中国科学院能源动力研究中心
Research Center for Clean Energy and Power, CAS

IGCC/Co-Production and Pre-combustion Capture

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1. Background
2. Research on IGCC with Carbon Capture
3. Research Center for Clean Energy and Power, CAS
4. International Collaboration
5. Closing Remarks

Primary energy and electricity depend on coal

- **Coal is the primary energy in China**
  - 2009: Primary energy consumption 3.07 billion tce, coal 70.1%
  - 2009: Primary energy production 2.8 billion tce, coal 77.5%
  - Coal: 92.6% of the remaining extractable fossil energy
- **Electricity depends on coal**
  - 2009: Installed capacity up to 874 GW, coal power 599 GW, 68.5%
  - 2009: Total electricity generation 3681.2 TWh, coal power generation 2866.5 TWh, 78%

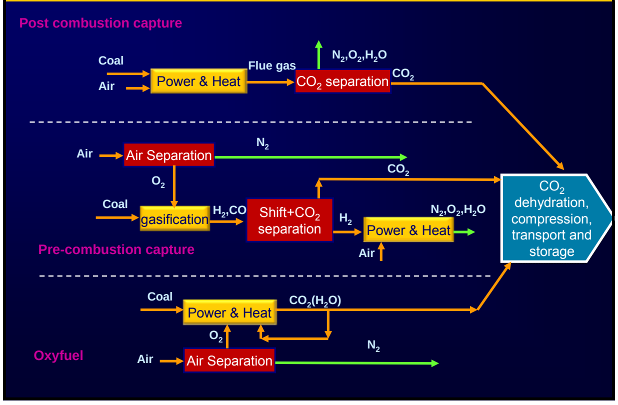
Projection of Power Capacity in 2020,2030,and 2050

	Total installed capacity 2020 (GW)	Coal power 2020 (GW)	Coal power 2030 (GW)	Coal power 2050 (GW)	Addition (2010-2020) (GW)	Addition (2010-2030) (GW)	Addition (2010-2050) (GW)
Low speed	1241	807	995	1056	208	396	457
Base	1393	914	1179	1216	**315**	**580**	**617**
High speed	1546	1023	1308	1468	424	709	869

Coal Power Technologies

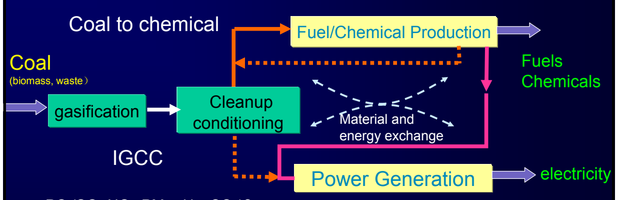
- Three Pulverized Coal (PC) technologies+ Pollution control technologies
  - Subcritical
  - Supercritical (SC)
  - Ultra-Supercritical (USC)
- Circulating Fluidized Bed (CFB)
- Integrated Gasification Combined Cycle (IGCC)

Technical Pathways to Reduce CO_2 Emissions from Coal-fired Plants



IGCC/Co-Production

More than ever, to be the end, It's got to be coal

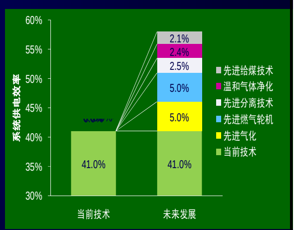


vs. PC (SO_x,NOx,$PM_{2.5}$,Hg, CO_2)?

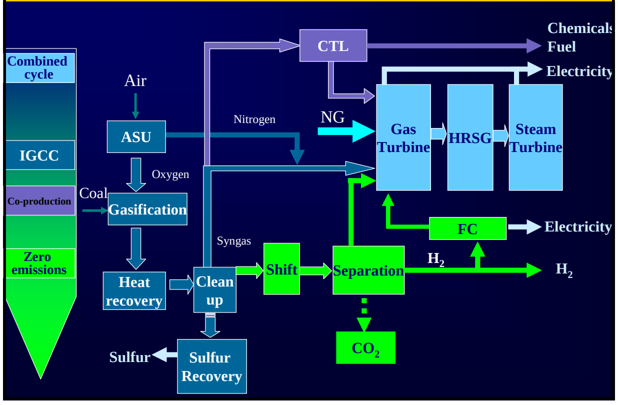
- Coal gasification based co-production
- Integration of coal-based material & energy production for co-producing power, clean fuels, chemicals & hydrogen, forward CCS
- Breakthrough for the limitation of raising efficiency, improving cost-effectiveness and controlling emissions in individual industry
- Effective solution to coal, power, oil and transportation

