中国科学院
Chinese Academy of Sciences

An Overview of Hybrid Systems in China

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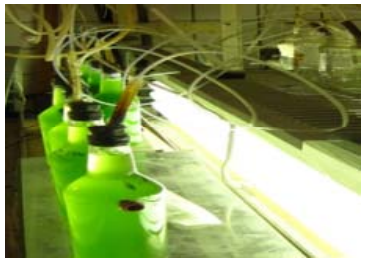
April 3, 2012 @ Salt Lake City

Outline

- ☺ Overview of Chinese Academy of Sciences (CAS)
- ☺ Review of Energy R&D in CAS
- ☺ Nuclear Hybrid Energy System being considered



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Chinese Academy of Sciences (CAS)

was founded on Nov. 1, 1949

- **Prime academic institution in natural sciences in China**
- **Prime consultative institution in science and technology**
- **Comprehensive research and development center in the natural sciences and high-technology**

Distribution of Institutes

12 Branches

100 Research institutes

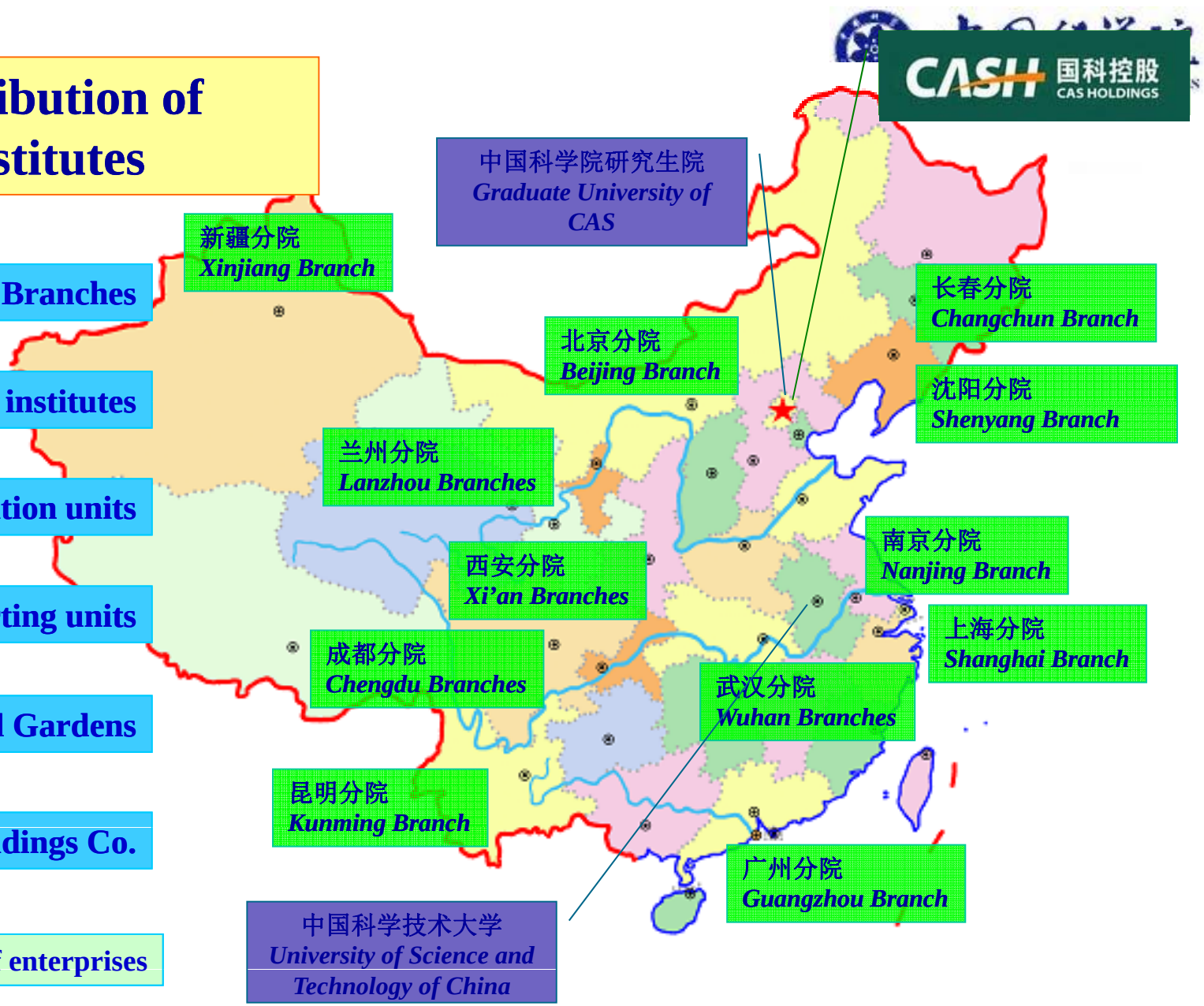
2 Education units

4 Supporting units

3 Botanical Gardens

1 CAS holdings Co.

Hundreds of enterprises



CAS Missions

- Scientific Research
- High Technology Development
- Education and Training
- Think Tank of Science Policies

