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Carbon Capture, Utilization and Storage (CCUS)

Actions in CHNG and China

China Huaneng Clean Energy Research Institute

July 7, 2017

Outline

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- Overview of CCUS in CERI
- Overview of CCUS in China
- Absorbent Development
- Pilot and Demo Plants

Overview of CERI

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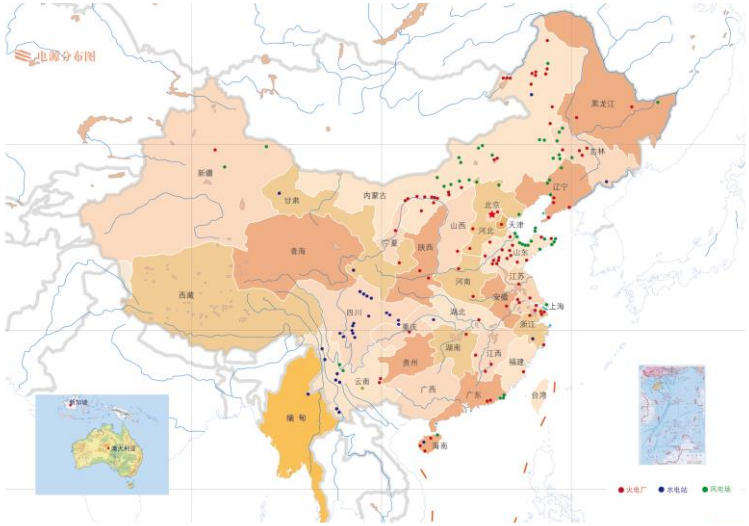
- Huaneng Clean Energy Research Institute (CERI) is a clean energy R&D institution directly under China Huaneng Group (CHNG).
- China Huaneng Group (CHNG) is a state-owned power company with an installed capacity of 165 million kW by the year of 2016, which is the largest in the world.



Overview of CERI

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Research Focuses in CERI

- Clean Coal Technology: Coal Gasification, IGCC, Coal to Clean Fuel
- Circulating Fluid Bed (CFB) Technology
- Renewable Energy, Energy Storage, Energy System Optimization
- Carbon Capture, Utilization and Storage (CCUS)

Overview of CCUS in CERI

CCUS R&D Team

- A family of 20 members, with 60% PhDs and with multidisciplinary educational background.
- 2 “Thousand Talents Program” experts; 1 “State Council allowance” experts; 1 “Beijing Outstanding Youth” expert
- Dr. Gao is the leader of CERI CCUS team. He is the project manager of both “3000 tpa CO_2 Capture Demo Project in Huaneng Beijing Thermal Power Plant” and “120,000 tpa CO_2 Capture Demo Project in Huaneng Shanghai Power Plant”.

Overview of CCUS in CERI

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Research Focuses:

燃煤/气烟气碳捕集技术开发
Coal and Gas-fired Flue Gas CO_2 Capture

新型吸收剂开发与性能评价
Novel Absorbent Development and Evaluation

工艺优化模拟和中试验证
Process Modeling, Optimization and Pilot Testing

二氧化碳与其它污染物协同脱除技术
Integrative Removal of CO_2 and Other Pollutant

捕集装置设计与工程总包
Design and EPC of Capture System

Overview of CCUS in CERI

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Research Focuses:

二氧化碳驱替煤层气利用技术
Enhanced Coal-bed Methane Recovery

二氧化碳矿化利用技术
CO_2 Mineralization Utilization

二氧化碳压裂技术
CO_2 Fracturing Technology

二氧化碳化工利用技术
CO_2 Chemical Conversion Utilization

Overview of CCUS in CERI

R&D Platform

- State key laboratory of coal-based clean energy
- Beijing key laboratory of CO2 Capture and Process
- NEA R&D Center of Clean Coal and Low-Carbon Power Generation
- Beijing International Cooperation Base for Clean Coal Technology Development

Overview of CCUS in CERI

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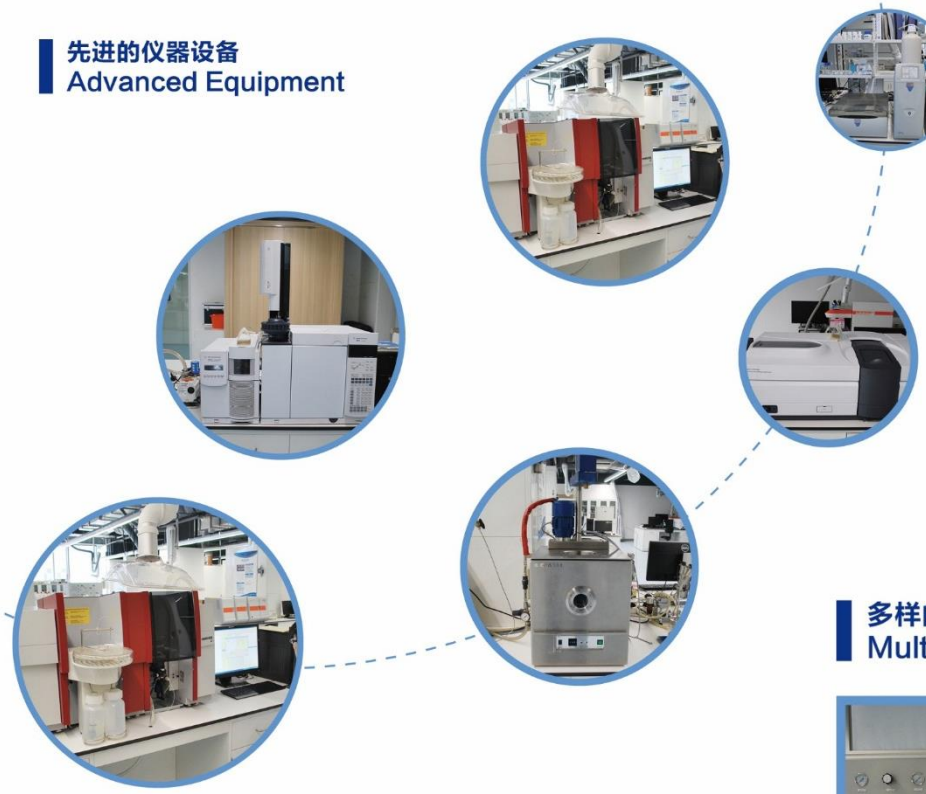
Laboratory Facilities

先进的仪器设备
Advanced Equipment



HPLC, GC, FTIR, MS, AAS, Calorimeter, TOC, etc.

多样的试验装置
Multi-scale Test Setups

Overview of CCUS in CERI

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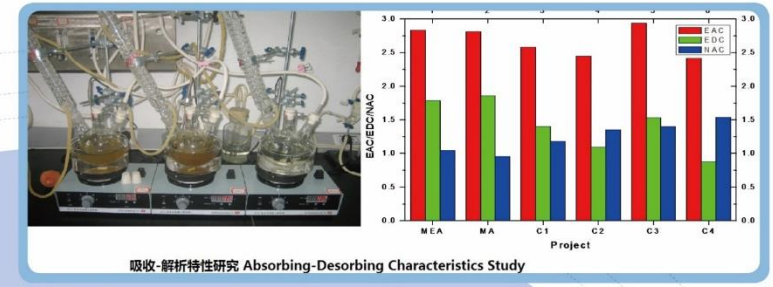
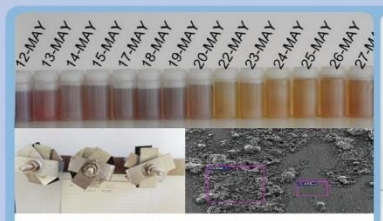
Fundamental Research

溶剂开发 Solvent Development



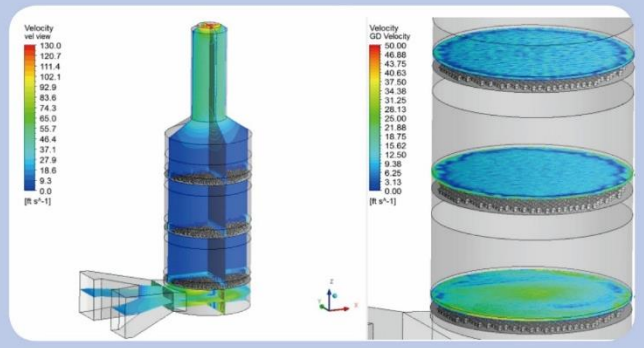
吸收-解析特性研究 Absorbing-Desorbing Characteristics Study



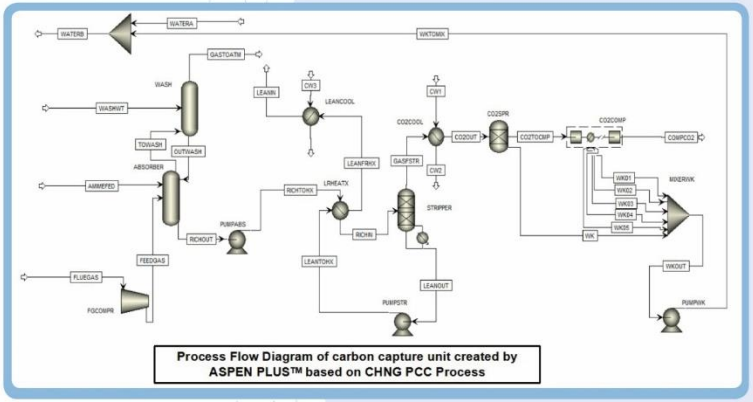
降解和腐蚀特性研究 Degradation and Corrision Study

分相吸收剂开发 Biphasic Solvent Development

设备开发 Equipment Development

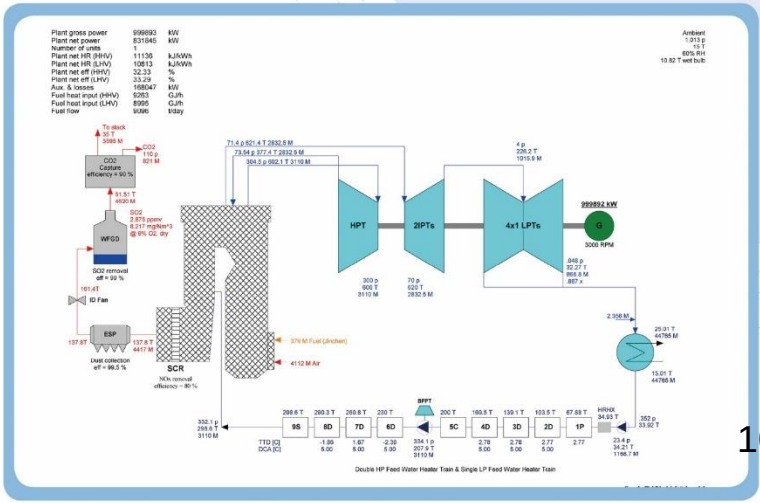


工艺开发 Process Development



Process Flow Diagram of carbon capture unit created by ASPEN PLUS™ based on CHNG PCC Process

系统集成 System Integration



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Pilot Plant

燃煤烟气碳捕集中试装置
Coal-fired Flue Gas Carbon Capture Pilot Plant

- 实况燃煤烟气 Real coal-fired flue gas
- 1000 吨 / 年 1000 TPA
- 位于长春热电厂 Changchun Thermal Power Plant
- 用于溶剂测试和工艺验证 Test novel solvent and process

燃气烟气碳捕集中试装置
Gas-fired Flue Gas Carbon Capture Pilot Plant

- 模拟燃气烟气 Simulated gas-fired flue gas
- 1000 吨 / 年 1000 TPA
- 北京 Beijing
- 燃气烟气碳捕集验证 Gas-fired CO_2 Capture Technology Verification

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Demo Projects

上海石洞口电厂 12 万吨 / 年碳捕集示范工程
120,000 t/a Carbon Capture Demo Project in Shanghai

In 2009, world's largest CO_2 capturing facility , with capturing capacity of 120,000 t/a, was put into operation in Huaneng Shanghai Shidongkou Power Plant.

北京热电厂 3000 吨 / 年碳捕集示范工程
3,000 t/a Carbon Capture Demo Project in Beijing

In 2008, China's first CO_2 capturing facility, with capturing capacity of 3,000 t/a, was put into operation in Huaneng Beijing Cogeneration Power Plant.