IGCC & Co-production

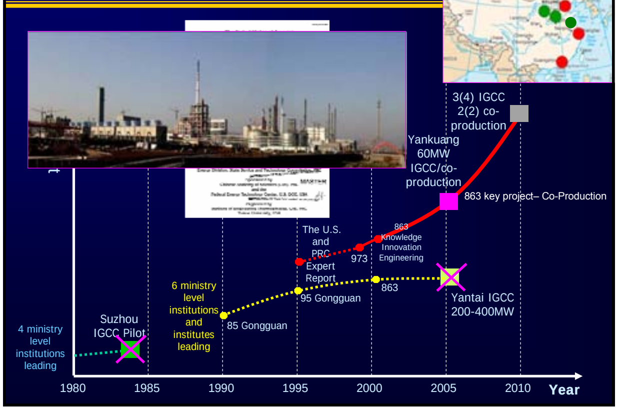
- Ultra clean
  - SO_2 and NO_x emissions <conventional PC 10%
- Low water consumption
  - Save up to 50%
- Efficiency
  - 40~43%(current)+15%↑(potential)
  - >52%（with CCS）
- Potential for cost reduction
  - Investment decrease 50%, COE decrease 50%
  - Capture CO_2, COE increase <10%
- Comprehensive utilization
  - Clean fuel, raw material and electricity co-production
  - Lignite, Bituminous coal, 80%
  - High ash, high Ash melting point, high sulfur content, 50%



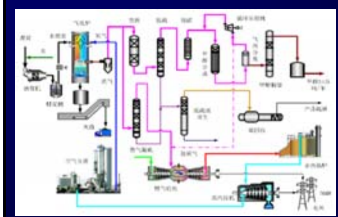
The solution– IGCC/Co-production/CCS



The Evolution of Co-production/IGCC in China



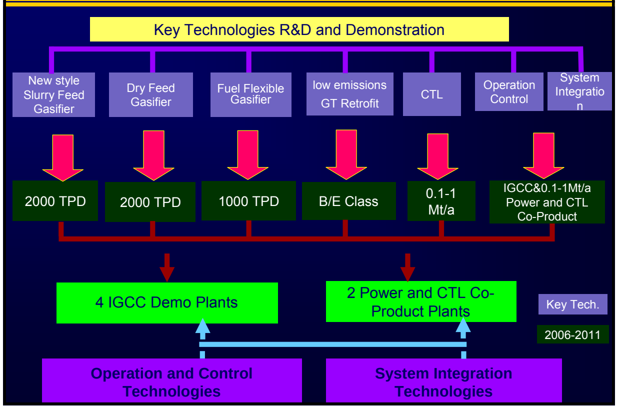
IGCC/Co-Production Breakthrough—Demonstration Project

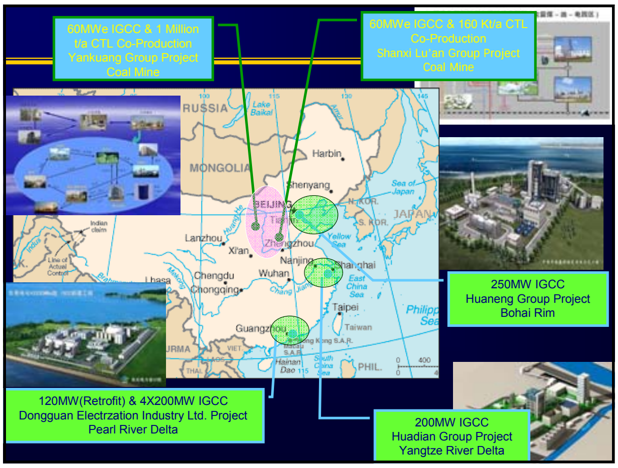


- 2×1150 TPD new style slurry fed, entrained bed
- 40MW syngas-fired gas turbine
- Put into commercial operation since May of 2006