Sectors of R&D Innovation

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Basic Research

- ✧ Mission-orientated, cross-disciplinary research in the frontiers of science
- ✧ Integrative Research Based on Major Science Facilities

High Technology

- ✧ Information Science & Technology
- ✧ Photoelectronics & Space Science
- ✧ Advanced Energy Technology
- ✧ Nanoscience, Advanced Manufacturing & New Materials

Sustainable Development Related

- ✧ Health & Medical Science
- ✧ Industrial Biotechnology
- ✧ Sustainable Agriculture
- ✧ Ecology & Environmental Studies
- ✧ Resources & Marine Science

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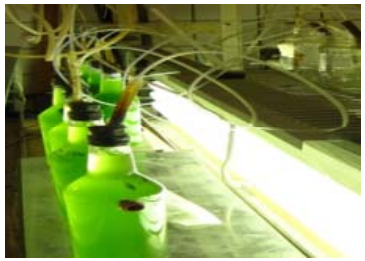
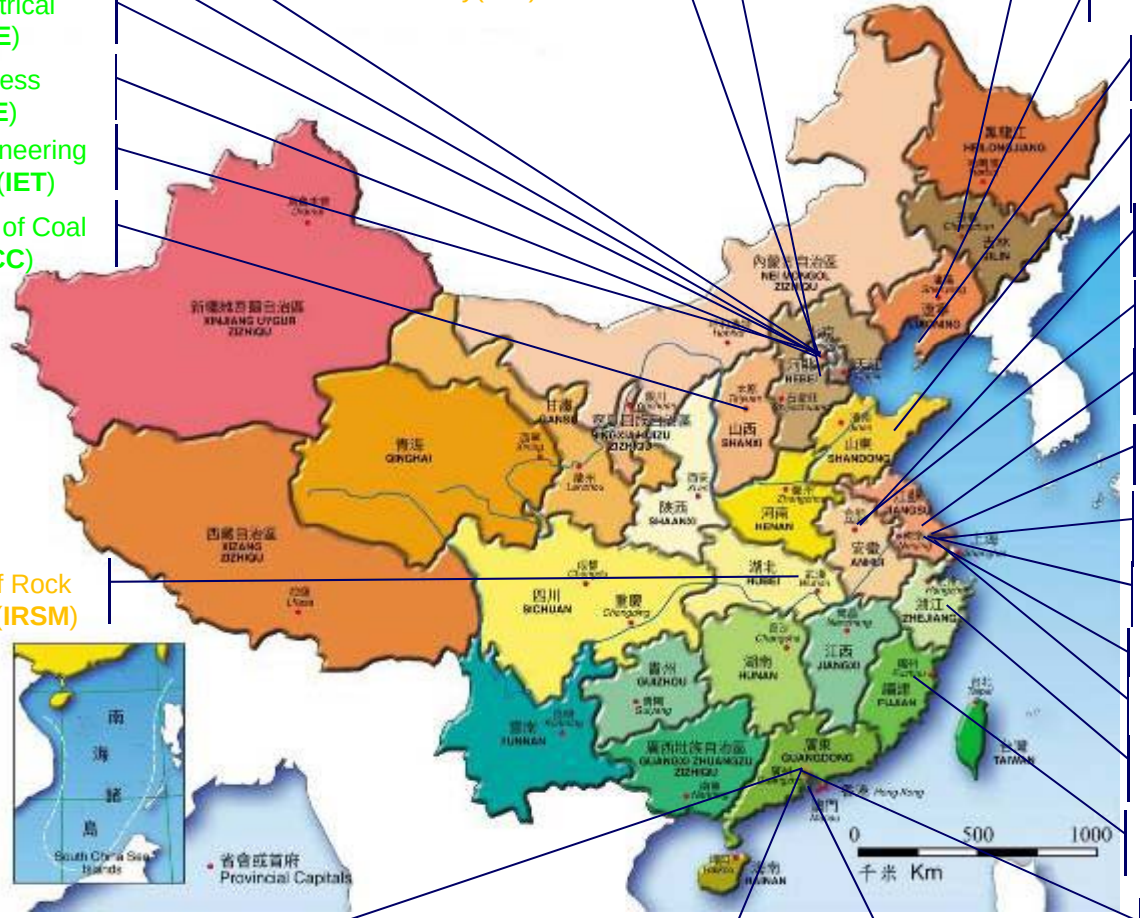


