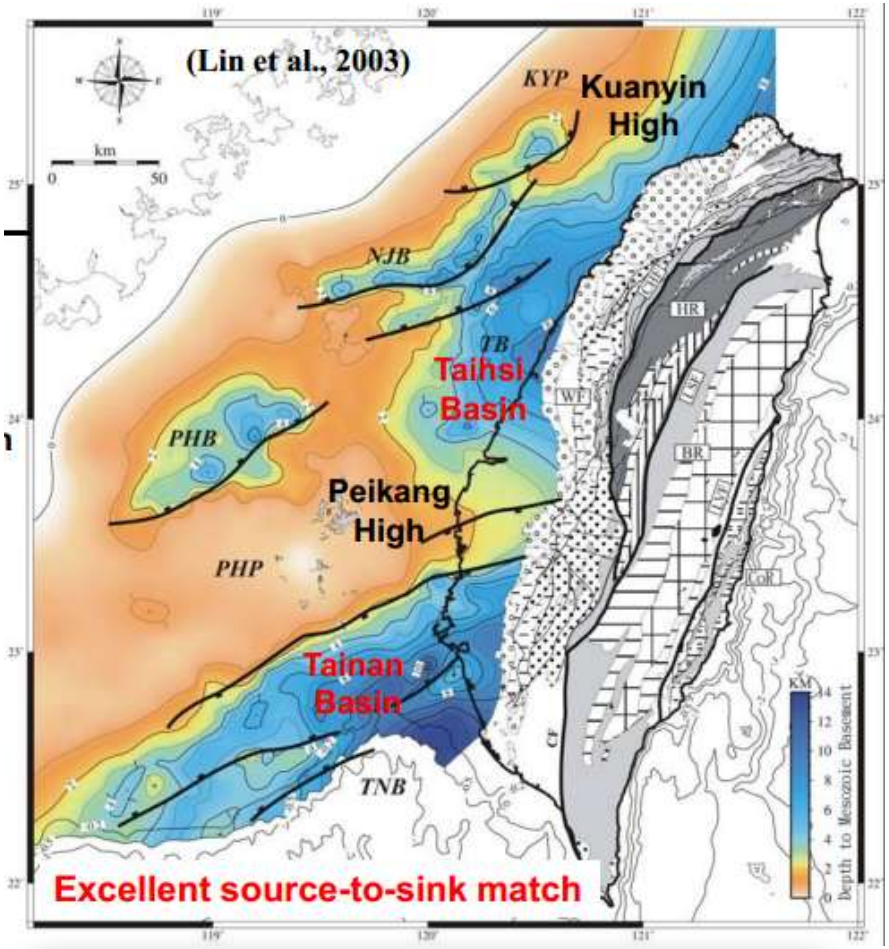
**Others**
- Intl. Cooperation
- Laws/Regulations
- Public Outreach

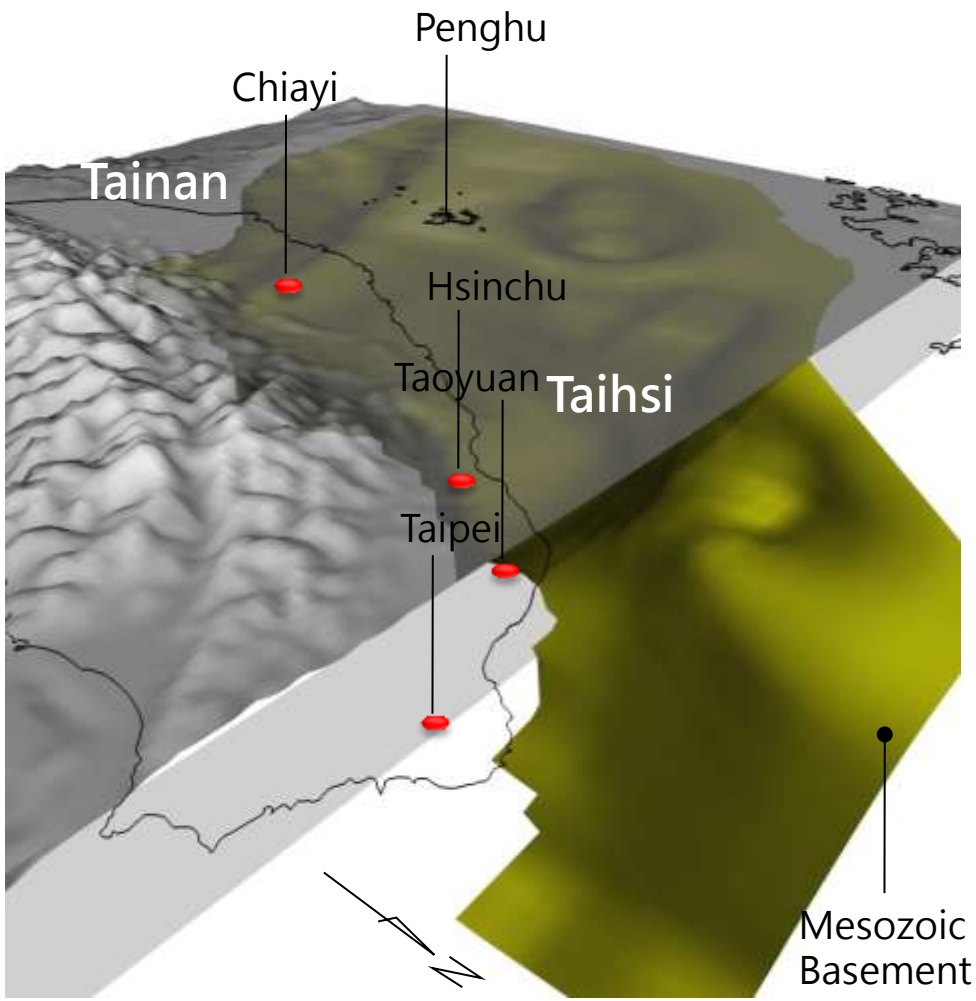
Phase I: 2009~2013
Phase II: 2014~2018

- $CO_2$ capture: Large and stationary point emitters
- $CO_2$ storage: Deep saline aquifers and Oil/gas structures

- $CO_2$ capture: technology and commercial-scale demo & verification before 2025 with solid sorbents or chemical looping
- $CO_2$ storage: pilot injection projects, site characterization, storage capacity assessment, simulation and prediction of $CO_2$ plume migration, MMV, and risk assessment

# Cenozoic Basins in western Taiwan



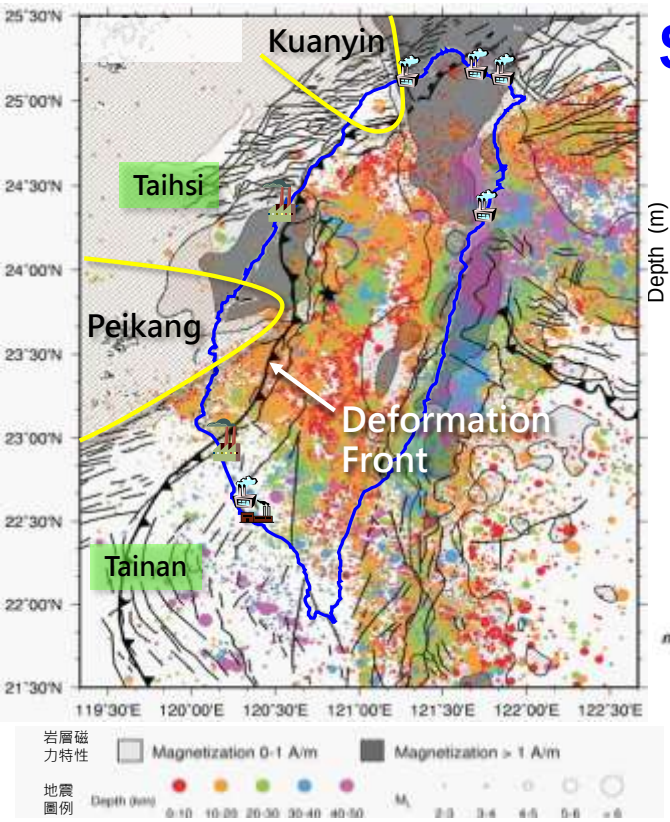



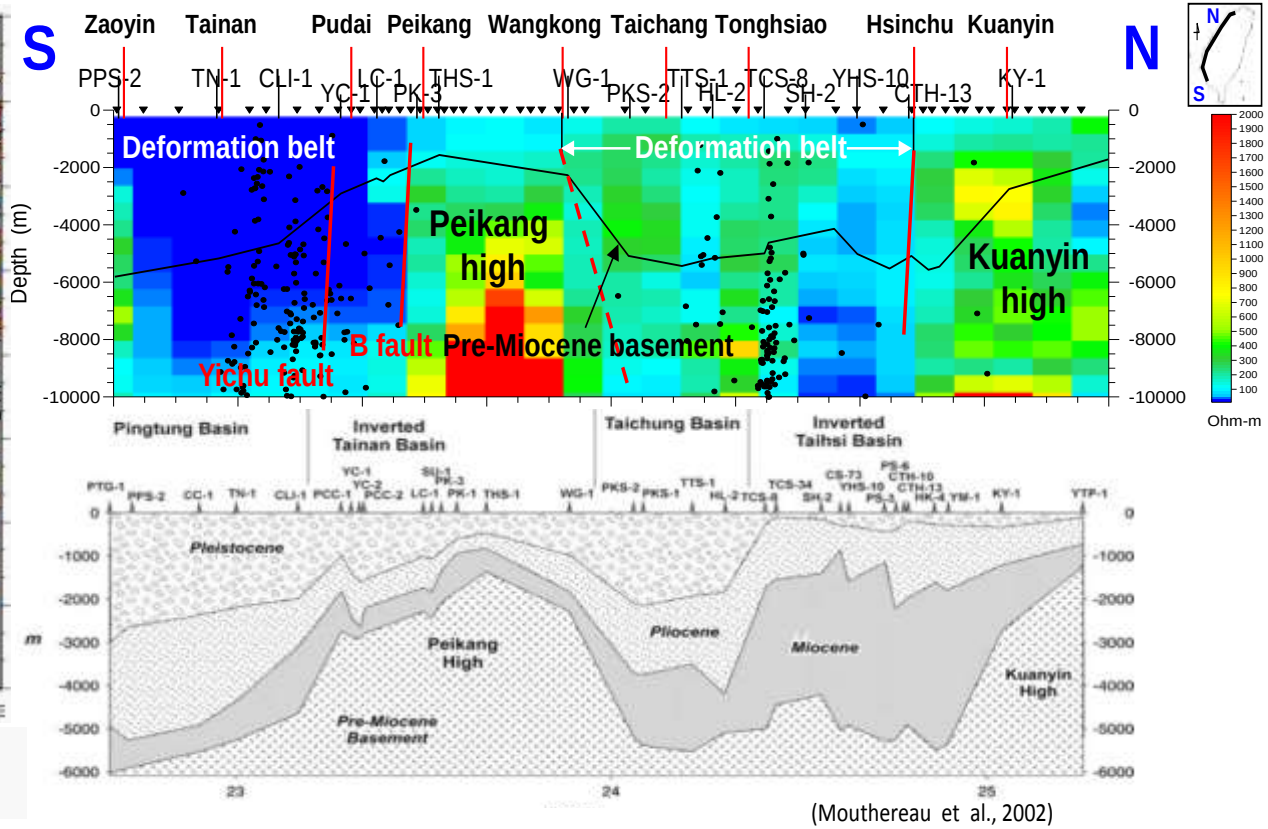

Cenozoic Basins

- ✓ **Up to 8 km thick sediment**
- ✓ **Western costal plain (saline)**
- ✓ **Taiwan strait (saline)**
- ✓ **Western foothills (o/g structure)**

(ITRI, 2008)

# Opportunities for Taiwan




(Mouthereau et al., 2002)

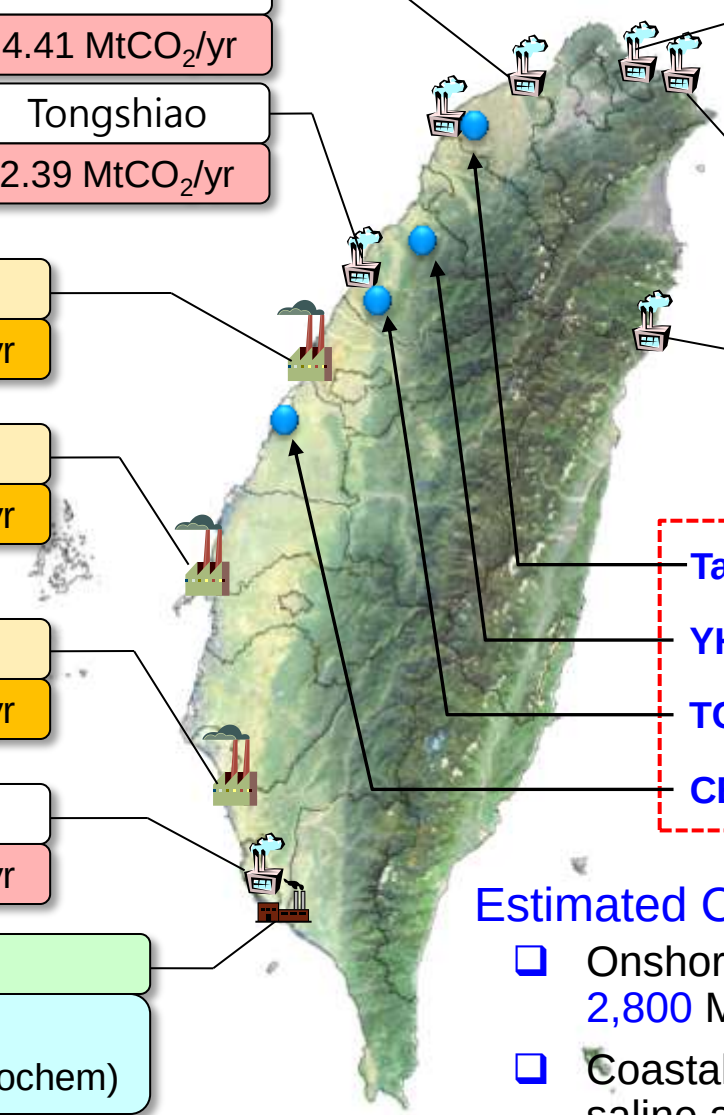
ITRI - Regional MT and Seismic Survey along Western Coast of Taiwan

- ✓ **Potential areas revealed by regional seismic and MT Survey**
- ✓ **Target formation: Miocene and Pliocene formation with suitable depth and reservoir – caprock matching**
- ✓ **Near and off-shore area away from deformation front**