	2006	2007	2008
Availability	87.57	89.06	90.15
Reliability	95.42	97.03	98.22

Key Technologies R&D and Demonstration





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Goals for the Analysis of Different Cases

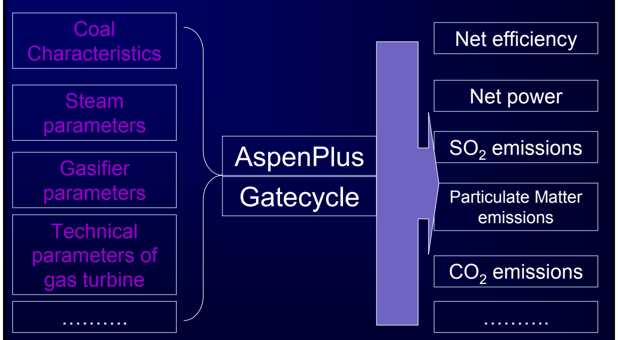
- To compare different IGCC power plant configurations
- To evaluate the technical and economic impacts of removing CO_2 from coal-fired electric power plant
- To evaluate the performance of all configurations examined
  - Net efficiency
  - Net power
  - Emissions (SO_2, NOx, Particulate Matter, CO_2)

Case Study: IGCC+CO_2 Capture

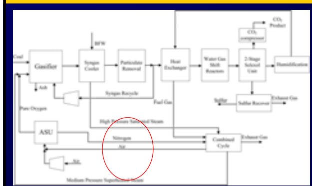
CASE	Gasifier	GT	Sulfur Control	NOx Control	Particulate Matter Control	CO_2 capture
1	O_2-blown Transport Gasification	F-class	Selexol	Fuel Humidification N_2 rejection	Candle filter	Selexol
2	Air-blown Transport Gasification	F-class	Selexol	Fuel Humidification	Candle filter	Selexol
3	GEE Gasification	F-class	Selexol	Fuel Humidification N_2 rejection	Candle filter	Selexol
4	Shell Gasification	F-class	Selexol	Fuel Humidification N_2 rejection	Candle filter	Selexol

- Coal：Da-tong Bituminous coal
- CO_2 Capture Percent: 30, 50, 70, 90 percent
- CO_2 compression pressure: 150bar

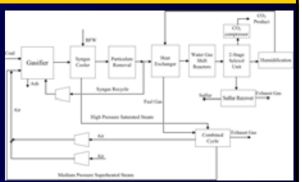
Calculation of Performance



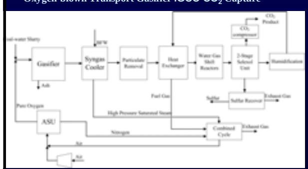
IGCC with CO_2 Capture



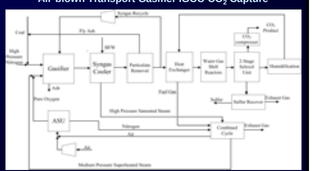
Oxygen-blown Transport Gasifier IGCC-CO_2 Capture



