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The Status of CCS Development in Taiwan

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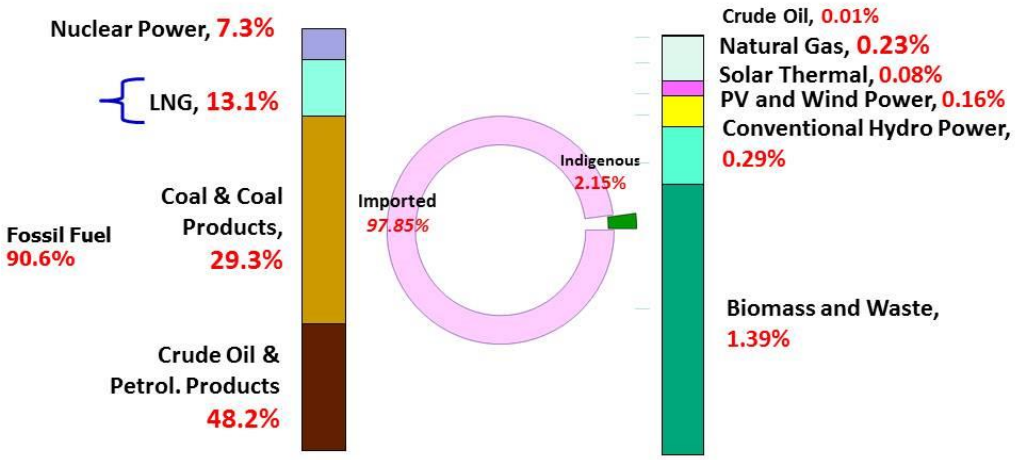
Energy Mix (1/2)

Total Primary Energy Supply (2015)
145 Million KLOE



Source: BOE (2016), Monthly Energy Statistics.

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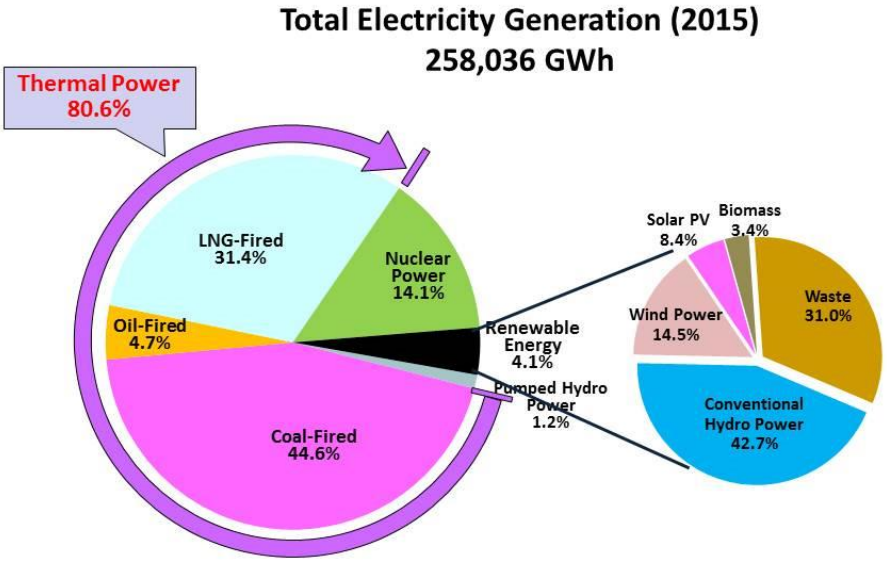
Energy Mix (2/2)



Source: BOE (2016), Monthly Energy Statistics.