(ITRI, 2009)

# Major $CO_2$ sources in Taiwan

Most power plants and industrial parks are located in the western part of Taiwan, where suitable sedimentary basins and rock formations for $CO_2$ storage are available



Linkou
4.41 $MtCO_2$/yr

Tongshiao
2.39 $MtCO_2$/yr

Shiehe
1.60 $MtCO_2$/yr

Shenao
2.64 $MtCO_2$/yr

Hoping
7.7 $MtCO_2$/yr

**87.3 $MtCO_2$/yr**

Taichung
39.7 $MtCO_2$/yr

Mailiao
32.4 $MtCO_2$/yr

Hsingda
15.2 $MtCO_2$/yr

Dalin
2.09 $MtCO_2$/yr

Linhai
Electricity Consumer
605,495 kW (steel/petrochem)

**Taoyuan Saline Aquifer**

**YHS Gas Field (CPC)**

**TCS Gas Field (CPC)**

**CB Industrial Park (TPC)**

Estimated $CO_2$ storage capacity :

- Onshore oil and gas structures: 2,800 Mtons
- Coastal and offshore deep saline aquifers: 9,000 Mtons

(ITRI, 2009)

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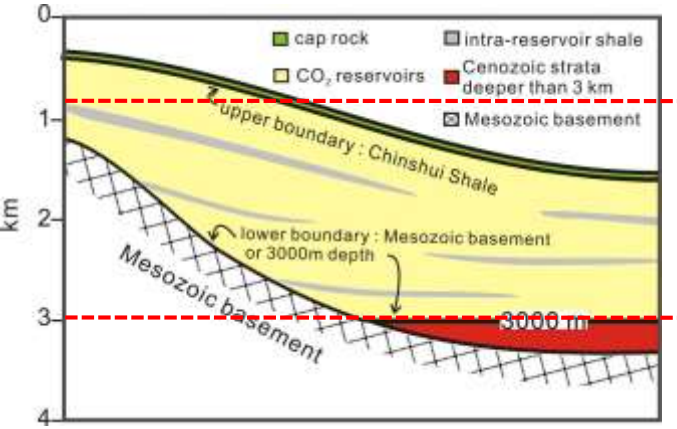
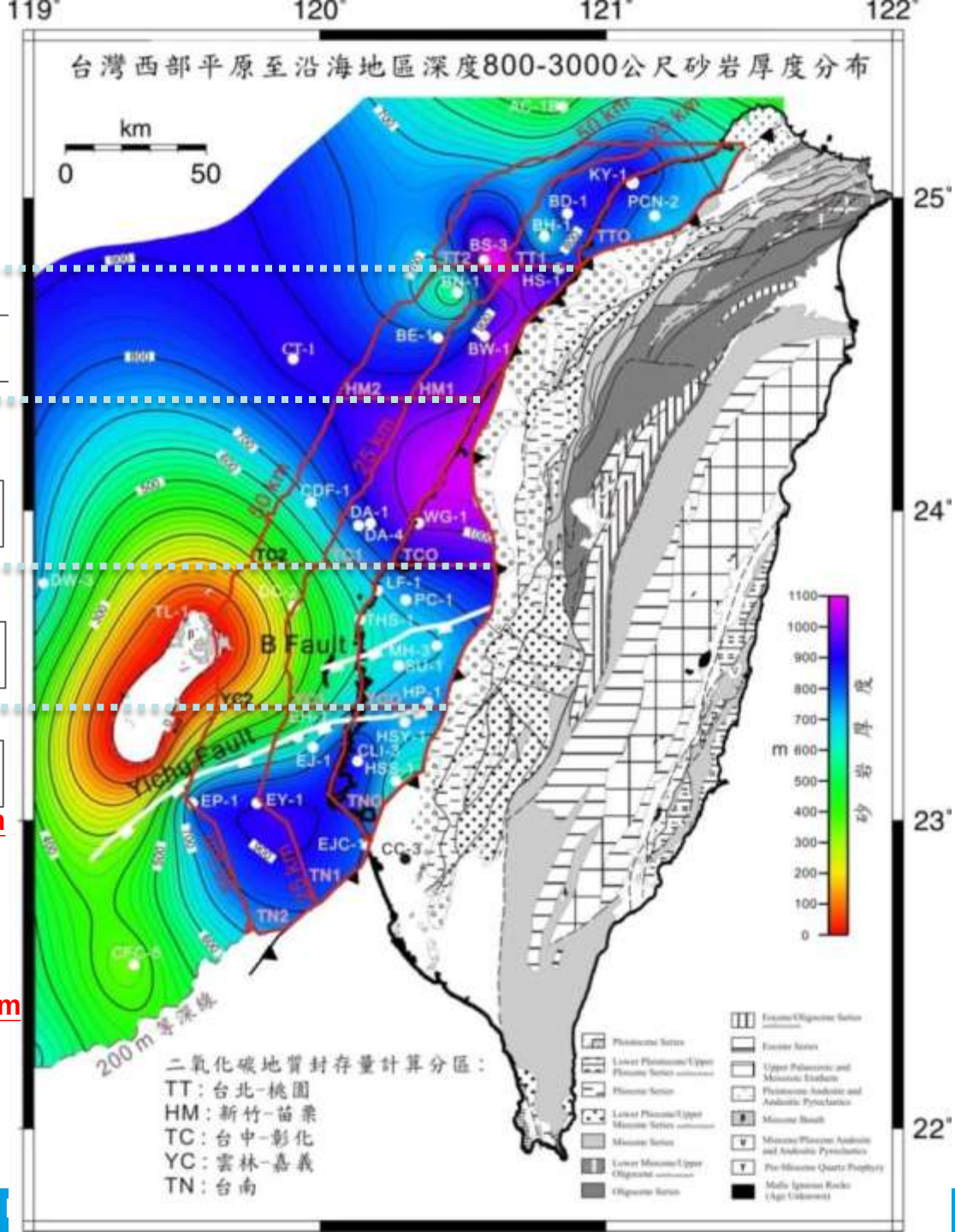
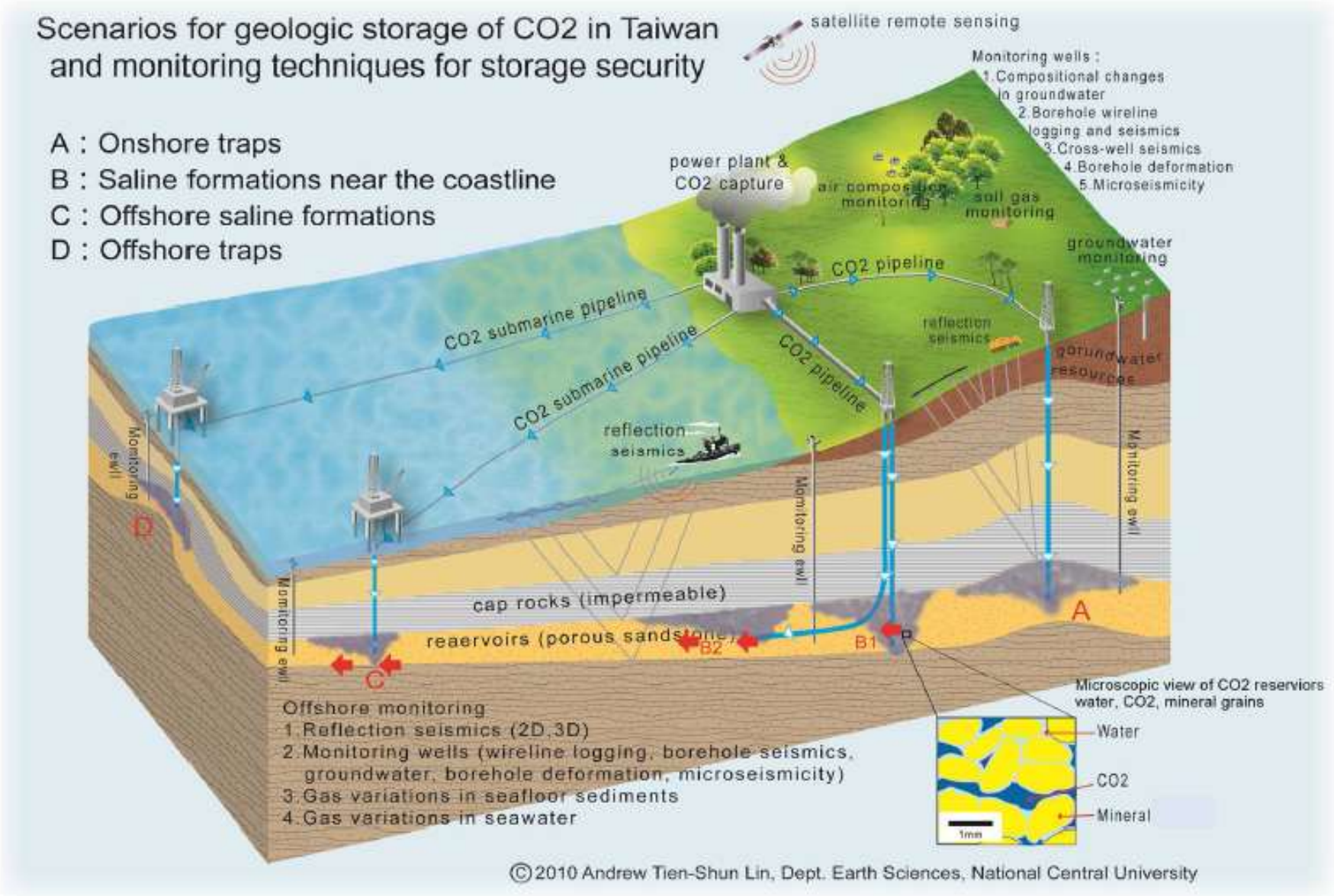
| ZONE | Onshore | Offshore 0-25 km | Offshore 25-50 km | Capacity (Mt) |
|---|---|---|---|---|
| TT | 25 | 30 | 33 | 8800 |
| HM | - | 34 | 34 | 6800 |
| TC | 37 | 43 | 34 | 11400 |
| YC | 49 | 21 | 10 | 8000 |
| TN | 27 | 40 | 42 | 10900 |
| Total | 138 | 168 | 153 | 45900 |



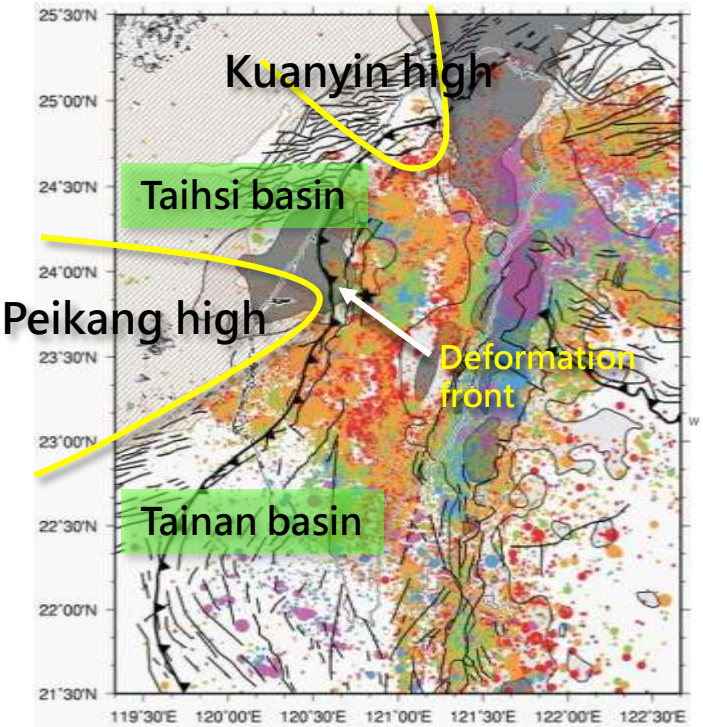

(Andrew T.S. Lin and C.N Yang, 2013)



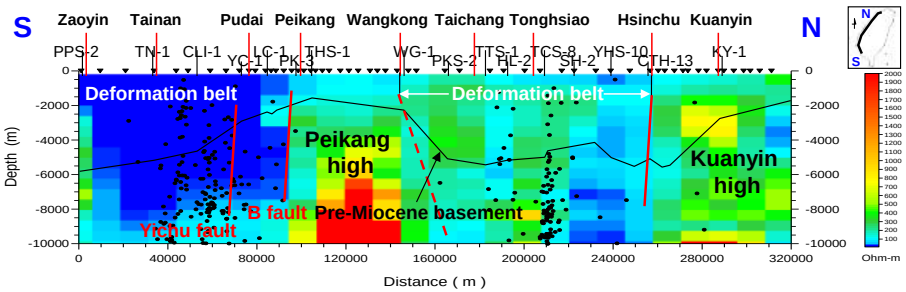



(Andrew T.S. Lin, 2010)

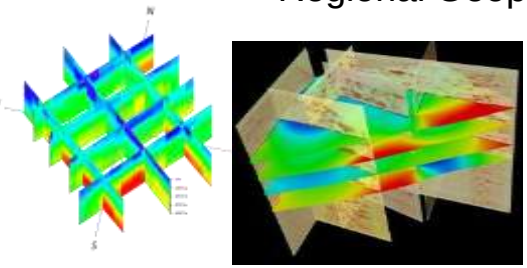
# ITRI Geological Storage Technology Development



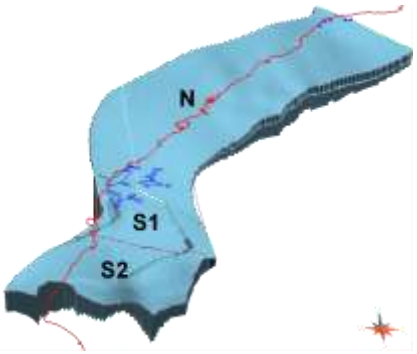

Site Screening

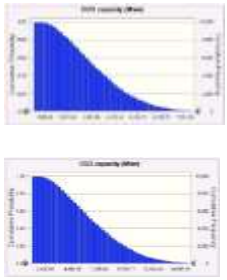



Regional Geophysical Investigation

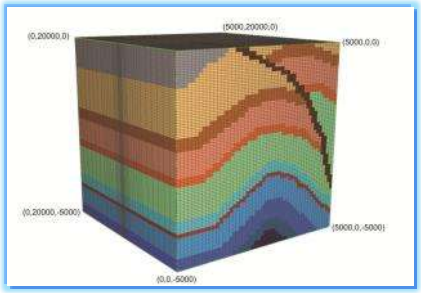


Site Characterization

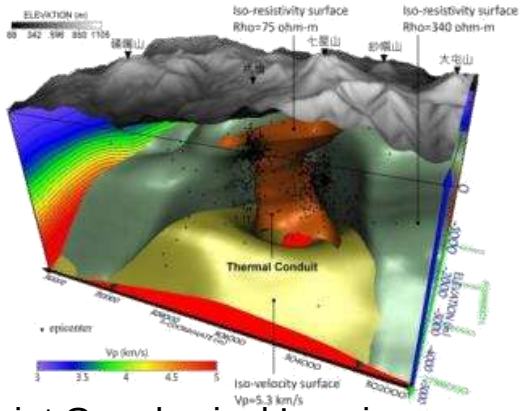


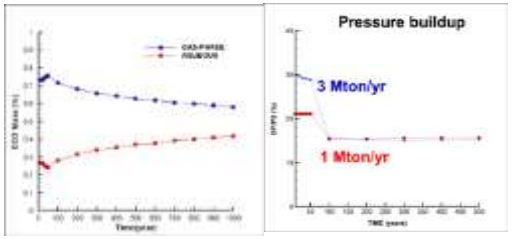
3D Geological Modeling (GOCAD)
Capacity Estimation

