Status and Cooperation Prospect for Coal/NG Chemical and CCUS Technology between China and US

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Energy Policies and Directions in China

Strategic Target of Energy Development for the 12th Five-Year Plan

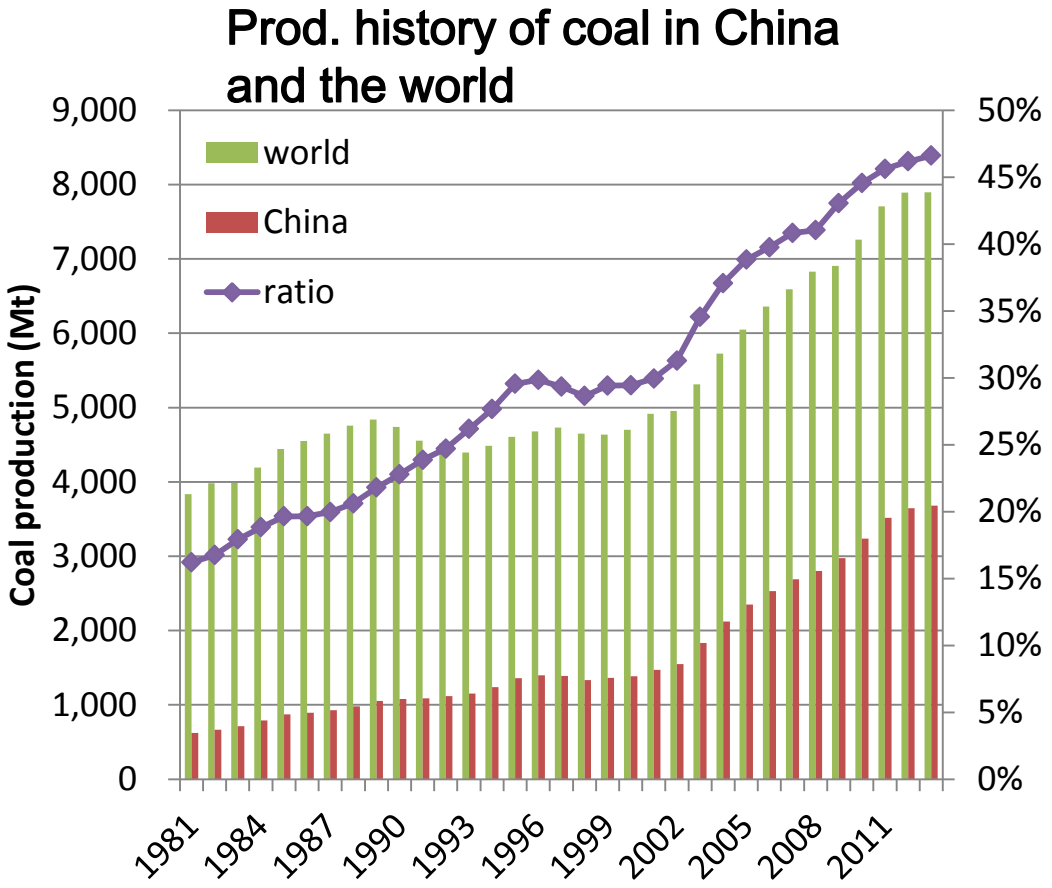
- Strengthen energy conservation and improve energy efficiency. By 2020, carbon dioxide emissions per unit GDP decrease 40％－45％ than that in 2005, as binding target, and establish corresponding domestic statistic, monitoring, evaluation system
- Strive to develop new energy and renewable energy source, endeavor to increase the share of non-fossil energy consumption in primary energy consumption to around 15% by 2020.

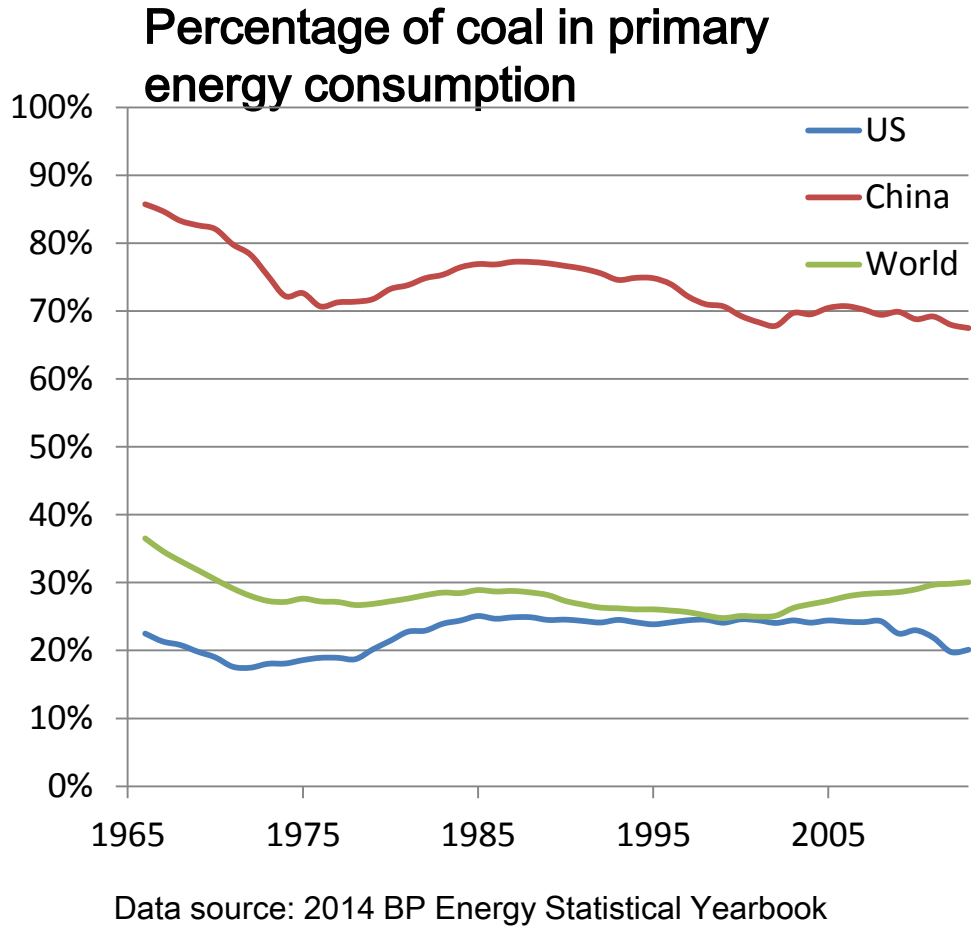
Main Technical Direction for Energy

- Clean coal technology
- Renewable energy source technology
- Advanced nuclear technology
- Smart grid technology
- Energy saving and storage technology
- Hydrogen energy and fuel cell technology

Role of coal/NG in energy development

Coal production and consumption history in China and the world



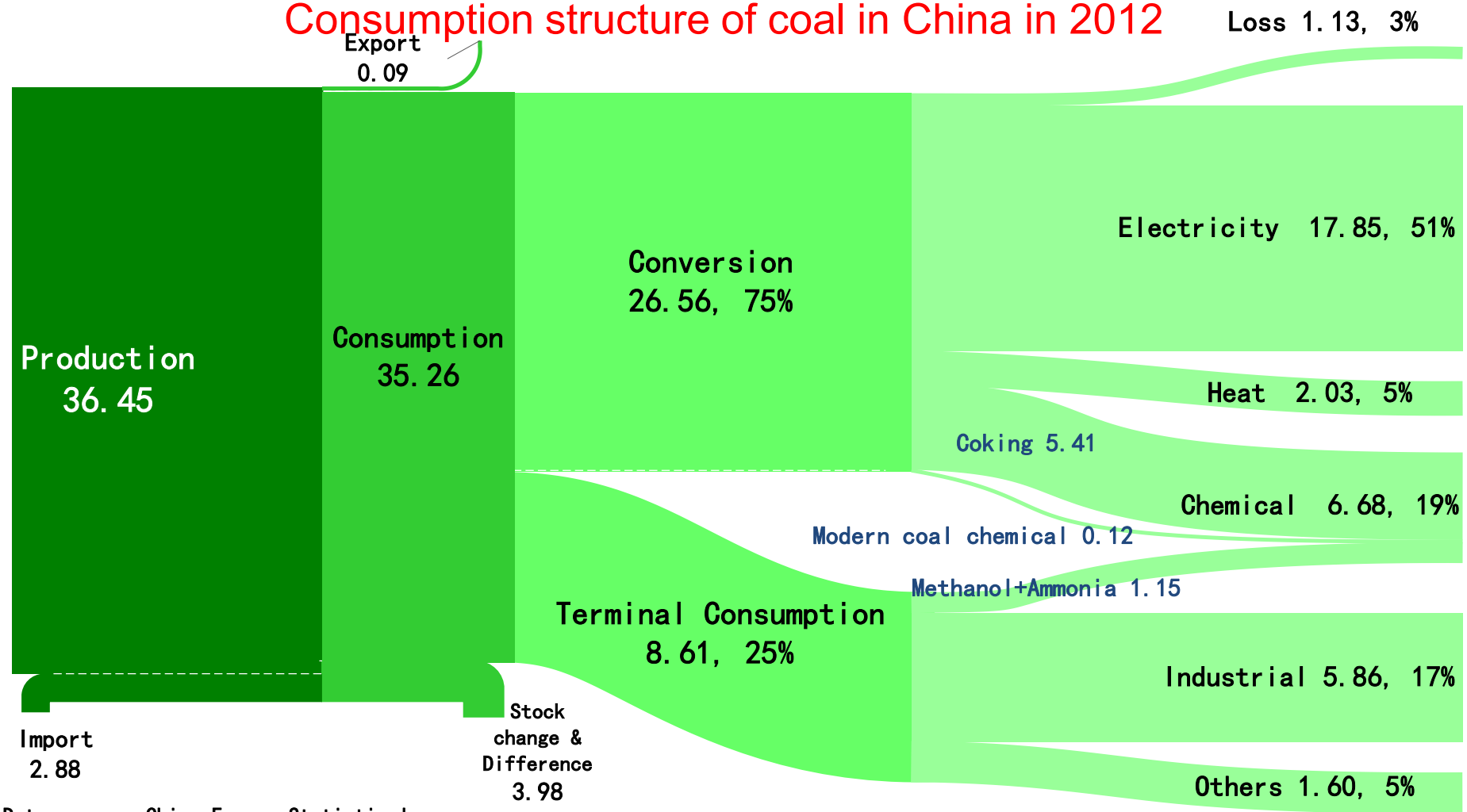


Data source: 2014 BP Energy Statistical Yearbook

- The world's coal production has been in a continuous increasing trend in the past half a century with world economy development, though its share in primary energy dropped first and then increases, which is 30% in 2013.
- China's share in the world's coal production has increased dramatically recently, which reached 47% in 2013.

Coal provides important back for China's rapid growth in economy development

Consumption structure of coal in China in 2012



Data source: China Energy Statistical Yearbooks 2013 (10^8t)

Taking 75% in China's total power generation

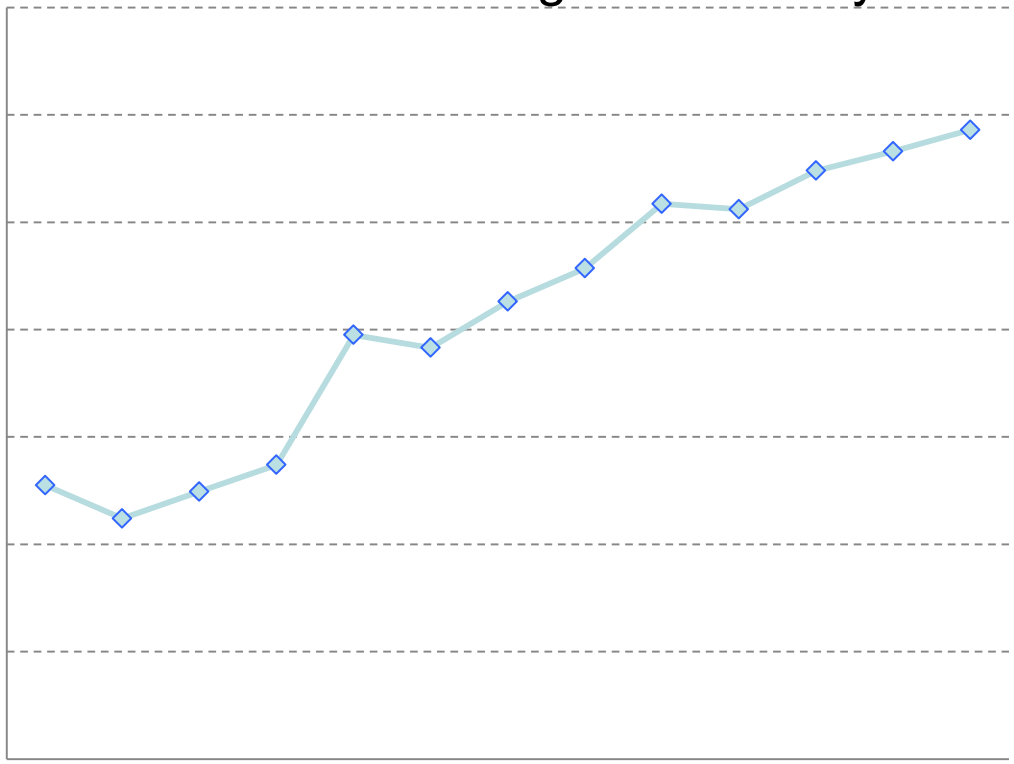
Providing 50% of the raw material for chemical industry

Providing more than 70% of total energy consumption by industry

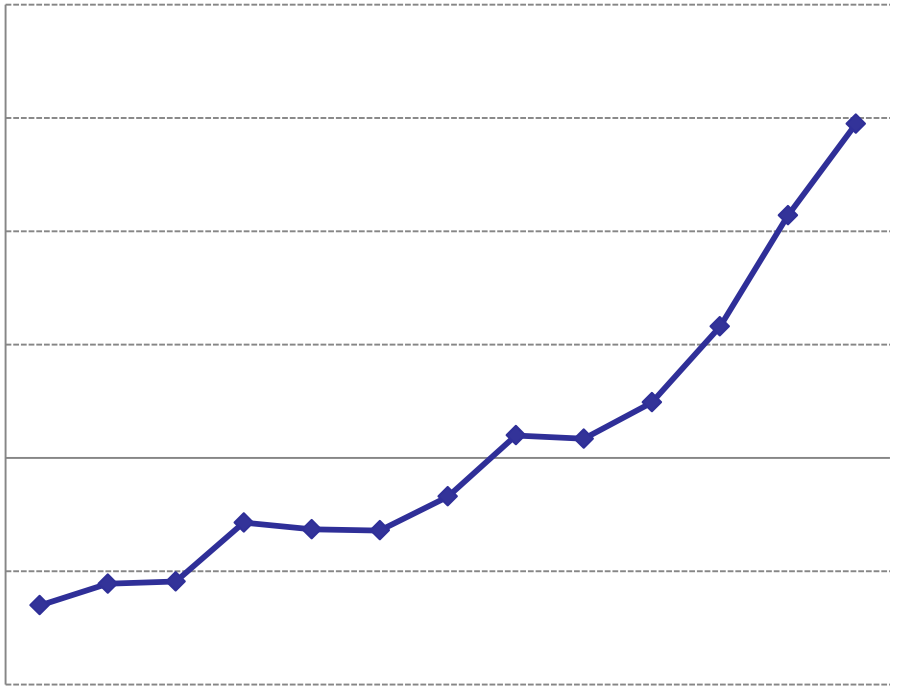
- Coal provides tough back for the dev. of China's industry and economy in middle and western part of China.
- Currently, power industry takes 90% of total coal consumption, and 80% in Germany.