CAS related Institutes in Energy R&D

- Institute of Chemistry(**IC**)
- Institute of Physics(**IPHY**)
- Institute of Electrical Engineering(**IEE**)
- Institute of Process Engineering(**IPE**)
- Institute of Engineering Thermophysics(**IET**)
- Shanxi Institute of Coal Chemistry(**SXICC**)
- Institute of Semiconductor(**ISEM**)
- Technical Institute of Physics and Chemistry(**IPC**)
- Changchun Institute of Applied Chemistry(**CIAC**)
- Institute of Metal Research(**CIAC**)
- Dalian Institute of Chemical Physics(**DICP**)
- Qingdao Institute of Biomass Energy and Bioprocess Technology(**QIBEBT**)
- University of Sci.&Tech. of China(**USTC**)
- Institute of Plasma Physics(**IPP**)
- Suzhou Institute of Nano-tech and Nano-bionics (**SINN**)
- Shanghai Institute of Technical Physics(**SITP**)
- Shanghai Institute of Ceramics(**SIC**)
- Shanghai Institute of Applied Physics(**SINAP**)
- Institute of Microsystem(**SIM**)
- Shanghai Advanced Research Institute (**SARI**)
- Ningbo Institute of Materials Tech. and Engi.(**NIMTE**)
- Fujian Institute of Research on Structure of Matter(**FIRSM**)
- Guangzhou Institute of Energy Conversion(**GIEC**)
- Wuhan Institute of Rock & Soil Mechanics(**IRSM**)



- South China Sea Institute of Oceanology(**SCISO**)
- Guangzhou Institute of Geochemistry(**GIG**)
- Shenzhen Institute of Advanced Technology(**SIAT**)

Fields of Energy R&D in CAS

- 1. Fossil Energy
- 2. Renewable Energy
- 3. Hydrogen Energy and Fuel Cell
- 4. Nuclear Energy
- 5. Advanced Energy Resources Power
- 6. Advanced Electric Power Technology

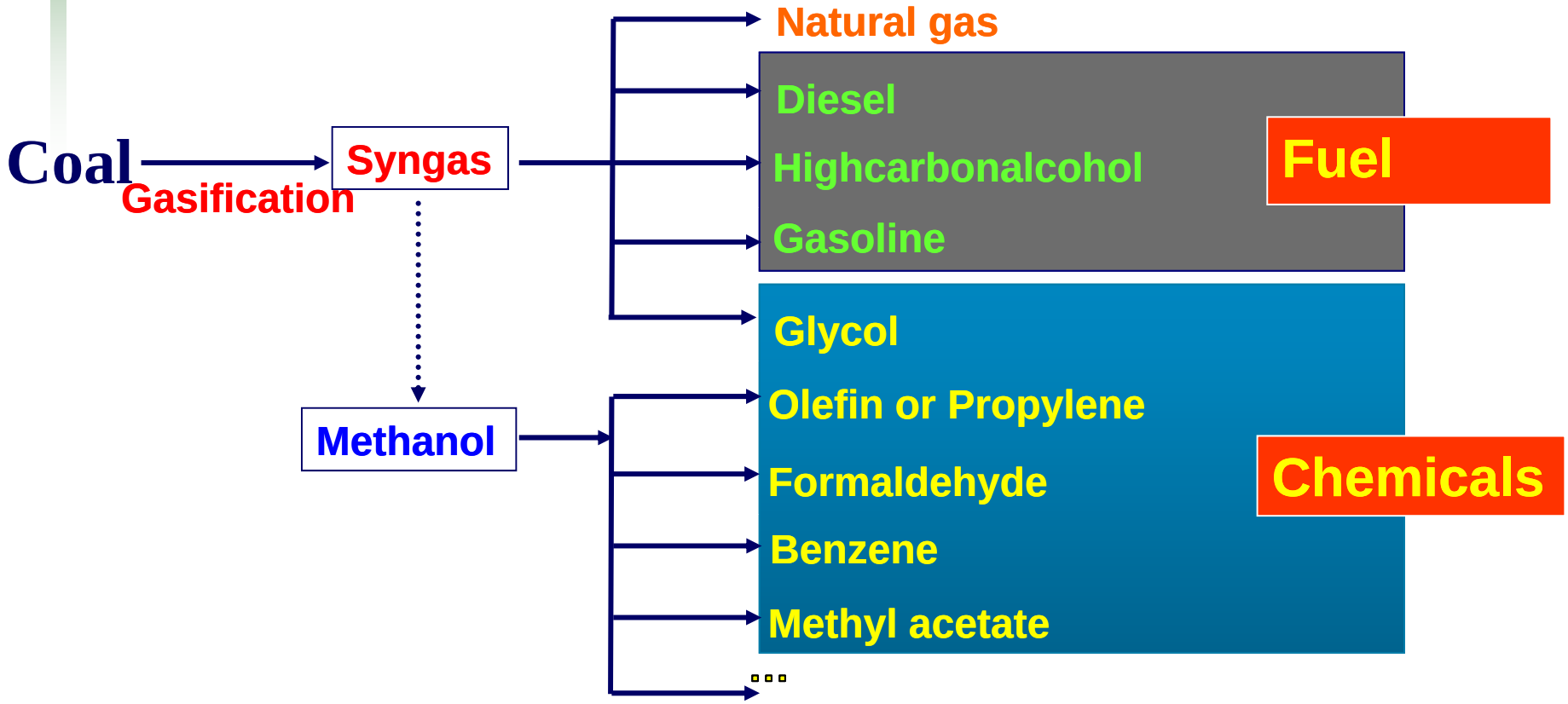
Frontier… R&D… Commercialization…

Roadmap of Energy R&D

Fossil Energy—Clean Coal Tech

- Coal derived clean fuel and chemicals
- Coal co-production & IGCC
- Advanced gasification technology
- Advanced combustion technology

Coal Derived Clean Fuel and Chemicals



Coal Derived Clean Fuel and Chemicals

Typical CTL/CTC Demos

CAS has developed the first generation CTL & CTC technology.