Overview of CCUS in CERI

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Milestones

2007

开展基础研究
（西安基地）
Fundamental Study
(XI'AN Research Base)

中国首个燃煤电厂碳捕集项目
（北京，3000 吨 / 年）
China's first PCC project in power plant
(Beijing, 3,000t/a)

2008

2009

当时世界最大燃烧后碳捕集项目
（上海，12 万吨 / 年）
World's largest PCC project at the time
(Shanghai, 120,000 t/a)

开发可移动式碳捕集测试平台
（陕西秦岭，300 吨 / 年）
Develop portable PCC test platform
(Qinling, 300 t/a)

2011

2013

中国首个燃气烟气碳捕集装置
（北京，1000 吨 / 年）
China's first gas-fired carbon capture pilot plant
(Beijing, 1,000 t/a)

高寒地区燃煤烟气中试装置
（长春，1000 吨 / 年）
Coal-fired carbon capture pilot plant under extreme cold conditions
(Changchun, 1,000 t/a)

2014

2016

中国首个百万吨级碳捕集项目可行性研究
China's first feasibility study on million ton scale PCC project

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Research Projects

- Key Technology and Equipment Development and Demonstration of CCUS Technology (China NEA)
- Demonstration of CO_2 Capture and ECBM Utilization(China MOST)
- China-US Joint-research on CCS Technology (China MOST)
- Optimization of Coal Utilization under Carbon Constraint (China CAE)
- Novel Absorbent Development and Application for Post-combustion CO_2 Capture (Beijing MSTC)
- Key Technology Development for CO_2 Capture Performance Improvement (Shanghai MSTC)
- R&D on CO_2 Mineralization by Coal Ash (Shanxi DOST)
- The Application of Membrane Concentration Technology in CO_2 Capture (CHNG)
- R&D on Novel Low Energy Penalty CO_2 Absorbent (CHNG)
- R&D on 1 MTPA CO_2 Capture System (CHNG)
- R&D on Rich-solvent Leaching Technology in CO_2 Capture (CHNG)
- Cooperation Action within CCS China-EU (COACH)
- EU- China The Near Zero Emissions Coal (NZEC) Project
- Scope Study of Technological Options for SOx treatment for CTSCo Project (ANLEC)

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Technology Application

- 3,000 tpa CO_2 Capture Demo Project in Huaneng Beijing Thermal Power Plant
- 120,000 tpa CO_2 Capture Demo Project in Huaneng Shanghai Shidongkou Power Plant
- 1,000 tpa Coal-fired Flue Gas CO_2 Capture Pilot Platform in Huaneng Changchun Power Plant
- 1,000 tpa Gas-fired Flue Gas CO2 Capture Pilot Platform in Beijing Miyun County
- 120,000 tpa CO_2 Capture Project in Shenhua Jinjie Power Plant (Design)
- 50,000 tpa CO_2 Purification Project in Shanxi Yanchang Coal Chemical Plant
- Australia-China PCC Feasibility Study Project of 1 mtpa CO_2 PCC in Changchun Power Plant
- Australia-China PCC Feasibility Study Project of 120,000 tpa CO_2 PCC in Millmerran Power Plant
- Pre-design of Norway 1 mtpa PCC Project
- Feasibility Study of 1 mtpa PCC Project for Canada Saskpower
- China-Italy Joint Research on 1 mtpa PCC Project
- Pre-feasibility Study of 1 mtpa PCC Project for US Duke Energy
- Feasibility Study of 300,000 tpa PCC Project for Huaneng Taicang Power Plant

Overview of CCUS in CERI

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Achievements & Honors

Honored by several ministerial level awards

授权发明专利 20 余项，发表论文 30 余篇
More than 20 Patents and 30 Papers

Overview of CCUS in CERI

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International Cooperation

So far, we have developed tight relationship with companies, research Institutes and universities in US, Canada, Australia, Germany, British, Italy, Norway, France, Spain, South Korean and Brazil.

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Social Influence

时任美国能源部长朱棣文访问上海石洞口项目
Former Secretary of US DOE Steve Chu visits Shanghai Shidongkou PCC Project

澳大利亚前总理陆克文范围北京电厂示范项目
Former Australia Premier Kevin Michael Rudd visits Beijing PCC Project

上海石洞口项目被评为“联合国环境友好城市示范项目”
Shanghai Shidongkou Project is Recognized as “Pilot Project of Shanghai Environmentally Friendly City Initiative” Project

华能碳捕集项目备受杂志媒体关注
Huaneng’s CO2 capture projects obtained massive media coverage.

Outline

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Overview of CCUS in China

China Power Investment Corporation (CPIC)

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10kt/a PCC from a 300MW Unit in Chongqing Shuangkui Power Plant

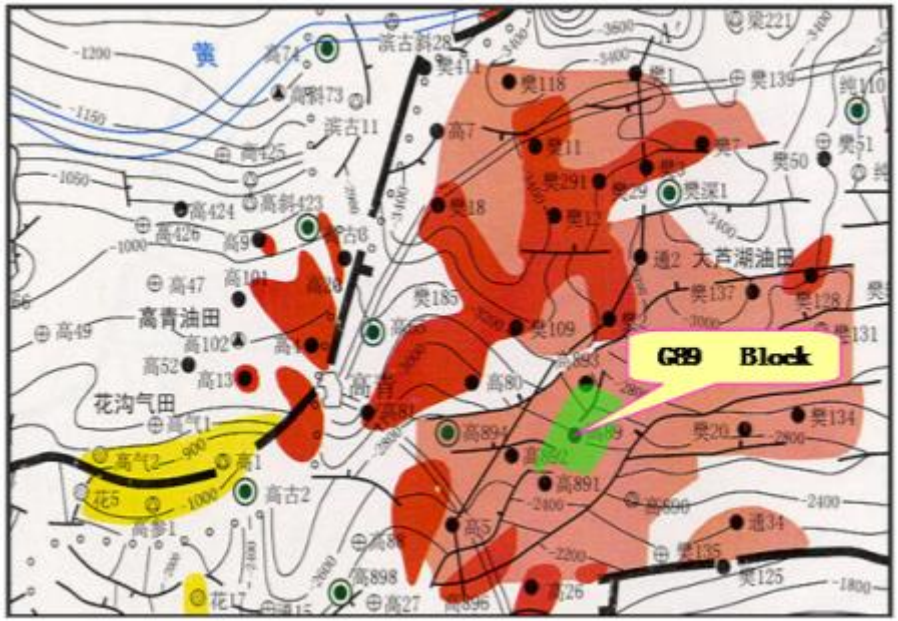
- Commission in Dec 2009, put into operation in Jan 2010
- Capture rate 95%, CO2 purity 99.5%
- CO2 utilization: shielding gas for welding

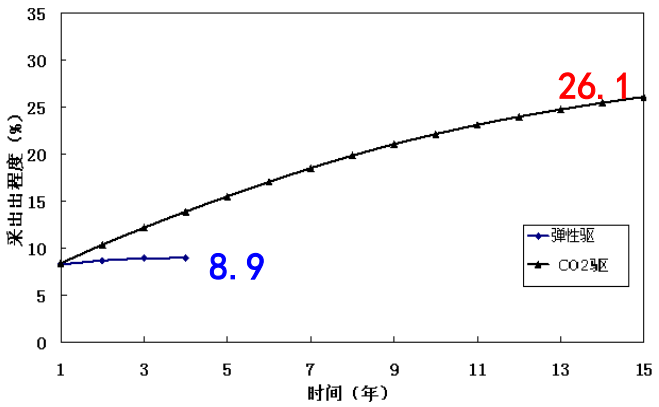
Overview of CCUS in China

Sinopec CCUS Project (Shengli Oil)

EOR & Storage：Shengli Oilfield G89

- **Project Scale: 40,000t/a**
- **CO_2 resource: Flue gas of Shengli Power Plant**
- **CO_2 capture: Post-combustion capture, chemical absorption**
- **CO_2 Transportation: 80km, truck**
- **Utilization: CO_2-EOR**
- **Low Permeability： 4.7mD**





- Initial gas injection : Jan.,2008
- By 2015, about 250,000 tons has been injected
- Estimated oil recovery can be increased by 17.2% in 15 years.

Overview of CCUS in China

PetroChina CCUS Project (Jilin Oil)

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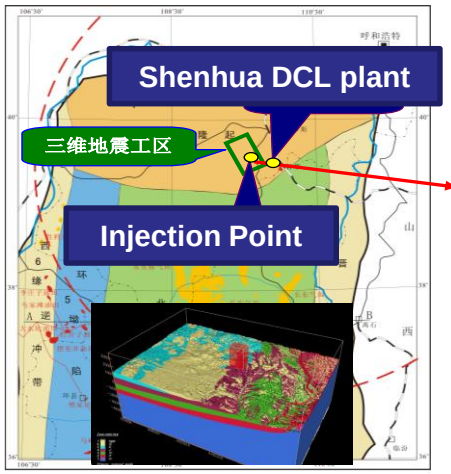
CO2-EOR & Storage with CO_2 captured from Natural Gas

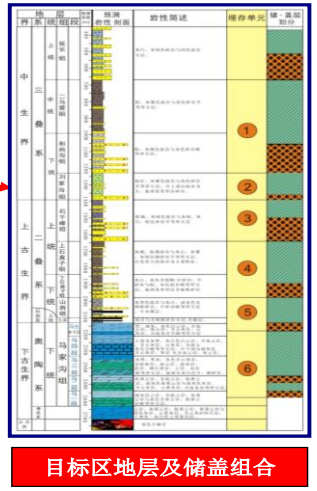
122,000tons of CO_2 were injected and 80,000 tons of CO_2 were storage.
51,000 tons of oil were recovered by May 2010.

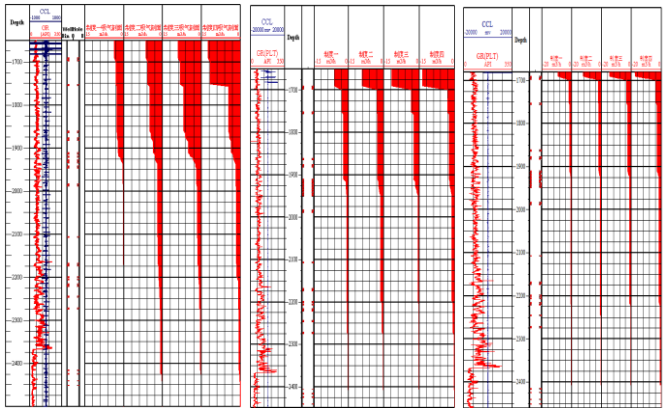
Overview of CCUS in China

China Shenhua CCUS Project (Erdos)

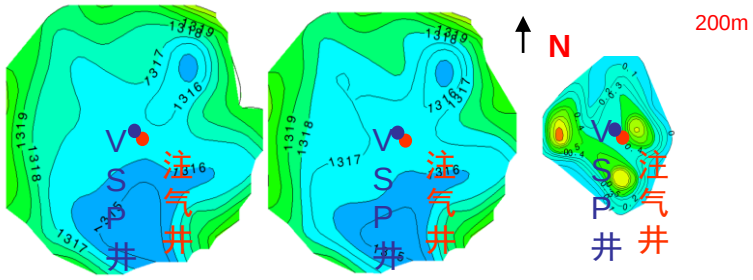
- China Shenhua is China's largest coal mining company and 5th coal-fired power company.
- 100,000tons/a CCS demo project
- CO_2 came from CTL (coal to liquid) Process
- Over 300,000tons had been injected




目标区地层及储盖组合


2011年5月 2012年6月 2013年9月

Evaluation the storage potential of different reservoirs.



煤层T0图（2011年） 2013年 煤层T0差图

CO_2 moving area are within 350m

Overview of CCUS in China

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China CBM CO2-ECBM Project

- Shanxi Qinshui Basin
- 4,000 tons CO2 has been injected by 2015
- China CBM and Huaneng CERI are currently work on a 1,000 ton CCUS full chain demo project.

Overview of CCUS in China

Yanchang Petrolum

- Shanxi Yulin
- Phase I: 50,000 TPA project (2012, CERI's technology)
- Phase II: 360,000 TPA Project (planning)
- CO2 captured from coal chemical plant utilizing rectisol method
- CO2 is used for EOR

榆林煤化5万吨/年CO_2捕集装置

Overview of CCUS in China

Oxy-combustion

Huazhong University of Science and Technology

1995 Fundamental Study

2005 300kWt PC small pilot study
Burner development
Data collection and Optimization
Thermal Design

2008 50kWt Oxy-CFB small pilot study

2011 3MWt PC large pilot study
7000T/a full chain validation
ASU-CPU coupling
FGC and drying

2012 2.5MWt CFB oxyfuel boiler
In-bed heat exchanger

2013 35MWt pilot plant
0.1 million ton capture
ASU-CPU-power generation integration and optimization

2014 40MWt pilot plant
Commercial scale burner
Long-term operation demonstration

2015-2020 200-600MWe full demo.
Millions ton CCS-EOR

Overview of CCUS in China

CTSA-CCUS

China Technology Strategic Alliance for CO_2 Capture, Utilization and Storage (CTSA-CCUS) was founded in Nov 2013.

Four Council Directors / 28 Members

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中国国电 CHINA GUODIAN

中国石化 Sinopec

中国石油

1st General-Secretary: CHNG-CERI

1st CTSA-CCUS Conference: Feb. 2014

2nd CTSA-CCUS Conference: Apr. 2015

- Develop highly efficient and low-cost CCUS technology
- Constantly improve the level of technology and engineering on CCUS
- Promote the demonstration and commercialization of CCUS projects
- Provide technical support for the government on climate change mitigation

Overview of CCUS in China

CHINA-US CERC

U.S.–China Clean Energy Research Center
中美清洁能源研究中心

- In Nov. 2009, President Barack Obama and President Hu Jintao announced the establishment of the Clean Energy Research Center (CERC).