Coal is an important supporting factor for China's energy security

Import dependence of oil has been increasing continuously



Import dependence of NG is now increasing fast



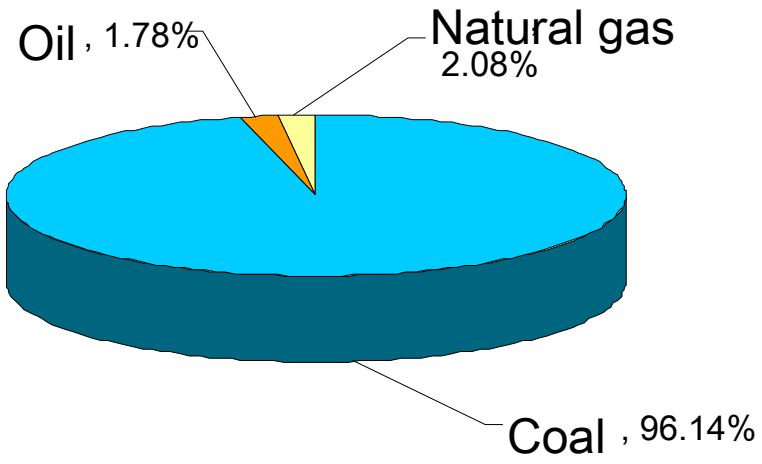
Source：Energy Statistics Annual Rep for 2013

- Import dependency of oil and NG has been increasing rapidly recently, and China is now facing severe situations in energy security.
- Coal can not only be converted to clean power, but also can be transformed to clean gaseous and liquid fuel, and chemical products as well, partly taking the place of oil and NG, so coal is an important supporting factor for China's energy security.

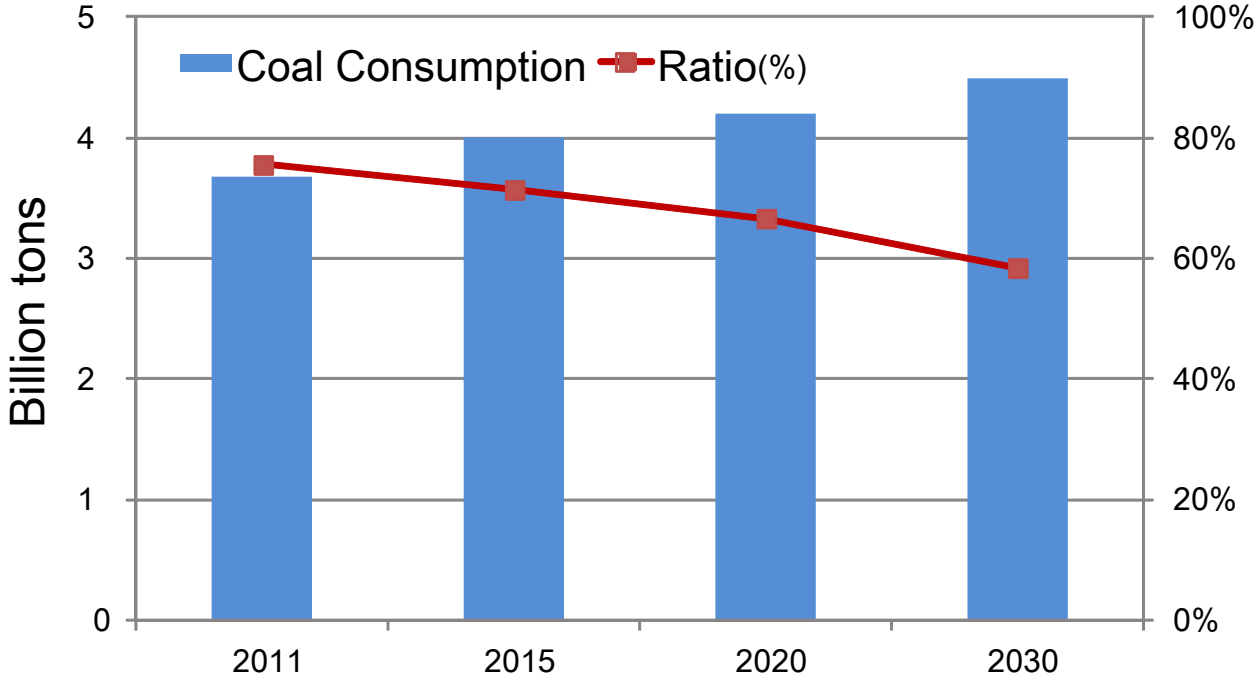
The dominant role of coal as China's major energy will not change in a rather long period

- Coal is the most abundant fossil energy in China with verified reserves (96%).
- In 2012, coal takes 81.7% and 70.6% in China's primary energy prod. and cons.
- China's coal consumption will still increase in a rather long period, with its peaking at ~4.5 billion tonnes.
- It is predicted that coal consumption will still take >55% in China's primary energy consumption in 2030.

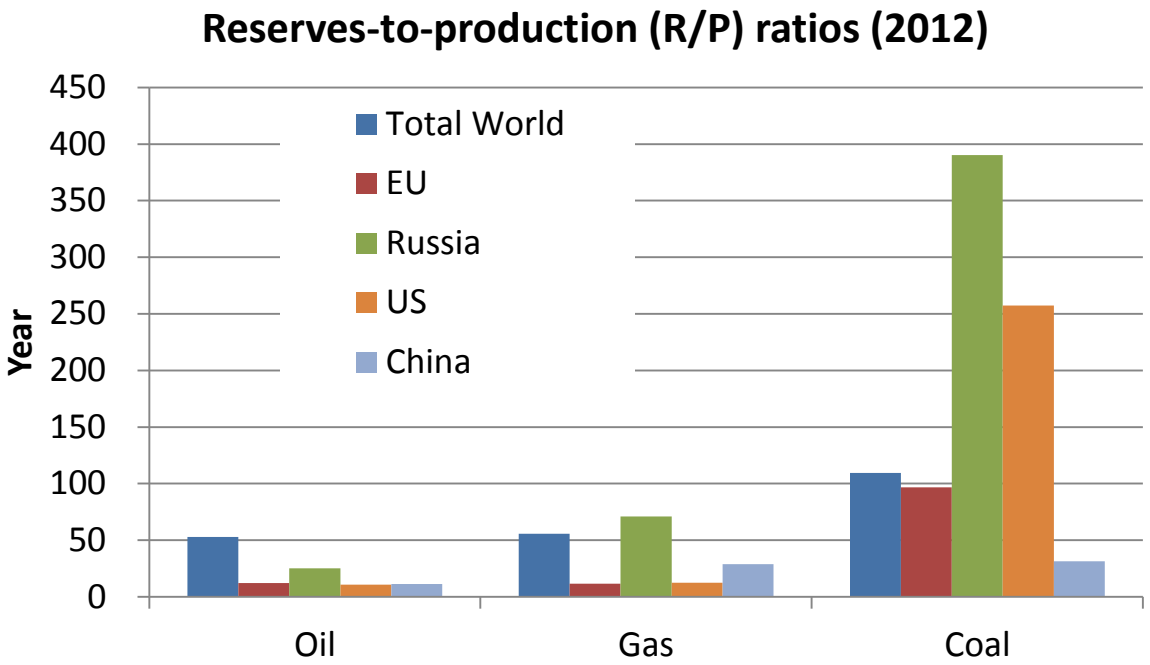
Verified reserves of China's fossil energy



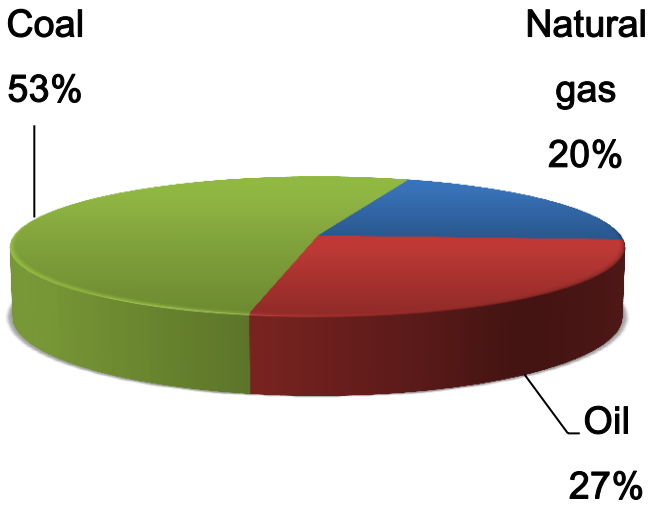
Coal consumption and share in China's total primary energy consumption before 2030



Coal is the most abundant and most fundamental energy resource in the world



Share of exploitable reserves of fossil energy in the world

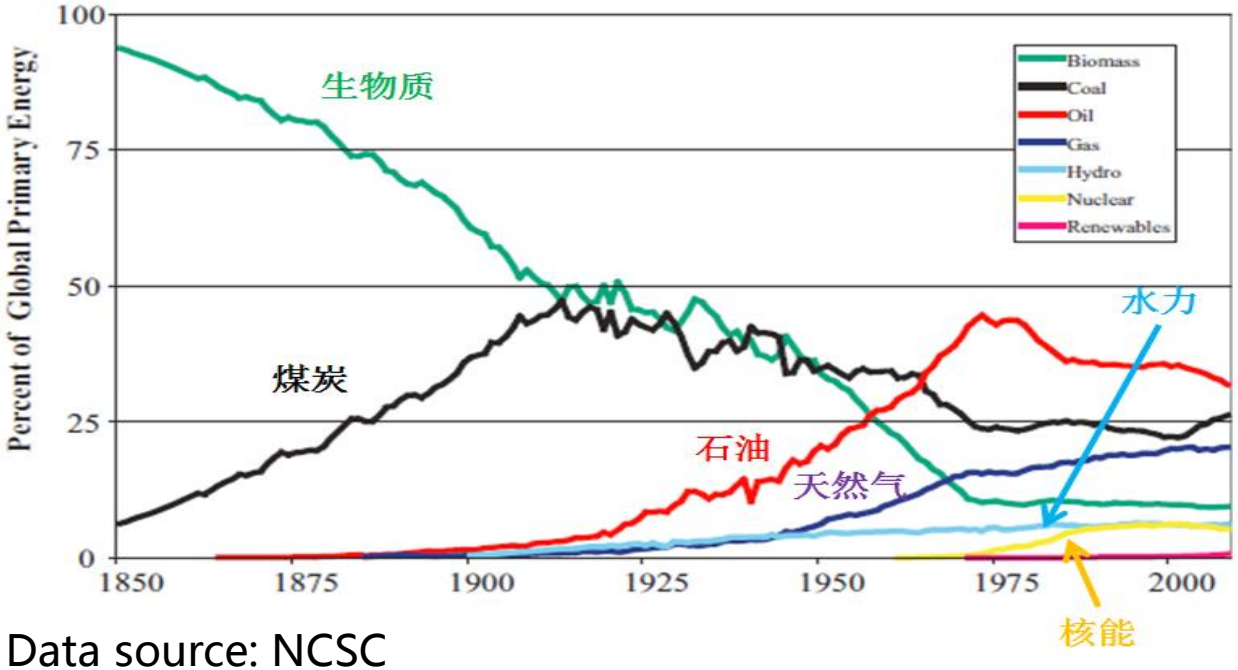


Data source: BP energy Statistics Yearbook 2013

- In all fossil energy, coal has a much bigger R/P ratio and longer economically exploitable period than oil and NG.
- Coal is easier and cheaper to acquire than oil and NG.
- Coal's important role in China's today, is very likely to appear in US or other countries or regions of the world in future.