Air-blown Transport Gasifier IGCC-CO_2 Capture



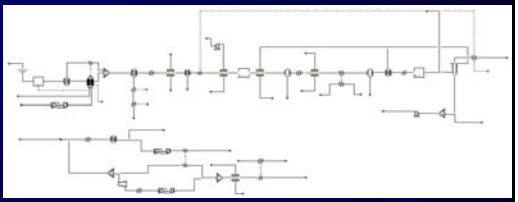
GE-E Gasifier IGCC-CO_2 Capture



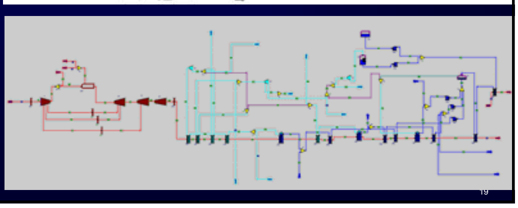
Shell Gasifier IGCC-CO_2 Capture

IGCC with CO_2 Capture in Aspen and Gatecycle

Gasification island



Power island



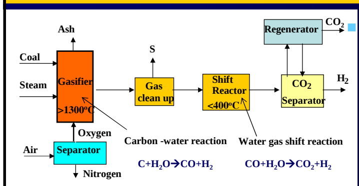
Results

Power plant	Transport-O_2		Transport-Air		GEE		Shell	
	Power (MWe)	Decreased by(%)	Power (MWe)	Decreased by	Power (MWe)	Decreased by	Power (MWe)	Decreased by
W/O capture	409.0	-	460.8	-	444.9	-	412.0	-
CO_2 capture 50%	389.1	4.9	431.1	6.4	415.9	6.5	395.0	4.1
CO_2 capture 70%	375.4	8.2	417.8	9.3	404.7	9.0	378.7	8.1
CO_2 capture 90%	361.8	11.5	404.0	12.3	393.2	11.6	362.3	12.1

Power plant	Transport-O_2		Transport-Air		GEE		Shell	
	Efficiency (%)	Decreased by	Efficiency (%)	Decreased by	Efficiency (%)	Decreased by	Efficiency (%)	Decreased by
W/O capture	45.7	-	45.8	-	43.6	-	46.3	-
CO_2 capture 50%	41.8	3.9	40.8	4.9	38.8	4.9	40.5	5.8
CO_2 capture 70%	39.9	5.8	38.9	6.9	37.2	6.5	38.3	8.0
CO_2 capture 90%	37.8	7.9	36.9	8.9	35.4	8.3	36.1	10.2

Transport-O_2, same output				
Capture level	30%	50%	70%	90%
Coal consumption for per CO_2 captured (kg/kg)	0.108	0.118	0.124	0.135

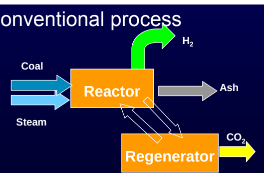
CO_2 capture ready gasification technology



Characteristics:

- Introduce CO_2 absorbent and integrate gasification, water-gas shift, and separation
- Heat integration
- Produce H_2 and sequestrable CO_2
- System efficiency
  - ✓ 60%→75%

Conventional process

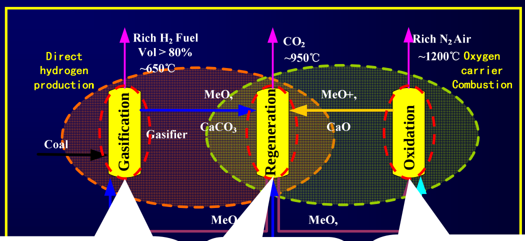


CO_2 capture ready process

Reactions：

- Steam gasification： $C+H_2O \rightarrow CO+H_2$
- Water-gas shift： $CO+H_2O \leftrightarrow CO_2+H_2$
- CaO hydration： $CaO+H_2O \leftrightarrow Ca(OH)_2$
- CaO carbonation： $Ca(OH)_2+CO_2 \leftrightarrow CaCO_3+H_2O$
- Overall reaction： $C+2H_2O+CaO \rightarrow CaCO_3+2H_2$

Problems to be Studied

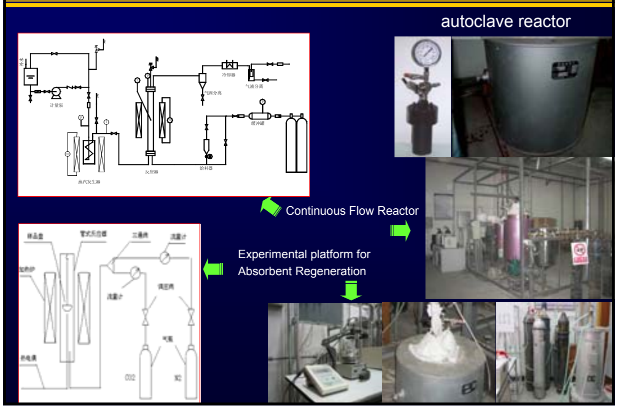


- Thermodynamic feasibility
- Heat balance
- Activities of CO_2 Absorber
- Efficiency
- Conversion
- Pollutants (Tar)