Coal Derived Clean Fuel and Chemicals

The DMTO process (DICP Methanol to Olefins) was a proprietary technology developed by DICP. On 8th August,2010, the first DMTO commercial unit in the world, with a production capacity of 600,000 tons of lower olefins per year, was proved to be completely successful in its first commissioning operation.

Renewable Energy

- Solar cell
- Solar Photovoltaic System Integration and Control
- Solar thermal power
- Wind
- Biomass

Solar cell

CIGS

a-Si / CdTe

Organic

High-performance concentrator

Dye-sensitized Solar cell: 640cmX180cm

Solar Thermal Power

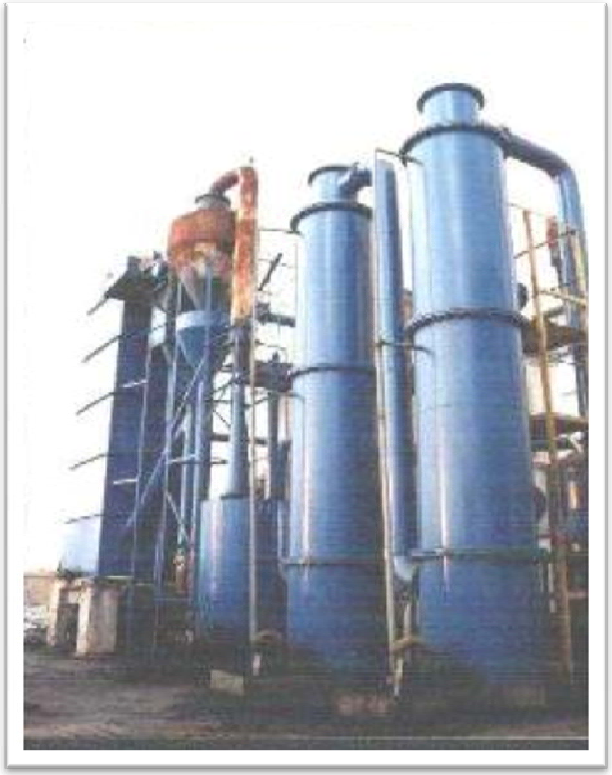
Dish Stirling Solar Thermal Power

1 MW Solar Concentrator Power Station

Wind Energy

Control System of Large-scale Wind Power Generator

Biomass Energy



5MW biomass gasification power plant in Jiangsu Province

Biomass Energy

Biomass derived liquid fuel

Middle-experiment platform of biomass gasified synthetic DME of 100 tons per year

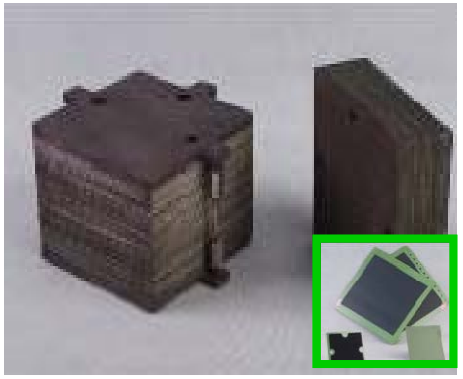
Middle-experiment setup of biomass pyrolysis liquefaction with a scale of thousand tons

Middle-experiment setup of biomass diesel of 150 tons per year

Hydrogen Energy and Fuel Cell

- **Hydrogen Energy Technology**
- **Hydrogen generation**
- **Hydrogen storage**

- **Fuel Cell**
  - **PEM Fuel Cell**
  - **Direct Alcohol Fuel Cell（DAFC）**
  - **Renewable Fuel Cell**
  - **Solid Oxide Fuel Cell**



Nuclear Energy

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■Fusion energy

EAST: The Experimental Advanced Superconducting Tokamak (EAST) Project

commissioning was completed in March 2006. Sept. 2006 First plasma discharges 3sec. @200 kA

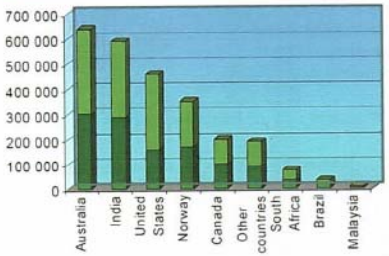
The Related Technology of EAST Project for ITER

Nuclear Energy - TMSR

- After about 52 years, CAS would like to engage in the nuclear fission field again and to develop advanced nuclear energy.
- Under the approval of the Central Government, CAS initiated “Innovation 2020” program and deployed first group of four Strategetic Pioneer Sci.&Tech. Projects in the begin of 2011. One of them is “advanced nuclear fission energy of tomorrow”, which includes TMSR and ADS.
- **TMSR ---Thorium Molten Salt Reactor Nuclear Energy System.**

About Thorium

India's thorium reserves stimulate its thorium power development.