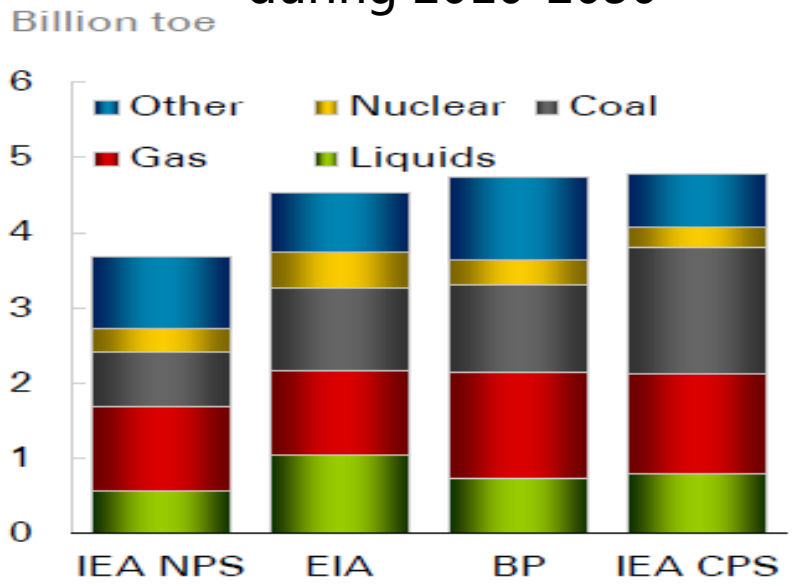
Coal will still taking an important role in the history of world energy development

Evolution of world's energy consumption structure



Data source: NCSC

Prediction of energy cons. increasing during 2010-2030

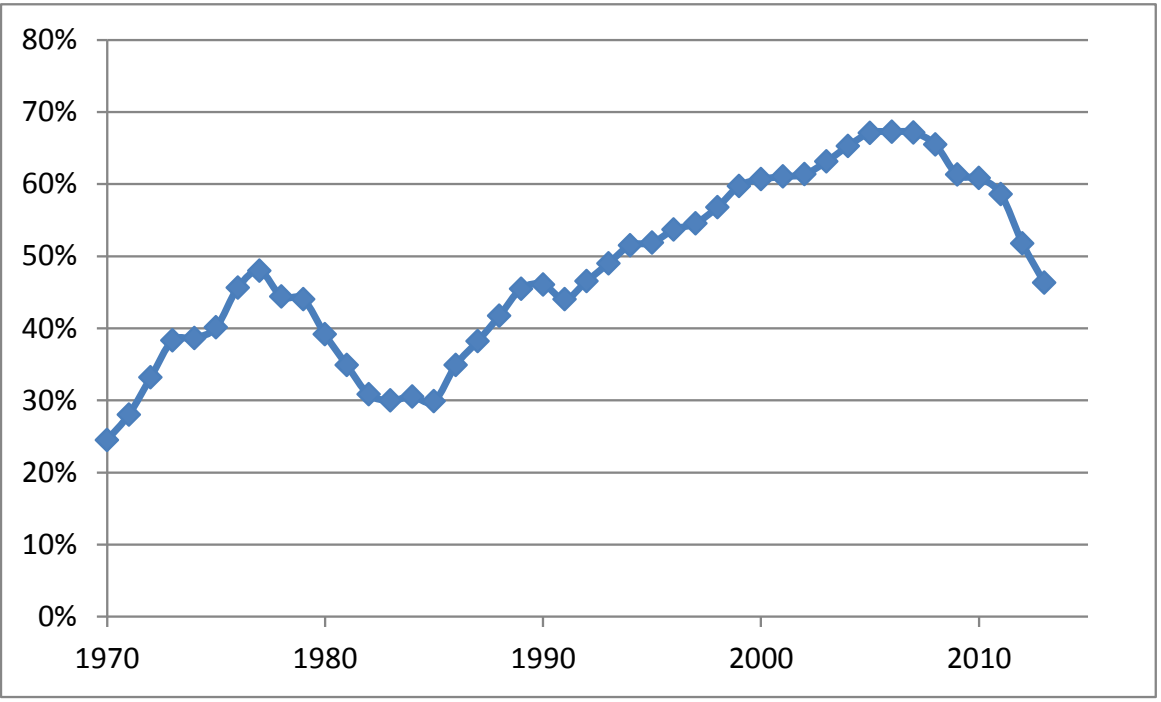


Data source: BP Energy Statistical Yearbook 2013

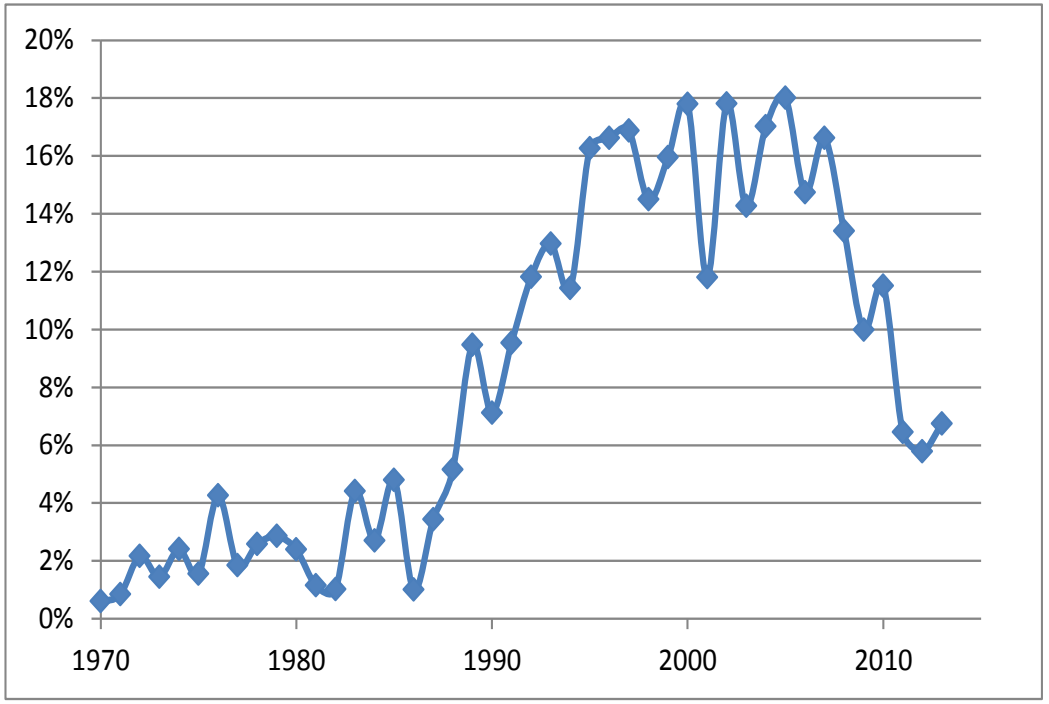
- Coal, oil and NG consumption will increased dramatically in the future; nuclear and renewable energy will replace part of power generation, but carbon-based chemical products will still rely on fossil energy.
- It is predicted that with current technology development trend, producing carbon-based chemicals to partly replace the currently used liquid fuel, especially the aviation fuel will become an important trend in the world.

Coal utilization is an important path for US to achieve “energy independency”

Import dependency of oil of US



Import dependency of NG of US

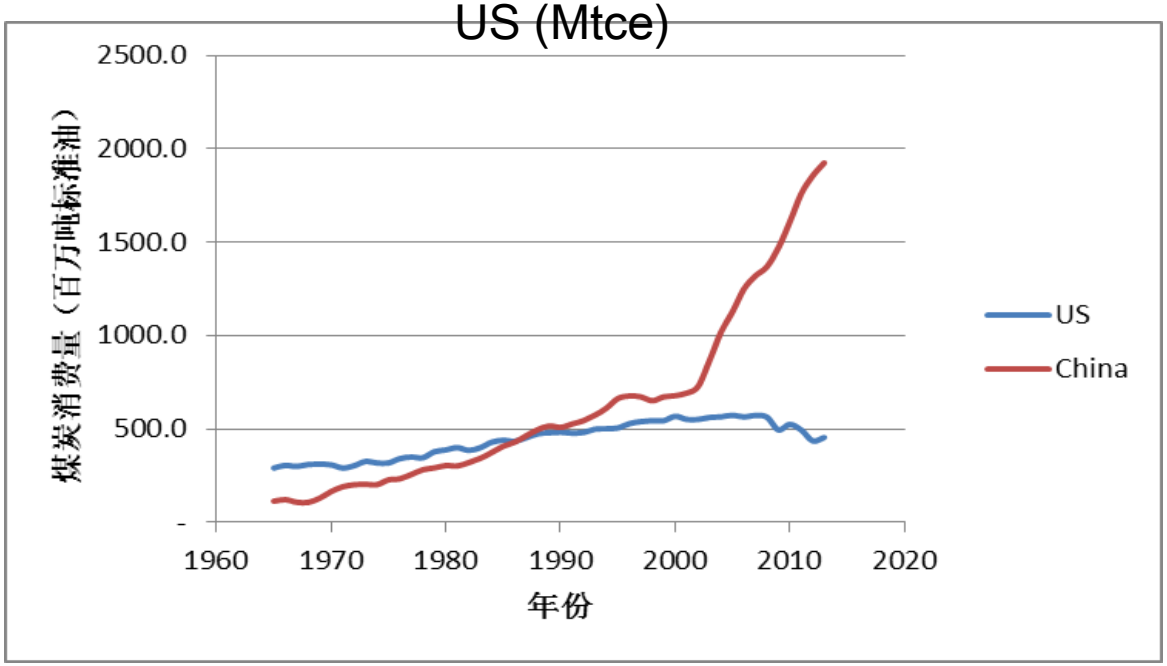


Data Source: BP Energy Statistical Yearbook 2013

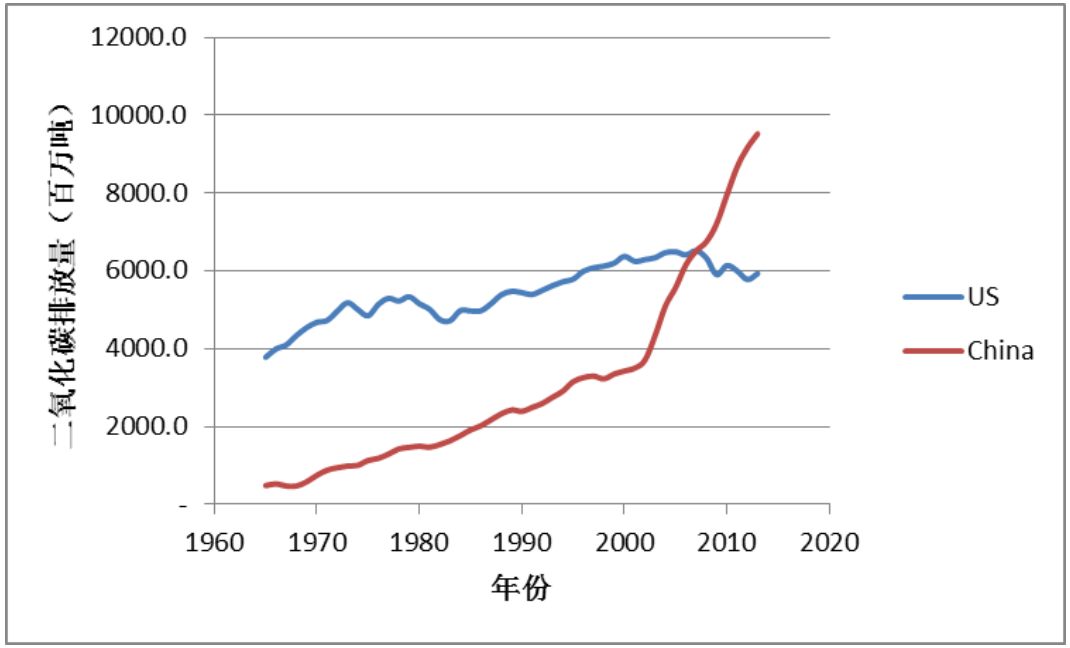
- Recently, thanks to the “shale gas revolution” and “energy independence”, import dependence of oil and NG has decreased at different rates in US, but oil import dependency is still as high as 45% currently.
- Taking use of the abundant coal resources to produce oil substitutes, and reduce the oil import dependency, is the real pathway for US to achieve energy independency.

CO_2 emission reduction is an important factor that promotes the transforming development of coal industry in China and US in the future

Change in coal consumption of China vs and US (Mtce)



Change in O_2 emissions of China vs US ($MtCO_2$)



- In the past 40 years, US coal consumption has not changed much, with a little decrease in recent years; while China's total coal consumption has been growing very rapidly.
- Curves for CO_2 emission change and coal consumption change for the two countries are basically same, indicating CO_2 emissions has close relationship with coal consumption. China and US are facing huge pressure for CO_2 emissions reduction.
- Facing the huge pressure for CO_2 reduction currently, China and US must working hard to develop clean and low carbon coal-conversion technologies.

Main points

- Coal is the most abundant fossil energy resource in the world.
- The important role of coal in the energy system in China, US and the world should not and cannot be neglected.
- Converting coal into special fuel and using coal as raw materials for carbon-based products is an important developing direction for future utilization.
- Coal conversion has already been or will be developed dramatically in China, US or other appropriate countries.

Status quo of coal/NG chemical and CCUS technologies in China

Comparison of coal chemical industry (by end of 2013)

	Percentage of coal converted	Coal to liquid			Coal to gas	Coal to chemicals		
		Direct	Indirect	MTG		Methanol	Ammonia	Olefins
China	20%	1 set 1.08 Mt	3 sets 0.50 Mt	3 sets 0.40 Mt	2 sets ~3 BNm^3	>200 sets >45 Mt	>420 sets >46 Mt	5 ~2 Mt
US	Low				1 set 1.6 BNm^3	1 set 0.1 Mt	1 set 0.25Mt	
South Africa	High		3 sets 7.60 Mt					
Others	——			1 set 0.1 Mt			1 set 0.3 Mt	

- China is the first to achieve large scale industrialization in direct coal liquefaction and coal to olefins.
- China has reached advanced level in the world in key technologies, catalysts, equipments, systematic technologies, and engineering technologies for coal to liquids, and coal to chemicals.
- US and some other countries have been doing industrial experiments or demonstrations in all areas in coal conversion, achieving the goal of technology reserve, and are now still doing continuous development for technology industrialization.