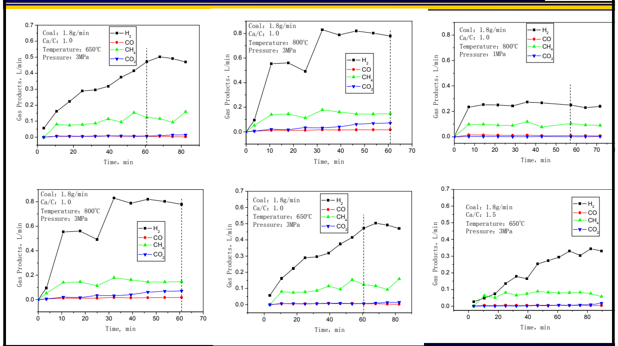
- Regeneration of CO_2 Absorbent
- Heat supply
- Activities
  - Residence time
- Pollutants (SO_2)

- Recycle characteristics
- Oxygen carrying capacity
- Oxidation temperature
  - Loading capacity
- Pollutants (NO_x)

Research Equipment

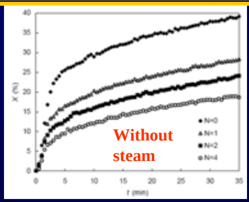


Experimental results continuous flow

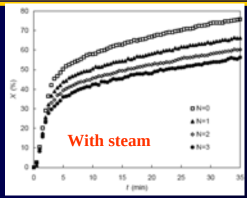


The efficiency reached 75%

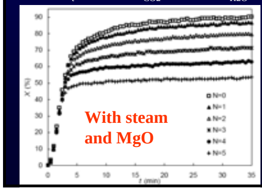
Effect of steam and MgO on the cyclic performance of CaO



923K, P_t=1.5 MPa, P_{CO2}=0.5 MPa, P_{H2O}=0

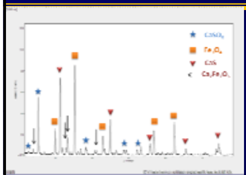


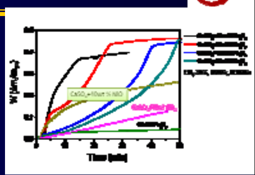
923K, P_t=1.5 MPa, P_{CO2}=0.5 MPa, P_{H2O}=0.1MPa



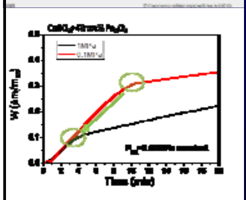
- Steam can improved the cyclic performance of CaO
- MgO can enhance the improvement of steam on the cyclic performance of CaO

Deactivation and Improvement Research of Ca-based oxygen carrier

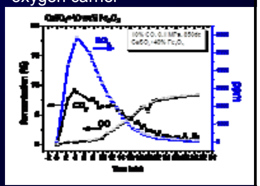




Improvement of Ca-based oxygen carrier



Mechanism of deactivation of Ca-based oxygen carrier



Emission of contamination

Policy Study

- Drivers for advanced technologies
  - Technology push
    - R&D
    - Demonstration projects
  - Market pull
    - Incentives
    - Regulations
    - Environmental policy
- IGCC policy study
- Near-Zero Emissions Coal-Fired Power Generation Technology