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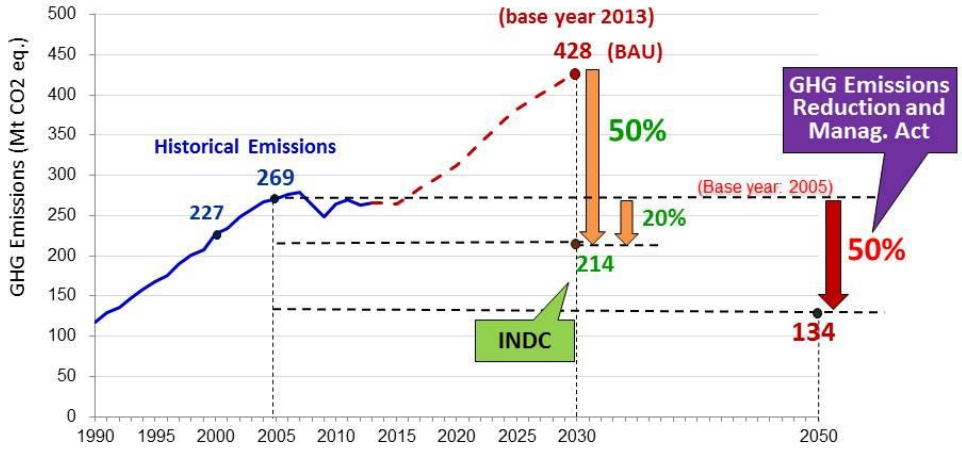
Long Term GHG Emissions Reduction Target



Note: 1. To achieve GHGs Reduction Target, energy saving and low-carbon energy supply measures should be undertaken aggressively, while carbon sink and GHG reduction abroad should also be promoted.
2. The main source of GHGs emission is fuel combustion, which accounts for 87.55%, and the GHGs emission from industrial process accounts for 7.19%.

Source: Environmental Protection Administration, R.O.C.

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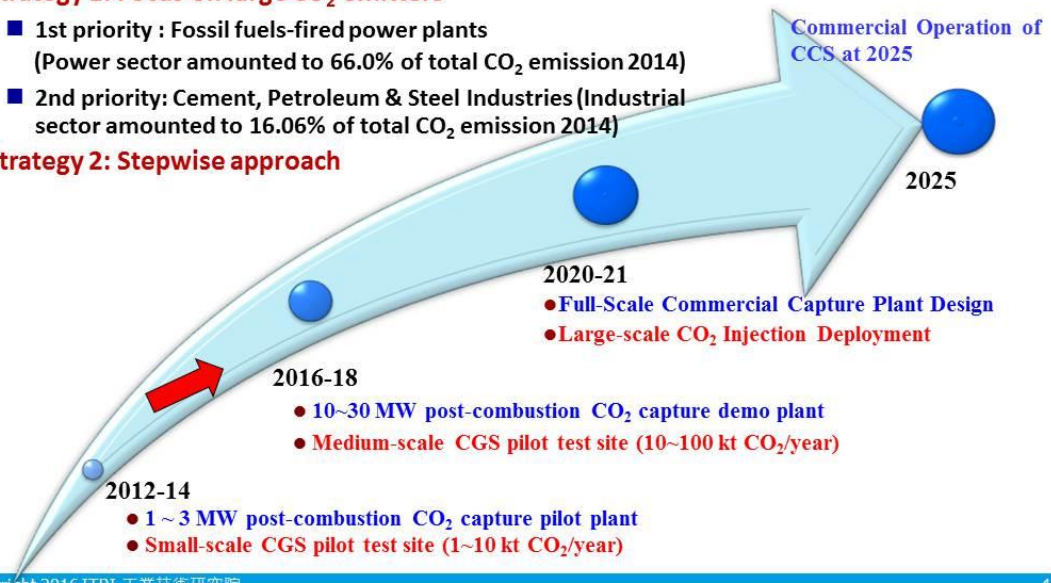
Proposed CCS Development Roadmap

MOEA has established a CCS R&D Alliance since 2010/01/18

Strategy 1: Focus on large CO_2 emitters

- 1st priority : Fossil fuels-fired power plants (Power sector amounted to 66.0% of total CO_2 emission 2014)
- 2nd priority: Cement, Petroleum & Steel Industries (Industrial sector amounted to 16.06% of total CO_2 emission 2014)