中国电力投资集团公司 CHINA POWER INVESTMENT CORPORATION

浙江大学 Zhejiang University

中国神华 CHINA SHENHUA

cpecc

West Virginia University

ENN 新奥

B&W thebabcock&wilcoxcompany

DUKE ENERGY

Lawrence Livermore National Laboratory

延长石油 YANCHANG PETROLEUM

上海交通大學

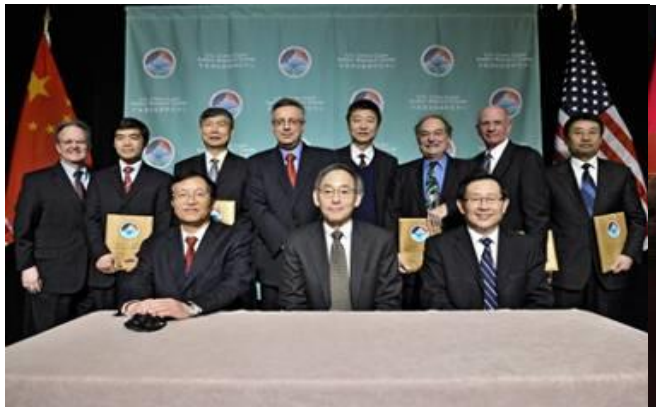
Los Alamos NATIONAL LABORATORY EST. 1943

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

University of Wyoming

UK University of Kentucky

World Resources Institute



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- Absorbent Development
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高性能CO_2捕集溶剂研发
High-performance CO_2 Absorbent Development

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- 二氧化捕集与处理北京市重点实验室（Beijing Key Laboratory of CO_2 Capture and Storage）

- 实验室研发设备 Instrument

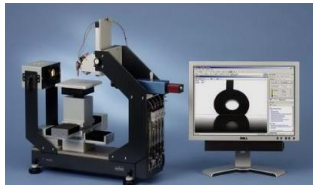
Reaction Heat Calorimeter

Ionic Chromatography

FTIR

UV-vis-NIR

TOC



Drop Shape Analyzer

GC-MS

ABS

高性能CO_2捕集溶剂研发
High-performance CO_2 Absorbent Development

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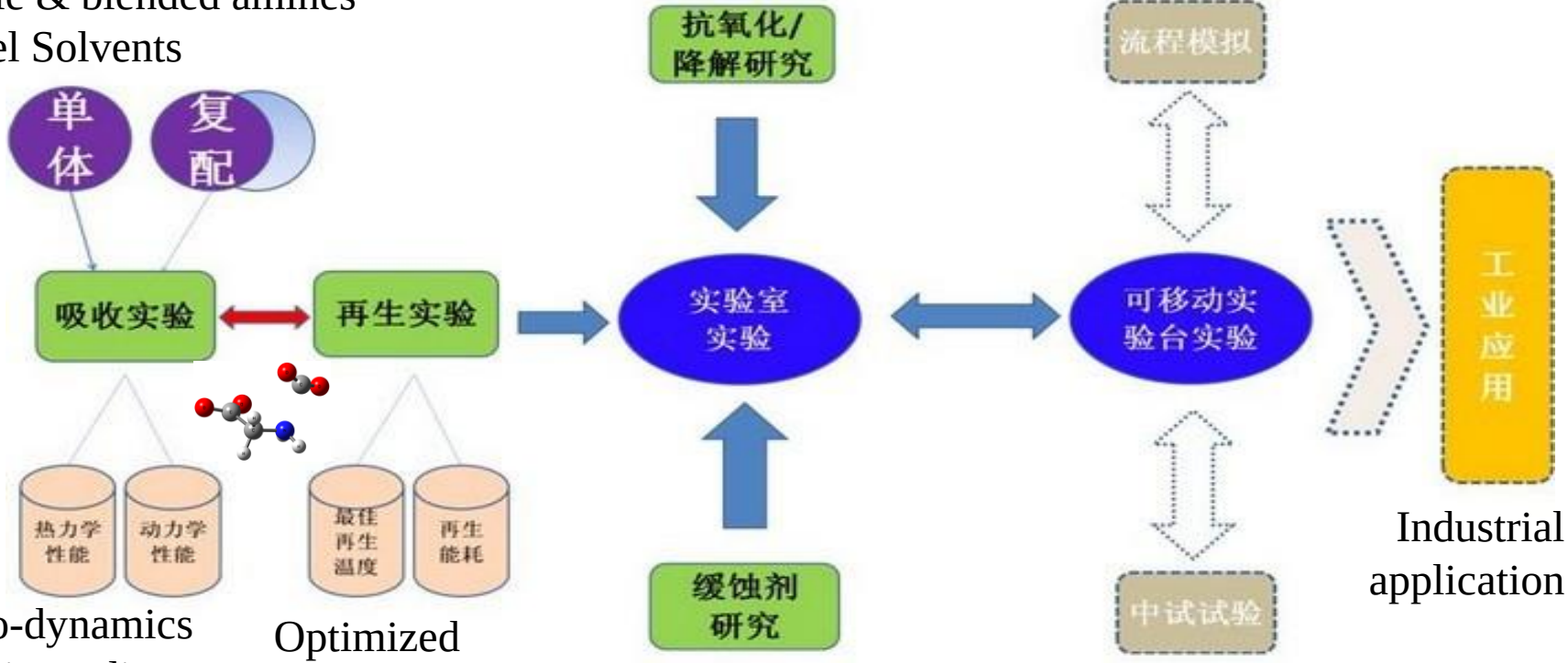
Single & blended amines
Novel Solvents

Anti-degradation inhibitor

Modeling



Thermo-dynamics
& kinetic studies

Optimized
regeneration
temperature &
energy
consumption

Anti-corrosion inhibitor

Pilot test

Industrial
application

华能清洁能源研究院
HUANENG CLEAN ENERGY RESEARCH INSTITUTE

高性能CO_2捕集溶剂研发
High-performance CO_2 Absorbent Development

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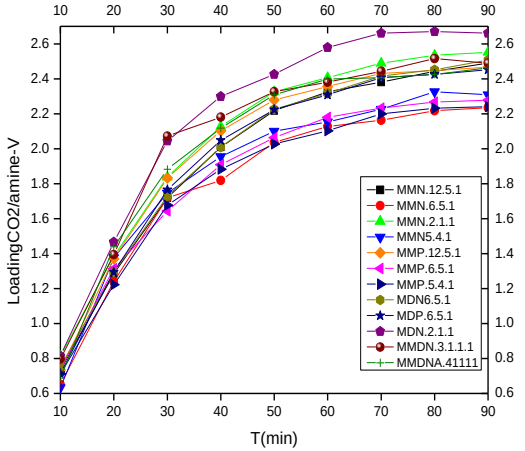
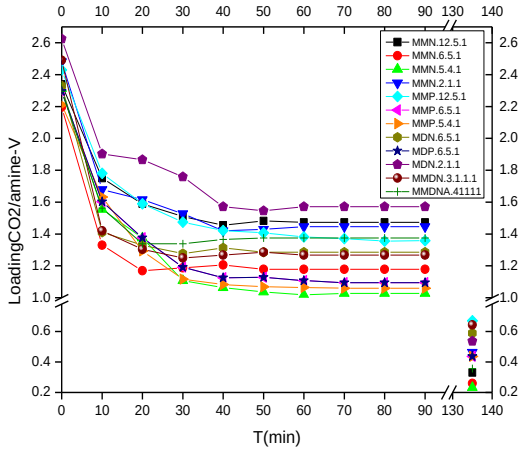
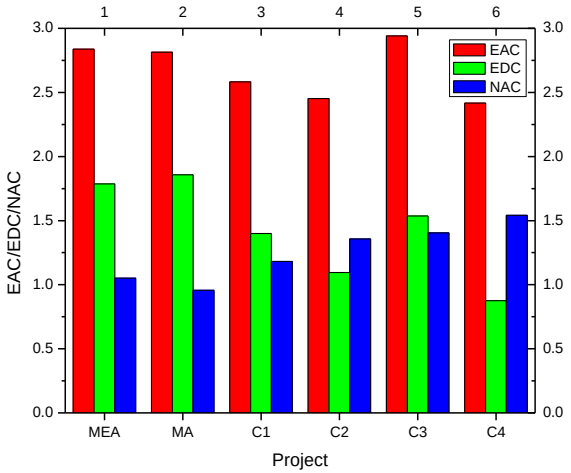
EAC: Equivalent Absorption Capacity
EDC： Desorption Capacity
NAC: Net Absorption Capacity NAC=EAC-EDC

◘ 复配型醇胺吸收剂（Blended Amines）

✓ 吸收、解吸性能测试 Performance test of absorption & desorption







✓ Testing condition: N_2:CO_2=85:15(V/V), absorption at 40ºC, Regeneration at 110ºC

Solvent	NAC	Increased	Note
MEA	1.051	109.9%	MEA
MA	0.956	100%	Was used at BJ and SH
C1	1.182	123.6%	Higher NAC
C2	1.357	141.9%	higher NAC
C3	1.405	147.0%	higher NAC; fast absorption
C4	1.542	161.3%	higher NAC; easy regeneration

高性能CO_2捕集溶剂研发
High-performance CO_2 Absorbent Development

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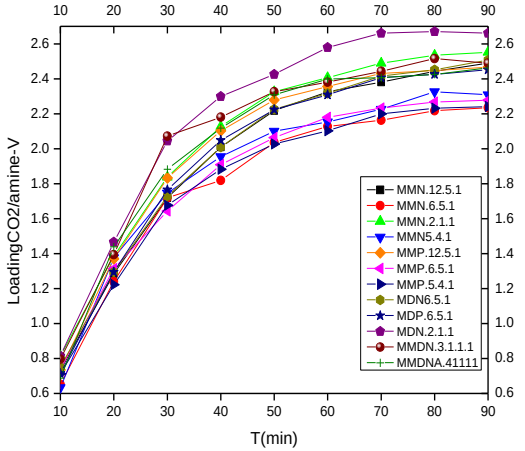
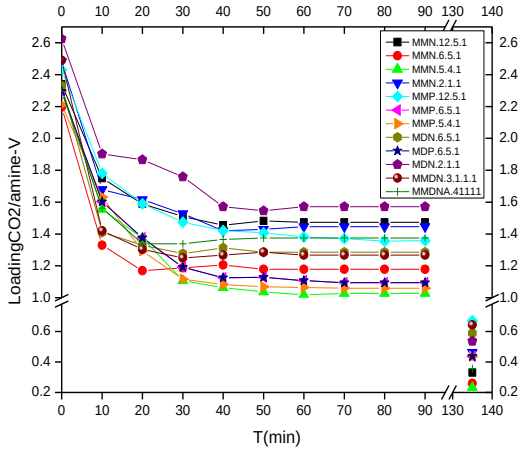
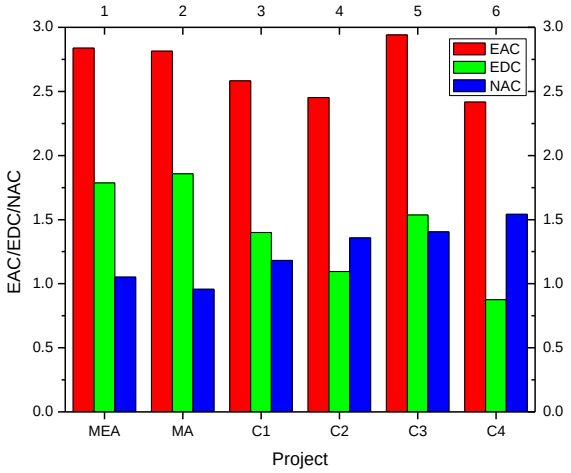
EAC: Equivalent Absorption Capacity
EDC： Desorption Capacity
NAC: Net Absorption Capacity　NAC=EAC-EDC

◘ 复配型醇胺吸收剂（Blended Amines）

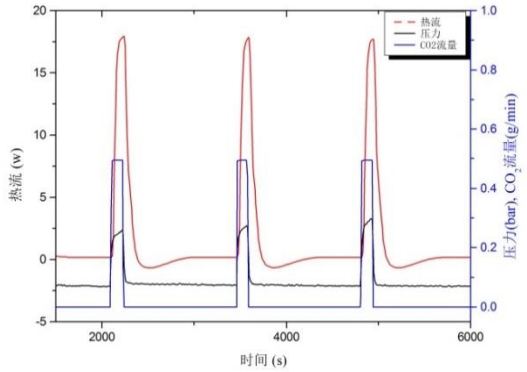
✓ 吸收、解吸性能测试　Performance test of absorption & desorption

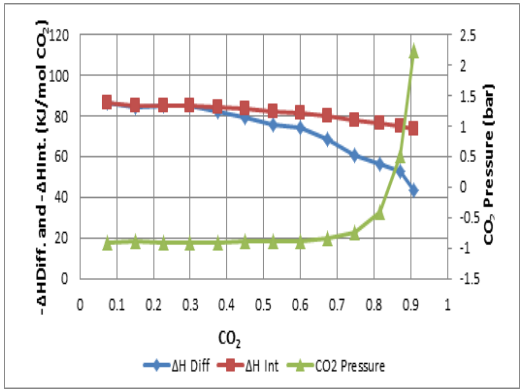


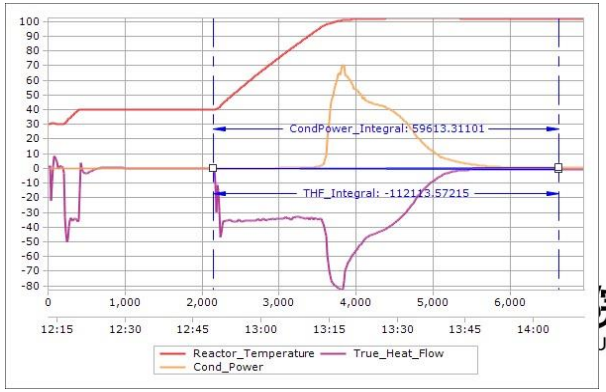




✓ 吸收、解吸热效应测评　Energy analysis of absorption & desorption by Calorimeter



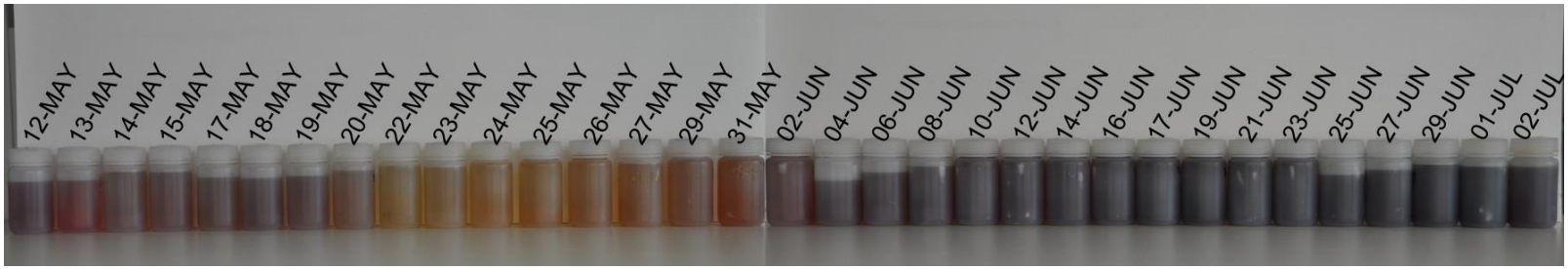




高性能CO_2捕集溶剂研发
High-performance CO_2 Absorbent Development

中国华能 CHINA HUANENG

- 复配型醇胺吸收剂（Blended Amines）
  - ✓ 降解损耗分析评估 Analysis of solvent degradation and solvent loss



- 开发出HNC1~HNC5系列溶剂(Developed commercial solvents: HNC1~HNC5)
  - ✓ 2015年新型HNC5吸收剂在上海石洞口二厂12万吨/年捕集装置完成了超过3000小时的连续运行验证。
    In 2015, the new HNC5 solvent was tested for more than 3000 hours in shanghai CO_2 capture plant.
  - ✓ 溶液有效成分浓度下降速度为MEA的40%，再生能耗为3.0GJ/tCO_2。该吸收剂可减少捕集成本约20%。
    Solvent loss is 40% of MEA; Regeneration energy is 3.0GJ/tCO_2; Reducing 20% CO_2 capture cost.