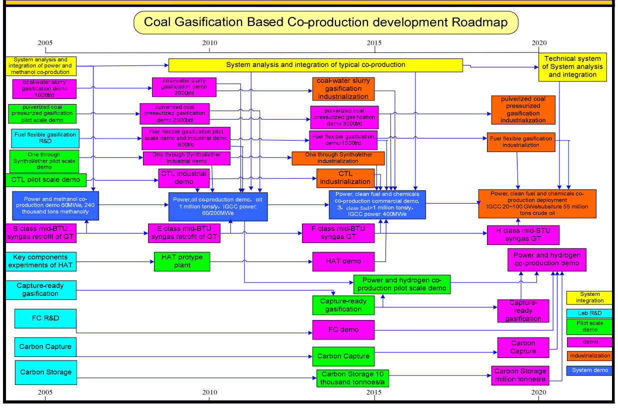
IGCC and Co-Production Development in China
---- Advantages, Barriers and Strategies Study

- **Barriers recognized**
  - Policy barriers
    - ✓ No special policies
    - ✓ Lack of market measurements or incentives
    - ✓ Environmental policies and standards need further improvement
  - Institutional/organizational barriers
    - ✓ Unfavorable sector structure and division
    - ✓ Low investment
    - ✓ Lack of market mechanism and effective government supervision
  - Technical barriers
    - ✓ Key technologies
    - ✓ System integration & design
  - Financial barriers
- **Breakthrough needed**
  - High-Tech
    - ✓ Gasification & syngas preparation
    - ✓ Syngas fired gas turbine
    - ✓ Fuels and chemicals synthesis
    - ✓ Hydrogen production and CCS
  - Industrial reform
    - ✓ Power utility
    - ✓ Coal chemical industry
    - ✓ Coal sector
    - ✓ Technology providers, engineering design, equipment manufacturing
  - Cooperation mechanism
    - ✓ Government
    - ✓ Industry
    - ✓ Institute
    - ✓ University

IGCC and Co-Production Development in China
---- Technology Roadmap

- Goals: Provides a blueprint for the coordinated, long term efforts required
  - Develop unified roadmap
  - Maintain high-level approach
- Supported by
  - Department of High and New Technology Development and Industrialization, MOST
  - Bureau of High-Technology Research and Development , CAS
  - NRDC
- Organized by
  - Institute of Engineering Thermophysics
  - The expert group for clean coal technology, 863 program
- Formulate overall goal for the development of co-production, stage goals for key individual technologies and system integration, and development goals for near zero emissions demonstration for 2020

IGCC and Co-Production Development in China
---- Technology Roadmap



Key Policy Options

- Developing a Nation-wide Roadmap
- Establishing Database for Better Understanding and Formulation of Policies
- Improving Efficiency in Coal Power Sector
- Formulating Stricter Emission Standards
- Regulating CO_2 Emissions
- Increasing the Level of Emission Charge
- Promoting the Deployment of Capture Ready Coal Power Technologies
- Promoting the RD&D of CO_2 Capture Technologies
- Formulating Incentive Policies
- Strengthening the Implementation of Policies, especially Environmental Regulations
- Mapping Geological Storage Location and Assessing Storage Capacity

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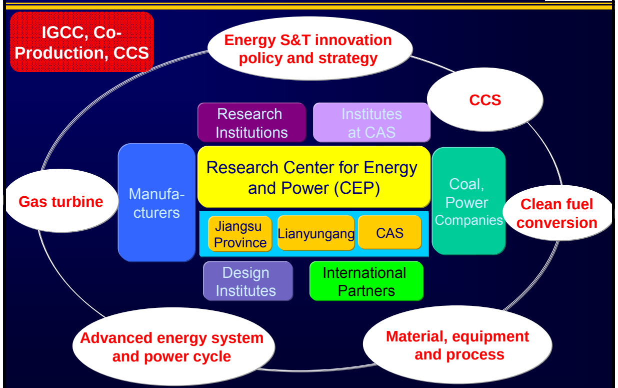
Research Center for Clean Energy and Power（CEP）



CEP Mission

- To achieve innovation in key technologies and system integration, find solutions to sustain the development of energy and power
- To organize, propose, undertake, and finish national key research tasks
- To train researchers
- To conduct research on S&T innovation strategy and provide consulting about the development of energy and industry
- To serve as collaborative platform domestically and internationally

Overall Goals

- To develop globally competitive energy and power technologies
- To build and run advanced clean energy technology development facility
- To establish a talented R&D team
- To explore and formulate innovative mechanisms for conducting researches effectively

