CO₂ 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 Award for Sidelighter and aFLASMA
2012 - R&D 100 Awards for Lightwow, TERRI, Sidelighter, aFLASMA, LightLight, and ARA Camp
2012 - Aviation Week’s A&D SIC Award for REDCO2
2011 - The Wall Street Journal’s 2011 Technology Innovation Award for 3R e-Paper and Spray-IT
2011 - ITRI as Excellent Organization, Solar Industry Awards, UK for Solar Radome
2011 - R&D 100 Awards for 2R e-Paper and HyTAC
2011 - Silver Award, The Society for Information Display (SID) Display of the Year Awards (DVA) for ITRI Flexible Substrate for Displays
2010 - R&D 100 Awards for REDCO2, 2GSDW, and FlexUFO
2009 - R&D 100 Awards for SCOSA (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 Drained Lighting System
2009 - Red Dot Design Award for Flexo 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 CO₂ Capture
- Chemical Looping
- Coal and Bio-mass Gasification

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

**Geological Technology**
- CO₂ Geological Storage
- Deep Geological Repository
- Advanced Geo-fluid Sampling

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

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

**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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- J.J. Ou, J.D. Chen, R.F. Shen (CSC Corporation)
- Shin-Tai Hu, Ta-Lin Chen, Chenners Chen-Hui Fan, Ch-Chung Tseng (CPC Corporation)
- Chung-Hui Chiao, Lian-Tong Hwang, Ming-Wei Yang (Taiwan Power Company)
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
- Emit approximately 270Mt CO₂ in 2010, ~0.89% of global CO₂ emission, ranked 20nd globally (IEA)
- CCS will contribute 12% CO₂ emission reduction, about 36.7 million tons CO₂ per year in 2025 according to proposed NAMAs
CO₂ capture: Large and stationary point emitters
CO₂ storage: Deep saline aquifers and Oil/gas structures

CO₂ capture: technology and commercial-scale demo & verification before 2025 with solid sorbents or chemical looping
CO₂ storage: pilot injection projects, site characterization, storage capacity assessment, simulation and prediction of CO₂ plume migration, MMV, and risk assessment
Cenozoic Basins in western Taiwan

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

(ITRI, 2008)
Opportunities for 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**

![Map of Taiwan with seismic survey results](image)

(Mouthereau et al., 2002)

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

ITRI, 2009
Major CO₂ 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 CO₂ storage are available.

- **Taichung**: 39.7 MtCO₂/yr
- **Mailiao**: 32.4 MtCO₂/yr
- **Hsingda**: 15.2 MtCO₂/yr
- **Dalin**: 2.09 MtCO₂/yr
- **Linkou**: 4.41 MtCO₂/yr
- **Tongshiao**: 2.39 MtCO₂/yr
- **Shiehe**: 1.60 MtCO₂/yr
- **Shenao**: 2.64 MtCO₂/yr
- **Hoping**: 7.7 MtCO₂/yr

87.3 MtCO₂/yr

Estimated CO₂ storage capacity:
- Onshore oil and gas structures: 2,800 Mtons
- Coastal and offshore deep saline aquifers: 9,000 Mtons

(ITRI, 2009)
(Andrew T.S. Lin and C.N Yang, 2013)
Scenarios for geologic storage of CO2 in Taiwan and monitoring techniques for storage security

A: Onshore traps  
B: Saline formations near the coastline  
C: Offshore saline formations  
D: Offshore traps

(Andrew T.S. Lin, 2010)
Large-scale CO$_2$ Storage Assessment

- Hypothetic Site
- 3D Mesh
- Stratigraphic Column
- Regional Seal CS
- KC
- NC
- Double Well Injection

International Journal of Greenhouse Gas Control 19 (2013) (Li et al., 2013; Joint efforts of ITRI and Beijing Normal Univ.)
CO₂ migrate toward seaside

KC could store 5Mt/yr by 50 yrs
CS could contain CO₂ for 500 yrs
5Mt/yr injection for 50 yrs (250Mt)

(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

(Li et al., 2013; Joint efforts of ITRI and Beijing Normal Univ.)
Elevation change due to CO$_2$ injection

Land Uplift

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

Recovery process is much slower, may take several hundred years

Proposed injection would introduce 0.1~2.3 cm uplift

Land Recovery
CO₂ Capture Pilot Plant

- CO₂ capture capacity: 1 ton/hr
- CO₂ 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 CO₂ 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 CO₂
- Iron/Steel Industry:
  - Similar concentration %
  - Limestone as feedstock

Taiwan inaugurates advanced carbon capture plant
June 11th on Taiwan Today, cited by CSLF, GCCS, CO₂ Capture Journal

Volume 36, Issue 9, pages 1525–1532, September, 2013
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Process Integration:
Aqueous Ammonia

Resource Integration:
Waste heat and water, slag, etc.