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高性能CO_2捕集溶剂研发
High-performance CO_2 Absorbent Development

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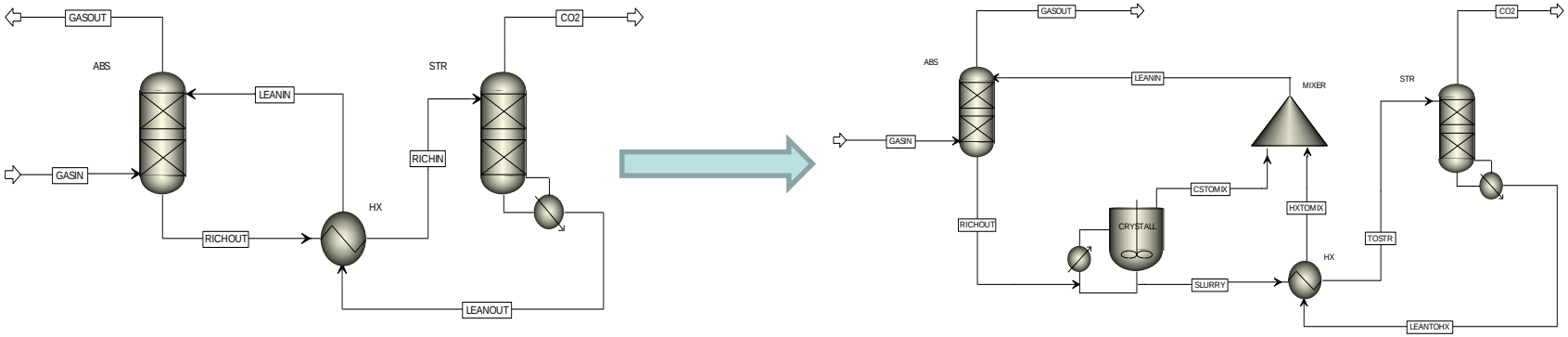
- 稠浆型CO_2吸收剂（Slurry-based CO_2 absorbent）
  - ✓ 传统吸收剂中水的比例较高（一般>70wt%），在CO_2解吸过程中水的升温与挥发消耗大量的能量，占再生消耗热量的50%以上。

    High water content in traditional solvent (usually >70%), a large part of energy (about 50%) is consumed by heating and evaporating the water in the solvent.
  - ✓ 在CO_2富液进入再生塔前进行浓缩预处理，实现CO_2在富液中的再分配，浓缩相进入再生塔解吸，从而降低高温解吸过程中水的参与度。

    Developing new absorption solvent and process to reduce the water involvement in regeneration is effective approach to lower energy cost.



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高性能CO_2捕集溶剂研发
High-performance CO_2 Absorbent Development

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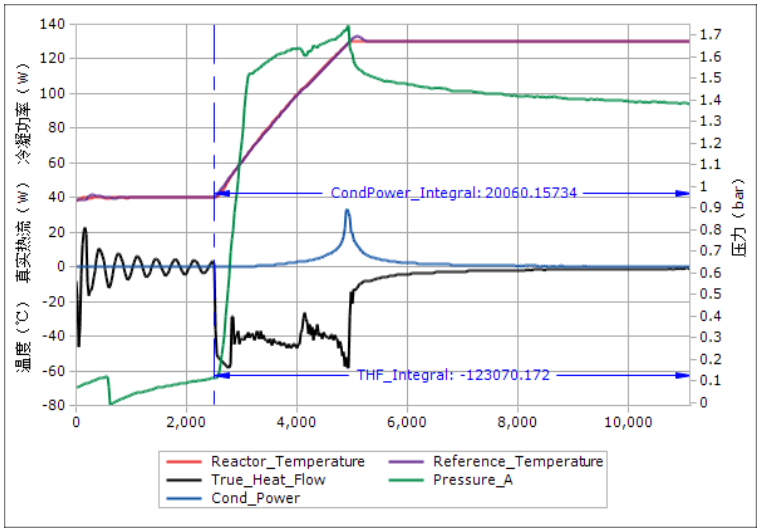
◘ 稠浆型CO_2吸收剂（Slurry-based CO_2 absorbent）

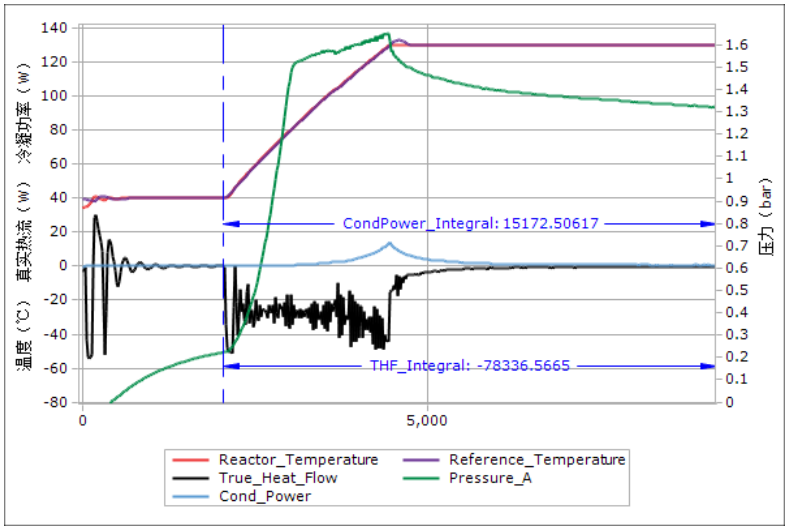
✓ 开发出基于碳酸钾溶液的稠浆型CO_2捕集吸收剂和过程工艺。

Potassium carbonate slurry-based CO_2 capture absorbent and process were developed.



富液直接解吸的加热量和冷凝量曲线

Energy curves of desorption without slurry



富液制浆解吸的加热量和冷凝量曲线

Energy curves of CO_2-riched slurry desorption

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High-performance CO_2 Absorbent Development

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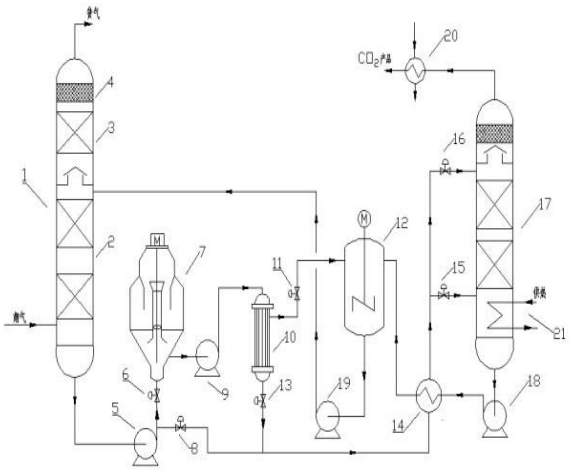
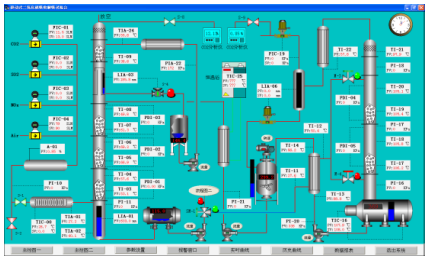
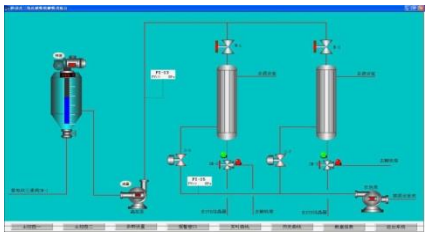
- 稠浆型CO_2吸收剂（Slurry-based CO_2 absorbent）
  - ✓ 完成实验室规模稠浆型CO_2捕集试验台的建造、测试和运行。

    Lab-scale pilot plant was built, tested and run for slurry-based CO_2 capture







  - ✓ 稠浆型CO_2捕集工艺再生能耗达2.6GJ/吨CO_2，稠浆型吸收剂的成本相比MEA吸收剂下降20%，损耗成本下降22%~50%。

    Regeneration energy is 2.6GJ/tCO_2; absorbent cost is 20% that of MEA. Solvent loss cost is 22%~50% that of MEA;

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高性能CO_2捕集溶剂研发
High-performance CO_2 Absorbent Development

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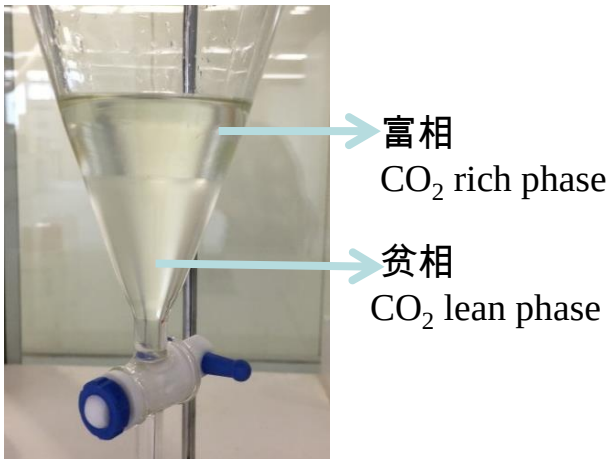
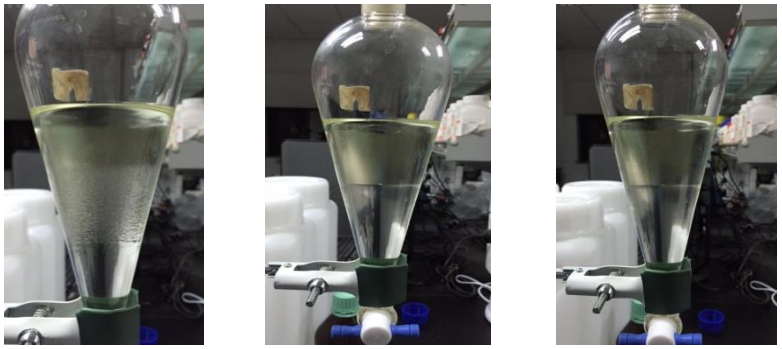
- 自浓缩相变型CO_2吸收剂（self-concentrated biphasic CO_2 absorbent）
  - ✓ 由胺、萃取剂和水混配而成

    Blended by amine, extractant and water.
  - ✓ 该类型吸收剂负载CO_2后可自动分层为液-液两相，实现CO_2的再分配。

    After absorbing CO_2, the absorbent can split into two liquid/liquid phase by itself, and almost all absorbed CO_2 transfer into the rich phase (more than 95%).
  - ✓ 该分相过程无需额外能耗，可有效实现CO_2在富相中的浓缩。

    No extra energy is needed for this process.