India's nuclear strategy

1. Heavy water reactors for unenriched, limited uranium reserves.
2. Fast breeder reactor for plutonium from spent fuel uranium
3. Thorium fast breeder reactor.

India has 13 heavy water reactors plus 4 under construction.

The CANDU-like technology allows breeding U-238 to Pu-239 and Th-232 to U-233.

India already has reprocessing facilities and a developmental breeder reactor.

Kamini reactor tests U-233 from Kalpakkam experimental breeder.

0.5 GW fast breeder reactor is under construction, due 2010.

20 GW of U and Th power by 2020. 30% of electricity from Th by 2050.

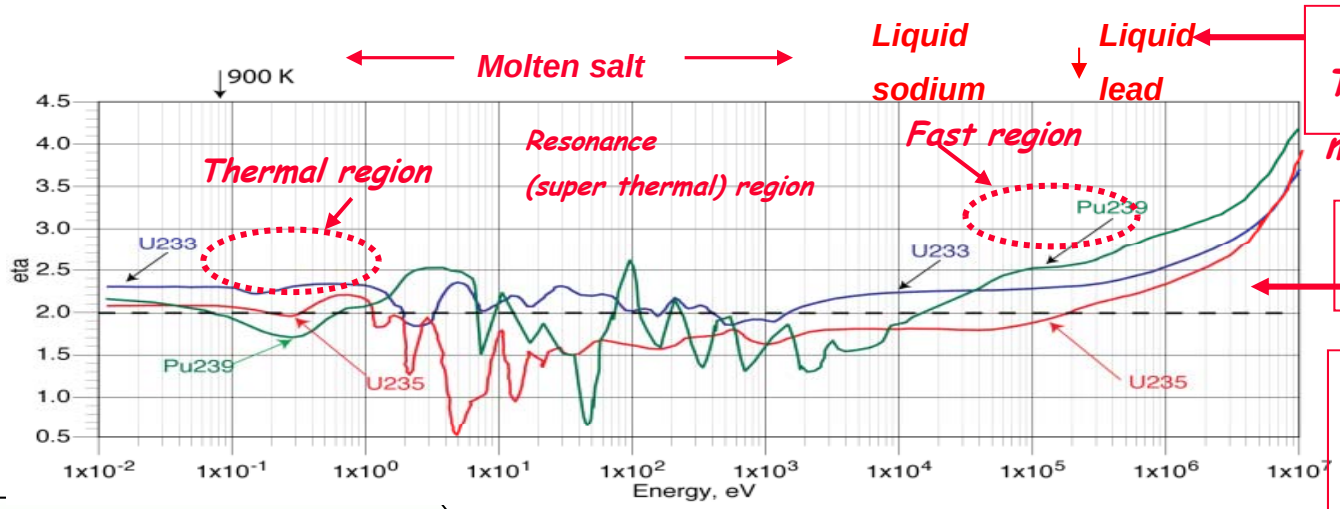
India has little uranium, which has been difficult to obtain, because India did not sign the Nuclear Non-proliferation Treaty.

India's thorium power reactor development uses solid fuel, not liquid fluoride salts as the LFTR uses.

CONCLUSION –C.Rubia

Unlike other energy sources, China's reserves of Thorium, may ensure the major domestic energetic supply for many centuries to come.

For instance the whole China's today electricity (3.2 Trillion kWh/year) could be produced during ≈20'000 years by well optimized Th reactors and 8,9 million ton of Th, a by-product of the China's REE basic reserves.



Possible Th232/U233 methods

$\eta = 2$

only fast neutron is suitable to U238/Pu239

Roadmap of TMSR in CAS

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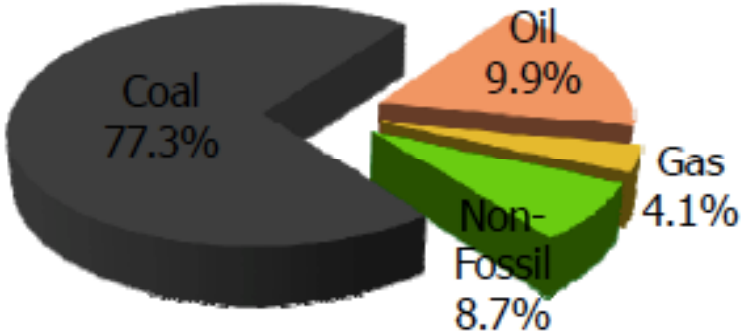
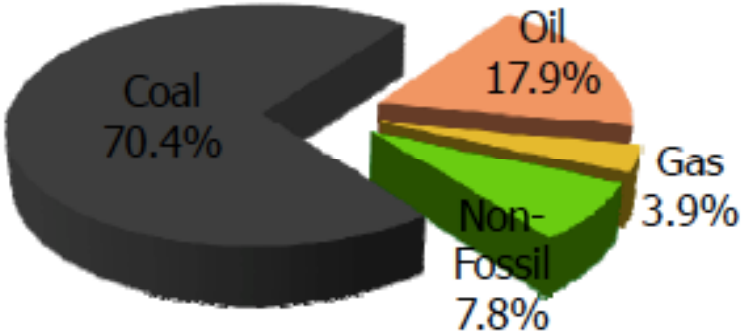
China Energy Production, Consumption