CSC Corporation

Amine/Aqueous Ammonia
Energy-efficient CO₂ Capture (Chemical Absorption)
100 kg-CO₂/d

Burner
Fuel → CO₂ → H₂O
Oxygen
Flue gas recirculation (mainly CO₂, H₂O)

CO₂ Capture

Stack

24x50L bio-photo reactor / 1.2t

Algae

Aqueous Ammonia

Process Modification

Coal Chemical Plant

Waste Heat for Regeneration

CO₂ Capture

CO₂
Planned Storage Pilot Projects

- **Kuanyin**
  - Saline Aquifer
  - Site Characterization

- **YHS**
  - Depleted Gas field
  - EGR/EOR

- **Changbin**
  - Saline Aquifer
  - 3,000m well

Map showing locations and details of the planned storage pilot projects in Taiwan.
Saline Aquifer Pilot Site Planning

Tai-hsi Basin Deep Saline Aquifer

Site Characterization Well 3000m Deep

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

2009

2010

2011 ~2013

2014

2015

2016

2017

2018

- 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

Regional Basin Geological Model

Reservoir

Marine Seismic

Onshore Seismic

Onshore

Onshore

TKS

CL

CS

KCL

(Chiao et al., 2012)
EGR Pilot Project Planning

Monitoring
- Soil Gas
- Atmosphere CO₂ conc.
- Reservoir Temp/Pressure
- Baseline (ITRI)

Simulation
- History Matching
- Capacity Assessment

CO₂ EGR/Storage
- Site Setting
- CO₂ Sources
- Facility Testing
- Infrastructure
- EGR parameter acquisition

International Organization
- GCCC

Public Acceptance
- Community
- Poll

Knowledge Management
- Website

CPC EGR Phase 1

Capacity Evaluation
- Existing wells/infrastructure
- Injection facility testing
- Purchased CO₂

Reworked Well
- Pilot scale injection
- CO₂ from ITRI/TPC
- 10~30kt

Well drilling
- Upper Saline Aquifer
- CO₂ from ITRI/TPC
- 50~100kt

Phase 1
(2010~2013)

Phase 2
(2014~2017)

Phase 3
(2018~2020)

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IEAGHG/IETS Iron and Steel Industry CCUS and Process Integration Workshop, Tokyo
**EGR Pilot Site Baseline Data**

- **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\textsubscript{2} monitoring & Recording

- Real-time Demo
  - Soil gas real-time monitoring
  - Field soil gas sampling
  - Cloud-based data archive
  - Microseismic
  - Cloud-based data archive

- Monitoring Station
  - Injection well using existing well

- Groundwater
  - Rain gauge
  - Meteorological station

- Injection well using existing well
Natural and Industrial Analogue Case

Natural Analogue

- Long-term containment evidence from deep natural CO₂ reservoir
- Natural occurrence of CO₂
  - Cold spring pH 6.0~6.8
  - CO₂ in daily live

Natural Analogue – Cold Spring

Industrial Analogue

- Underground Gas Storage
CO₂ 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

- CO₂ 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 CO₂ flux and the activity of the fault, more than 900 Mt CO₂ were stored in the reservoir
- CO₂ emission in the fault zone of studied area is ca. 28~31 kt • day⁻¹ => 11 Mt/y (Cheng et al, 2013)
Natural Analogue – \( \text{CO}_2 \) Reservoir

- **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

(1) **Igneous Province:** High \(^3\)He/\(^4\)He 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)

(T.Y. Yang, 2013)
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 load balancing

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

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**

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**

(J.H. Hung and P.C. Yan, 2012)
Reactivation risk of faults at the depth 2750 m

Mohr Diagram for Slip Stability (Pcp contour)

Reactivation Envelope

μ=0.6

μ=0.4

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

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