Strategy 2: Stepwise approach



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CCS Technology Development

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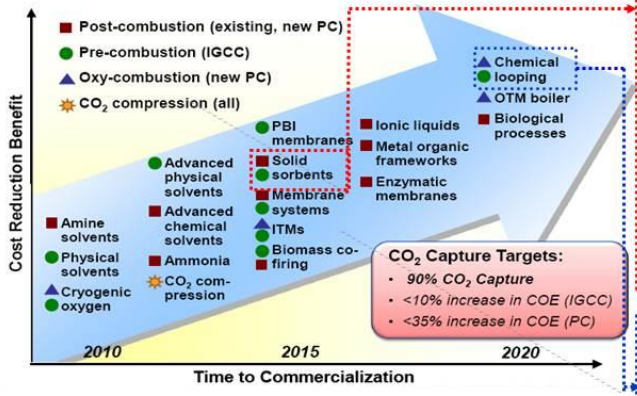
CO_2 Capture Technology Approach-ITRI



Post-combustion

- **Calcium looping**
  - limestone ($CaCO_3$) is cheap and abundant in Taiwan
  - high temperature waste heat has higher valued application
- **Solid sorbents (MSP)**
  - high porous volume and adsorption capacity
  - low energy consumption.

Oxyfuel / Pre-combustion

- **Chemical looping (Iron looping)**
  - metal oxidizer to substitute ASU
  - obtain high purity CO_2 and H_2
- **Gasification**
  - coal and biomass co-gasification
  - integrated CO_2 capture with zero emission

- PBI: polybenzimidazole
- ITM: ion transport membrane
- MOF: metal organic framework
- CAR: Ceramic Autothermal Recovery
- OTM: oxygen transport membrane
- MSP: mesoporous silica-based particles

Source: José D. Figueroa, National Energy Technology Laboratory (NETL), USDOE

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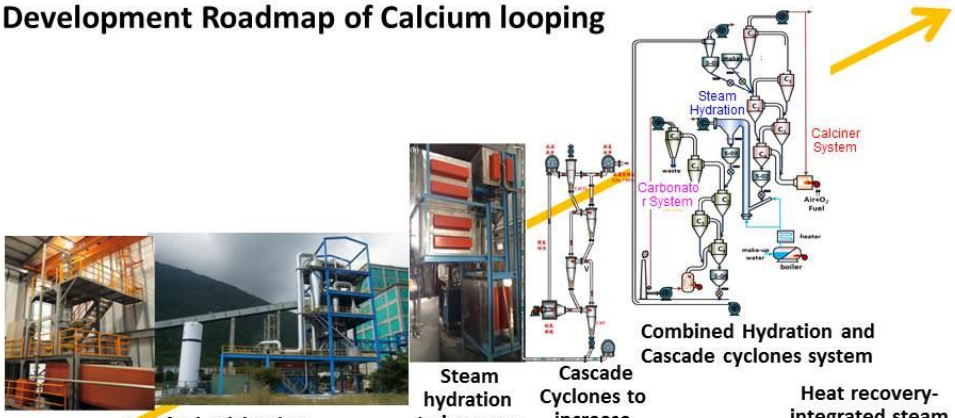
ITRI – R&D Activities(1/6)

■ **Development Roadmap of Calcium looping**



Oxy-fuel calcination with FGR

Steam hydration to increase cycle times

Cascade Cyclones to increase Energy Efficiency

Combined Hydration and Cascade cyclones system

Heat recovery-integrated steam generation

Scale	3kWt	1.9MWt	30MWt	Full Scale
Capture Cost		USD 45/t CO_2	USD 30/t CO_2	USD 20/t CO_2

2008 2010 2015 2020 2025

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ITRI – R&D Activities(2/6)