Direct coal to liquid technologies

Direct coal to liquid technologies

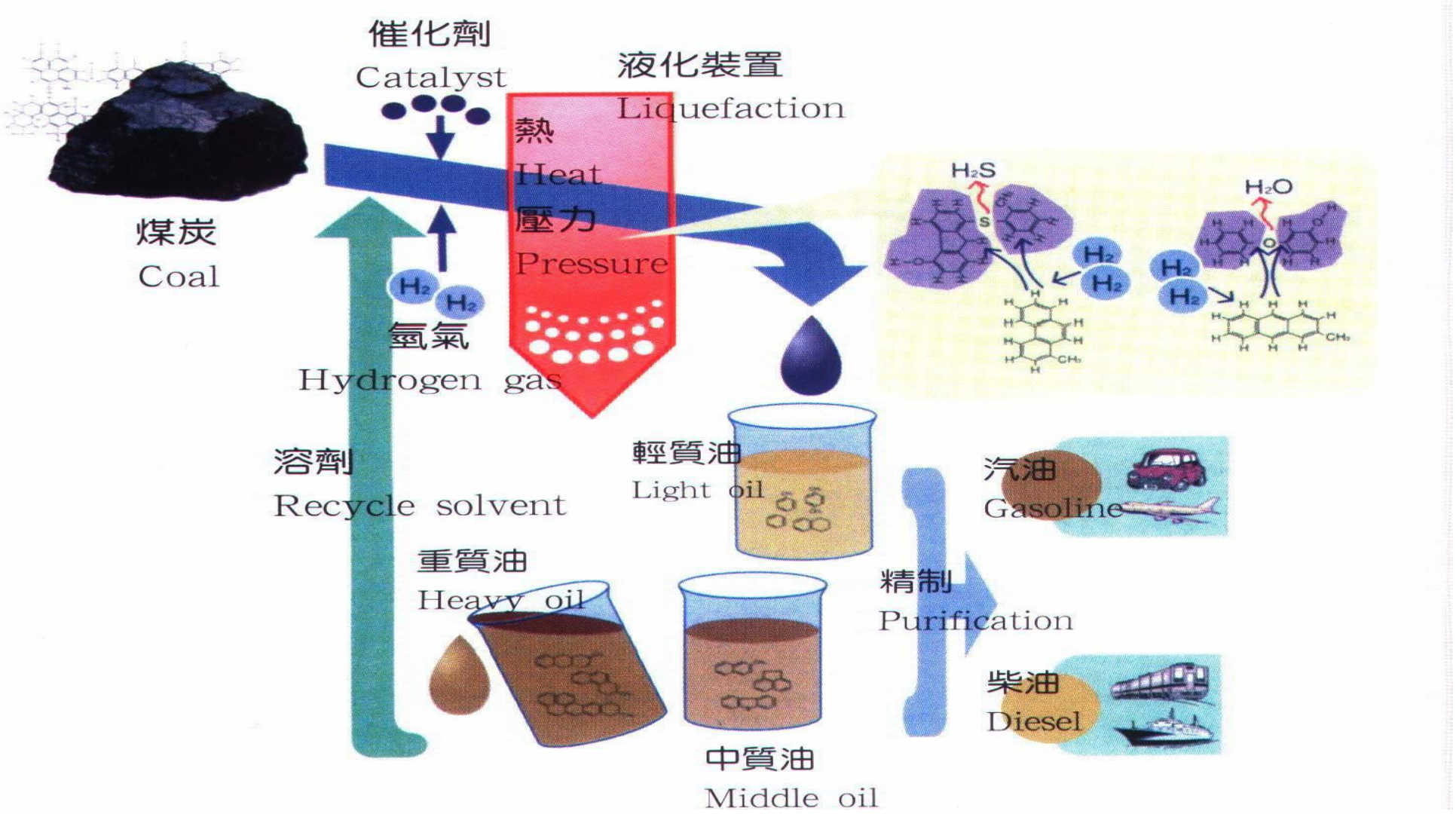
- A 1.08mt/a industrial demonstration plant was installed in 2008, the first modern large scale direct coal to liquid plant.
- This plant has achieved a continuous operation of nearly 300days last year.

Products scheme for the dem. Plant

Prod.	kt/a
LPG	100
naphtha	250
diesel	720
chemicals	10
Sum	1080

Direct Coal Liquefaction Technology

煤炭直接液化示意圖

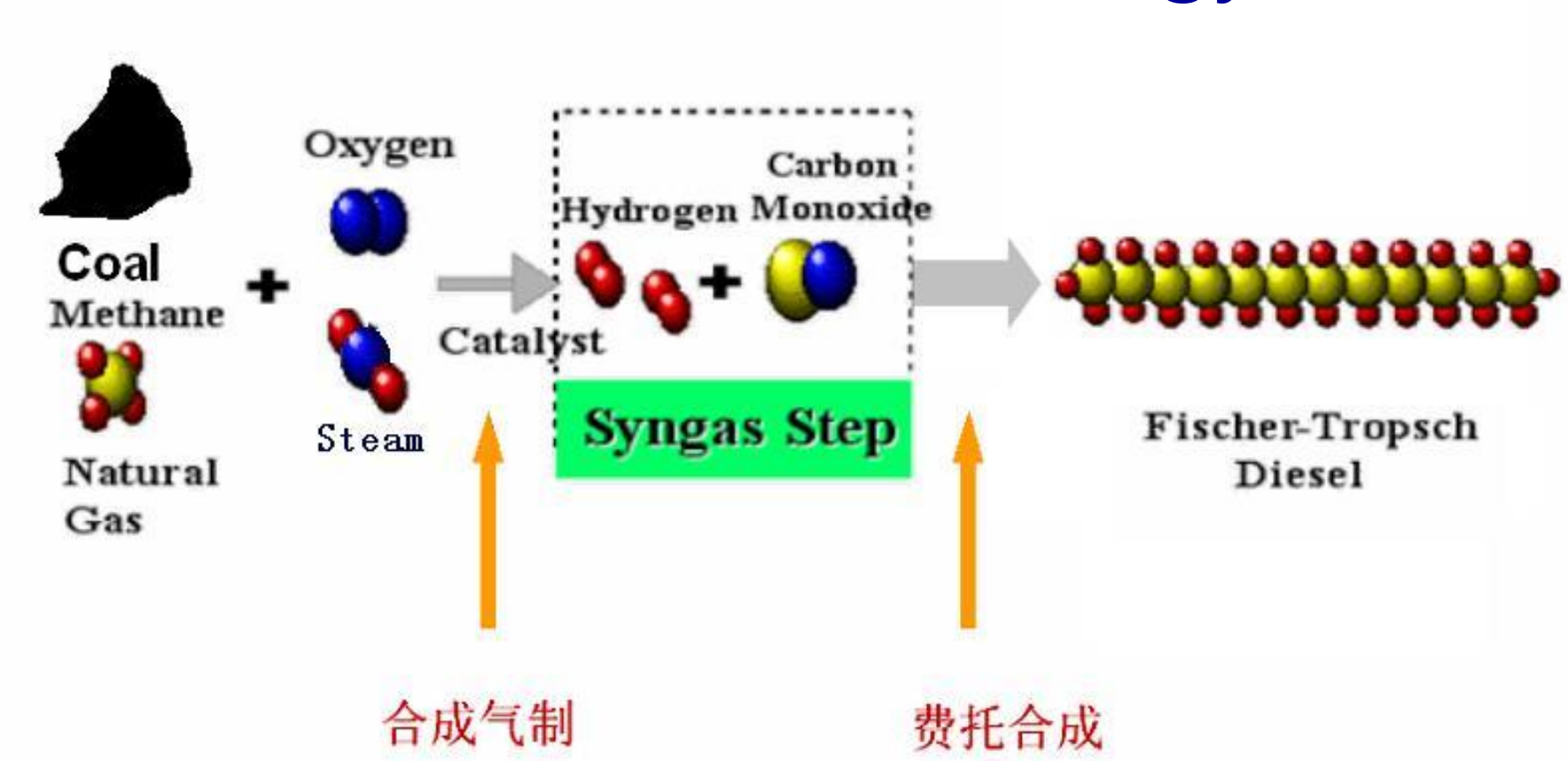


Indirect coal to liquid technologies

Indirect coal to liquid technologies

- From 2010, China has installed and put into operation of 3 sets of 160-180 kt/a indirect coal to liquid industrial demonstration plants, applying Fe based catalyst, and slurry bed process.
- A 1Mt/a Mid-T, Slurry bed demon plant is expected to be put into operation in 2015.
- A 4Mt/a commercialized plant is now under, and is expected to be put into operation in 2016.
- 3 sets of 1Mt/a High-T, Slurry bed demon plants are now under construction.
- A 140kt/a Co-based, Slurry bed industrial demon plant is now under construction.
- A 100kt/a Co-based, static-bed industrial demon plant is expected to be put into operation by end of this year.

Indirect CTL Technology



- Various of process and catalysts have been developed, including:
  - iron-based catalyst used for : high-, medium- and low-temperature slurry bed
  - Cobalt-based catalyst used for: medium-temperature slurry bed and fixed beds

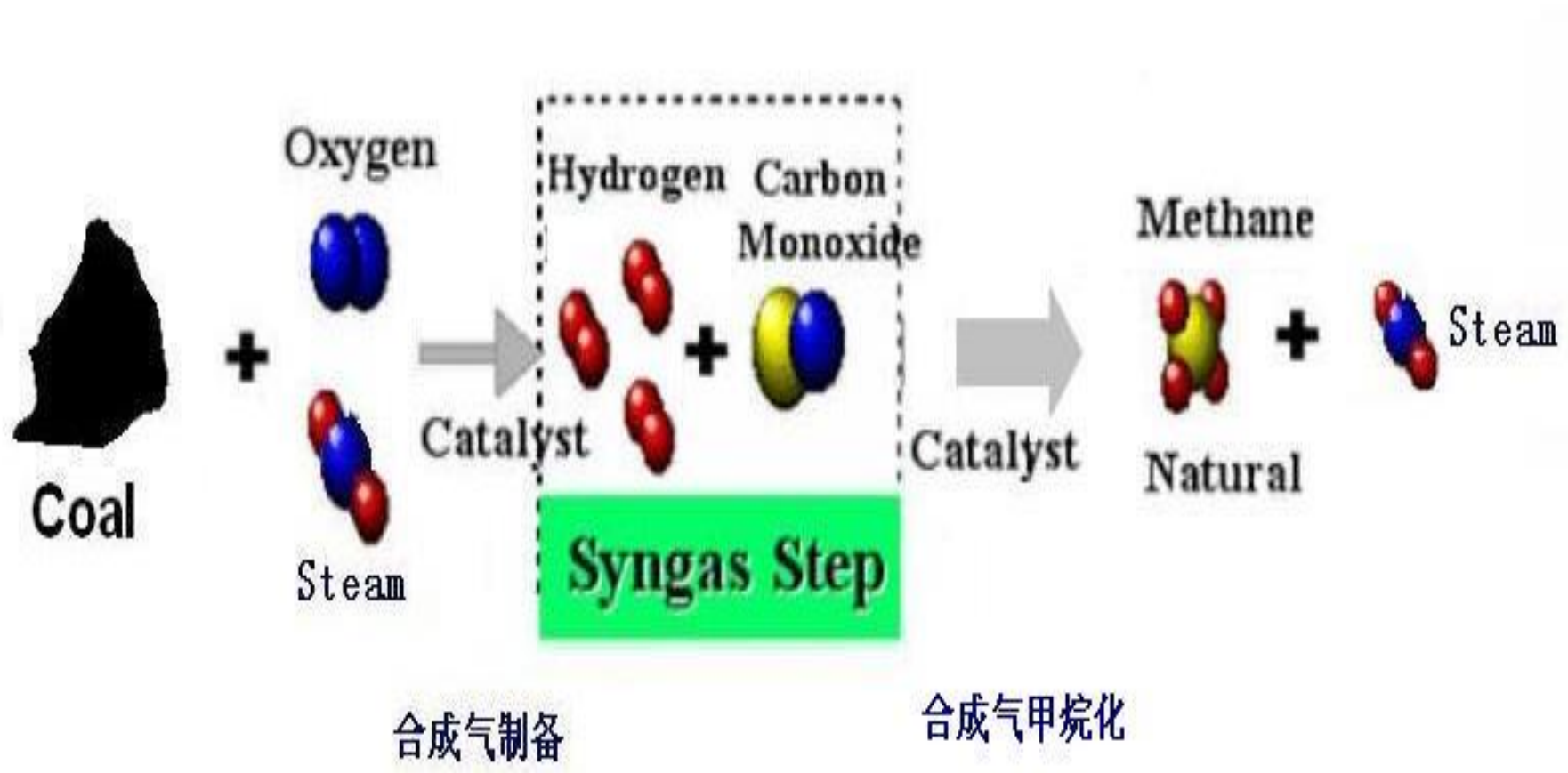
Coal to NG technologies

Coal to NG technologies

- The 4 billion Nm^3/a coal to NG plant in Inner Mongolia is the 1st coal to NG plant, which was put into construction in 2009, and 1st phase project (1.3bNm^3/a) was completed and put into operation in 2012.
- The 4 billion Nm^3/a coal to NG plant is now under construction in Fuxin, Liaoning.
- The 2 billion Nm^3/a coal to NG plant is to be completed and put into debugging soon.

- A 1.3 billion Nm^3/a coal to NG plant. has entered the phase of trial operation in Xinjiang.
- A 4.0 billion Nm^3/a coal to NG plant is now under construction in Xinjiang.
- Multiple projects have been ratified by the government.

Coal to NG Technology



- China has made a breakthrough in R&D of catalyst and process and set up pilot plants by use of new technology.