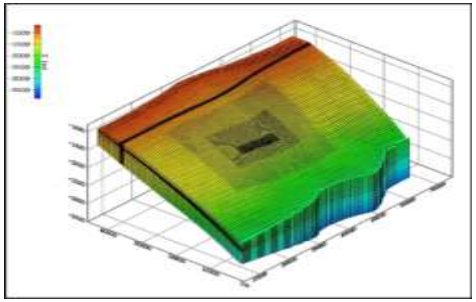


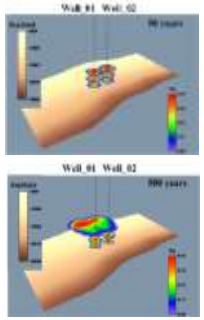
3D Mesh Construction




Joint Geophysical Imaging

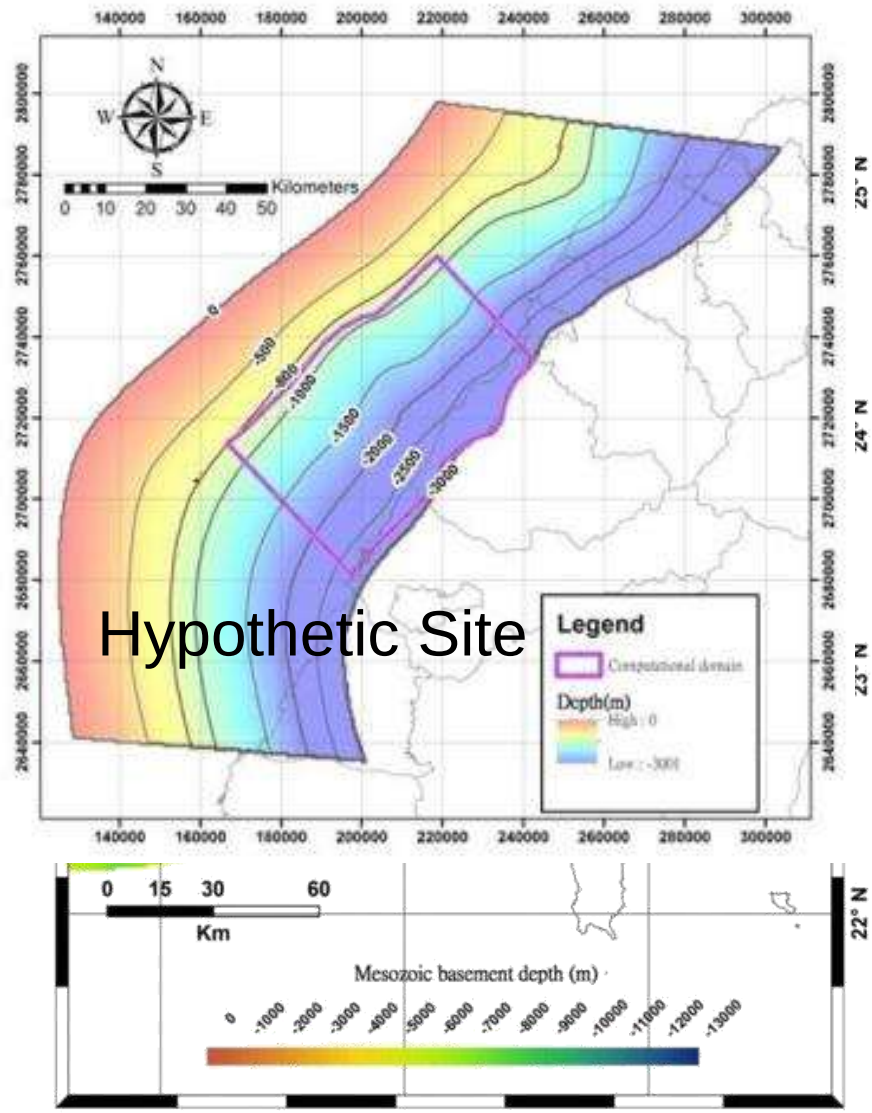


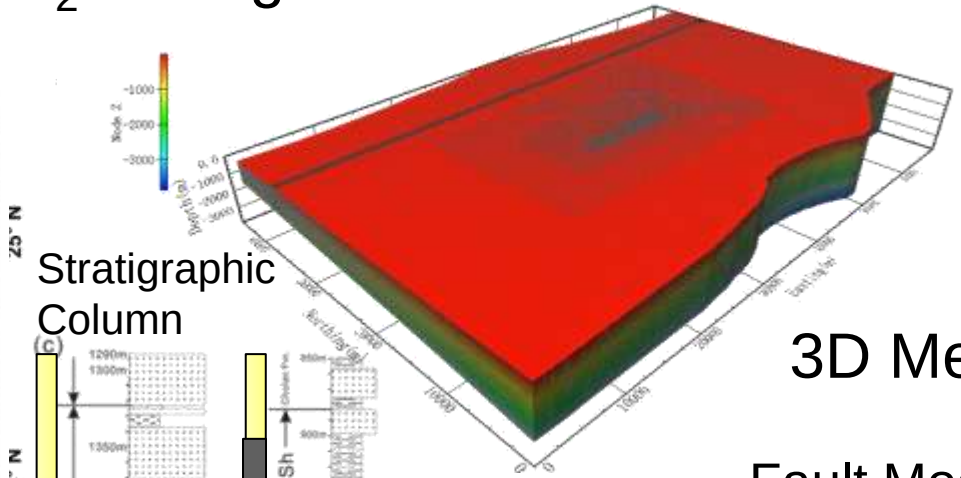


TOUGH2/TOUGHREACT
Simulation and Risk Assessment

# Large-scale $CO_2$ Storage Assessment

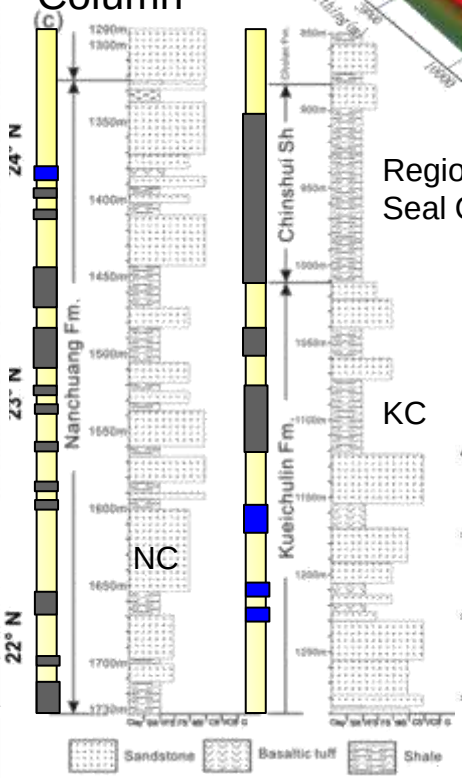



Hypothetic Site

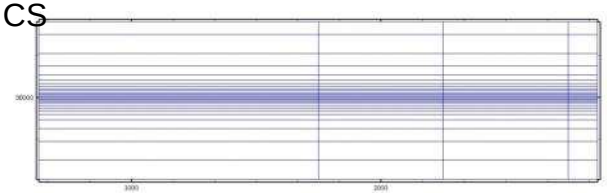


3D Mesh

Stratigraphic Column

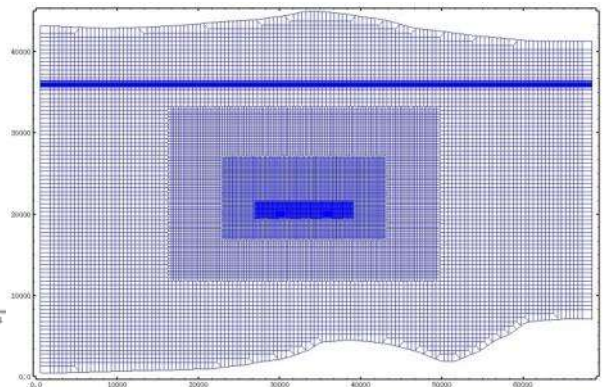


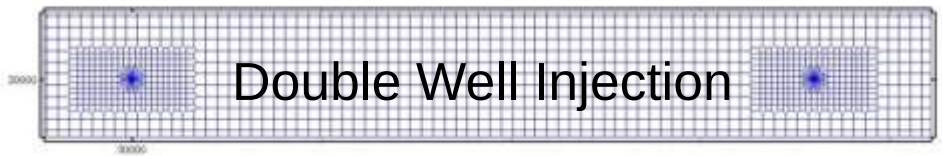

Regional Seal CS



Fault Model

KC



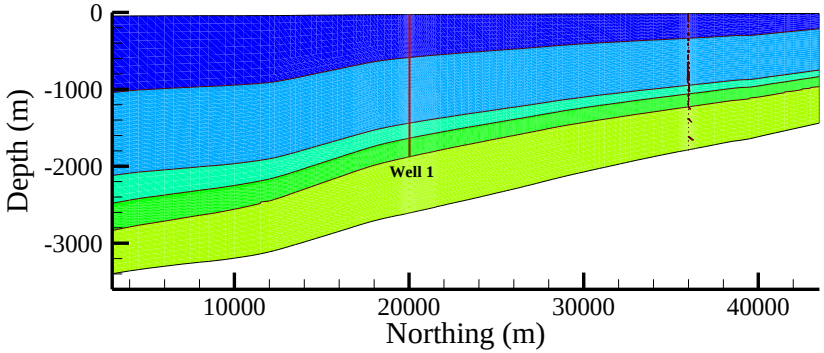


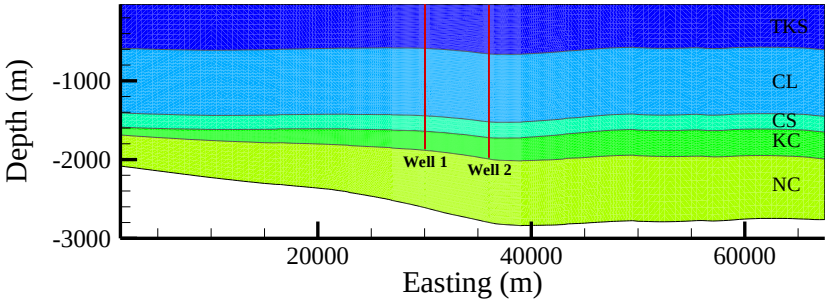
Double Well Injection

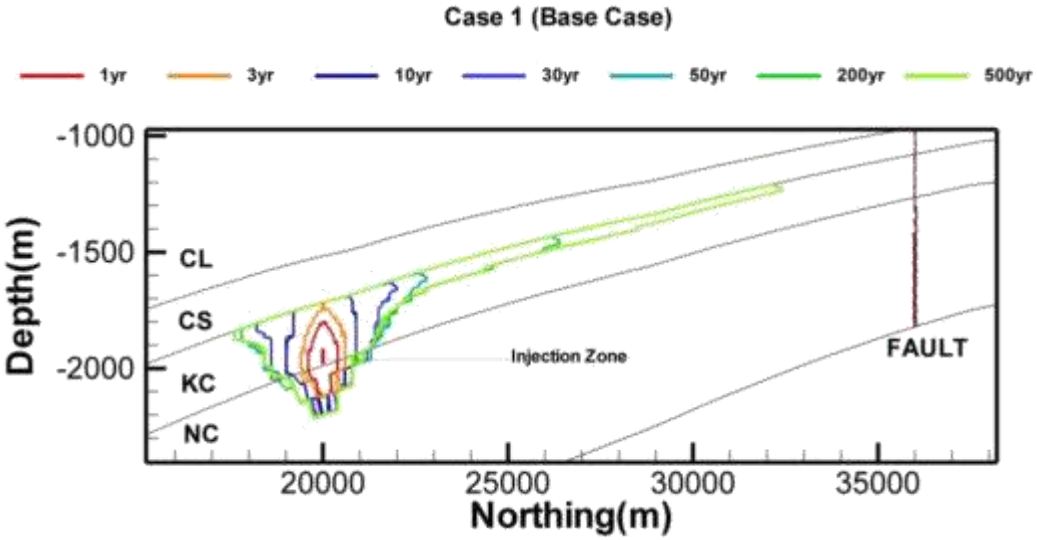
International Journal of Greenhouse Gas Control 19 (2013)

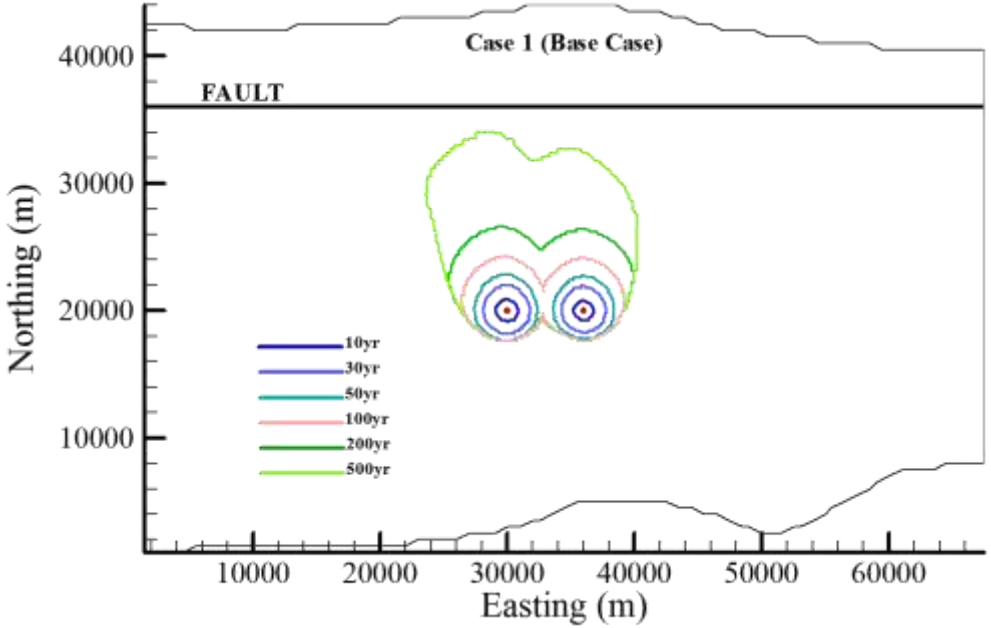
(Li et al., 2013; Joint efforts of ITRI and Beijing Normal Univ.)