- **Establish the world's largest pilot plant for carbon dioxide capture using calcium looping in 2013**
  - Scale: ~ 1.9 MWt (flue gas: 3.1 t/hr, capture rate: 1ton CO_2/hr)
  - Carbonator: Fluidized bed
  - Calciner: rotary kiln (oxy-fuel combustion and flue gas recirculation)
  - Accumulation operation time about 2600hr, Continuous run time>106hr
  - Capture efficiency> 90% and calcination efficiency> 80%
  - Deactivated adsorbent completely serves as cement raw material

$CO_2 + CaO \rightarrow CaCO_3 + 178.8$ kJ

$CaCO_3 \rightarrow CO_2 + CaO - 178.8$ kJ

- **Won the 2014 R&D 100 Awards in the "Environmental Technologies" category**

Ca-Looping test facility site located Hoping Cement plant

1.9MWt Pilot Plant & 500kWt New Generation System

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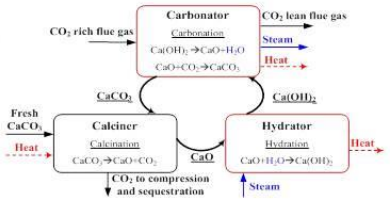
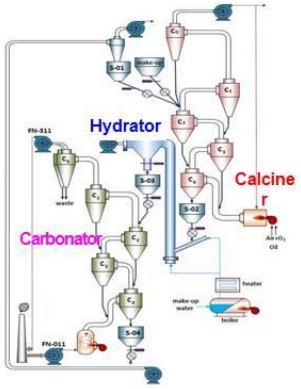
ITRI – R&D Activities(3/6)

■ New Generation Cal–Looping System

- **Integrate a steam hydration process into the calcium looping system**
  - Convert CaO to $Ca(OH)_2$ via steam hydration
  - Sorbent reactivate its activity to increase conversion rate
  - Decrease sorbent circulation amount (reactor size)
- **Utilize cascade cyclones to develop a new calcium looping system**
  - Combine calcination and carbonation in a cascade cyclones system
  - Enhance heat exchange performance
  - Reduce the land acquisition demand

- **Established 500kWt Test Facility**
  - Carbonator: Cascade cyclone
  - Hydrator: Entrained-bed
  - Calciner: Cascade cyclone and Oxy-fuel combustion
  - 0.16 ton/hr CO_2 capture capacity





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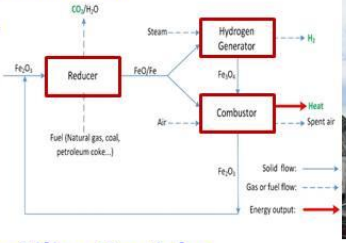
ITRI – R&D Activities(4/6)

Iron Based Looping Process for CO_2 Capture and H_2 Generation

- 30 kWt Iron Looping System in southern Taiwan
  - ✓ Main components: reducer, oxidizer and combustor
  - ✓ Counter-current moving bed for oxygen carrier
  - ✓ Gas and Solid fuel feedstock design
  - ✓ ~99% CO_2 generated from the reducer, while methane could be completely consumed by oxygen carrier
  - ✓ ~95% H_2 generated from the oxidizer



30 kWt Iron Looping System

Amine-Functionalized Mesoporous Silica Particles (MSP) Adsorption

- Development of various modification technology, the adsorption capacity more than 120mg CO_2/g
- Establish a pilot-scale spray drying manufacturing system, production rate of MSP is 1 kg /h
- Setup a bench-scale fixed-bed adsorption system
  - ✓ Gas Flow rate : 5~100 L/min, loading: 200 g~1 kg of MSP

Bench-scale adsorption system

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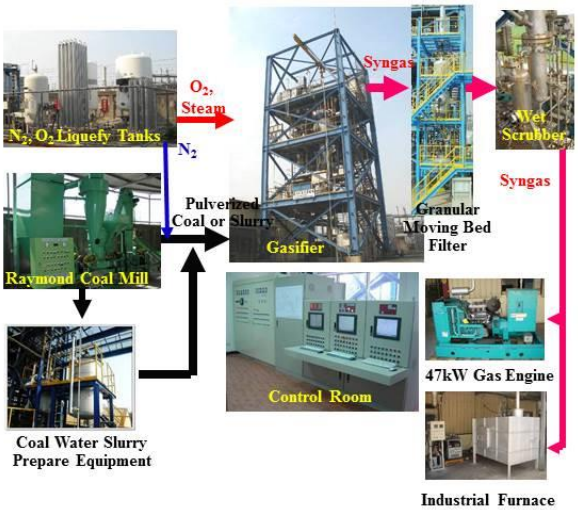
ITRI – R&D Activities(5/6)