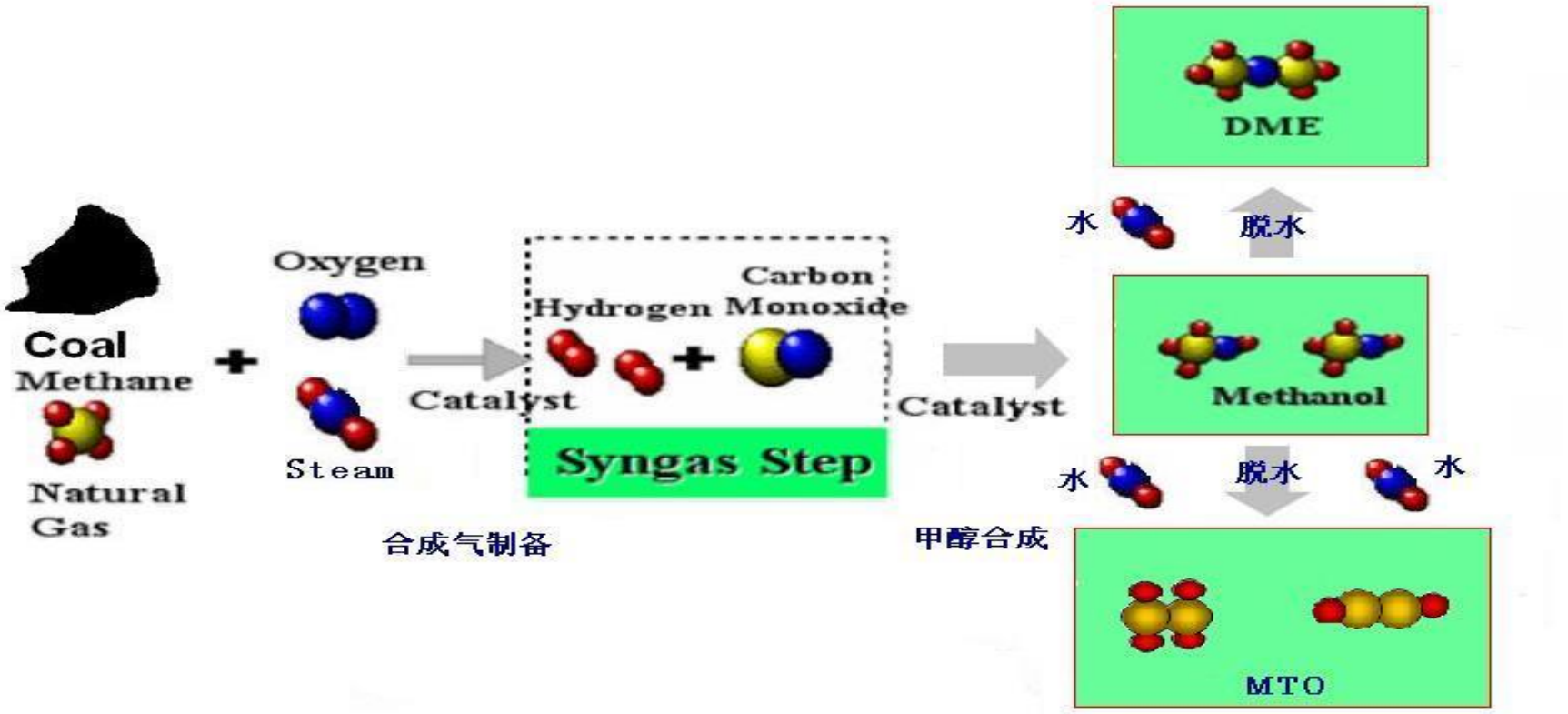
Coal to olefins technologies

Coal to olefins technologies

- Baotou coal to olefins project is the world's first large scale coal to olefins plant, applying the domestic methanol to olefins technologies (DMTO) with China's own proprietary rights.
- Installed and put into trial production in 2010.
- Put into commercial operation in 2011.

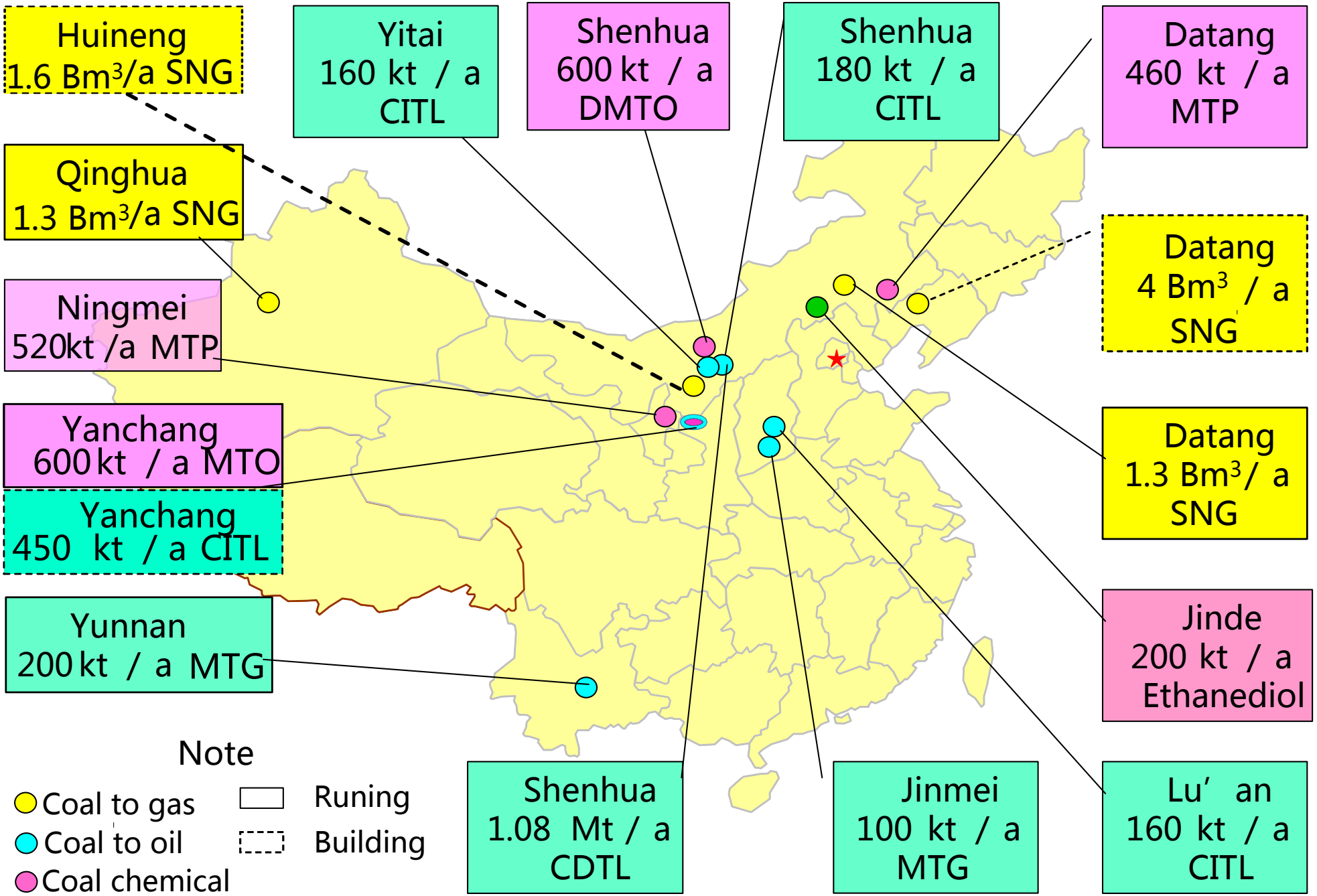
- Has been operating for >300d accumulatedly.
- 2.6Mt raw coal can be treated and gasified.
- 1.6Mt methanol as intermediate products.
- 0.51Mt/a poly-olefins can be produced.

Coal to Olefin Technology



- China has developed various of process and new catalyst for coal to olefin
- 3 10,000 t/a pilot plants have been set up
- China has set up a coal to aromatic plant

Major industrial demonstrations of coal chemical plants in China



CCUS

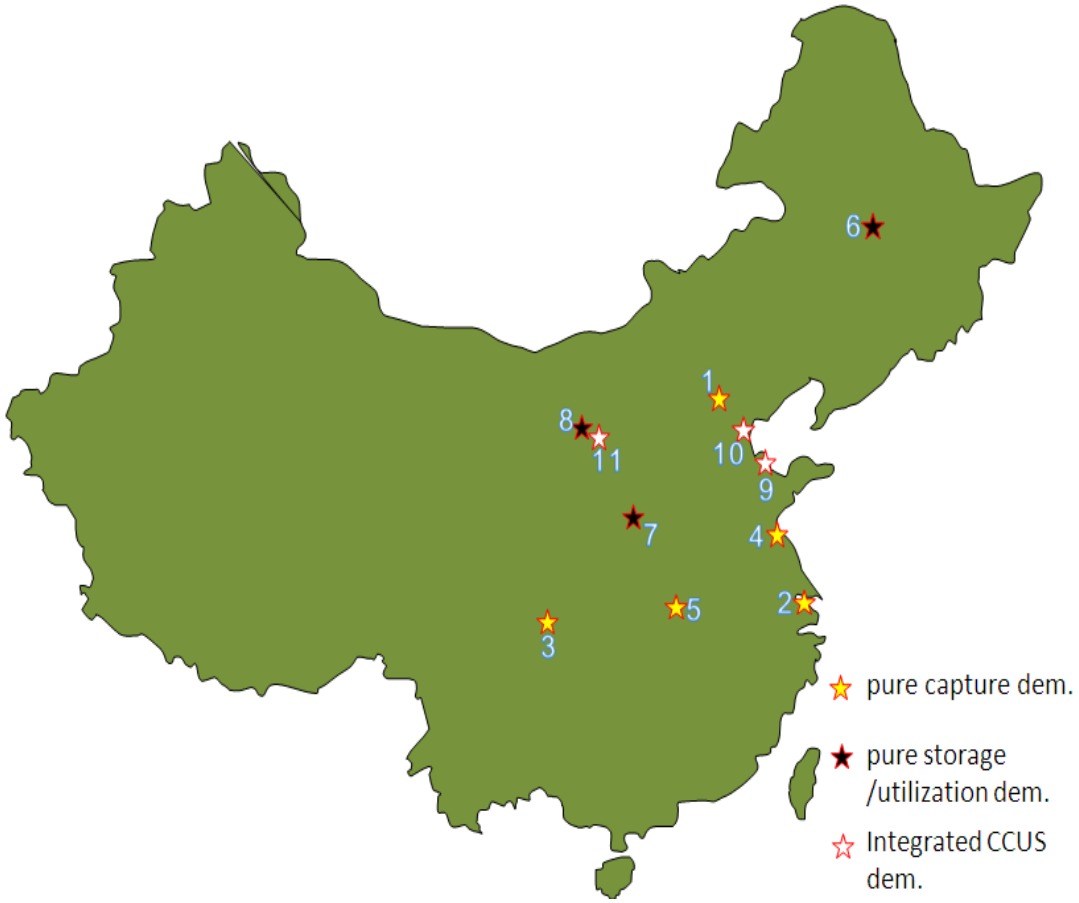
Analysis and comparison of CO_2 emissions for typical coal chemical plants

	Unit	Total CO_2 emissions	High concentration CO_2 emissions	Percentage of high concentration emissions
Direct liquefaction	tCO_2/t-oil	>5.00	>3.00	>50%
Indirect liquefaction	tCO_2/t-oil	>6.00	>5.00	>70%
Coal to NG	tCO_2/kNm^3	>4.00	>2.00	>60%
Coal to olefins	tCO_2/t-olefin	>10.00	>6.00	>60%

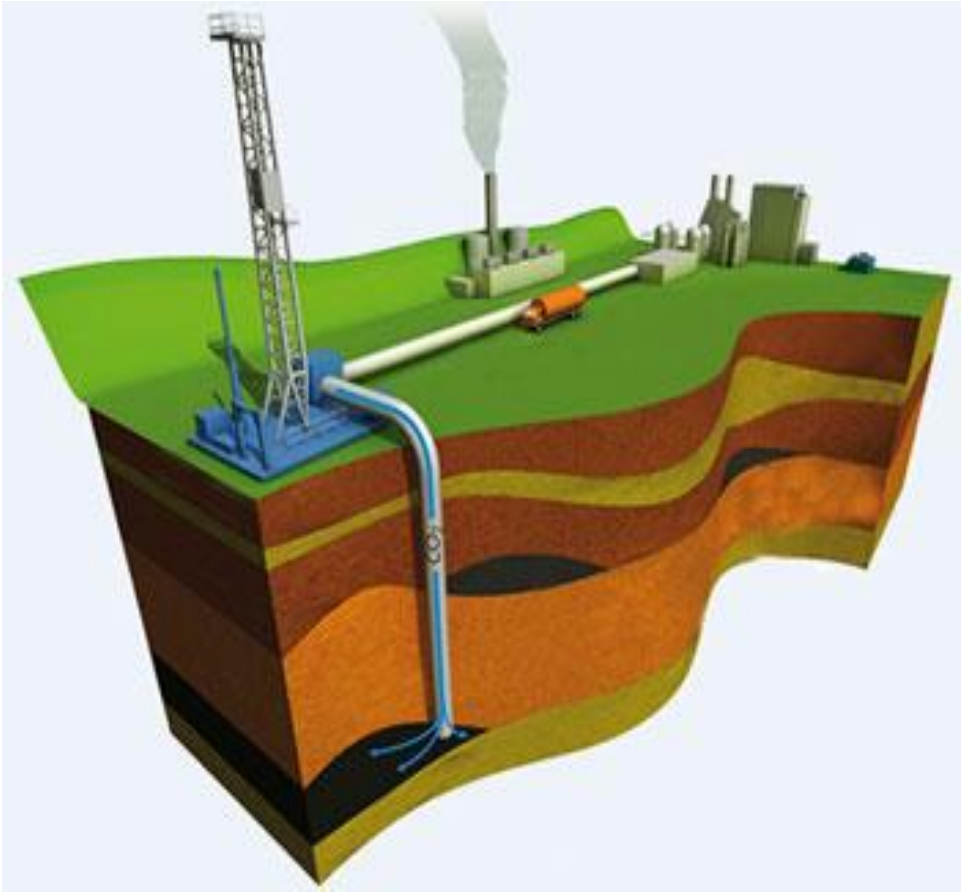
- Compared with coal-based generation and other coal utilization plants, part of the CO_2 from coal chemical plants are emitted in high concentration, and capturing this part of CO_2 only takes 1/3 cost compared with capturing CO_2 from other sources with mid or low CO_2 concentration sources, so coal chemical plants are superior for CCUS compared with other sources.
- The high-concentration CO_2 mainly comes from the purification unit in coal chemical plants. Per unit CO_2 emissions are a little different for different crafts.
- Total CO_2 emissions and percentage of high-concentration CO_2 are closely-related with the specific technical configuration in each plant, so these 2 numbers vary significantly for different plants.