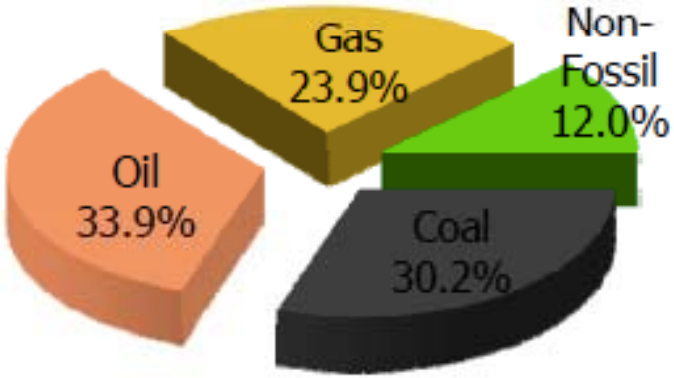
China Energy Production 2009



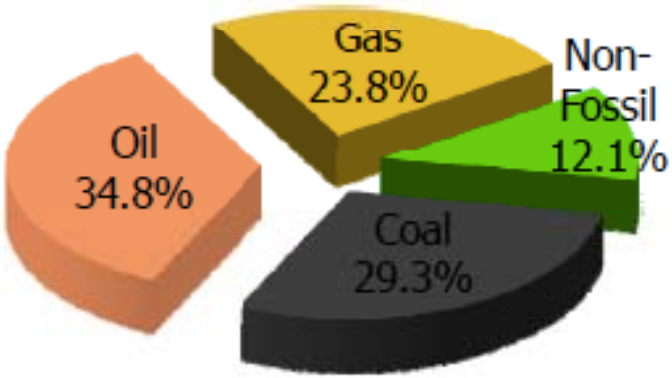
China Energy Consumption 2009



World Energy Production 2009