# Base Scenario




KC could store 5Mt/yr by 50 yrs

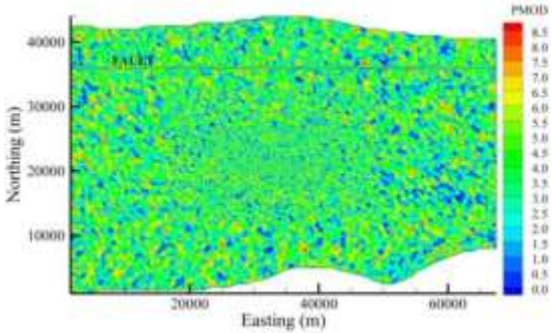
CS could contain $CO_2$ for 500 yrs

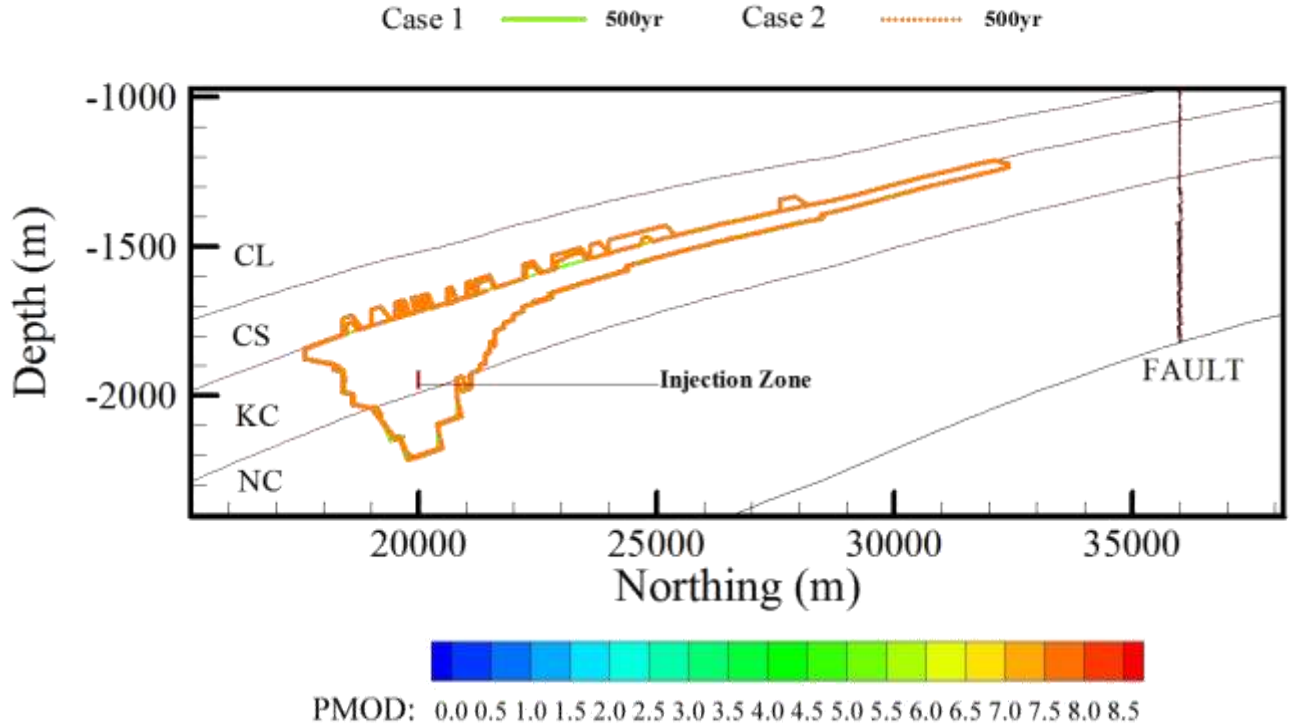
5Mt/yr injection for 50 yrs (250Mt)

$CO_2$ migrate toward seaside

International Journal of Greenhouse Gas Control 19 (2013)

(Li et al., 2013; Joint efforts of ITRI and Beijing Normal Univ.)

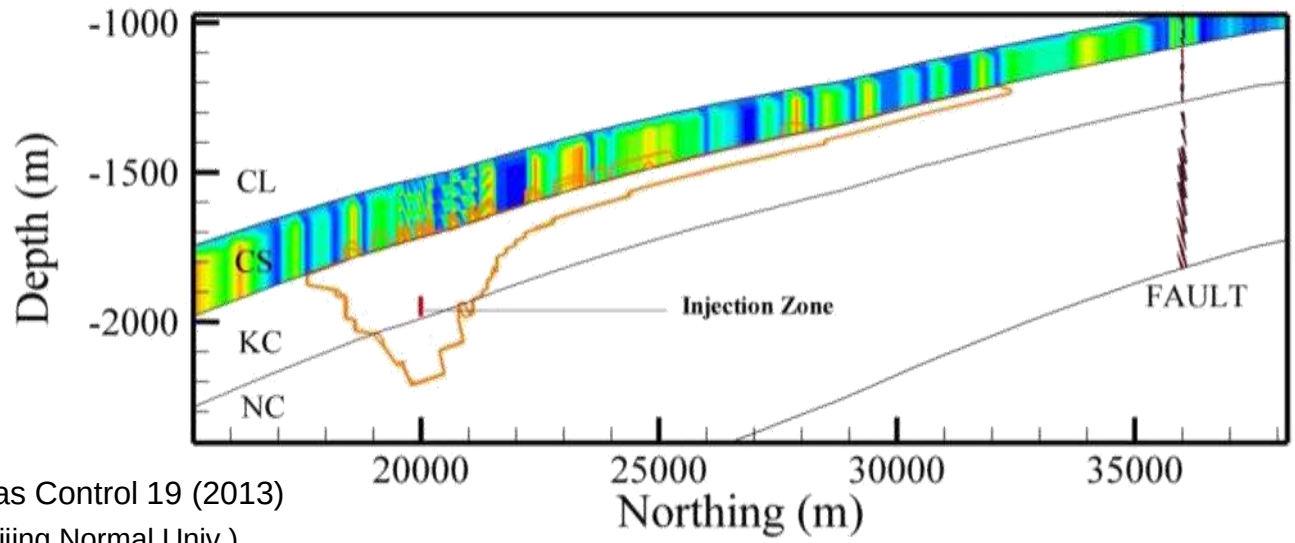



Heterogeneous permeability for CS caprock

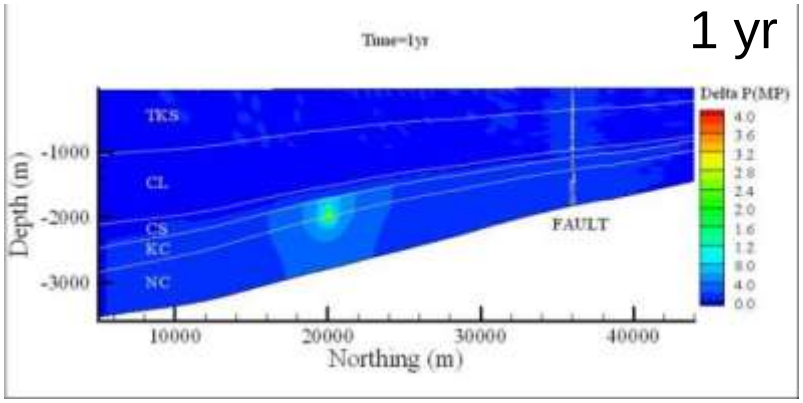
Some amount of $CO_2$ could penetrate into sealing cap

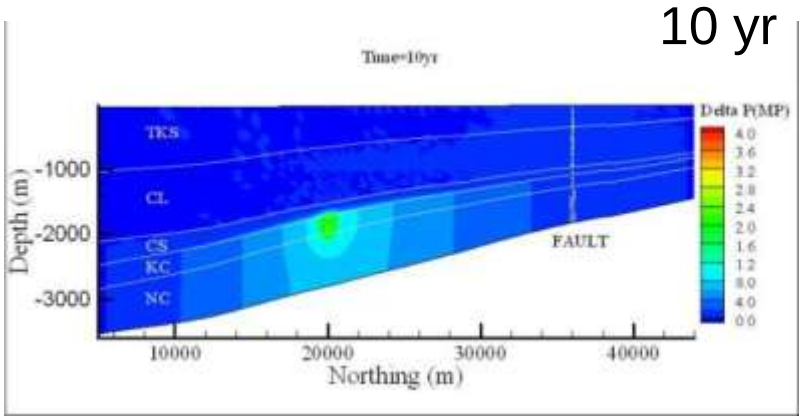
No evidence shown $CO_2$ pass through

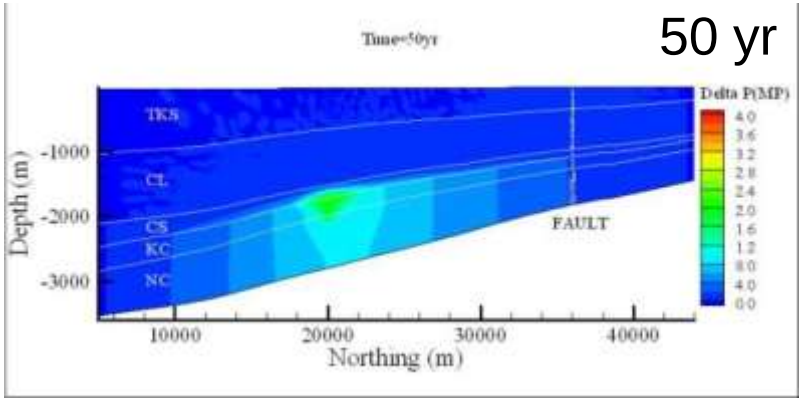


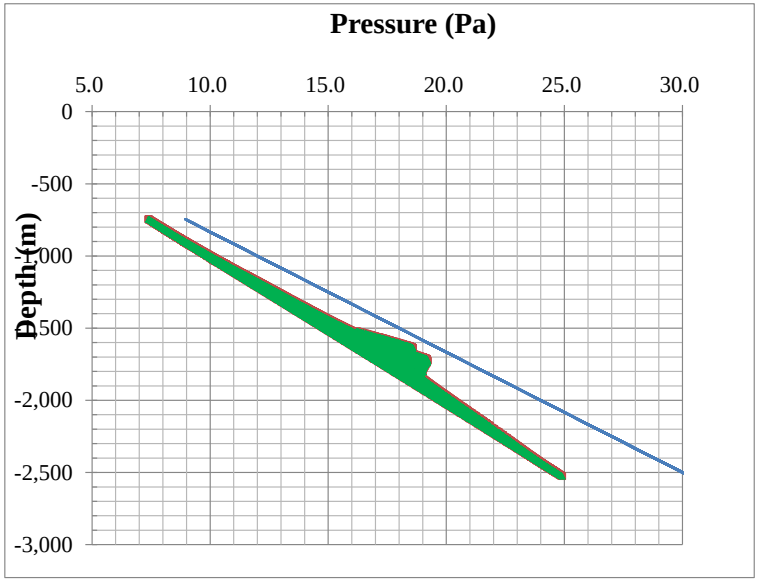

International Journal of Greenhouse Gas Control 19 (2013)
(Li et al., 2013; Joint efforts of ITRI and Beijing Normal Univ.)

# Pressure build up simulation



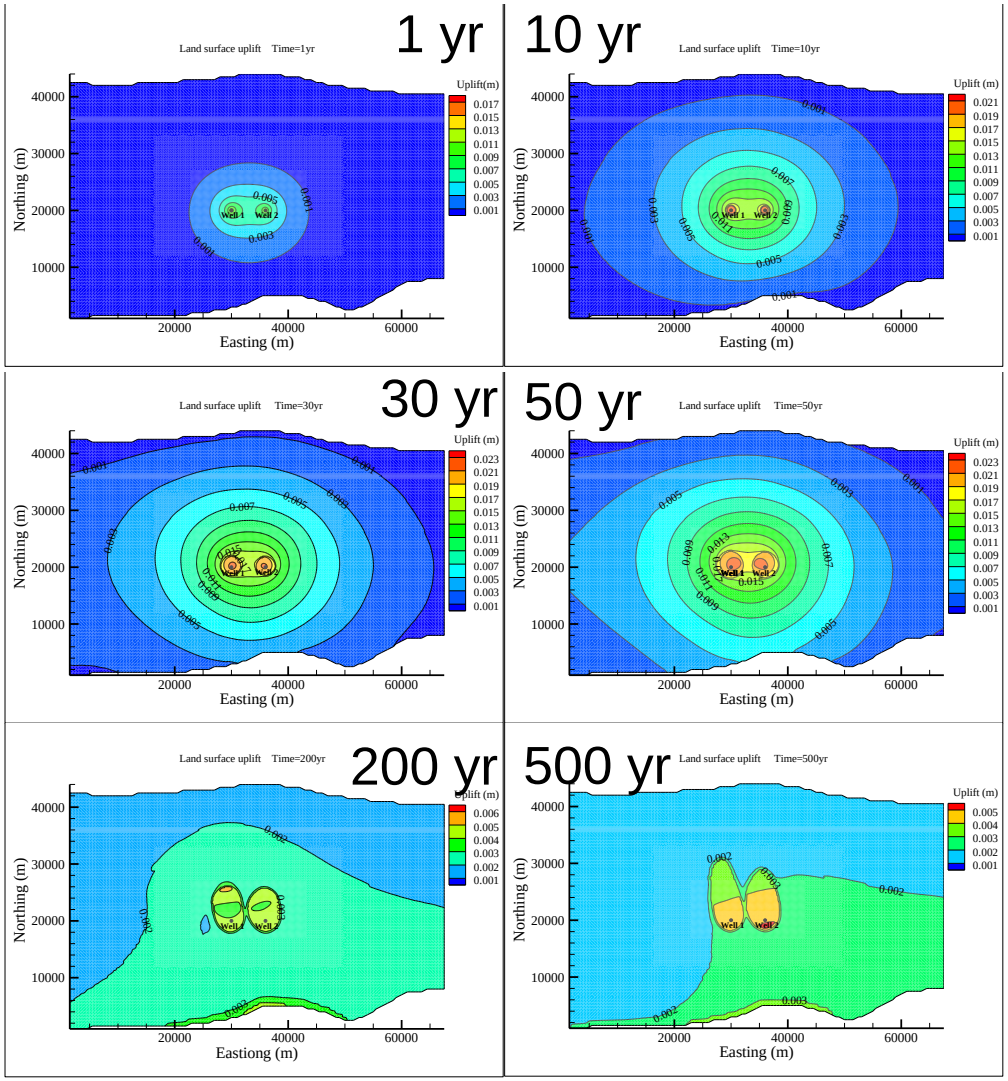

Pressure increased and extensively

All geological formation could stand pressure build up and regional seal remain untouched