CCUS industrial demonstrations are in operation in China

- China is now implementing the largest number of CCUS industrial demonstrations around the world
- China has marched to the forefront in the world to develop and promote CCUS
- China's effort in CCUS development will do great contribution to the world in climate change mitigation



CCUS industrial demonstration projects in China



Integrated CCUS demonstration projects in China

No.	Project Name	Type	Site	Scale (tonnes CO_2/yr)	Year Begun
1	Huaneng Gaobeidian CO_2 Capture Project	Post-combustion capture (PCC) from power plant flue gas	Beijing	3000	2008
2	Huaneng Shidongkou CO_2 Capture Project	PCC from power plant flue gas	Shanghai	100,000	2010
3	China Power Investment Co. Shuanghuai CO_2 Capture Project	PCC from power plant flue gas	Chongqing	10,000	2010
4	CO_2 Capture Project by Institute of Advanced Energy & Power, CAS	Pre-combustion capture from IGCC fuel gas	Jiangsu	~10,000	2013
5	HUST CO_2 Capture Project	CO_2 capture from oxy-fuel combustion	Hubei	100,000	2013
6	Jilin Oilfield Project, PetroChina Co.	CO_2 EOR / storage	Jilin	300,000–1,000,000	1997
7	CUCBM Project, ChinaCoal Co.	CO_2 ECBM / storage	Shanxi	~1900	2005
8	ENN Project, ENN Co.	CO_2 utilized for microalgae cultivation and biodiesel production	Dalate	20,000	2010
9	Integrated CCUS Project by Shengli Oilfield Power Plant	PCC from power plant flue gas + CO_2-EOR with storage	Shandong	30,000	2010
10	Integrated CCUS Project by GreenGen, Huaneng	pre-combustion capture from coal-based fuel gas of IGCC plant + CO_2 EOR / storage	Tianjin	60,000–100,000	2012
11	Integrated CCUS Project by Shenhua Coal-to-Liquid Co., Ltd.	pre-combustion capture from coal-based fuel gas of chemical plant + saline aquifer storage	Ordos	100,000	2011

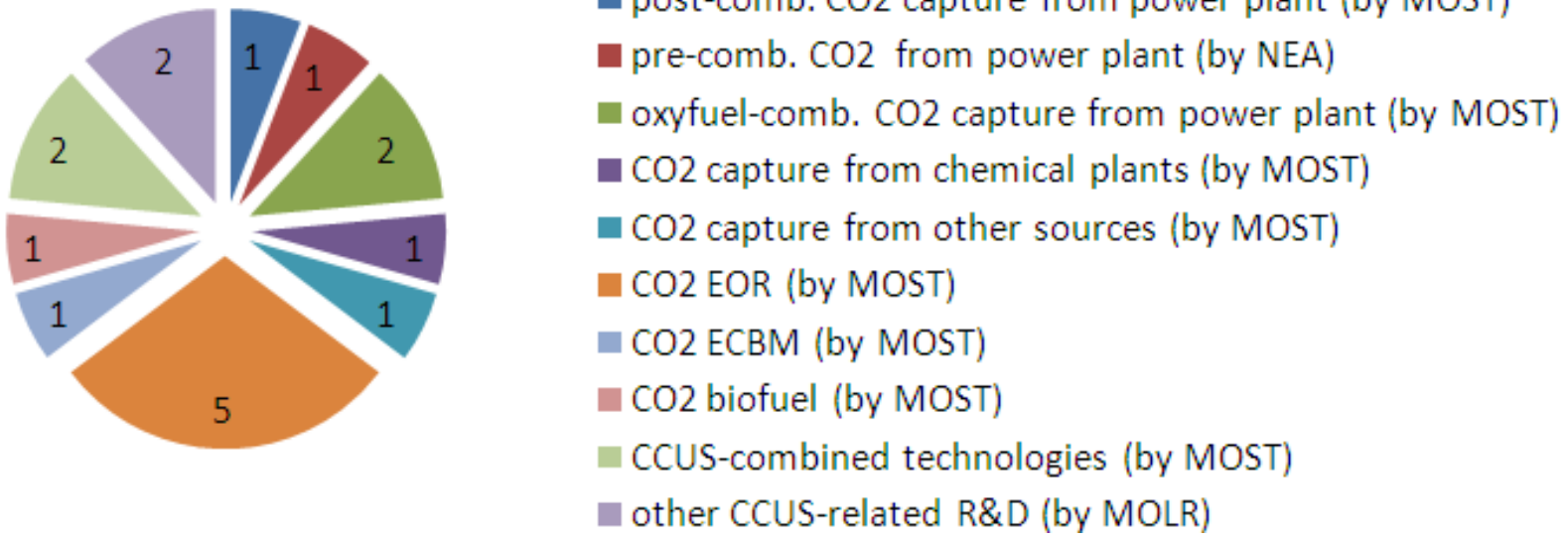
China participates in CCUS international cooperation programs

Project name	Sources of financial support	Executi on time	Major participants
The China Australia Geological Storage of CO_2 (CAGS) Project	Ministry of Science and Technology (China) and Department of Resources, Energy and Tourism (Australia)	2009–2011	China side: The Administrative Centre for China's Agenda 21, China Geological Survey, Tsinghua University, etc. Australia side: GeoScience Australia;
Joint research on the lower emission technology for IGCC between China and U.S	Ministry of Science and Technology of China and U.S. Department of Energy	2010–2012	China side: Chinese Academy of Sciences; U.S. side: National Energy Technology Laboratory, Pacific Northwest National Laboratory;
Sino-Italian CCS technology cooperation project	Cooperation Action within CCS China-EU,COACH, Italian Ministry for the Environment, Land and Sea	2010–2012	China Side: The Administrative Centre for China's Agenda 21, Huaneng, Tsinghua University, Chinese Academy of Sciences, etc. Italian Side: Ministry for the Environment, Land and Sea, Enel, etc.
Cooperation Action within CCS China-EU，COACH	Ministry of Science and Technology of China and EU	2006–2009	China side: The Administrative Centre for China's Agenda 21, Huaneng, Tsinghua University, Zhejiang University, Chinese Academy of Sciences, etc. EU side: Imperial College, Air Products, Alstom, Shell, British Geology Survery, SINTEF, etc.
UK-China Near-Zero Emissions Coal project (NZEC)	Ministry of Science and Technology of China, Department of Environment, Food and Rural Affairs of UK	2007–2009 (Phase I) 2010-2012 (Phase II)	China side: Administrative Centre for China's Agenda 21, Xi'an Thermal Power Research Institute, Tsinghua University, Zhejiang University, CAS, etc. UK side: Alstom, British Geological Survey, BP, Shell, Schlumberger, Doosan Babcock, Cambridge University, etc.
U.S.-China Clean Energy Research Center	Ministry of Science and Technology of China and U.S. Department of Energy	2010–2015	China side: Huazhong University of S&T, S&T and Industrialization Center of Ministry of Housing and Urban-Rural Development, Tsinghua University, etc. U.S. Side: West Virginia University, Lawrence Berkeley National

Chinese government sponsors many CCUS related R&D programs

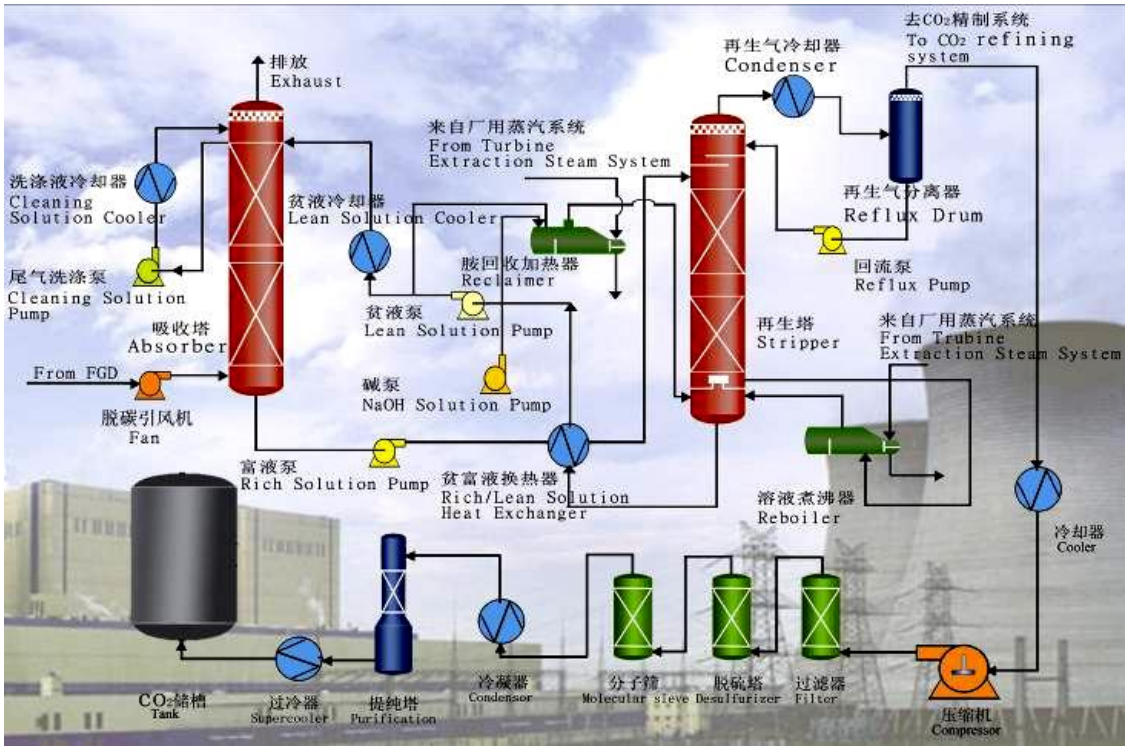
- The R&D programs are mainly carried out by joint-body of enterprises, universities and institutes through collaboration
- Covering a wide range of technology approaches for all sections of CCUS including CO2 capture, storage and utilization
- The sponsoring programs mostly last for 3~5 years, but there might be new programs that will continue to provide support according to the progress made by each program

Distribution by type of the major CCUS R&D programs sponsored by Chinese government



Projects - Huaneng Shidongkou CO2 cap. Dem.

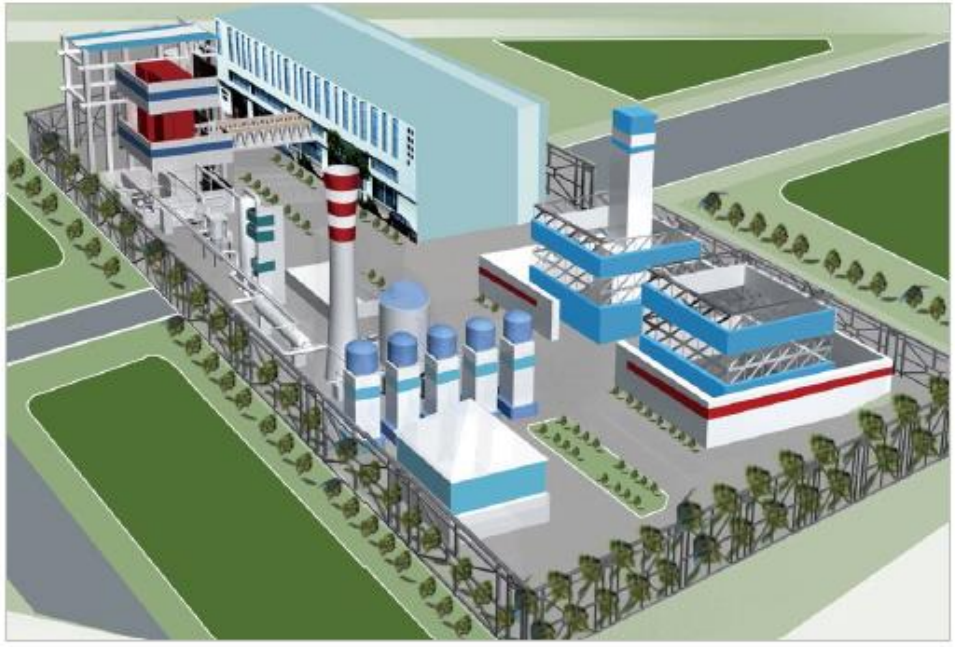
- Adopting the same technology and process as Gaobeidian Dem. at a much larger scale, with flue gas treating capability of 66,000Nm3/h, and capturing 100~120 ktCO$_2$/year
- The largest post-combustion CO$_2$ capturing project in power plant in the world till now
- CO2 is sold to chemical plants and food factories as raw material at a normal price constrained by a limited market



Projects - Oxyfuel Dem by Huazhong Univ. of S&T

- Establishing China's 1st, the world's 3rd 3MWth oxyfuel combustion CO2 capturing dem. in Wuhan in 2009, capturing 7000 tCO2/year
- Now a 35MWth oxyfuel combustion CO2 capturing dem. with capturing capability of 100,000 tCO_2/year, which is the world's largest, is under construction
- This dem. marks the forefront of development of oxyfuel combustion CO2 capture technology in the world

400kWt 富氧循环燃烧装置



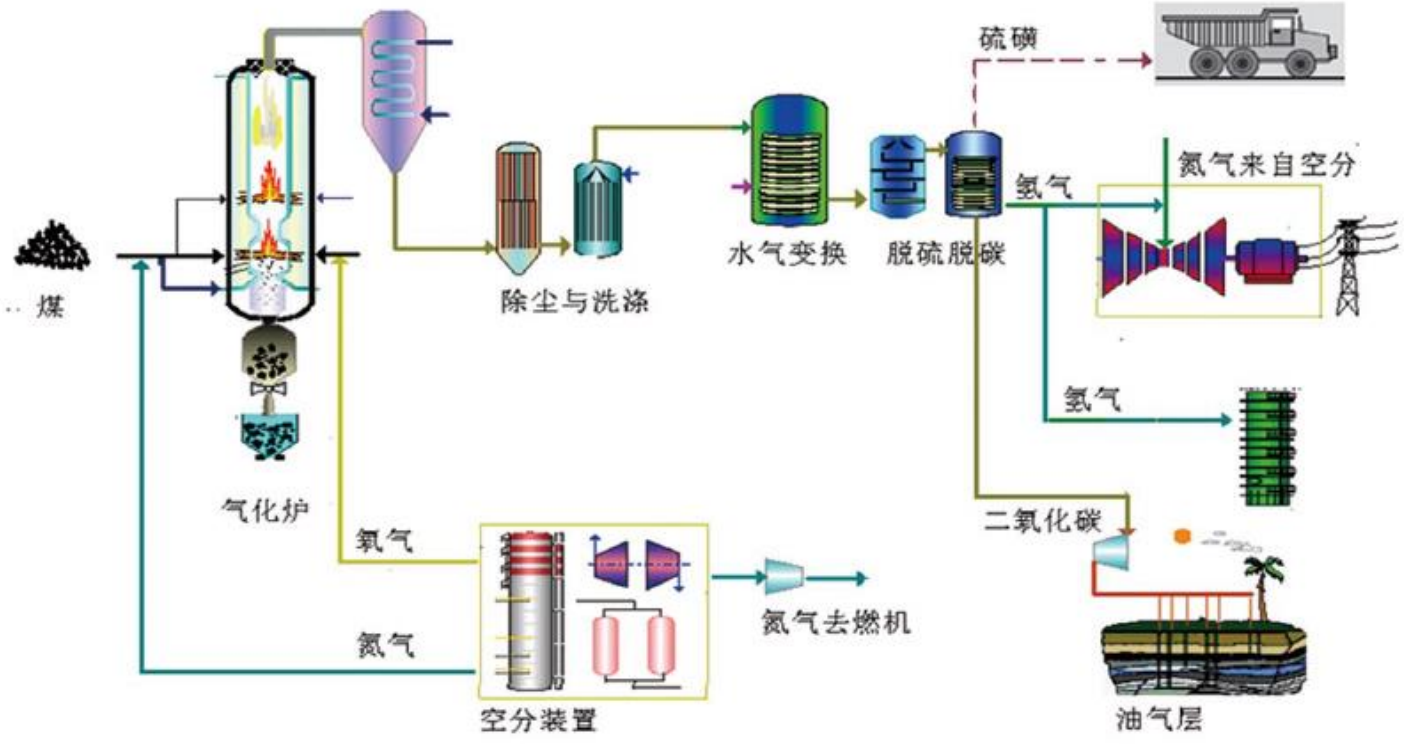
3MWt 富氧燃烧示范项目示意图

Projects - CO_2 EOR dem. in Jilin Oilfield of CNPC

- Jilin Oilfield has been working on CO_2 EOR since 1997, with targeting support from MOST and CNPC
- Now 150,000 tCO2 is injected annually, and crude oil production rises by 80%, with most of the injected CO_2 effectively stored in the oilfield
- It is planned that annual CO_2 injection rate into the oilfield will be increased to 300,000-1,000,000 tCO_2
- It is the first demonstration of this kind in China. This dem. has great significance to understand the technical and economical performance of EOR