ITRI's Experience in Coal Gasification

- Pressured gasification experimental system in Taiwan
  - ✓ 2 tons coal/day entrained-flow gasifier
  - ✓ Oxygen blown, dry and slurry feedstock, operating pressure below 10bar
- Gasification characteristics for coal and petroleum coke
  - ✓ Testing of gasification characteristics for six types of coals and CPC's petroleum coke
  - ✓ Carbon conversion rate and cold gasification efficiency are 95% and 75%, respectively
- Technology focuses on
  - ✓ 50~100 tons coal/day gasification system design and planning
  - ✓ Feeding technology
  - ✓ Biomass co-gasification technology
  - ✓ System control & simulation



ITRI's Gasification Plant (located at Kaohsiung)

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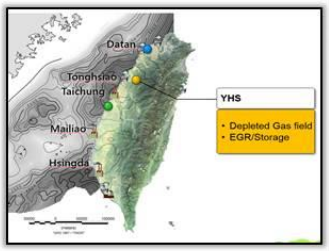
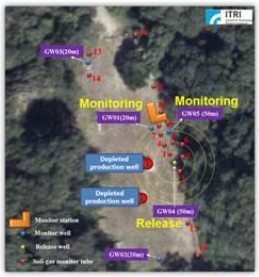
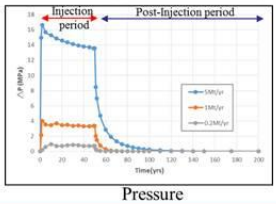
ITRI – R&D Activities(6/6)

Carbon Storage Research

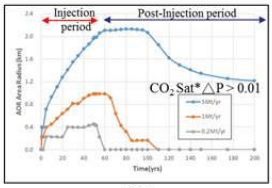
- CPC YHS potential storage/EGR site in northeastern Taiwan
  - ✓ Baseline data collection
  - ✓ Technology validation platform
- International collaboration with U.S.DOE National Energy Technology Laboratory
  - ✓ Monitoring: Surface monitoring
    - ✓ PFC tracers
    - ✓ fiber optics for leakage detection
  - ✓ Risk Assessment: Quantitative risk assessment framework (NRAP-IAM-CS)







Pressure



AOR

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INER – Carbon Reduction and Clean Coal study

INER

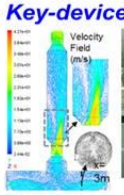
Feeds
- Coal
- Biomass
- Wastes
- Pet coke
- Oil shale
- Heavy oil
- Natural gas
- Combination of feeds shown above

Oxygen

Syngas

Slag

◦ *Key-device design* ◦



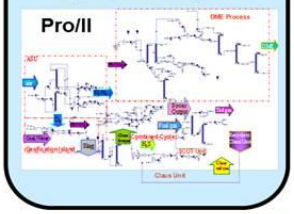
ANSYS Fluent


Benchmark platform

Clean-up
- Particulate removal
- Sulfur removal
- CO_2 separation

→ **Chemicals:** Methanol, DME
→ **Refineries:** Hydrogen, Power, Steam
→ **Coal to gas:** SNG
→ **Electricity:** Polygen, Refueling, Repowering

◦ *System design* ◦



➢ **CO_2 capture sorbents:**
- ✓ Capture capacity > 50wt%
- ✓ Stability > 90% in multi-cycle process at 750°C.
- ✓ A kg-class sorbent manufacturing system has been commissioned.