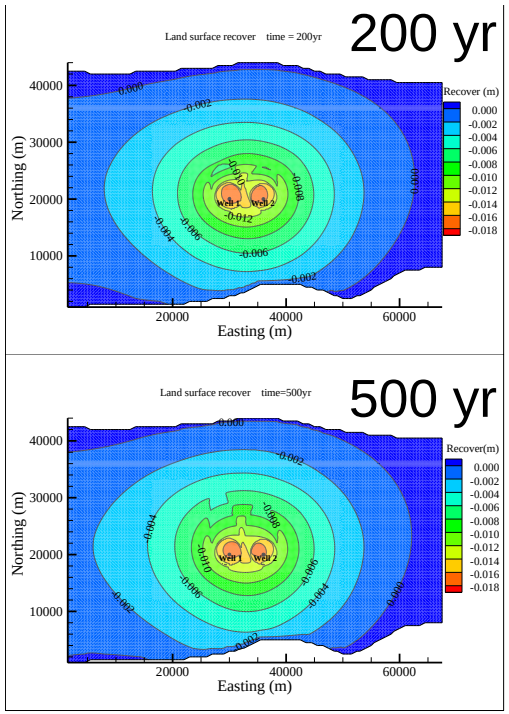
For heterogeneous permeability case, pressure only affect CS and above formation

International Journal of Greenhouse Gas Control 19 (2013)
(Li et al., 2013; Joint efforts of ITRI and Beijing Normal Univ.)

# Elevation change due to $CO_2$ injection




Land Uplift




Land Recovery

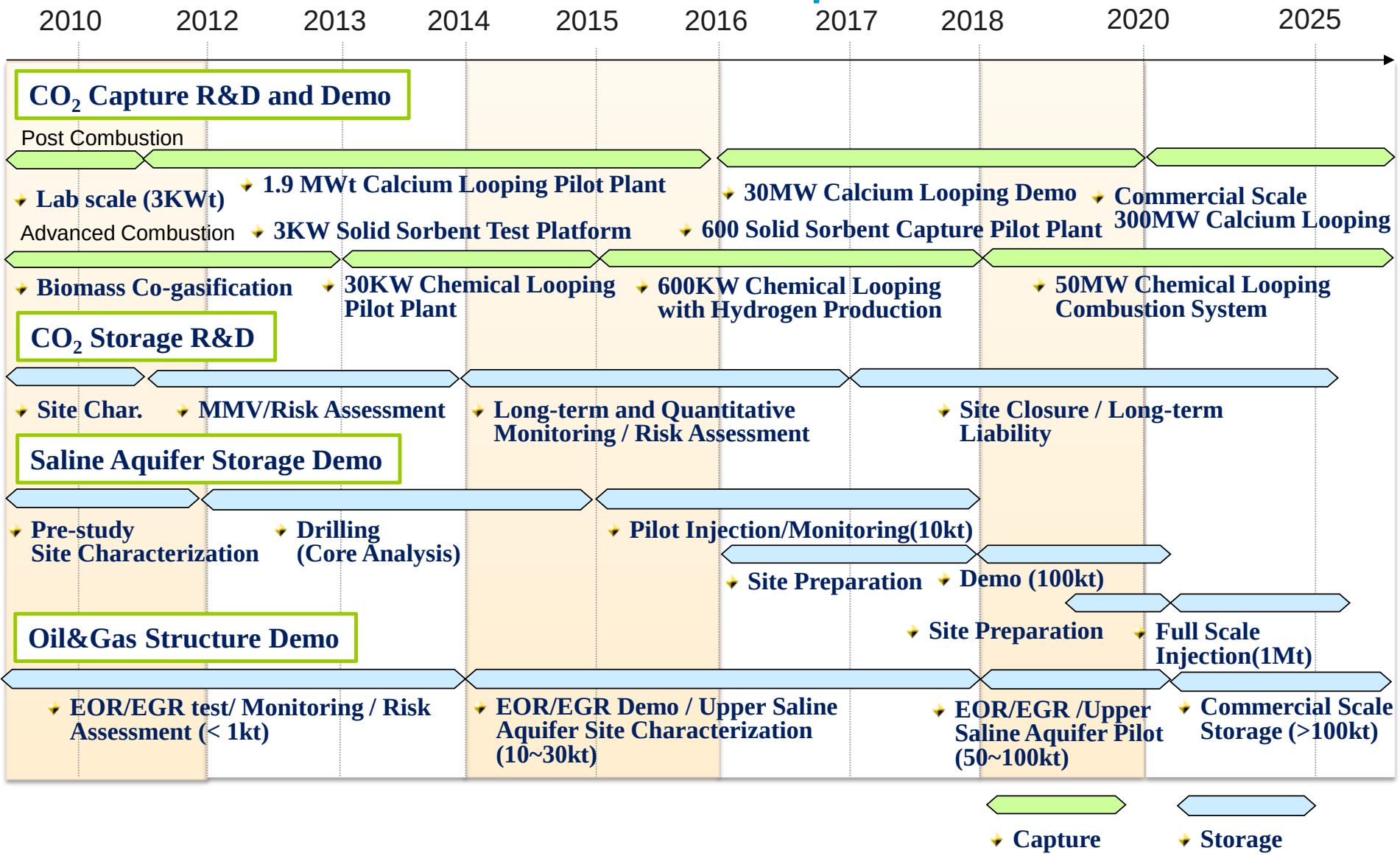
Proposed injection would introduce 0.1~2.3 cm uplift

Recovery process is much slower, may take several hundred years

International Journal of Greenhouse Gas Control 19 (2013)

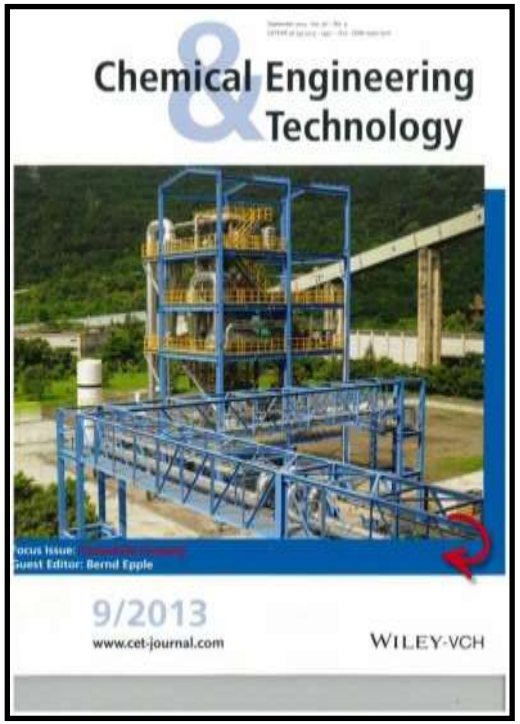
(Li et al., 2013; Joint efforts of ITRI and Beijing Normal Univ.)

# CCS RD&D Roadmap in Taiwan



# $CO_2$ Capture Pilot Plant

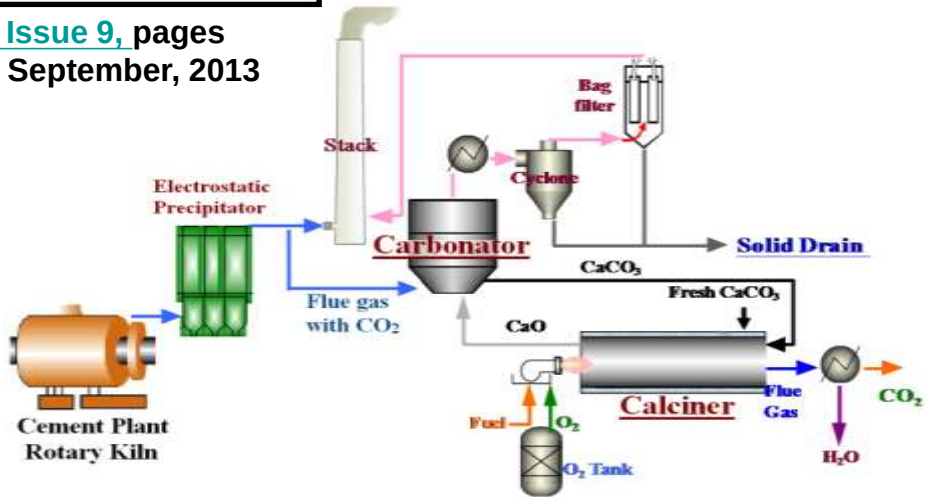
- $CO_2$ capture capacity: 1 ton/hr
- $CO_2$ Removal efficiency: >85%
- Fluidized-bed carbonator
- Carbonation rate：20~30%
- Rotary kiln with direct Oxy-fired design for calciner
- Flue gas recirculation for calcination
- Captured $CO_2$ will be liquefied for storage and utilization
- Inactive sorbent vented will be feedstock of cement plant
- Energy Penalty estimated less than 20%
- Capture cost target less than USD 40/t $CO_2$
- Iron/Steel Industry:
  - ✓ Similar concentration %
  - ✓ Limestone as feedstock




Volume 36, Issue 9, pages 1525–1532, September, 2013


Taiwan inaugurates advanced carbon capture plant

June 11th on Taiwan Today, cited by CSLF, GCCSI, $CO_2$ Capture Journal



# CSC Corporation

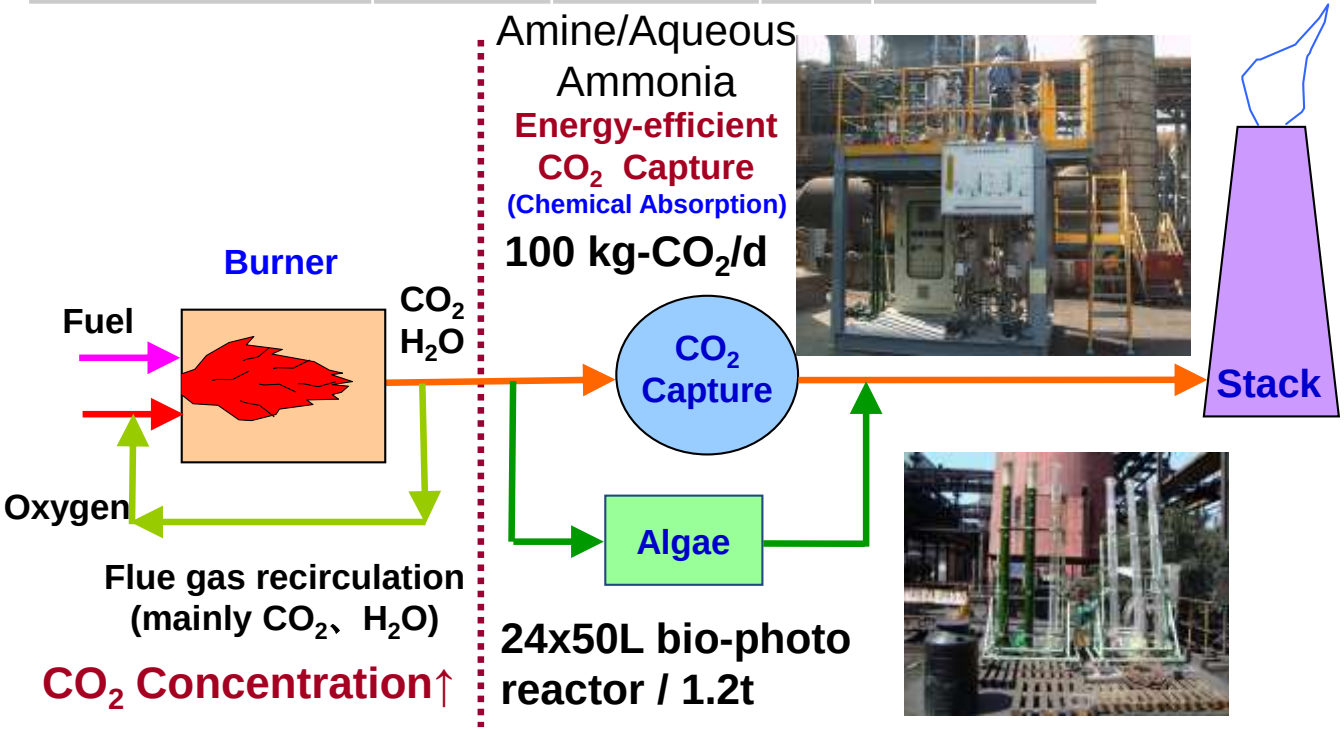
| | Lab work | Simulation | Pilot | Observe |
|---|---|---|---|---|
| Chemical Absorption | ✓ | ✓ | ✓ | ✓ |
| Physical Absorption | | ✓ | | ✓ |
| Molecular sieve | ✓ | | | ✓ |
| Mineral sequestration | ✓ | | | ✓ |
| Algae (bio-fixiation) | ✓ | | ✓ | ✓ |
| Calcium Looping | | | | ✓ |
| Other | | | | ✓ |

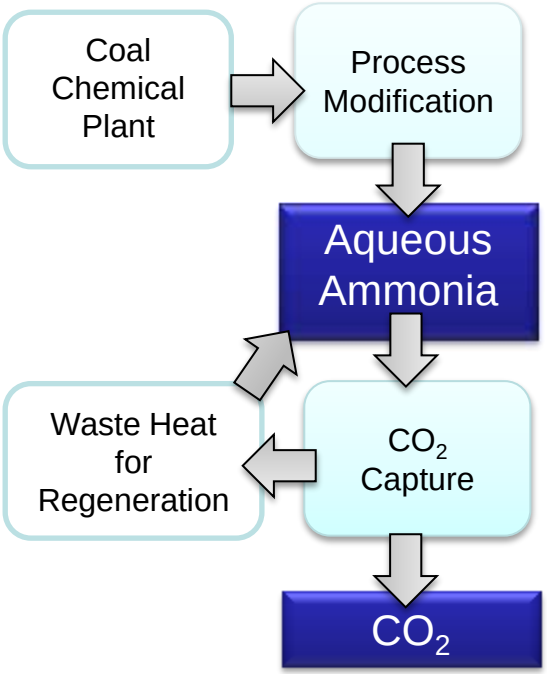
## Process Integration:

Aqueous Ammonia

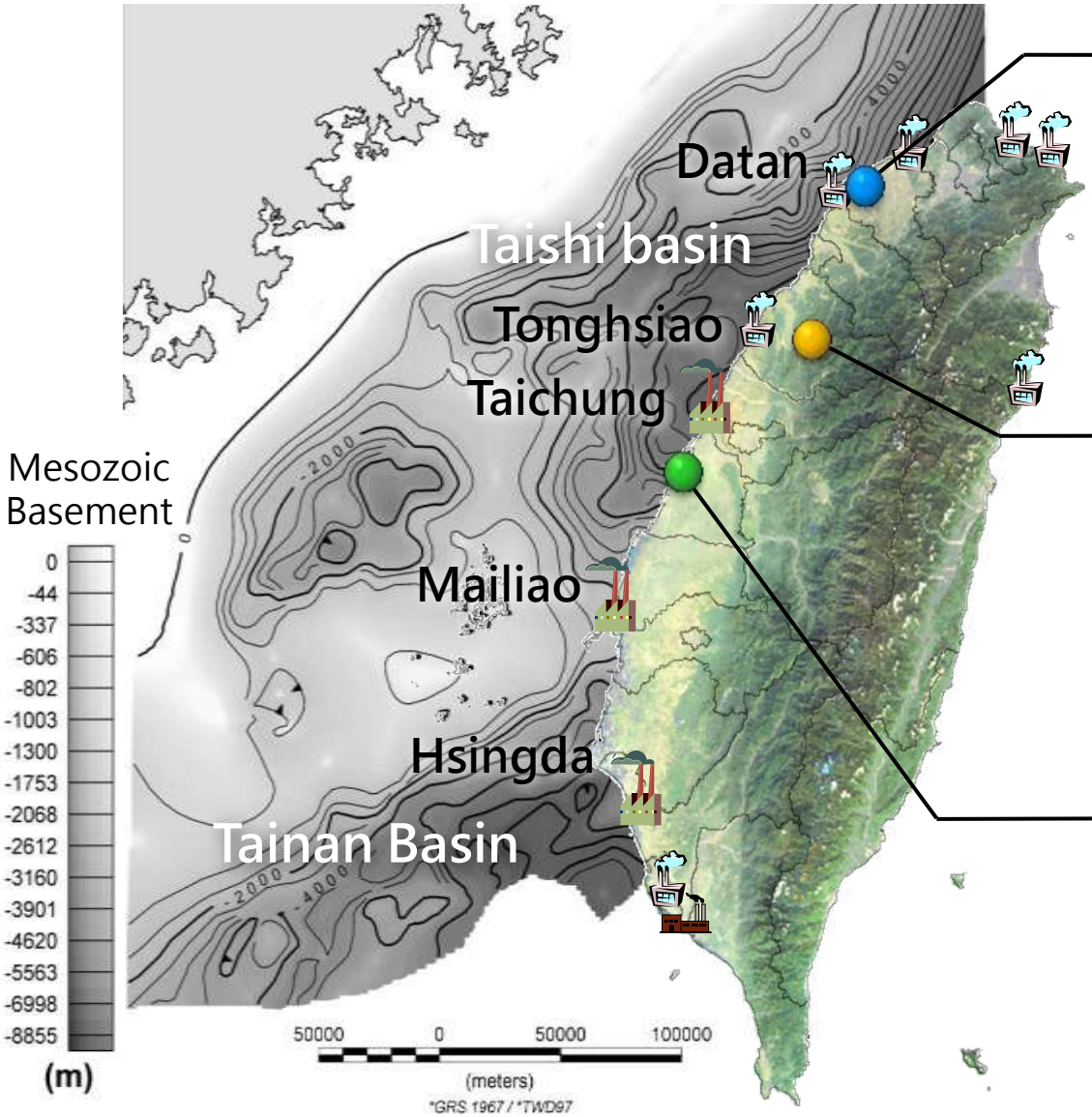
## Resource Integration:

Waste heat and water, slag, etc.



# Planned Storage Pilot Projects




## Kuanyin

- Saline Aquifer
- Site Characterization

## YHS

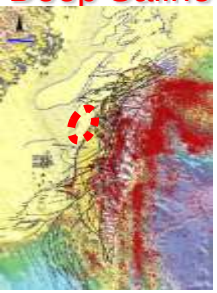
- Depleted Gas field
- EGR/EOR

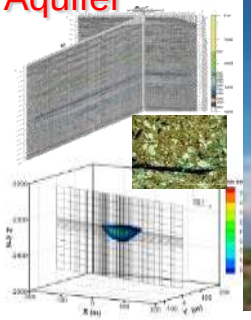
## Changbin

- Saline Aquifer
- 3,000m well

# Saline Aquifer Pilot Site Planning

Tai-hsi Basin
Deep Saline Aquifer

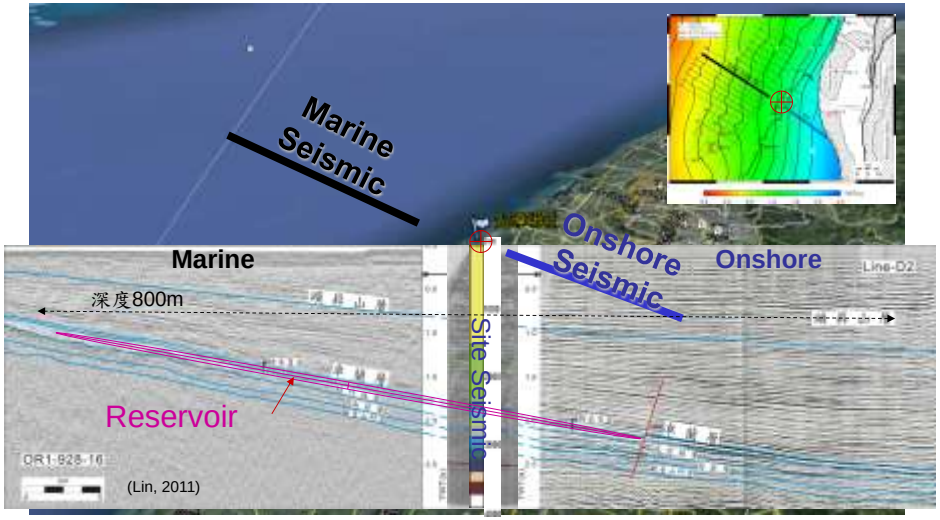


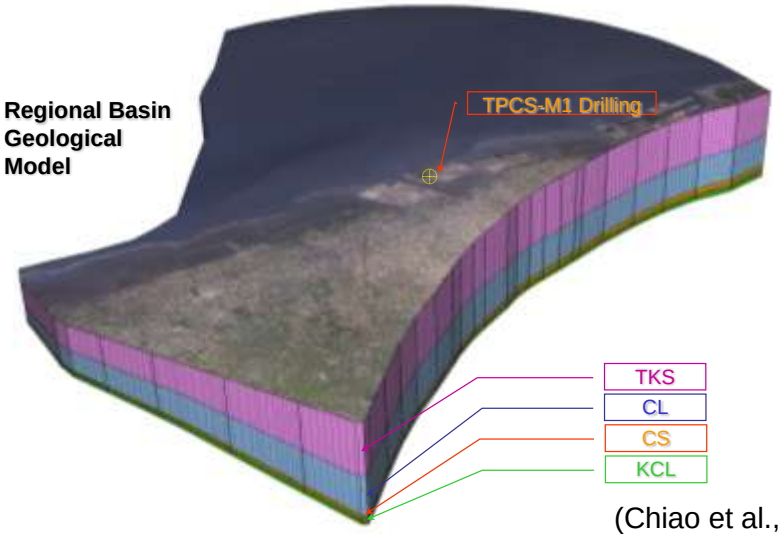



- 2012/Jul/25 Drilling Start
- 2012/Aug/03 Reach 1500 m (Cutting)
- 2012/Aug/11-12 First Round Open-hole Logging (SLB)
- 2012/September PQ Core Drilling
  1500-3000m Start-up
- 2013/Jul/31 down to 2663m (337m left)
- Will Become one of the monitoring wells


- Site screening
- Site characterization
- **Drilling**
- Core sampling
- Core analysis
- Geological analysis
- Monitoring well
- Geological analysis
- Injection well
- Geological analysis
- Injection test
- Monitoring

| 2009 | 2010 | 2011 ~2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|



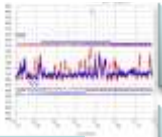




(Chiao et al., 2012)

# EGR Pilot Project Planning

**Monitoring**

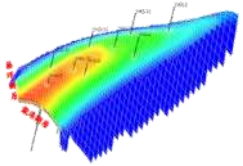
- Soil Gas
- Atmosphere $CO_2$ conc.



- Reservoir Temp/Pressure
- Baseline (ITRI)

**Simulation**

- History Matching
- Capacity Assessment



**$CO_2$ EGR/Storage**

- Site Setting
- $CO_2$ Sources
- Facility Testing
- Infrastructure
- EGR parameter acquisition

**International Organization**

- GCCC

**Public Acceptance**

- Community
- Poll

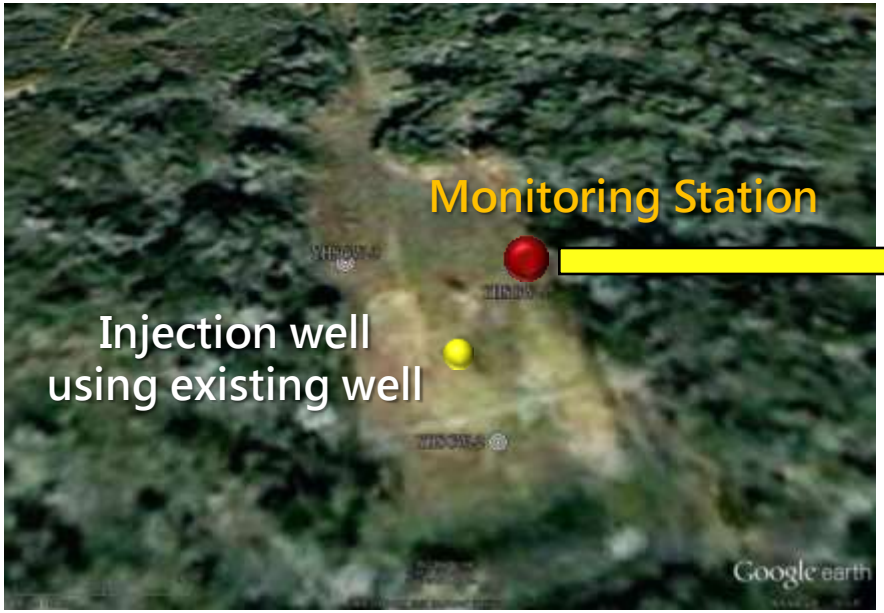
**Knowledge Management**

**Website**

**CPC EGR Phase 1**

| Phase 1 (2010~2013) | Phase 2 (2014~2017) | Phase 3 (2018~2020) |
|---|---|---|
| Capacity Evaluation<br>Existing wells/infrastructure<br>Injection facility testing<br>Purchased $CO_2$ | Reworked Well<br>Pilot scale injection<br>$CO_2$ from ITRI/TPC<br>10~30kt | Well drilling<br>Upper Saline Aquifer<br>$CO_2$ from ITRI/TPC<br>50~100kt |

# EGR Pilot Site Baseline Data



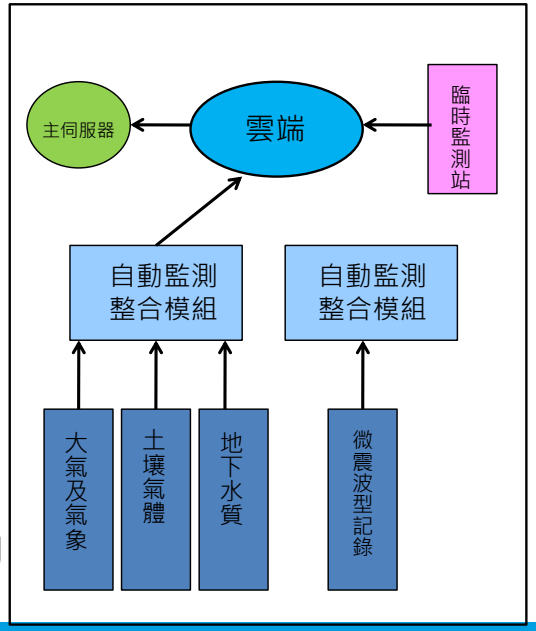



Real-time Demo

Soil gas real-time monitoring

## Multiple monitoring mechanism

- Regional groundwater sampling
- Shallow groundwater well x 3
- Regional microseismic (15 stations)
- Regional soil gas monitoring
- Meteorological station
- Leveling and GPS survey
- Atmospheric $CO_2$ monitoring & Recording