Clean Energy Technology RD Facility

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Construction Contents

Power generation
- Syngas combustor
- Turbine
- Compressor
- High temperature FC

Cleanup
- Syngas filtration
- Hot syngas cleanup
- CCS

Syngas conversion
- Substitute fuel
- Basic chemicals

Syngas

The sources of syngas
- CO_2 capture ready gasification
- Oxygen-blown and air-blown gasification
- Feedstocks flexible gasification

Ancillary facilities, measurement and control system, analytical instruments

Elemental analyzer | Dynamic measurement | Distributed Control | Safety Instruments

Flue gas analyzer | Scanning electron microscope | Pressurized thermogravimetric instrument | Ash melting Tester

Transformer substation | ASU | Feeder | Coal preparation | Steam boiler | Liquid fuel | Water treatment

The Construction of RD Facility

Technology Development

Gasification Technologies and CCS

1. Fuel-flexible gasification
2. CO_2 capture-ready gasification
3. One step system for coal to SNG
4. Syngas heat recovery
5. Warm syngas filtration
6. Warm syngas sulfur removal
7. Hot syngas cleanup
8. Continuous coal feed and ash removal
8. CCS

Technology Development

Gas Turbine

1. Modeling and Numerical Simulation of Gas Turbine
2. Multistage Matching in Axial Compressor and Radial Compressor
3. Technology to Maximize Blade Loading
4. Edge-Matching Technology for Axial Turbomachinery
5. Counter-Rotating Turbomachinery
6. Thermo Management in Turbine Environment
7. Syngas nozzle design
8. Combustor cooling design and analysis
9. Advanced Structure, Materials and Manufacture
10. Hydrogen Combustion

Technology Development

Syngas conversion and fuel cell

1. CTL, CTG
2. Separation and refinement
3. Catalyst
4. High temperature fuel cell using syngas as fuel

Clean Energy Innovation Park Project

- Advanced IGCC
- 650℃ USC
- High temperature thermal solar power
- Co-generation (heat, power, cooling)
- Co-production (SNG, liquids, hydrogen)
- CO_2 capture and storage
- Inherent Cyclical Economy by integrating with oil refinery & chemicals, and iron & steel as well

Located in Clean Energy Innovation Industrial Park in Lianyungang, Jiangsu Province

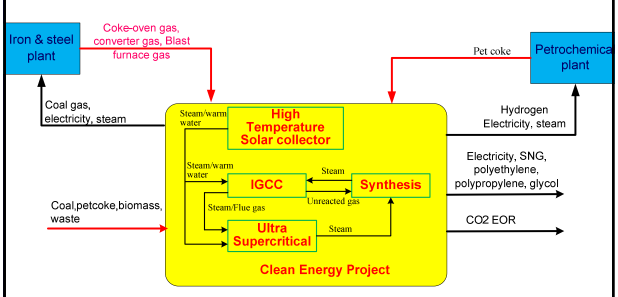
Construction Contents

- 2500 MW power
  - 1200 MW IGCC
  - 1300 MW ultra supercritical PC power
  - High Temperature Solar collector
- Multiple downstream products
  - 5.38 × 10^8 Nm^3 SNG
  - 0.6 Mt polyethylene/a
  - 0.6 Mt polypropylene/a
  - 0.5 Mt glycol/a
- 1 Mt/year CO_2 will be captured in IGCC and ultra supercritical PC

Three Options on CO_2 Storage

- Aquifer storage, 100 kilometers away from Lianyungang
- North Jiangsu oil field for Enhanced Oil Recovery (EOR), 200 kilometers away from Lianyungang
- The utilization of the captured CO_2

Clean Energy Innovation Park Project



National Strategy

- The Standing Committee of State Council endorsed “The development plan for Jiangsu coastland” on June 10th, 2009.

‘Actively support the collaboration on energy and power between Jiangsu Province and CAS, and build clean energy innovation park.’