吸收剂负载CO_2后的动态分层情况（2min、4min和10min）

Solvent phase separation upon CO_2 absorption after 2min, 4min, 10min

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高性能CO_2捕集溶剂研发
High-performance CO_2 Absorbent Development

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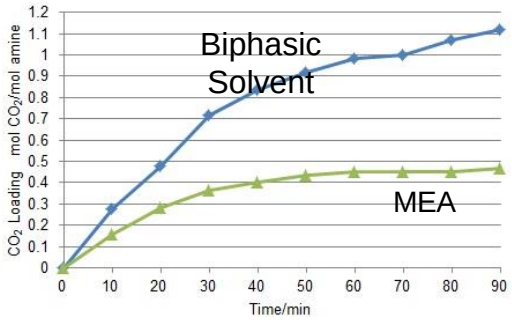
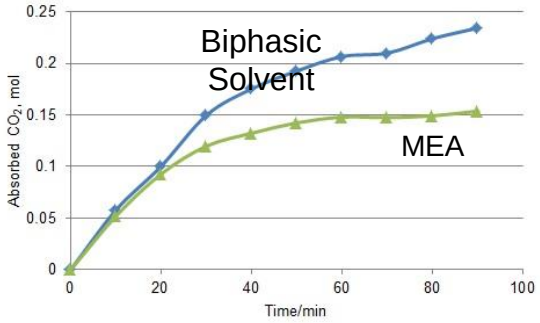
- 自浓缩相变型CO_2吸收剂（self-concentrated biphasic CO_2 absorbent）
  - ✓ 吸收速率和平衡负载高于MEA溶液

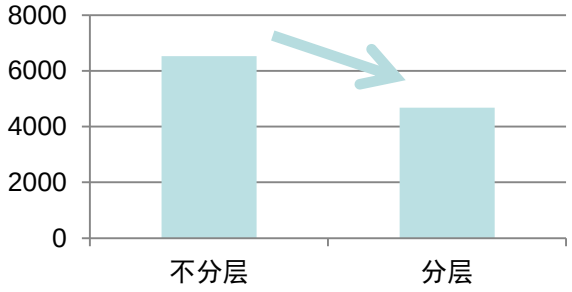
    Absorption rate and CO_2 loading are higher than those of MEA solutions.

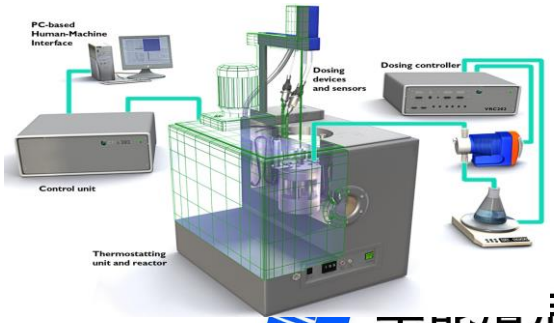




  - ✓ 量热实验表明：分层后的CO_2富相解吸可进一步降低20%~30%的再生能耗。

    Calorimeter experiments show that the desorption of CO_2 rich phase can reduce 20%~30% regeneration energy.





高性能CO_2捕集溶剂研发
High-performance CO_2 Absorbent Development

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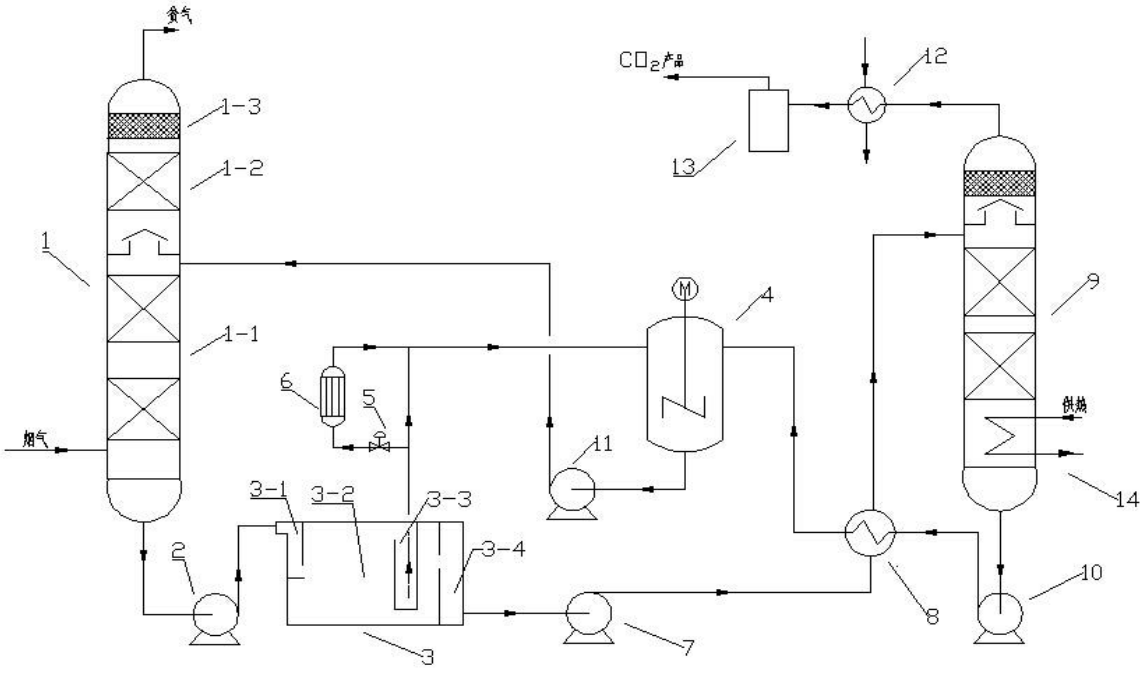
- 自浓缩相变型CO_2捕集工艺

  Designed capture process for biphasic CO_2 absorbent

  ✓



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Outline

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- Overview of CCUS in CERI
- Overview of CCUS in China
- Absorbent Development
- Pilot and Demo Plants

Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

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- The 100kg/h PCC pilot plant is based in Changchun coal-fired plant
- Purpose: (1) to evaluate the screened solvents;
  (2) to evaluate the operation of PCC plant under extreme cold conditions.
- Completed on May 2014 and have tested 3 solvents with 1000hrs for each solvent.

Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

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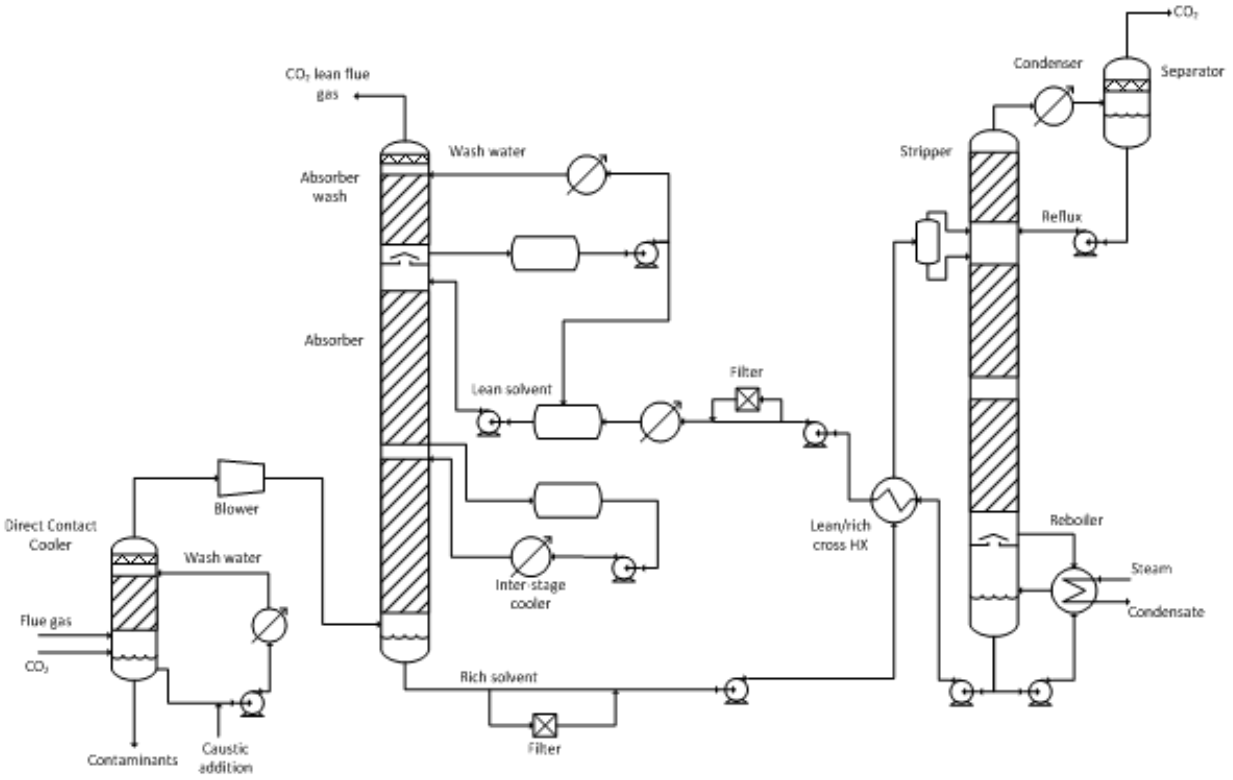

Columns	Pipe size	Packing height, m	Packing materials
DCC	DN450	3.055	316L
Absorber	DN350	8	316L
Wash	DN350	1.88	316L
stripper	DN250	8.56	316L

Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

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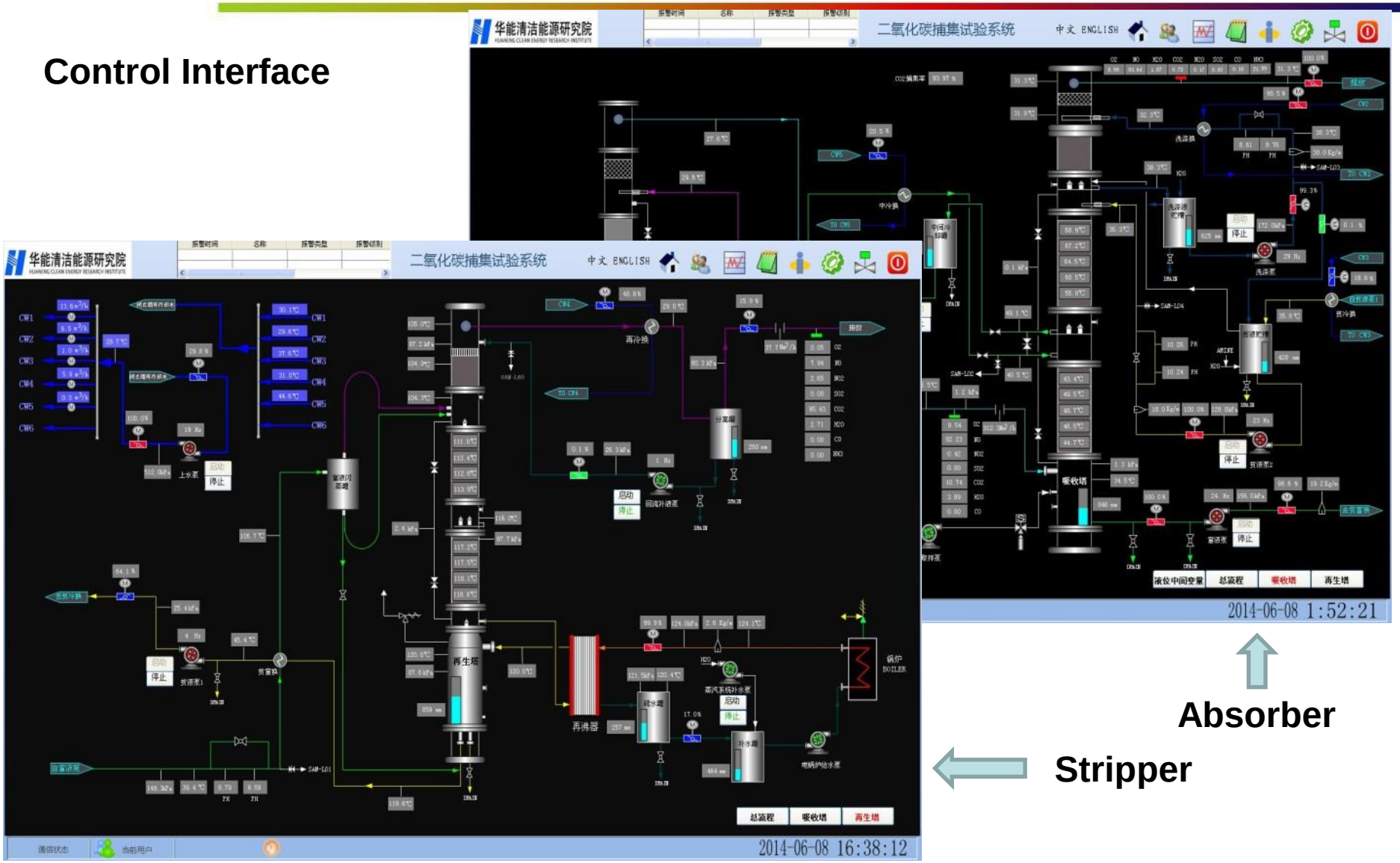
Control Interface



Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

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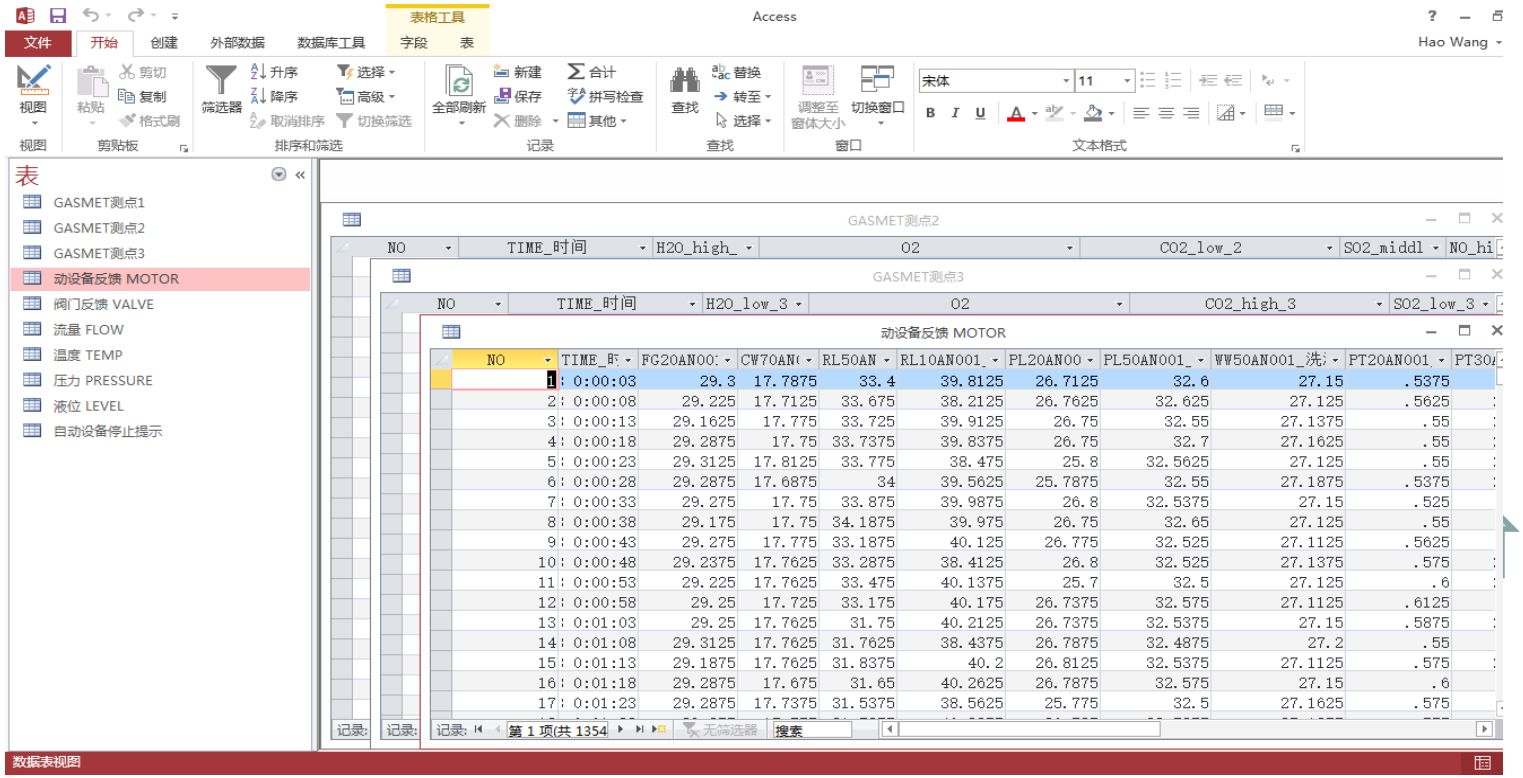
Data Acquisition

- All data are stored in the database every 5 seconds;
- Access files are generated day by day;
- Data recorded include flue gas composition (GASMET), pressure/temperature of gas and liquid flow, liquid level in columns, PH value of solvent, etc.



Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

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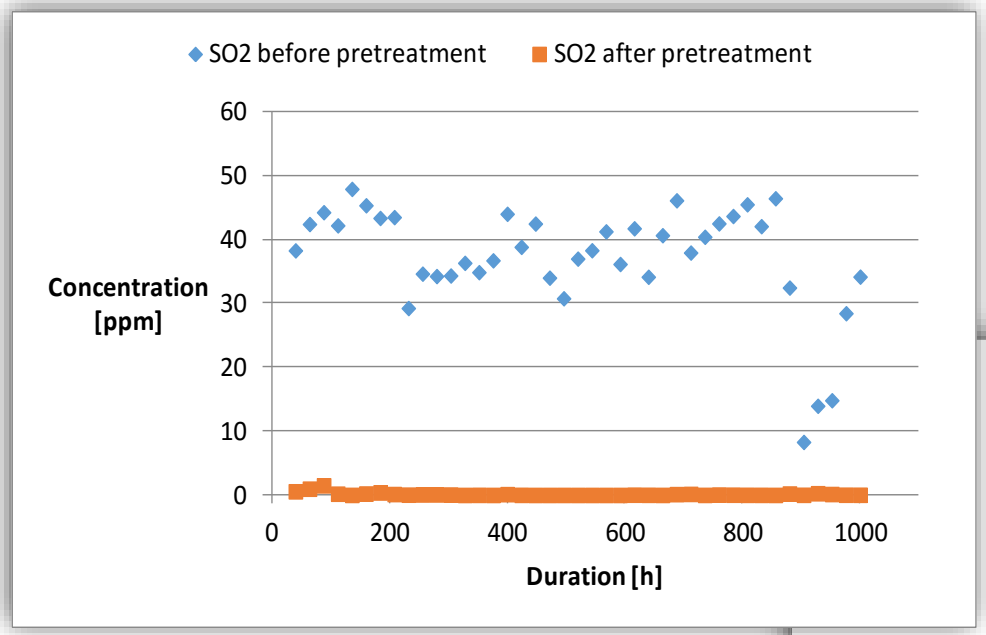
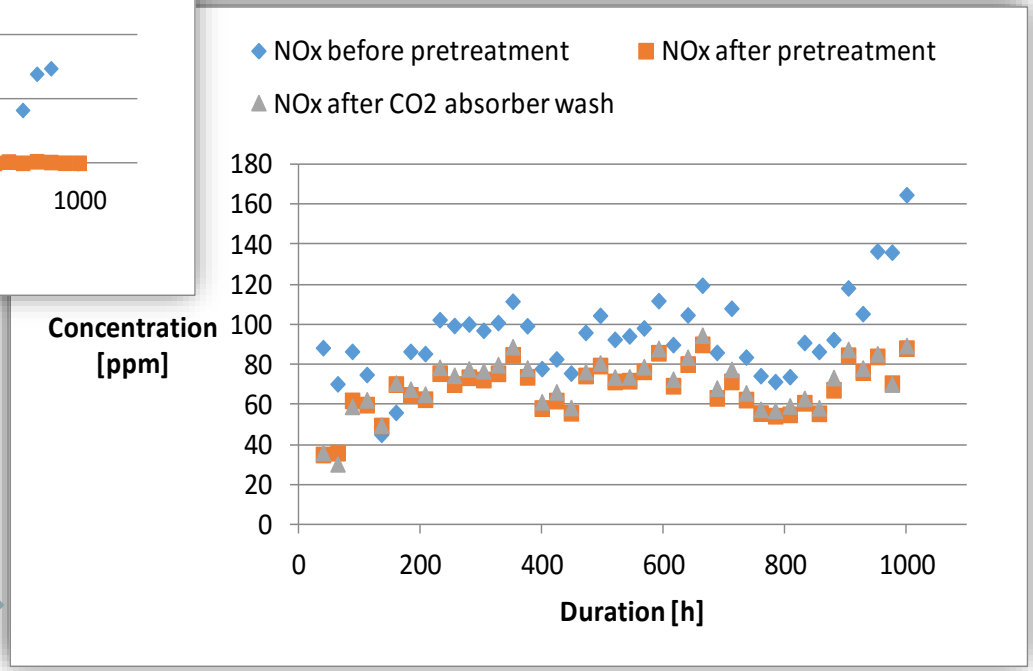
Pretreatment Performance



- SO2 concentration is below 5 ppm after pretreatment;
- NOx removal rate is limited due the insoluble NO.

SO2 concentration in flue gas before and after pretreatment

NOx concentration in flue gas before and after pretreatment



Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

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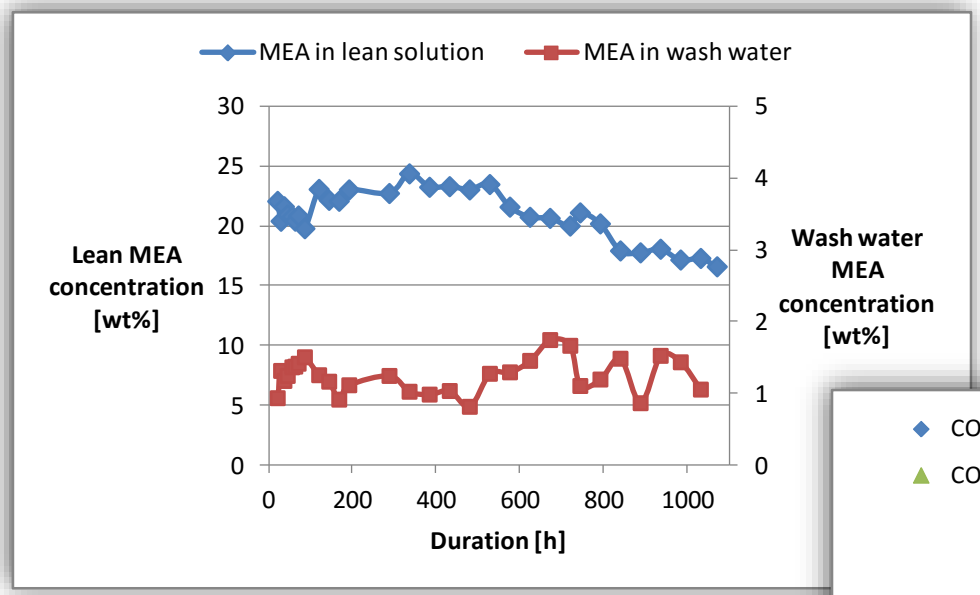
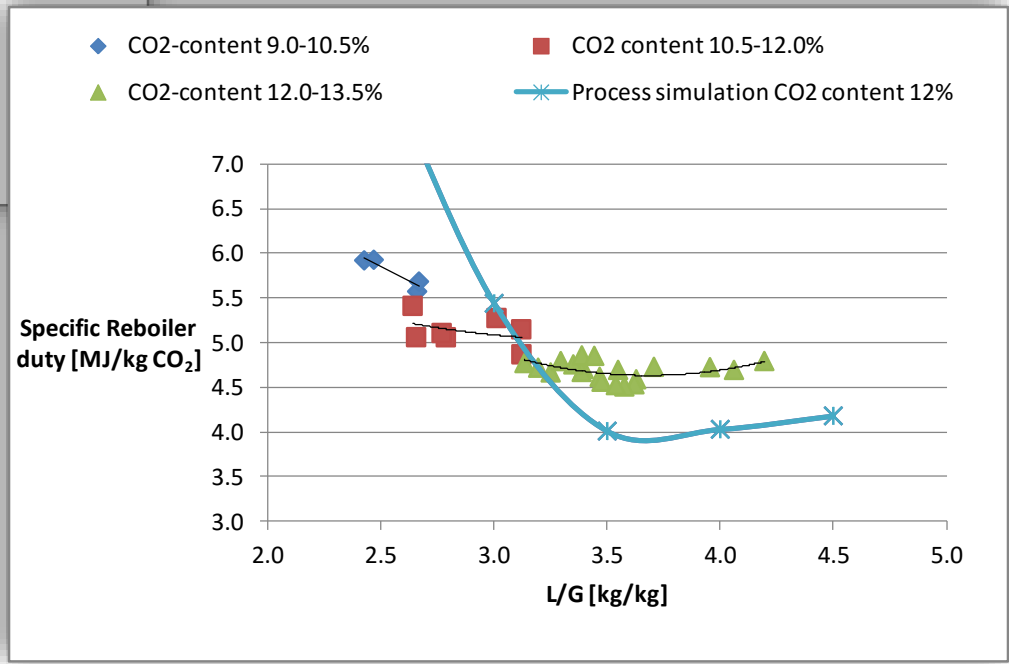
Test on MEA



MEA concentration in absorbent circuit and wash-water circuit through-out the campaign