Microseismic

Field soil gas sampling

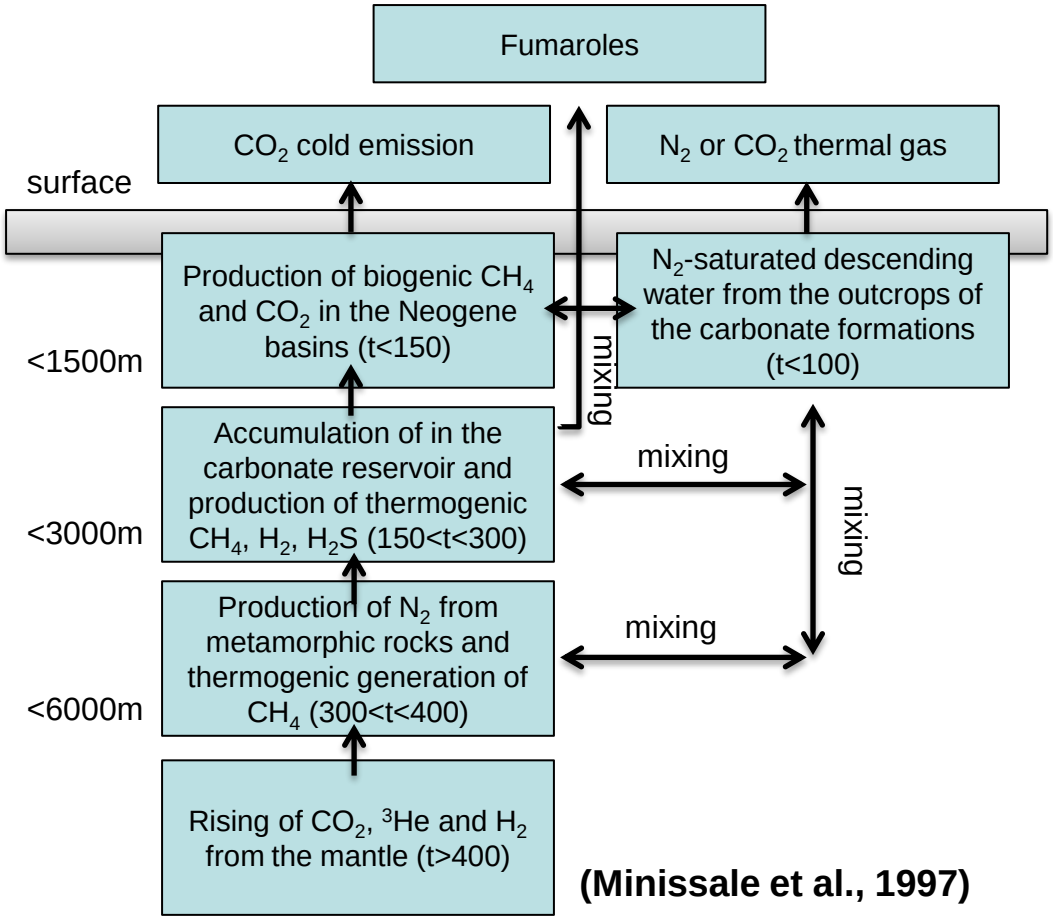
Cloud-based data archive

# Natural and Industrial Analogue Case

## Natural Analogue

- Long-term containment evidence from deep natural $CO_2$ reservoir
- Natural occurence of $CO_2$
  - ✓ Cold spring pH 6.0~6.8
  - ✓ $CO_2$ in daily live

Natural Analogue – Cold Spring




**(Minissale et al., 1997)**

## Industrial Analogue

- Underground Gas Storage

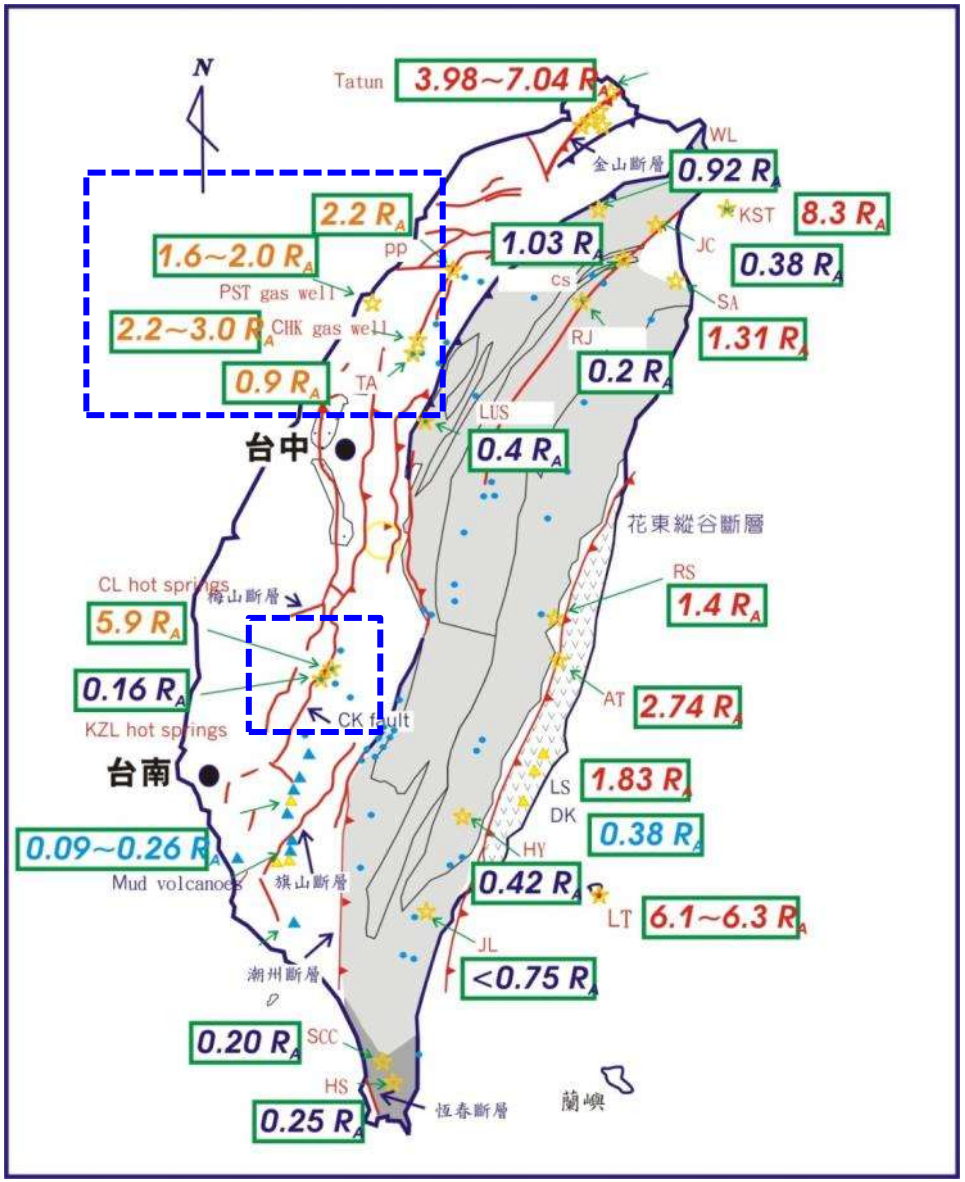
# $CO_2$ flow continuous monitoring

- The monitoring system: big funnel (1m x 1m) is used to cover the bubbling gas of the mud pool
- Thermo mass flow meter recorded the flow rate every 10 minutes
- Continuous monitoring since March 13, 2008

- $CO_2$ accounts for 87% of bubbling gas from CL mud pool, and its flux can be estimated 83~242 t・$yr^{-1}$ (mean =114 t・$yr^{-1}$)
- Considered the $CO_2$ flux and the activity of the fault, more than 900 Mt $CO_2$ were stored in the reservoir
- $CO_2$ emission in the fault zone of studied area is ca. 28~31 kt・$day^{-1}$ => 11 Mt/y

(Cheng et al, 2013)

# Natural Analogue – $CO_2$ Reservoir




(T.Y. Yang, 2013)

(1) Igneous Province:
High $^3He/^4He$ ratios (4.0~8.4 Ra) magma related

(2) Central Range Province:
0.1~0.9 Ra ➔ Crustal components

(3) W. Sedimentary Province:
Mud volcanoes are crustal component dominant (0.1~0.26 Ra)

However, unusually high ratios were obtained (up to 6.5 Ra)

- **Mantle-derived gas reservoirs do exist beneath western Taiwan**
- **$CO_2$ Miocene extensional magmatism and normal faulting and brought to shallow crust**
- **$CO_2$ have been stored more than 5 million years – long-term containment**

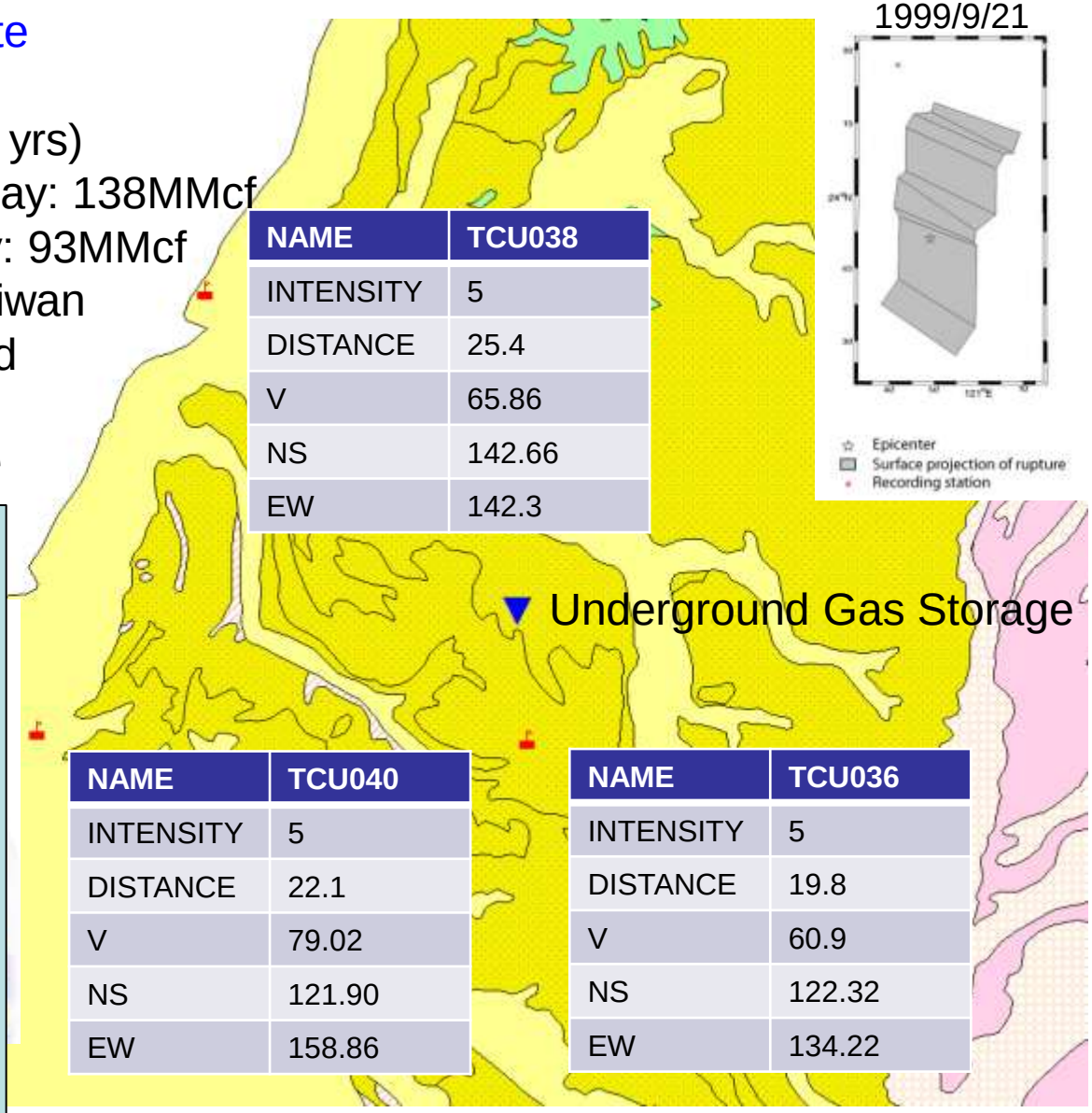
# Industrial Analogue – TCS Field

## Underground Gas Storage Site

- ✓ Produce from 1965
- ✓ Operation from 1990 (> 20 yrs)
- ✓ Maximum production per day: 138MMcf
- ✓ Maximum injection per day: 93MMcf
- ✓ Seasonal demand in N. Taiwan
- ✓ Balance market swings and production capability
- ✓ LNG terminal and pipe-line

### Chi-Chi Earthquake

- ➢ 1999/9/21 Mw 7.7
- ➢ 2,415 deaths, 29 missing
  11,305 severely wounded
  51,711 buildings destroyed
- ➢ Shallow thrust fault with large rupture area
- ➢ No leakage during earthquake
- ➢ Continuous monitoring and simulation




| NAME | TCU038 |
|---|---|
| INTENSITY | 5 |
| DISTANCE | 25.4 |
| V | 65.86 |
| NS | 142.66 |
| EW | 142.3 |

| NAME | TCU040 |
|---|---|
| INTENSITY | 5 |
| DISTANCE | 22.1 |
| V | 79.02 |
| NS | 121.90 |
| EW | 158.86 |

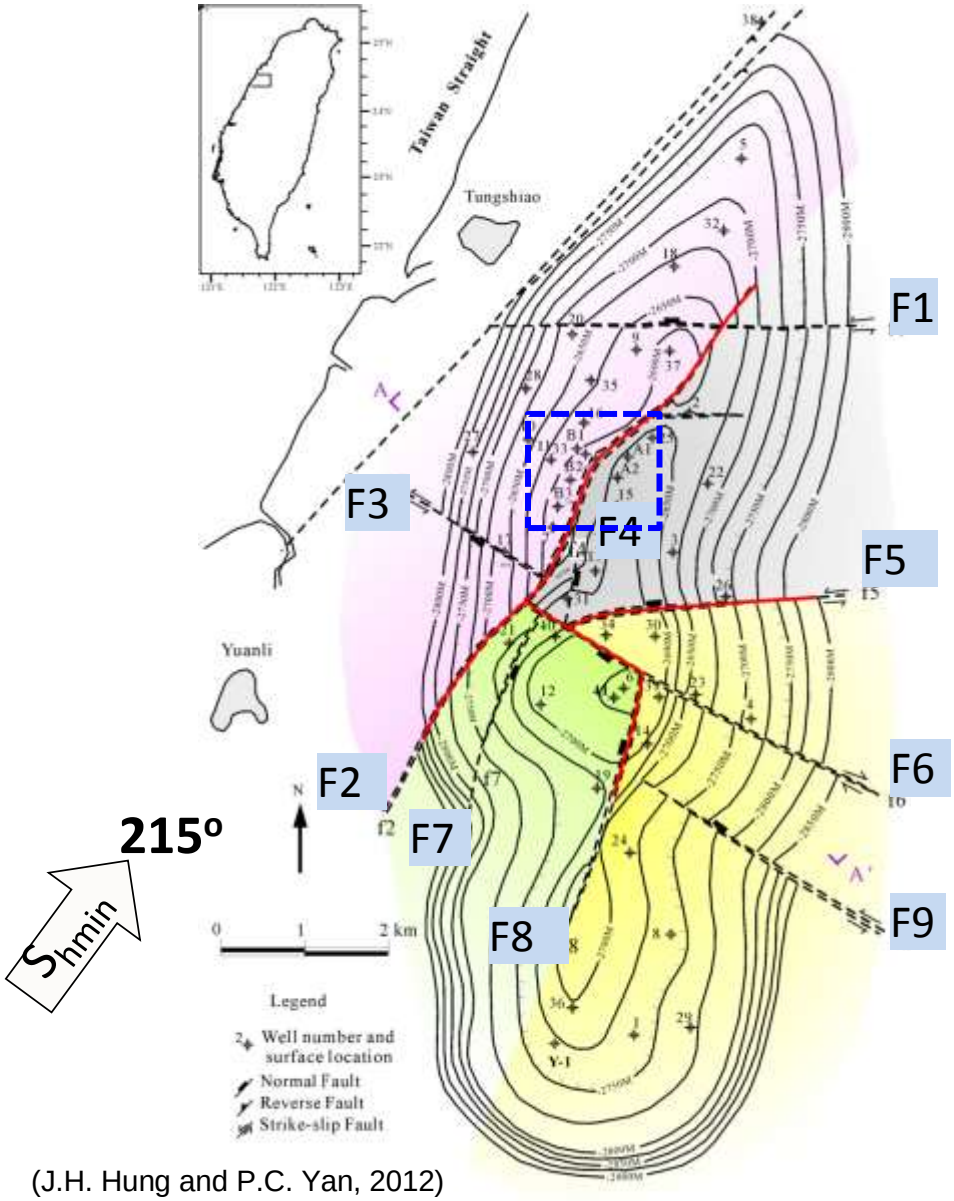
| NAME | TCU036 |
|---|---|
| INTENSITY | 5 |
| DISTANCE | 19.8 |
| V | 60.9 |
| NS | 122.32 |
| EW | 134.22 |