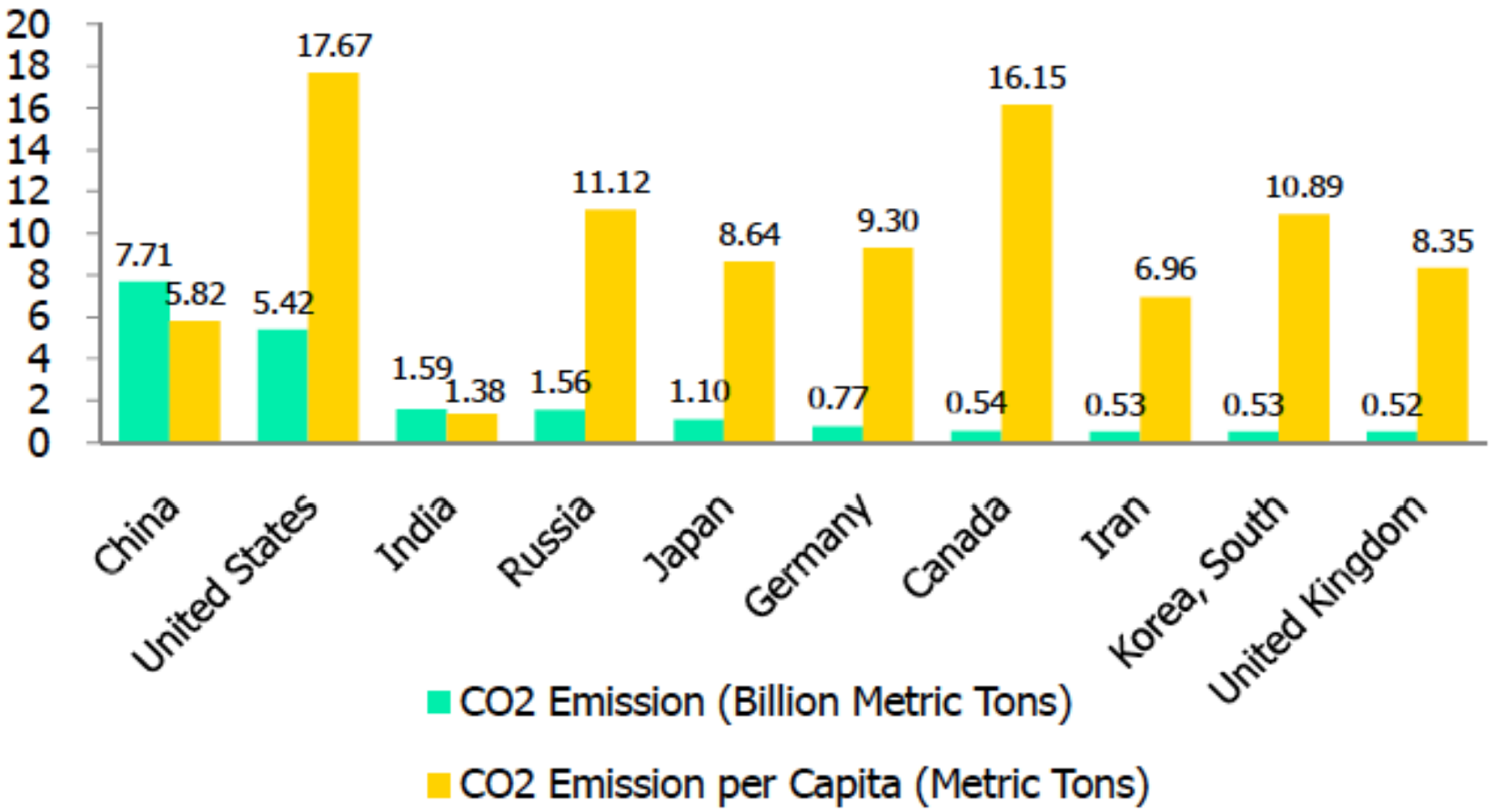


World Energy Consumption 2009



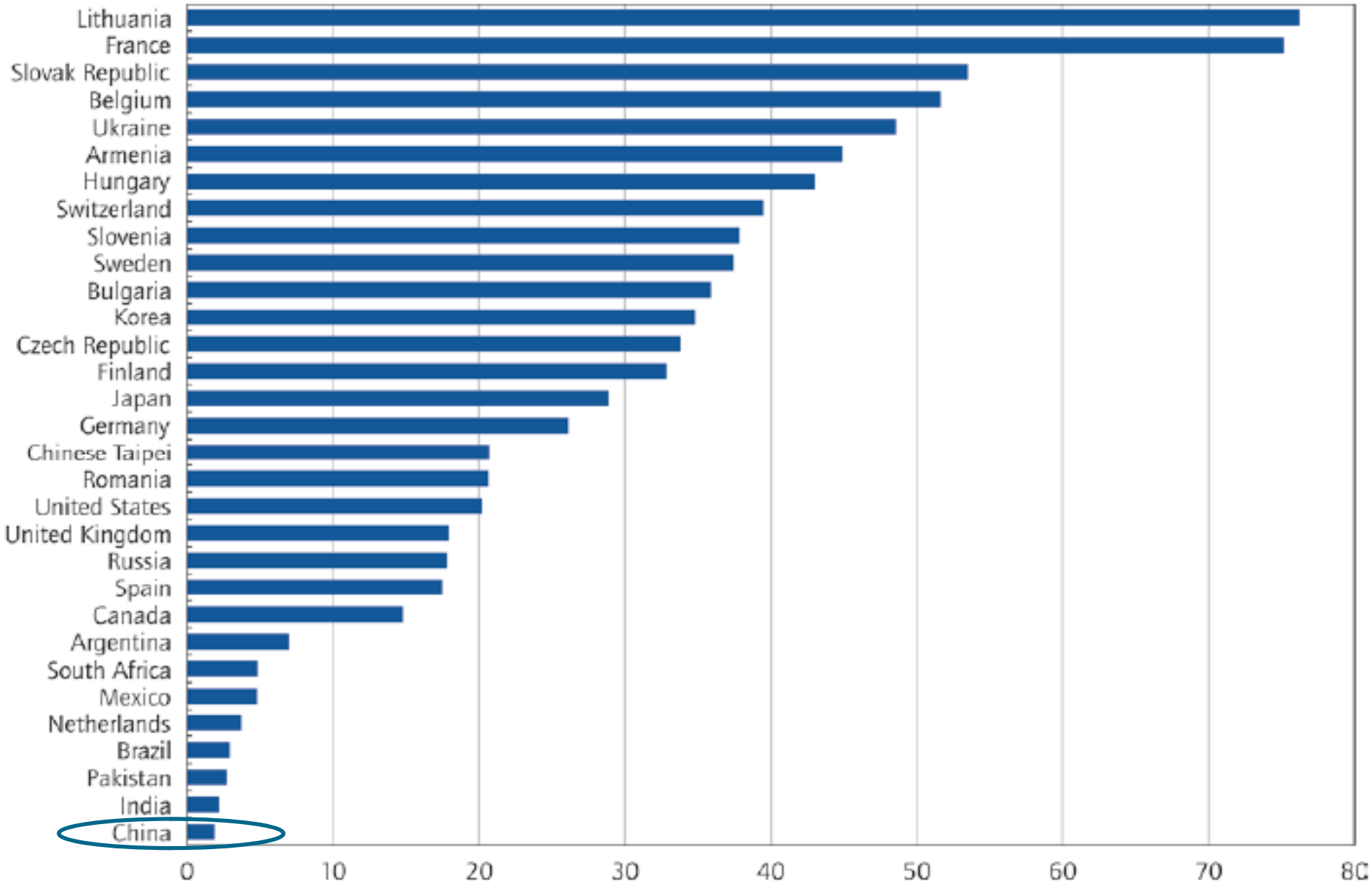
Source: National Bureau of Statistics of China, BP Statistical Review of World Energy