Specific reboiler duty as a function of liquid/gas flow ratio



Pilot and Demo Plants

(1) 1000 t/a coal-fired pilot plant

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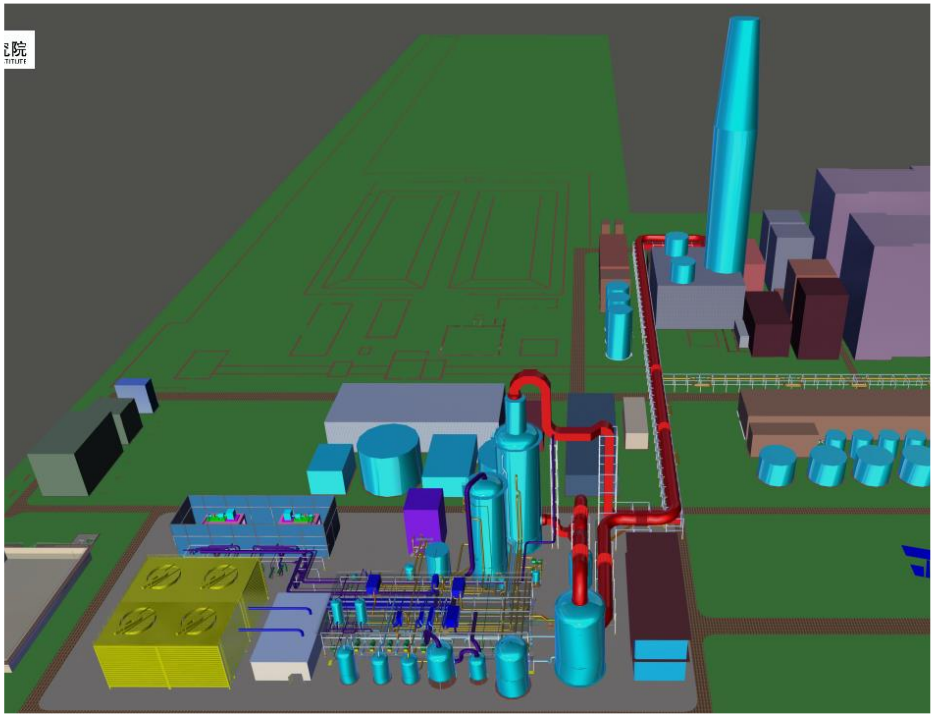
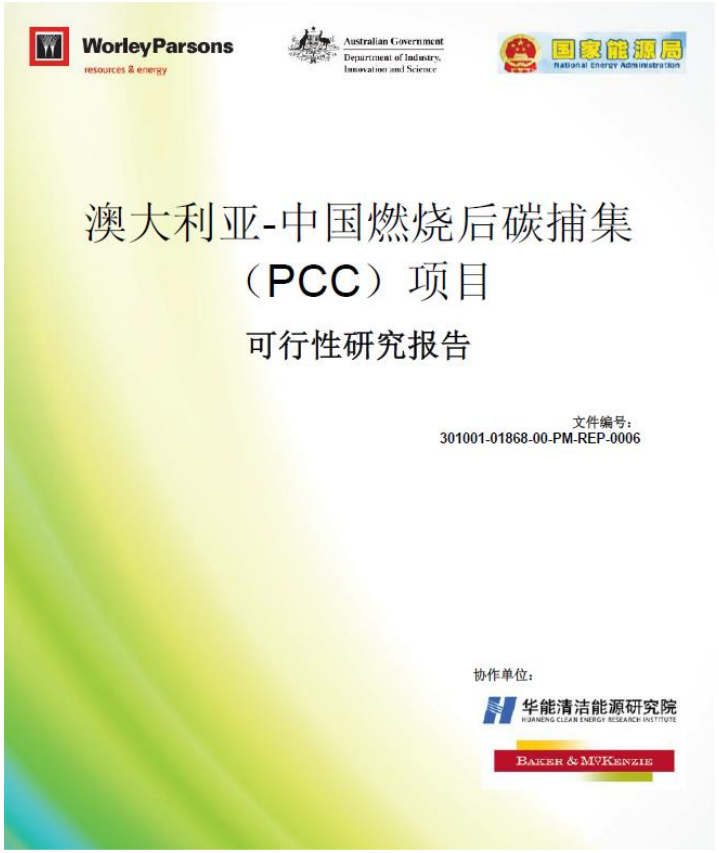
The pilot test is an important part of the Australia-China PCC Feasibility Study which in conducted by CERI in 2016





Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

1000t/a PCC for NGCC plant

- China's first CO_2 capture pilot plant for gas-fired NGCC plant with a capacity of 1000t/a; installed in Miyun county of Beijing in 2012.
- Simulated flue gas by industrial burner

  CO2 in flue gas: 6 vol% (11% for coal fired)

  O2 in flue gas: 12 vol% (5% for coal fired)

  Flue gas temperature: 90C (50C for coal-fired)
- This plant is served as a verification plant for Norway CO_2 Capture Mongstad (CCM) project
- Verification plant has been running stably for 3000 hours with capture efficiency >85%（85%~92%）
- Win the bidding of Norway Statiol CO_2 Capture Mongstad Project (Huaneng CERI-Powerspan JV)

Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

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- **Major Specs of NGCC plant**

Absorber and Wash Section		
Information	**CCM Full scale design**	**CERI Verification Plant**
Column ID		0.48 m
CO_2 Absorber Packed Beds	15.2 m total packing – 2 beds with 7.6 m in each bed Inter-cooler between beds	
Packing type	Raschig RSP 250 316 SS, 250 m^2/m^3	
Materials of construction (vessel walls and internals)	316 SS	Vessel walls 304 SS, internals 316 SS
Absorber Gas Velocity and Liquid Load	2.7 m/s (gas) 3.9 kg/m^2-s (liquid)	
Wash Section Packing and Liquid Load	3.0 m in single bed, Raschig RSP 250, 316 SS, 4.2 kg/m^2-s	

Regenerator		
Information	**CCM Full scale design**	**CERI Verification Plant**
Column ID		0.22 m
Packing	12.2 m total 2 beds with 6.1 m per bed	
Packing type	Raschig RSP 250 316 SS, 250 m^2/m^3	
Materials of construction (vessel walls and internals)	316 SS	
Liquid Load	18.6 kg/m^2-s	
Reboiler types	Kettle	

Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

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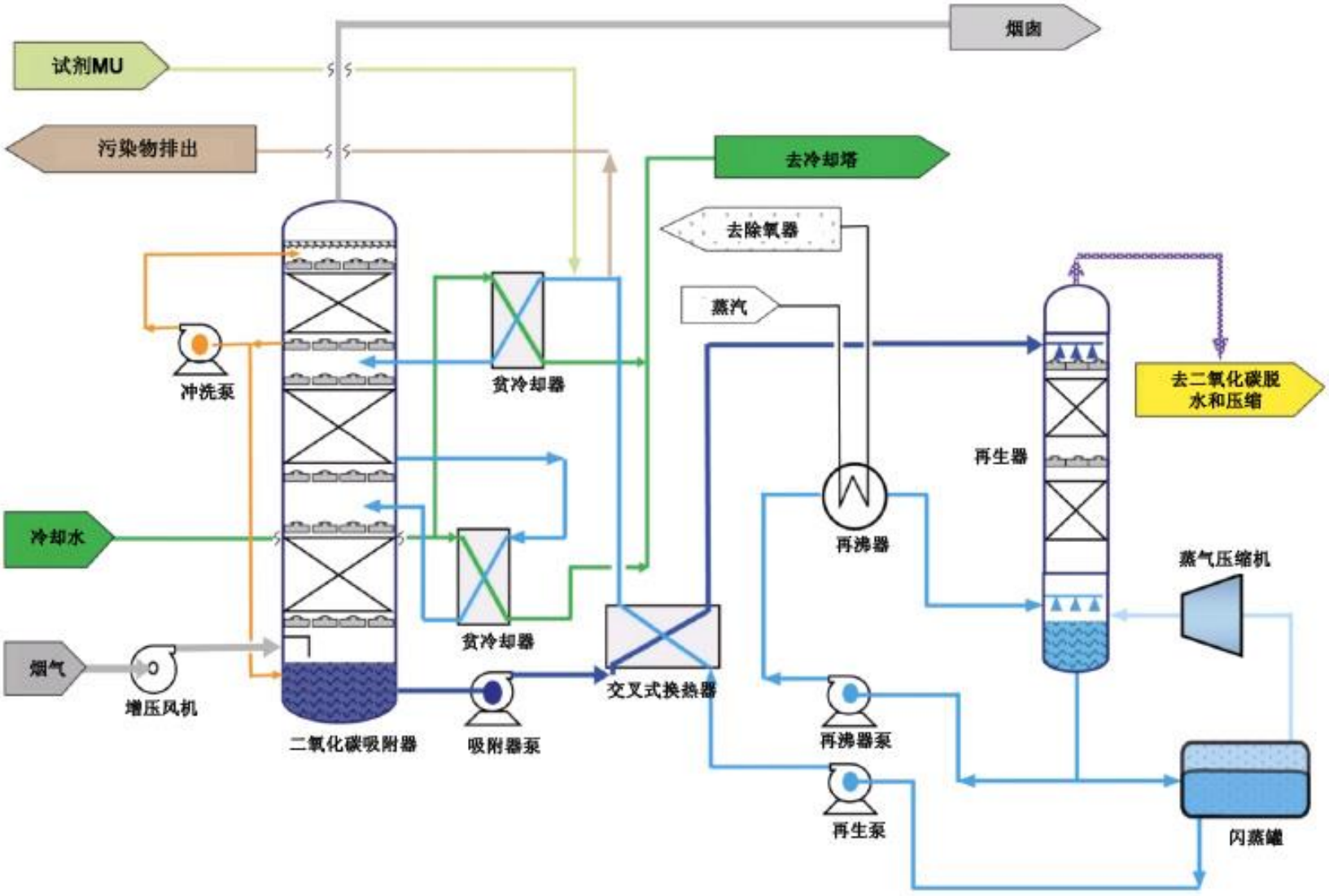

Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

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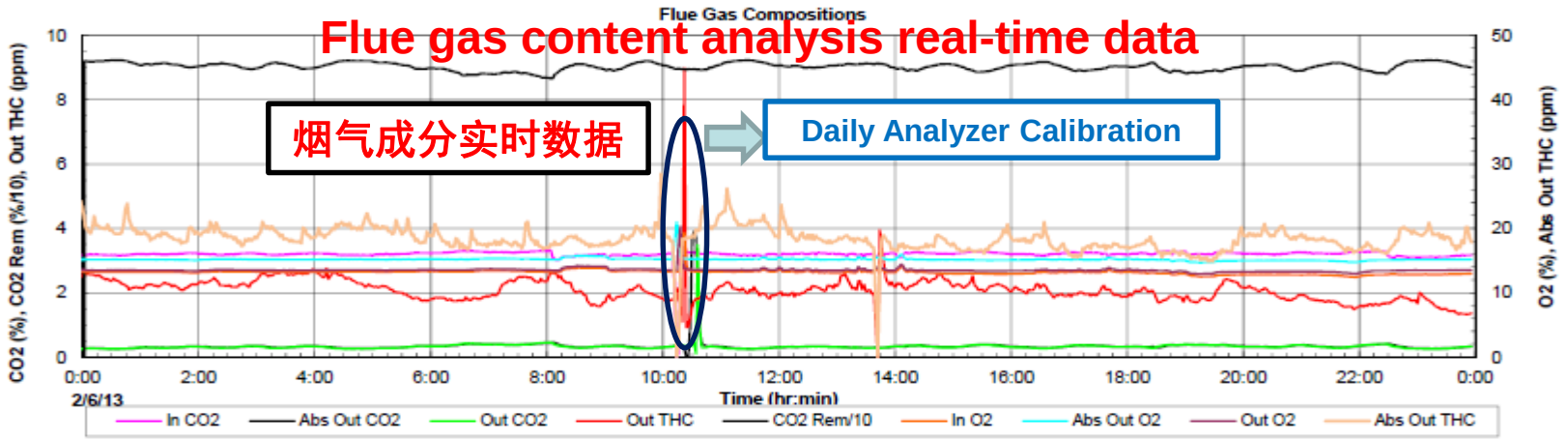
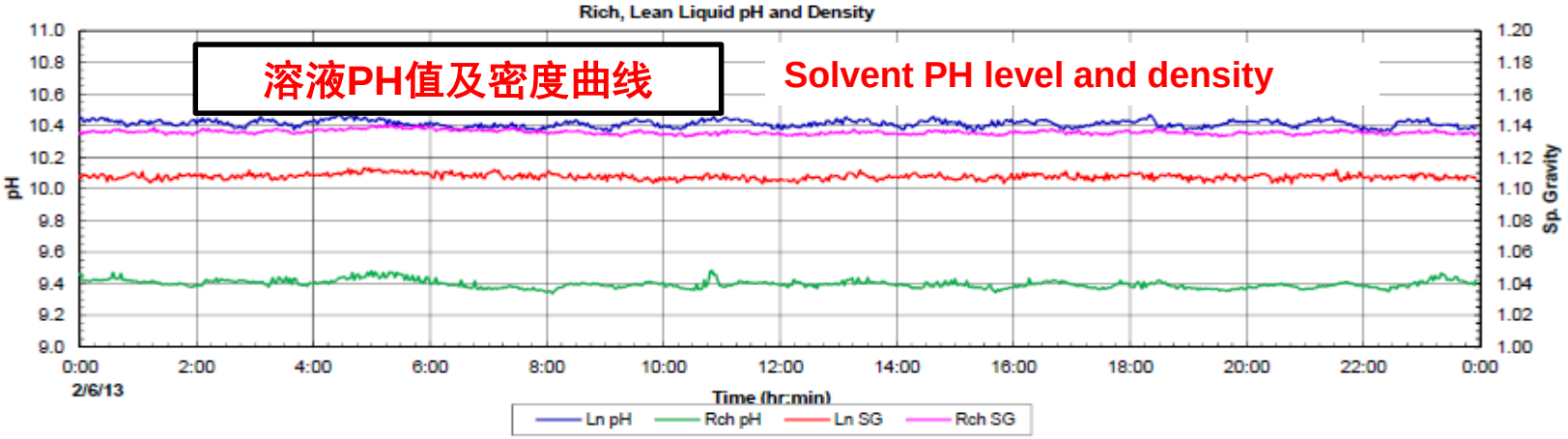
- Automatic Data Collection Every 5 Seconds, and Generating Performance Curves





Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

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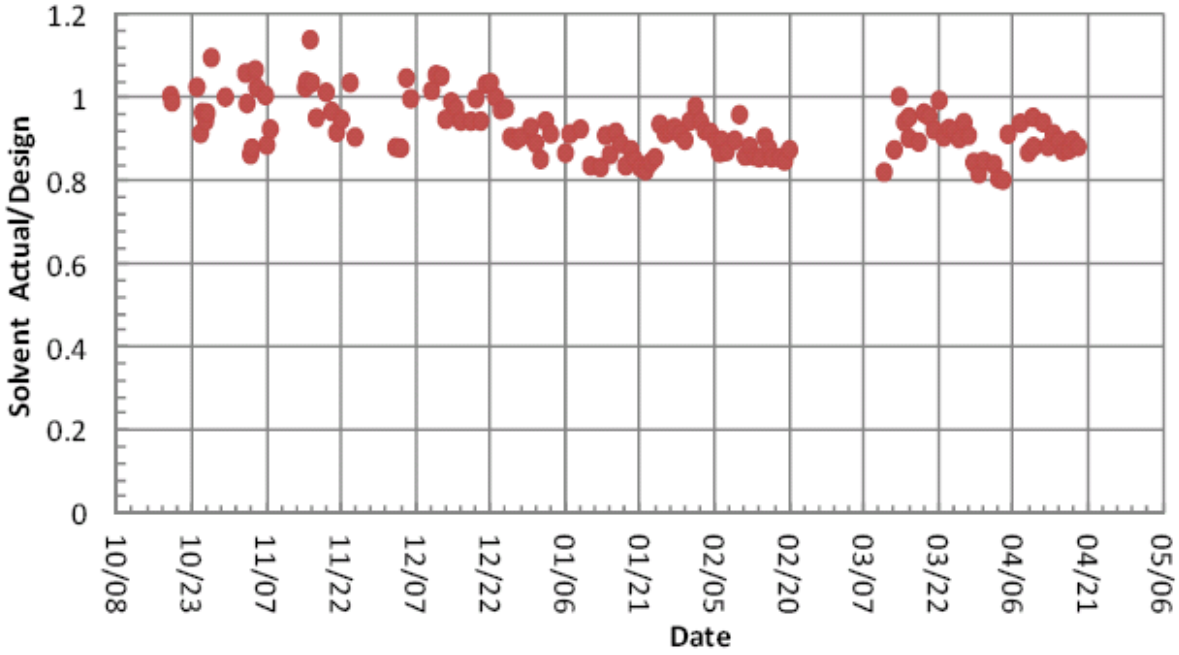
- Daily Solvent sampling
- Three solvent additions added during the operation from Mar. 7 to Apr. 2.
- Estimate Solvent consume (0.3~0.45) kg / tCO_2



Solvent concentration variation duringn 3000 hours test
Y= Actual concentration / Design Concentration

Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

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Emissions
总体排放

气相排放组分 Gas emissions component	尾气浓度 Stack concentration
溶剂 Solvent	0.17ppmv
总亚硝胺 Total Nitrosamine(TONO)	3 μg/Nm^3 as NDMA
氨 Ammonia	12.7ppmv
乙二胺 Ethylene Diamine	< 0.001 ppmv

Pilot and Demo Plants

(2) 1000 t/a gas-fired pilot plant

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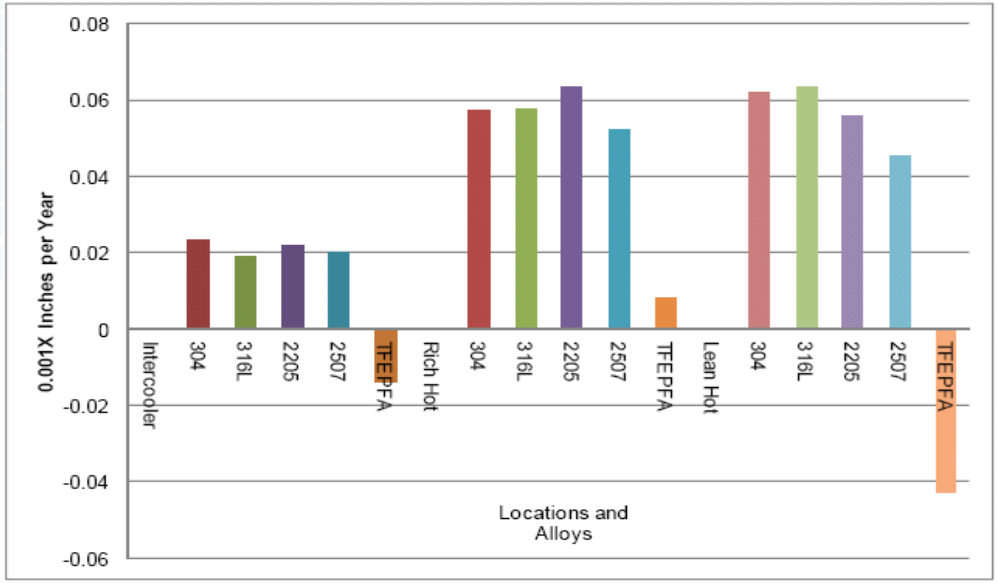
Corrision Analysis

位置—材料 Location M	速度Rate，0.001×英寸in/年Y		
中间冷却 intercooling		热富液 Hot Rich	
304	0.0232	304	0.0573
316L	0.0189	316L	0.0579
2205	0.0219	2205	0.0632
2507	0.0198	2507	0.0522
EPDM70	-8.4795	EPDM70	-24.5093
TFEPFA	-0.0134	TFEPFA	0.0081
热贫液 Hot Lean			
304	0.0619		
316L	0.0634		
2205	0.0561		
2507	0.0455		
EPDM70	-19.3614		
TFEPFA	-0.0422		

- Materials tested: 316L, 304, 2205, 2507, EPDM-70 and TEFLON(PFA);
- Total exposure time is 3888hours. For all Alloys, lower than 0.0016mm/y
- TEFLON perform fine, while EPDM experience swelling in hot location



Pilot and Demo Plants

(3) 3,000 t/a Demo plant

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- China's first post-combustion CO2 capture plant with a capacity of 3000 t/a.
- Designed by CERI, completed in 2008 and still in scheduled operation.
- CO_2 product was sold to food industry such as Yanjin Beer.
- R&D platform of CERI.

3000 t/a PCC plant in Huaneng Beijing Thermal Power Plant

Pilot and Demo Plants

(3) 3,000 t/a Demo plant

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Items	Introduction
Capture Process	Amine-based Post combustion Capture
Feature	PC power station, CO2 12-15% in flue gas
Scale	3,000tpa CO_2
Solvent	MEA
Energy consumption	<3.5GJ/t CO_2
Capture Ratio	>85%
CO_2 Purity	Food Grade, >99.997%
Others	New solvent developed by CERI was put in use since 2011, Energy consumption<3.2GJ/t CO_2
	Stable running over 5years, tests on corrosion, solvent purification and energy saving technologies

Pilot and Demo Plants

(4) 120,000 t/a Demo plant

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- Designed by CERI and ECEPDI, completed in 2009.
- Capacity: 120,000 t/a; it was word's largest PCC plant. (boundary dam,
- Cost: 100 million RMB (16 million USD)

Pilot and Demo Plants

(4) 120,000 t/a Demo plant

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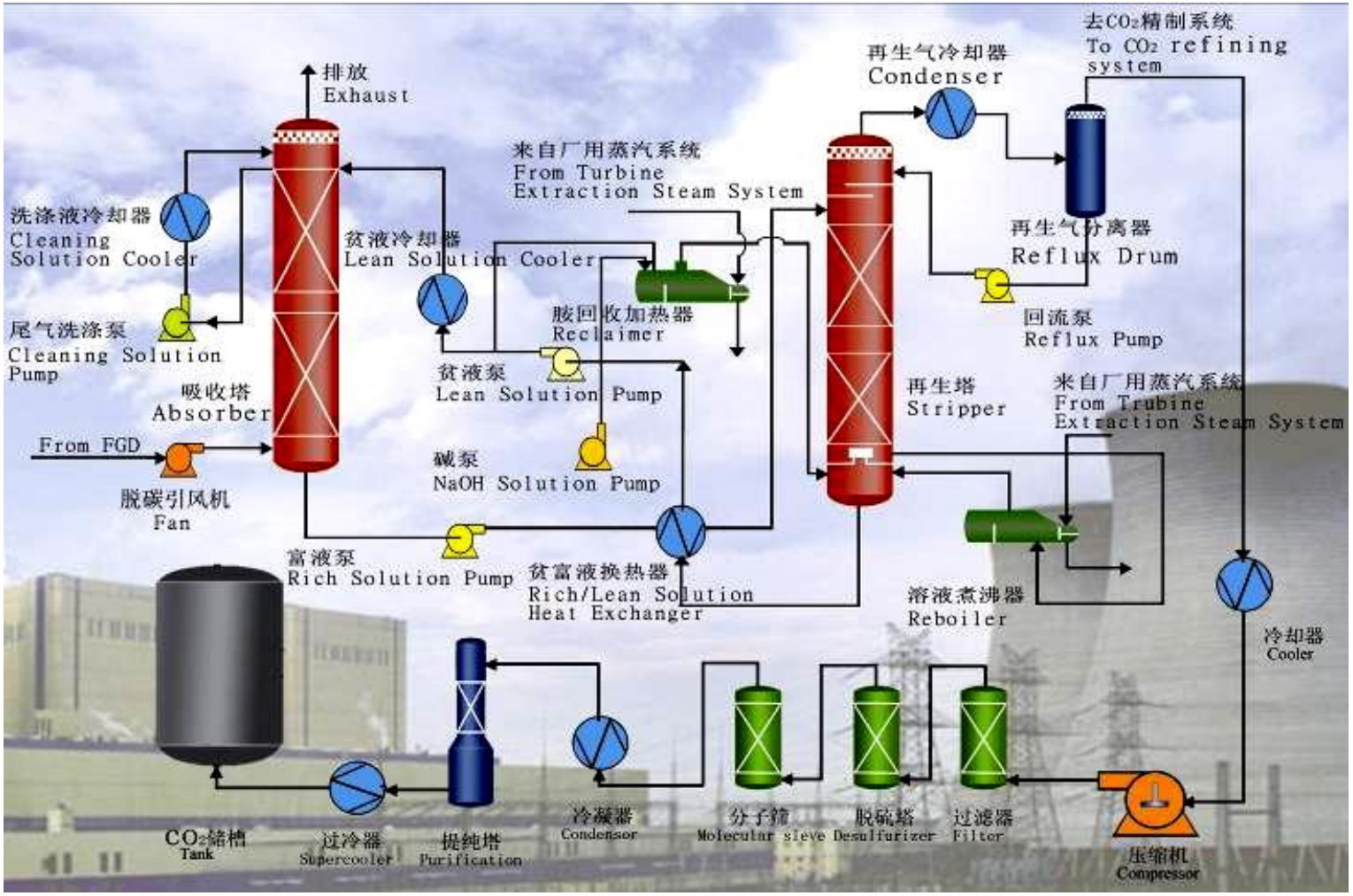
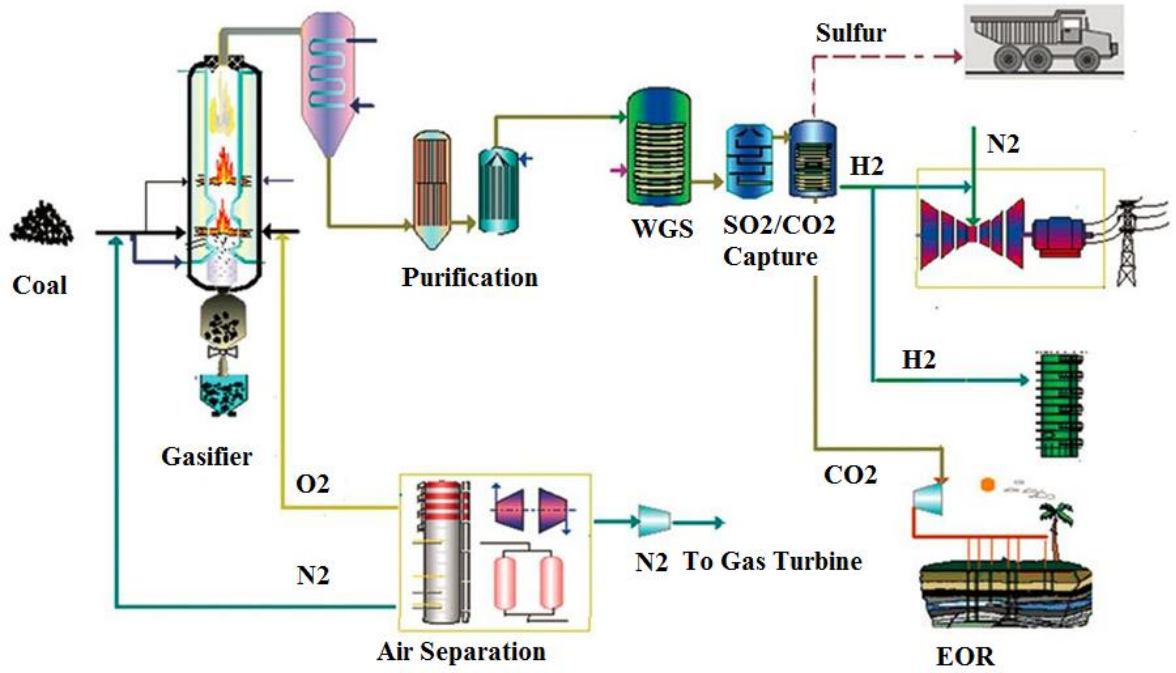


Pilot and Demo Plants

(5) Tianjin IGCC Based Pre-combustion Capture

中国华能
CHINA HUANENG



- The 30MWth pre-combustion CO_2 capture facility is being installed and will go into operation in 2016.
- The first pre-combustion CO2 capture with EOR and storage in China
- 200m^3/h palladium membrane H_2/CO_2 separation system

Pilot and Demo Plants

(5) Tianjin IGCC Based Pre-combustion Capture

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Items	Introduction
Capture Process	Amine based Pre-combustion Capture
Feature	IGCC based full chain CCS
Scale	60,000-100,000tpa CO_2($30MW_{th}$)
Energy consumption	<2.5GJ/t CO_2
CO_2 Transportation	Tanks
CO_2 Storage	≥60,000tpa CO_2 EOR+ ≥60,000tpa CO_2 storage
Others	Shift reaction heat power≥50kW $CO/H_2/CO_2$ tunable
	H_2/CO_2 membrane separation capacity≥6Nm^3/h, 10-15% reduction in energy consumption