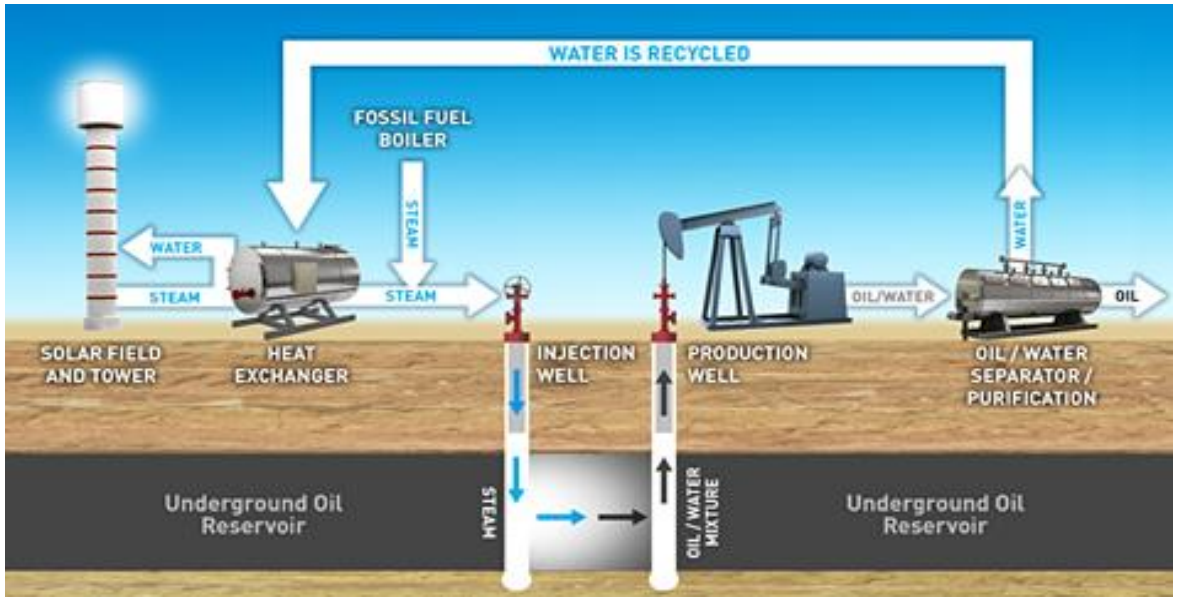
Projects - the IGCC+CCS dem. by GreenGen

- GreenGen Co. established China's first 265MW IGCC dem. plant in 2012
- GreenGen plans to carry out an pre-combustion CO_2 capture dem. project on part of the flue gas applying the Selexol CO_2 capture technology in 2015. Annual capturing capability is 60-100 ktCO_2 /year
- If successful, a full-scale fuel gas CO_2 capturing retrofit will be performed.
- The captured CO_2 is planned to be used for EOR or stored in saline aquifer. The area around Dagang Oilfield is preliminarily selected.



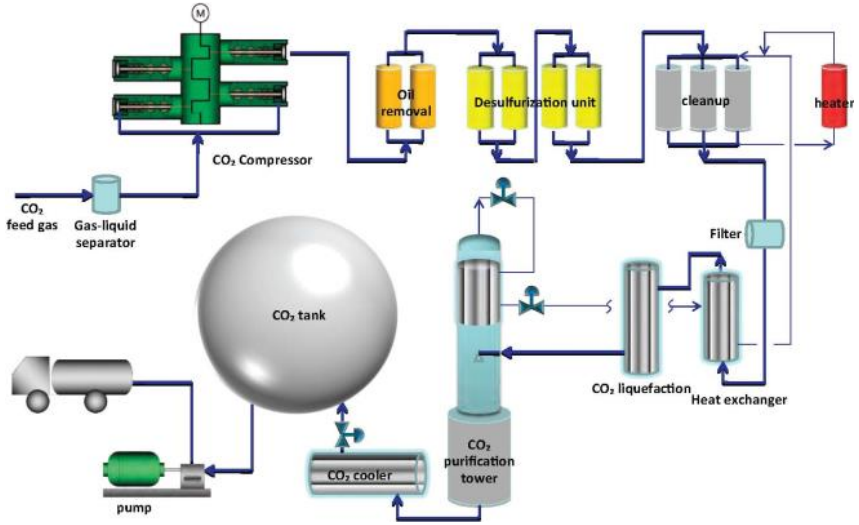
Projects - whole process CCUS dem. by Shengli Oilfield

- Applying an proprietary MEA CO_2 capture technology by Sinopec, Shengli Oilfield conducted a post-combustion CO_2 capture retrofit on its self-generation power plant, and CO_2 is used for EOR dem.
- The first whole process CCUS dem. project for conventional pulverized coal-fired power plants. 40,000t/a (100t/d) CO_2 is captured.
- Up till May 2014, accumulated 177kt CO_2 has been injected into the oil deposit, with 40kt oil yield increasing.
- Shengli plans to enlarge this whole process CCUS demonstration into 1MtCO_2/a in 2015.



Projects - CCUS integrated dem. by Shenhua Co.

- Shenhua established the world's first 1Mt/year direct coal-to-liquid (DCTL) facility in 2009
- In 2011, Shenhua established a CO_2 pre-comb. capturing dem. facility for the high CO_2 content waste gas, which can capture 10,000 tCO2 per year
- The captured CO_2 is transported to a site 17km away, and then injected into and effectively stored in the saline aquifer 2244m deep, up to 200,000tCO2 has been stored up till June, 2014
- China's first CO_2 geology storage demon project, and also the first whole-process integrated CCUS dem. project, providing lots of important geological data and engineering experience for China



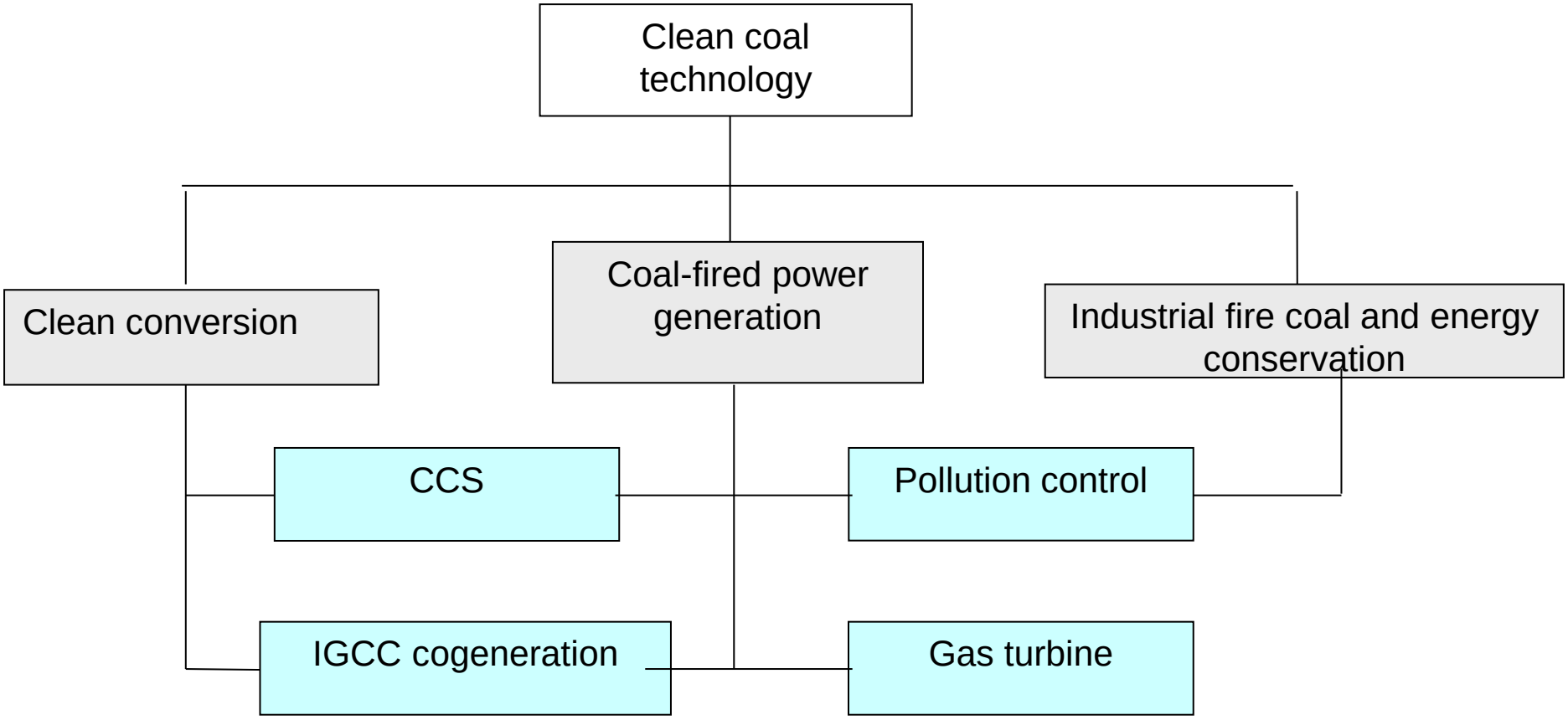
Main points

- Modern coal chemical has become an important development direction for China coal utilization technologies.
- China has made great breakthroughs in the field of modern coal chemical industry.
- >50% of the CO_2 emissions from modern coal chemical plants are of high concentration.
- Pollutants including S, N, and Hg, etc., can be removed and utilized as resources at rather low cost.

Progress in Clean Coal Conversion Technology in China

Key Directions of Clean Coal From Goverment

Key Directions



Key Directions

- Key basic research
- Key core technology development
- Major technology integration and project demonstration

Key Basic Research

- Basic research for quality improvement and conversion of coal
- Basic research for highly efficient clean fired-coal power generation
- Basic research for gas turbine technology

Key Core Technology Development

1. Coal quality improvement and integrated resource application
2. Power generation by highly efficient and clean coal
3. Coal-based clean fuel
4. Highly efficient fire coal and industrial energy conservation and emission reduction
5. CO_2 capture, storage and application technology before, in the middle and after combustion.
6. Pollutant control and resource application

Major Technical Integration and Industrial Demonstration

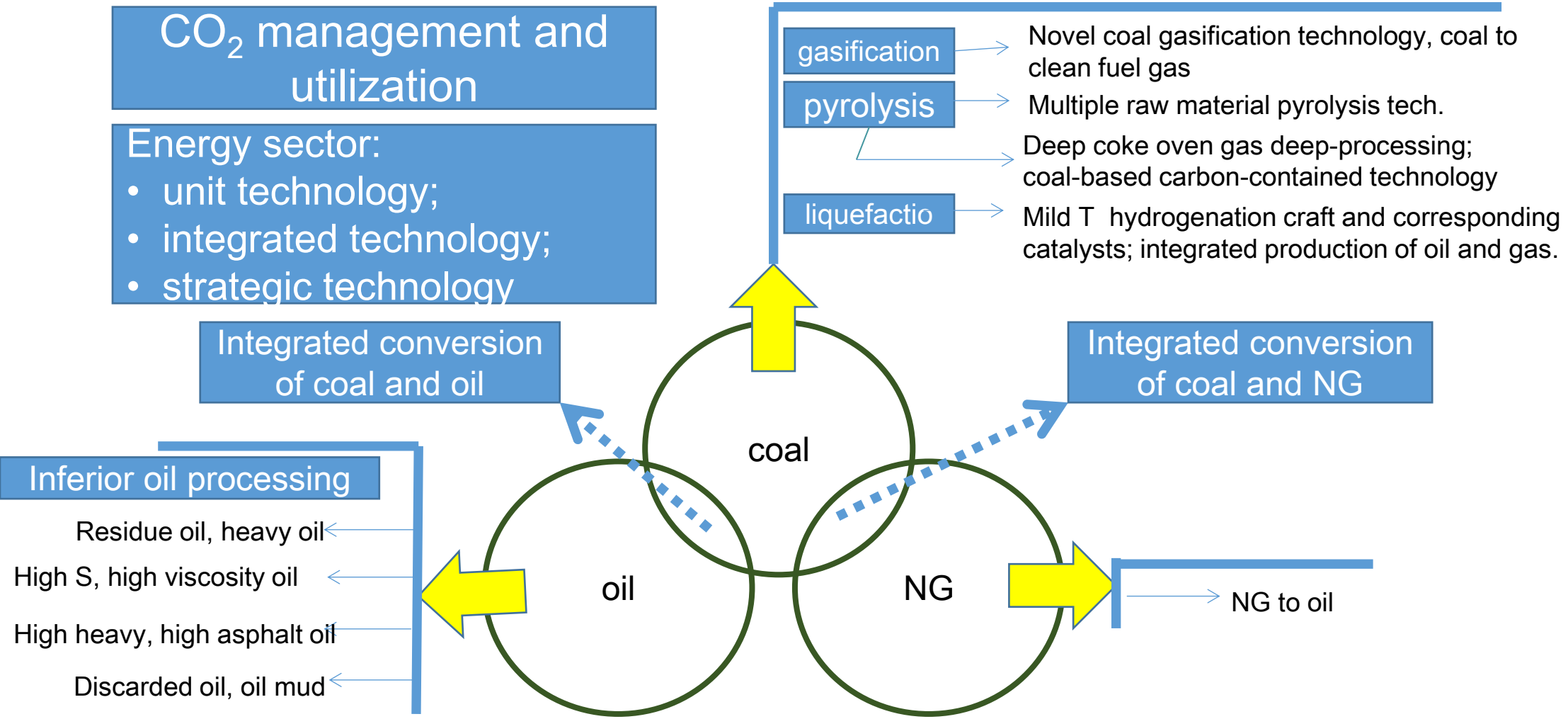
1. IGCC-coal-based polygeneration integrated demonstration, 400-500MW grade power plant, 1 million ton grade liquid fuel, 3000 t/d grade gasification furnace, 9F grade low heat value gas turbine, etc.