➢ **Hot Model of Moving Granular Bed Filter:**
- ✓ The only operating HT-MGBF (@500°C) in Taiwan.
- ✓ Filtration efficiency > 90% at elevated temp.

➢ **Acid Gas Removal:** Stability of **desulfurization** solid **sorbents** maintains over 90% during multi-cycle tests.

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China Steel Corp. – R&D Activities

Carbon reduction target:

ton-CO_2/ton-steel 2.2->1.97(2020)

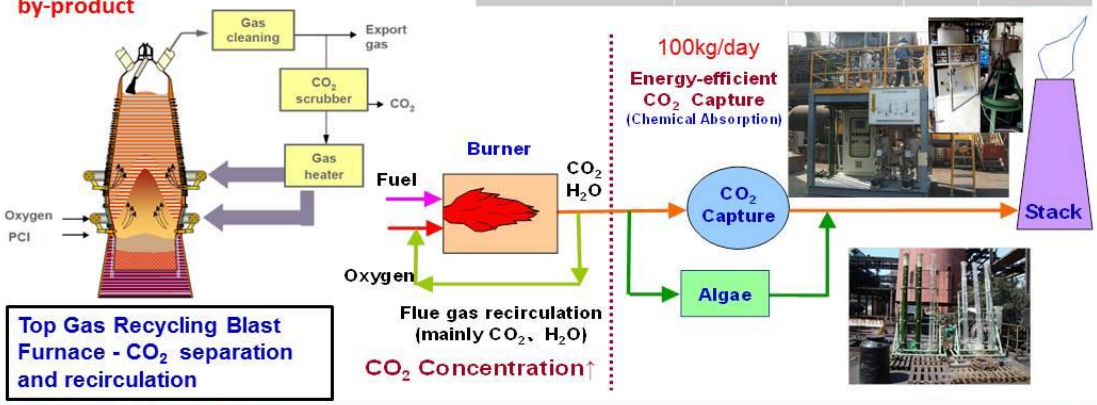
Capture for steelmaking:

Waste heat and water, slag, material, etc.

Capture ready:

Aqueous NH_3 produced from coke oven by-product

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



Top Gas Recycling Blast Furnace - CO_2 separation and recirculation

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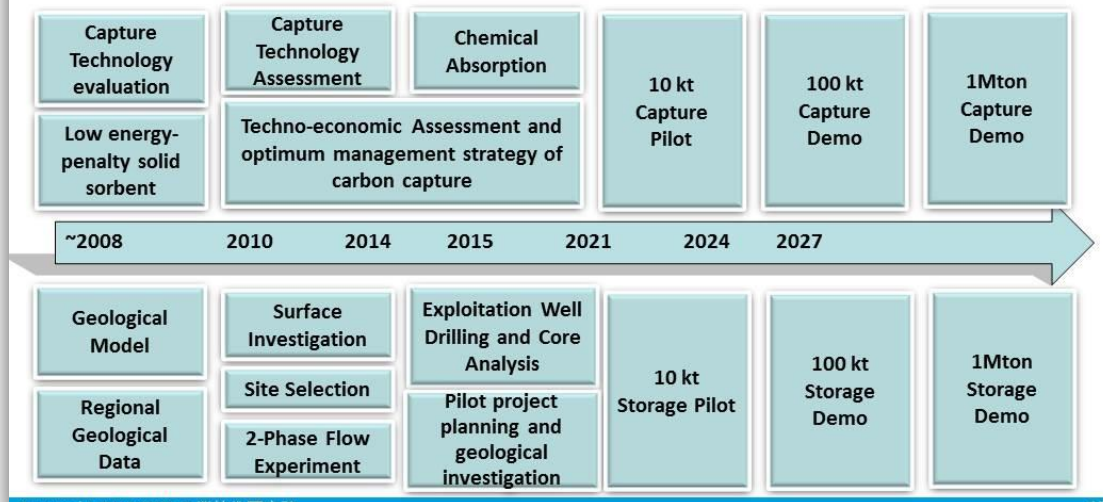
Taipower– R&D Activities