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Cooperation between Harvard University, MOST, and CAS

	Time	Venue	Topic
1	October 2002	Beijing China	Clean Coal Energy
2	September 2003	Boston USA	The Roles of Government in the Innovation and Use of Clean-Coal Technologies in the United States and China
3	May 2004	Hangzhou China	The Cooperation in Clean-Coal Technologies Between the United States and China
4	September 2005	Boston USA	Advanced Coal Technologies in a Sustainable Energy System
5	May 2007	Beijing China	IGCC & Co-production and CO_2 Capture & Storage
6	April 2009	Boston USA	Promoting the Development and Deployment of IGCC/Co-Production/CCS Technologies in China and the United States

2007' International Workshop on IGCC & Co-production and CO_2 Capture & Storage

- Convened by:
  - Department of High and New Technology Development and Industrialization, MOST
  - Bureau of High Technology Research and Development, CAS
- Organized by:
  - The National Joint Expert Group and Office for IGCC and Co-Production Demonstration Engineering of 863 Program for MOST
  - John F. Kennedy School of Government, Harvard University
  - Research Center for Energy and Power and Institute of Engineering Thermophysics, CAS
- Sponsored by：
  - The Royal Society (UK)
  - Woods Hole Research Center, and William and Flora Hewlett Foundation
  - Energy Foundation

A Joint Workshop on Promoting the Development and Deployment of IGCC/Co-production/CCS

- Convened by:
  - Department of High and New Technology Development and Industrialization, MOST
  - Bureau of High Technology Research and Development, CAS
- Organized by:
  - the Energy Technology Innovation Policy research group, Harvard Kennedy School
  - CEP, CAS
  - the National Joint Expert Group for IGCC and Co-Production Demonstration Engineering of China
- Participants:
  - Ministry of Science and Technology, CAS, Local governments, Academia, Manufacturers, Engineering companies, Power companies, Coal companies

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Ideas for Sino-U.S. Cooperation on Advanced Coal and CCS Technology and Policy

Technology

1. Explore the idea of co-financing joint demonstration of commercial-scale IGCC and Co-Production in China
2. Assess the adaptability of certain advanced technologies
3. Establish at least two large-scale joint carbon sequestration demonstration projects
4. Arrange a study tour of selected U.S. carbon sequestration demonstration sites for Chinese researchers
5. Carbon storage capacity assessments

Policy

1. Policy research on effective policies for IGCC/Co-Production/CCS demonstration deployment
2. Study the efficiency of current U.S.-China energy cooperation, and how to improve it
3. Policy research on legal issues related to demonstration and early deployment of CCS in the United States compared with China
4. Study on suitability of policy harmonization
5. Joint Workshop on Sequestration RD&D Policy
6. Gather, standardize, and share data on government investments in energy research, development, demonstration, and deployment
7. Study of barriers to technology transfer for coal gasification, co-production, and CCS

Education

1. Continue and expand CAS-MOST-Harvard annual workshops
2. Student and faculty fellowships for exchanges

Cooperation between CEP, NETL, PNNL

- Objective- Jointly perform RD&D
- Common Vision – Establish a joint R&D center to advance the clean fossil energy technologies
- Technical areas:
  - High volume CO_2 capture, sequestration and utilization
  - Advanced gasification and gas turbine
  - Advanced syngas conversion technologies

Other Collaboration

- The William and Flora Hewlett Foundation
- Energy Foundation
  - IGCC policy study
  - The Path to Near-Zero Emissions Coal-Fired Power Generation Technology in China
- Natural Resources Defense Council
  - Advantages, Barriers and Strategies Study on Gasification-Based Co-Production
  - Roadmap for the Development of Coal Gasification-Based Co-Production Technologies in China
- Blue Moon Fund
  - Mobile Biomass Pyrolysis for Biochar
- U.S. Power Consult Co.

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Closing Remarks

- The IGCC and co-production demonstration projects pave the path to incorporate CCS into IGCC system.
- Clean energy technology R&D facility will play a significant role. Welcome to conduct joint research on the facility.
- All these efforts will make great contributions to maintain coal as a significant component in the energy mix for economic development in a carbon-constrained world.