http://www.stanford.edu/~bakerjw/pulse_classification_v2/1480.html

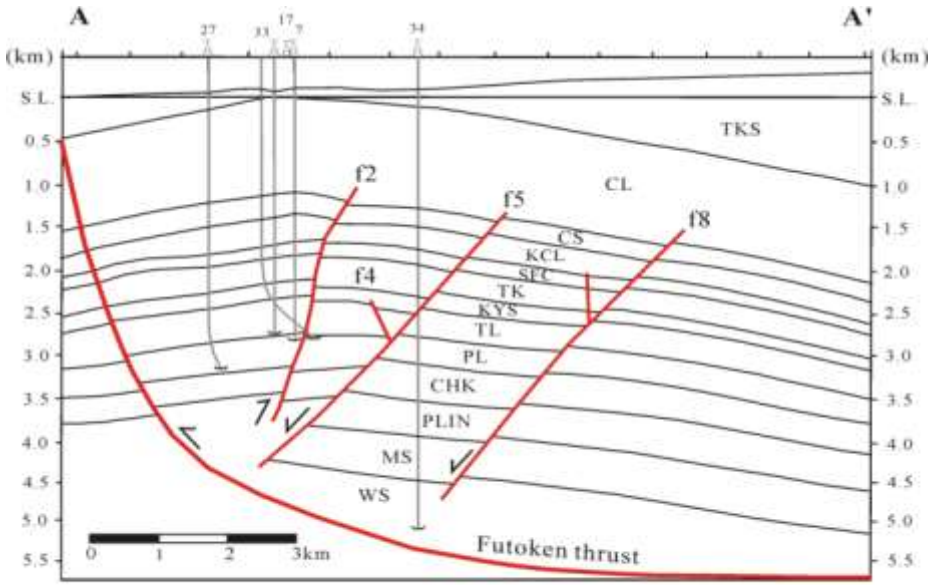
# Underground Gas Storage – TCS Field

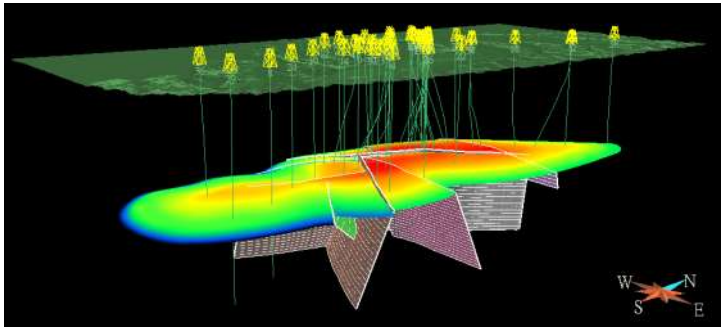
**Stress State at the top of Talu (T1 Ss)**

**Reverse/Strike-slip faults**



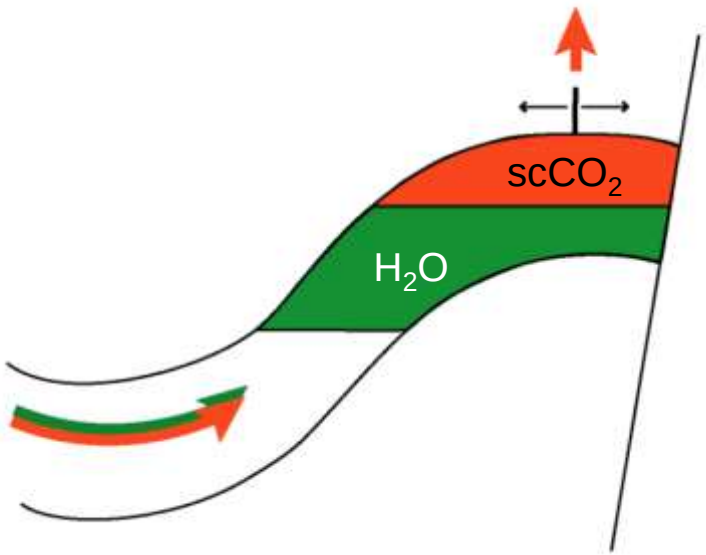

(J.H. Hung and P.C. Yan, 2012)



## Hydraulic fracturing of cap rock

**Pressure at crest has reached "leak off"**

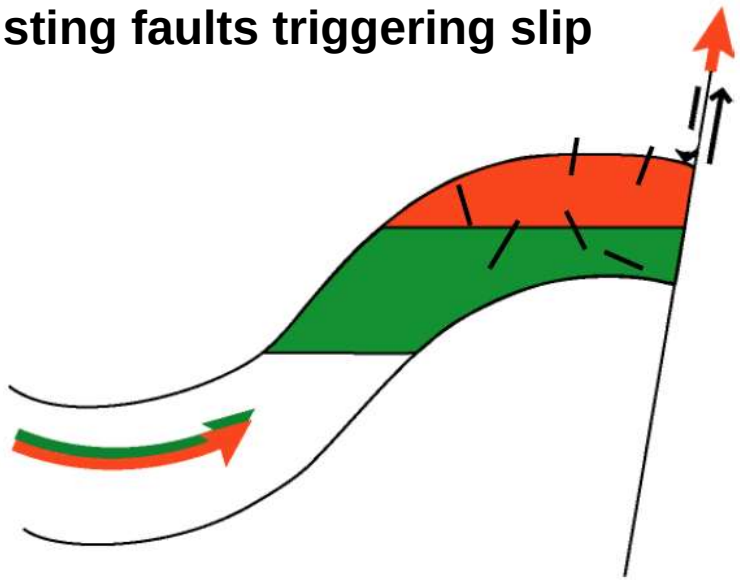



In normal faulting regime:
buoyancy pressure = Shmin
Results in **vertical hydrofracture**

(J.H. Hung and P.C. Yan, 2012)

## Pressure Increase – Fault Reactivation

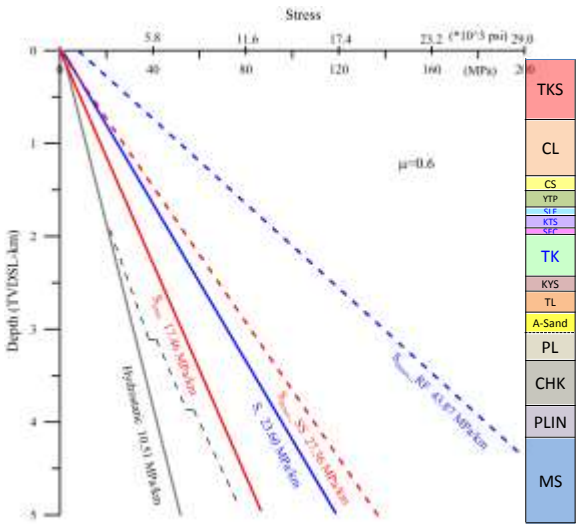
**Fluid injection reduces the effective normal stress on optimally oriented pre-existing faults triggering slip**

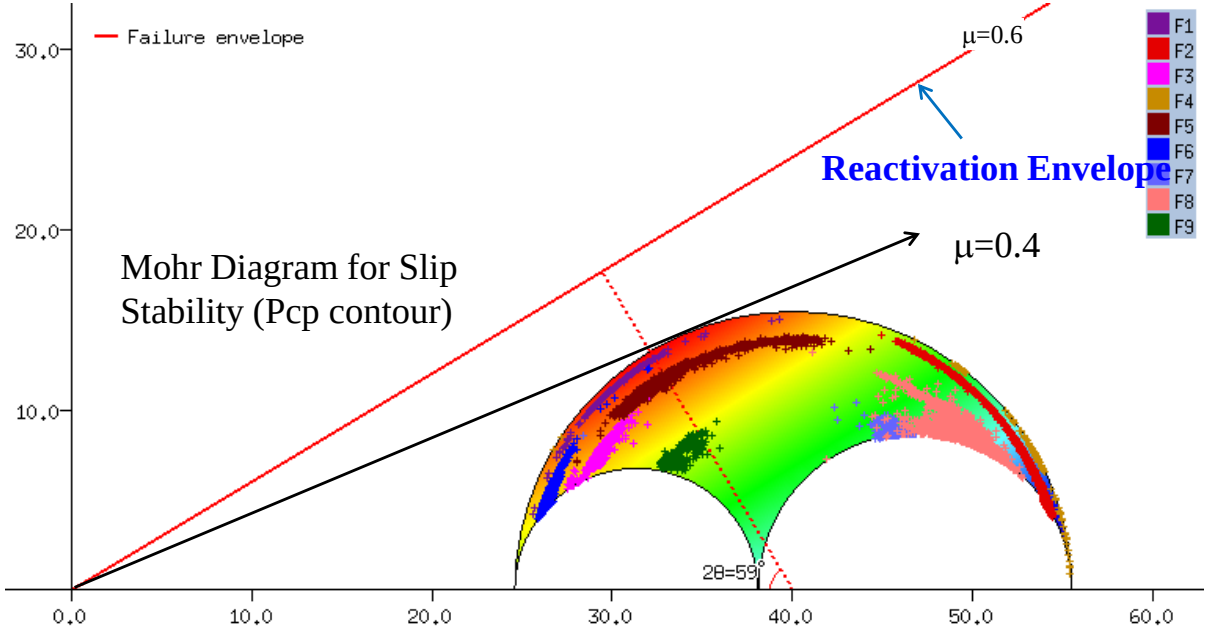


- High-permeability pathways within the reservoir
- Induced seismicity

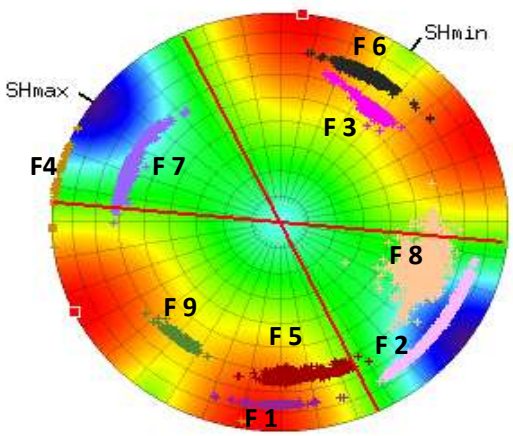
Buoyancy Pressure =
Critical Pore Pressure
(based on Coulomb Failure Criterion)
results in **slip on optimally oriented faults**

# Reactivation risk of faults at the depth 2750 m

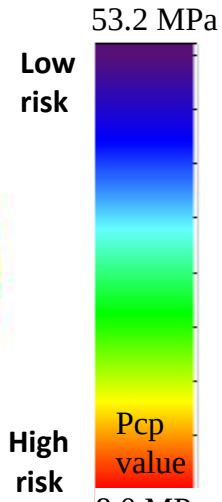


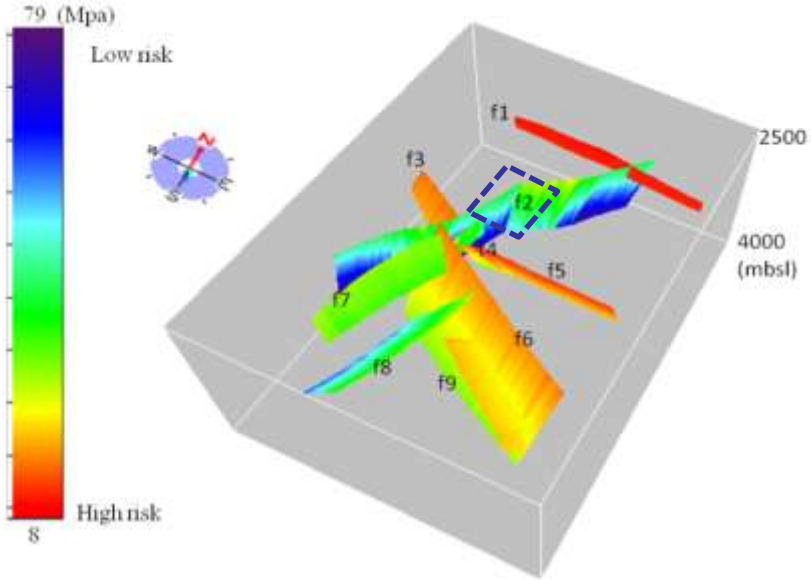




## Stress Summary




Polar projection- pole to fault surface




(J.H. Hung and P.C. Yan, 2012)

## Fault reactivation risk for all faults at depth from T1 to -5 km

# Brief Summary of TCS field

- Geomechanical analysis shows that gas injection into the Talu sand of the TCS anticline will not induce slip on pre-existing mapped faults or fracturing of cap rock.
- There is no documented evidence of casing failure in 40 wells due to fault reactivation or any reported leakage indicators from monitors deployed in the surface
- In addition, there has been no induced seismicity associated with fluid injection over the past 20 years
- The best strategy is to avoid injecting into faults, and if pore pressure builds, wait until flow rate increase in the reservoir.

(J.H. Hung and P.C. Yan, 2012)

# Conclusion

- CCS is an important carbon reduction technology for Taiwan – solution and green opportunity
- Assessment of Geological Storage in Taiwan
  - Adequate potential – near and off-shore
  - Pilot storage projects underway – public acceptance is an important issue
  - Suitable environment for long-term storage of $CO_2$
  - Safe operation experience for underground gas storage for decades

# Acknowledgements

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And co-contributors

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工業技術研究院
Industrial Technology
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# Thank you