2. Demonstration for large scale efficient coal-based conversion and polygeneration, system efficient is increased over 5% and direct energy consumption for critical products is reduced more than 10%

3. Industrial demonstration for complete set of technology of >600℃/1200MW grade ultra supercritical power generator

Key Directions of Clean Coal From Baoju

Main technical areas and directions for Baoju S&T Co.



- Judgement database and model of coal for coal gasification and liquefaction
- A gasification of integrated processing of coke oil, residue oil and inferior oil is now under construction.

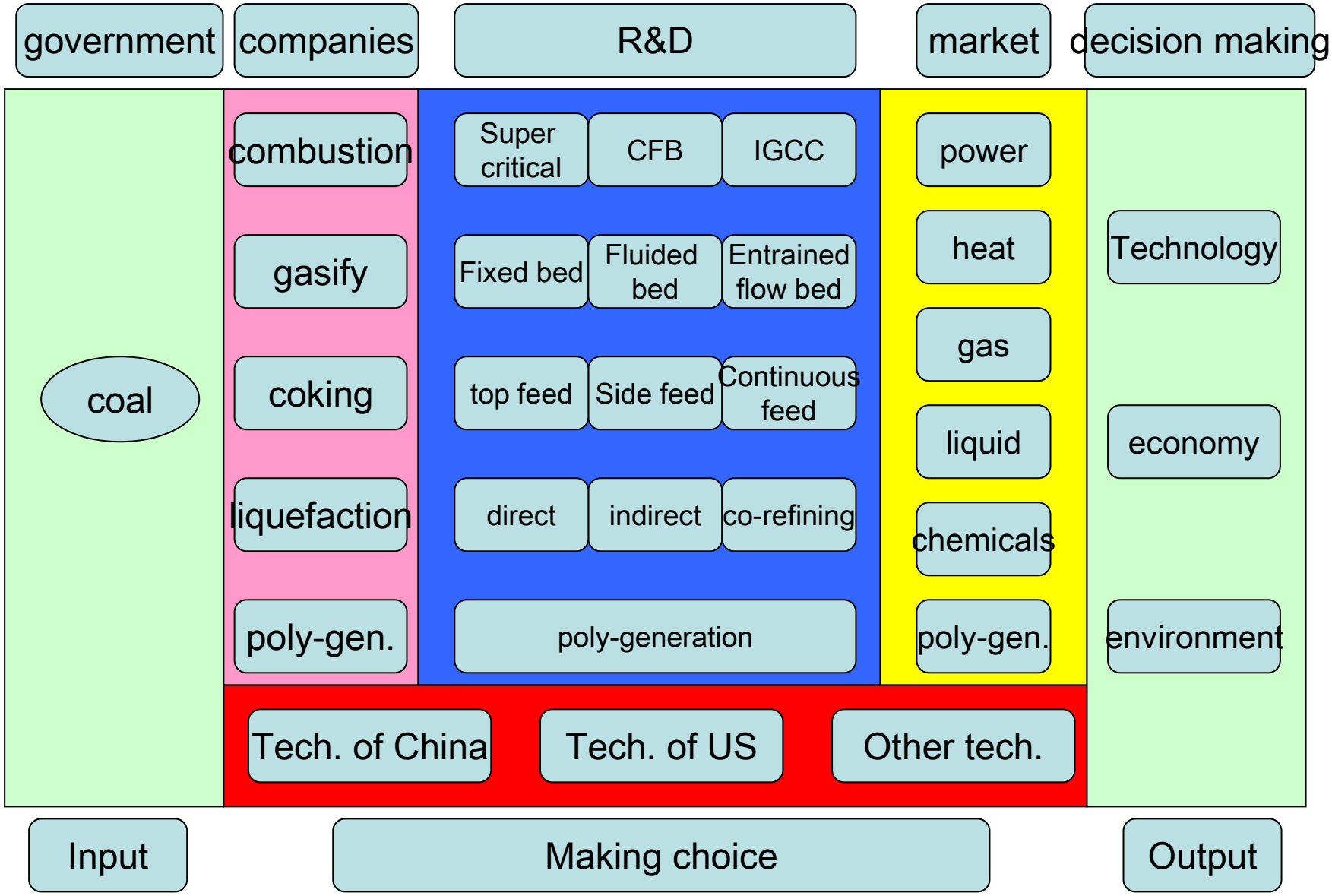
Suggestion for Development of Coal/NG Chemical and CCUS in USA

To Establish the Assessment System for the Development Strategy of Coal/NG Conversion in USA

Baoju's Coal Conversion Evaluation System

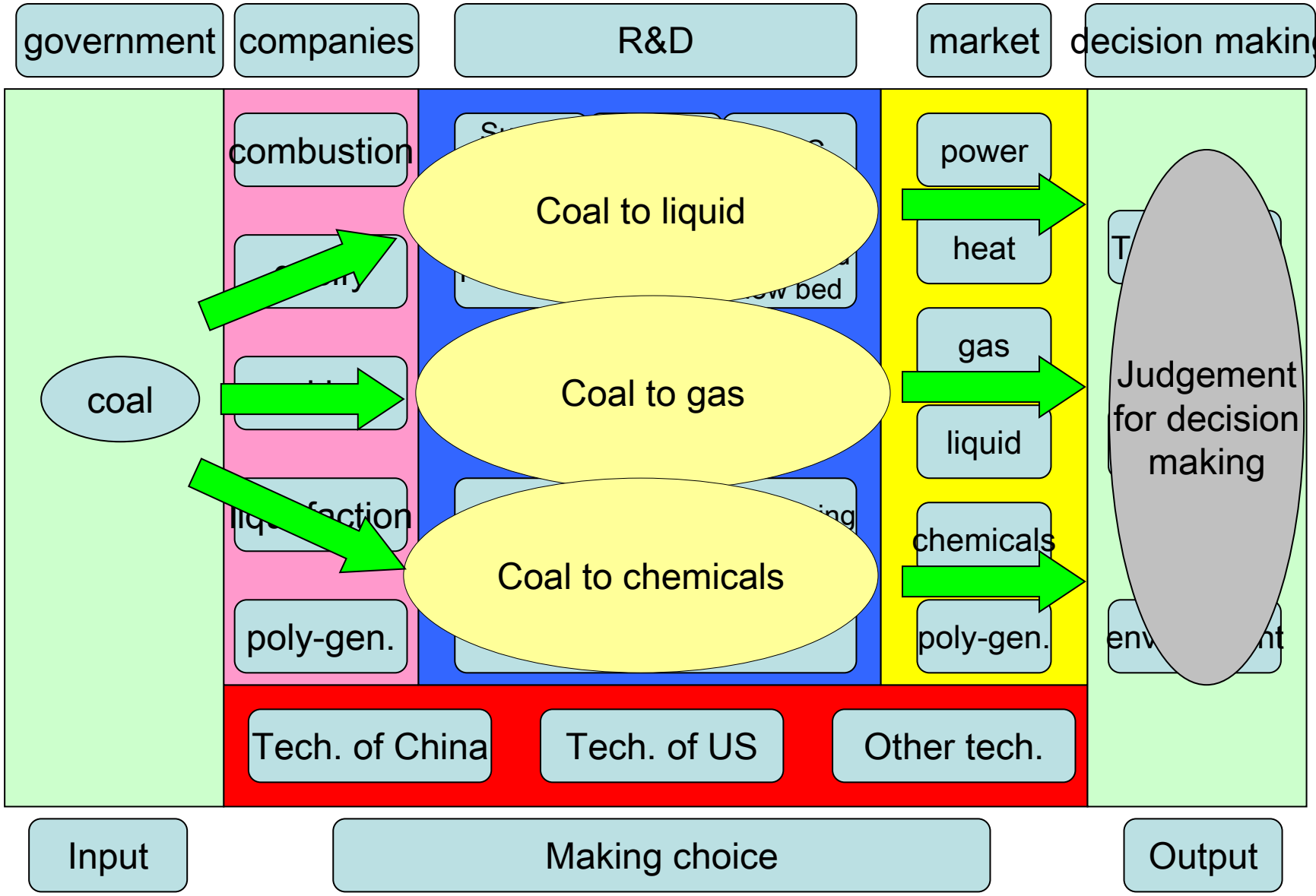
- **Baoju has developed a number of project evaluation systems**
  - **Gasification**
  - **Liquefaction**
  - **Coal and oil Co-processing**
  - **And so on**
- **Items to be evaluated**
  - **Technology**
  - **Economy**
  - **Environment**

Evaluaiton system for decision making on development strategy for coal conversion industry



Judgement system for decision making on development strategy for coal conversion industry

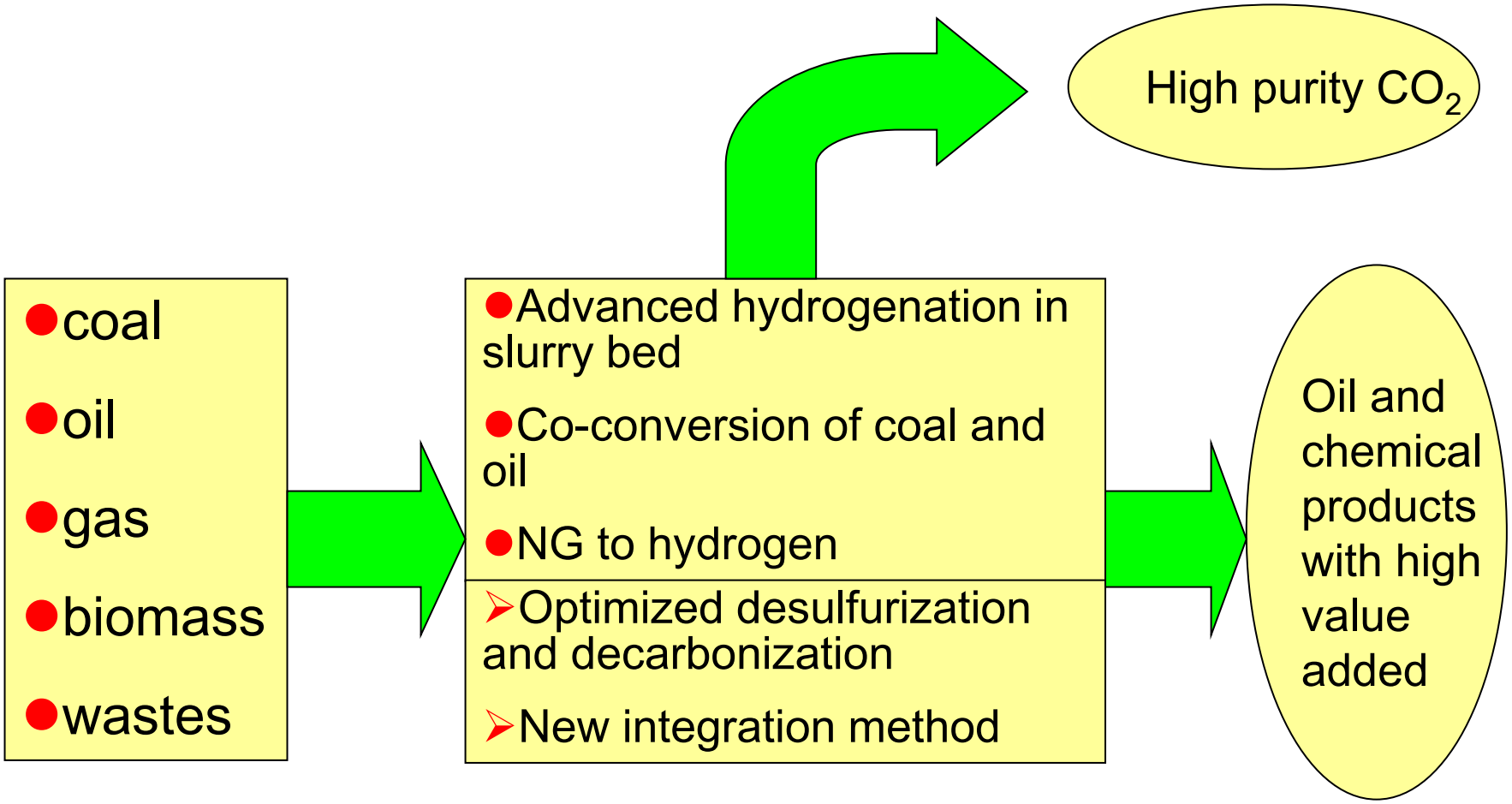
Evaluation system for decision making on development strategy for coal conversion industry



Judgement system for decision making on development strategy for coal conversion industry

It is suggested USA build a CCUS industrial demonstration unit based on coal chemical industry

An innovative coal conversion system based on CO_2 capture



- The high-efficiency, and clean conversion and utilization of coal, will be an essential road for the world to adjust its energy structure and ensure sustainable economic development.
- We are willing to help promote cooperation between energy companies of the two countries, especially in the field of clean coal technology and CCUS technology.

Thank you!