R&D Target:

- Optimum operation strategy and sustainable power plant operation
- Technology assessment and development for carbon capture
- Carbon storage pilot project – exploration and geological investigation



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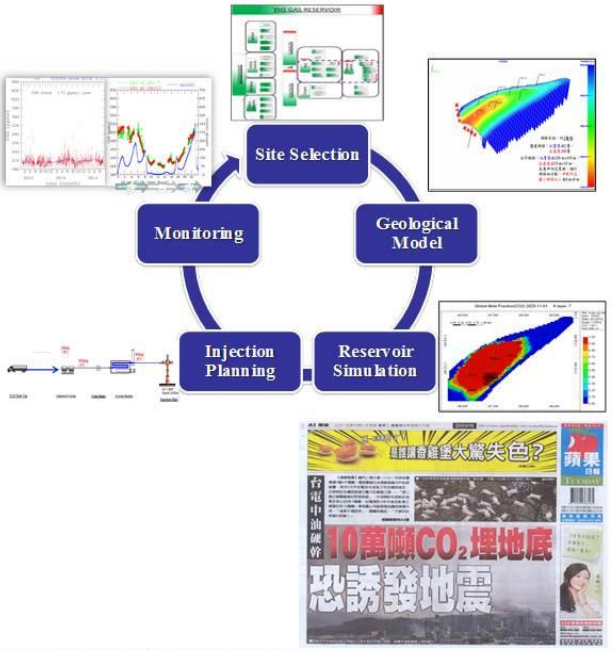
CPC Corp. – R&D Activities



Public Outreach

Baking soda and Citric acid
Geological Model Demonstration

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減碳淨煤主軸中心 Carbon Reduction and Clean Coal Focus Center

National Energy Program-Phase II

Carbon Reduction and Clean Coal Focus Center

■ Mission

1. Development of advanced combustion systems
2. Development of CCSU technologies
3. Cooperation among industry, academia and research institute to build up pilot plants at large CO_2 emission sites and establishment of CCSU industries
4. Promotion of international collaboration


CO_2 capture demonstration plant chemical absorption (1 ton/day)

Development of CO_2 capture technologies

- ✓ One CO_2 capture demonstration plant using chemical absorption in RPB and PB (1 ton/day) at Formosa Petrochemical (technology is transferred from NTHU)
- ✓ The research of CO_2 capture using chemical absorption and adsorption by mesoporous adsorbents grafted with amines is being carried out by ChangChun Petrochemical Group and NTHU

Development of CO_2 utilization technologies

- ✓ One demonstration plant for cultivation of microalgae using the captured CO_2 has been built and in operation at Greenyn Biotechnology (technology is transferred from NCKU)
- ✓ The research is being carried out by ChangChun Petrochemical Group and NTHU

Development of CO_2 storage technologies

- ✓ Several universities, Taipower and China Petroleum Corp are integrated to explore the CO_2 storage potential sites and storage capacity as well as to establish the monitoring technology

Development of advanced combustion systems

- ✓ 1 kW moving-bed CLP (NTUT) have been built
- ✓ 100 kW oxy-fuel combustion furnace has tested using multiple feedstock (NCKU)
- ✓ 1 kW solid oxide fuel cell (SOFC) system (NCKU)
- ✓ The establishment of MW gasification plant in Coastal Industrial Park is being assessed

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Closing Remarks

- As almost 90% of the Taiwan's total energy supply come from fossil fuels and 44.7% of power generation from coal, CCS technologies are needed here for reducing the CO_2 emission while burning fossil fuels.
- In particular, CCS is envisioned to play a very important role for Taiwan's situation.
  - Speed-up of the RD&D is necessary.
  - Urgent needs for policy and regulatory framework to guide the CCS development and deployment.
- It is also important to cooperate with industries for CCS technologies.
- International cooperation and information exchange are essential to expediting the global CCS technology development and deployment.
- Public outreach and acceptance to CO_2 geo-sequestration, however, is a critical issue that can not be ignored.