World Top 10 Countries of CO_2 Emission in 2009



Source: Carbon Dioxide Information Analysis Center (CDIAC)

Figure 3. Share of nuclear power in total electricity, 2009 (%)



Source: IAEA PRIS.

Note: Lithuania closed its only nuclear plant at the end of 2009 and now has no nuclear capacity.

Nuclear Power in China

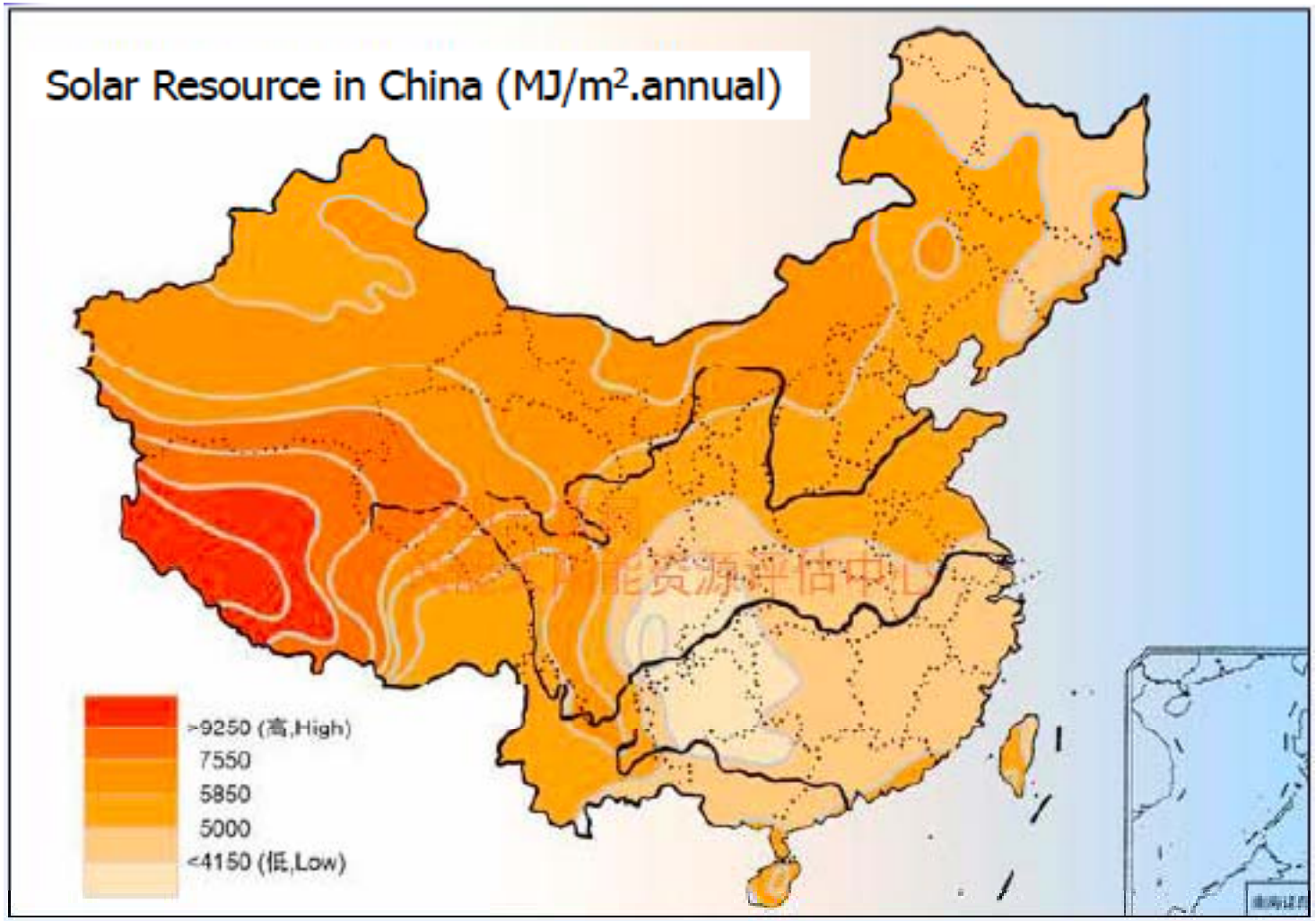
China's electricity is produced from fossil fuels (80% from coal, 2% from oil, 1% from gas in 2006) and hydropower (15%).

Source: World Nuclear Association 2010.4.22

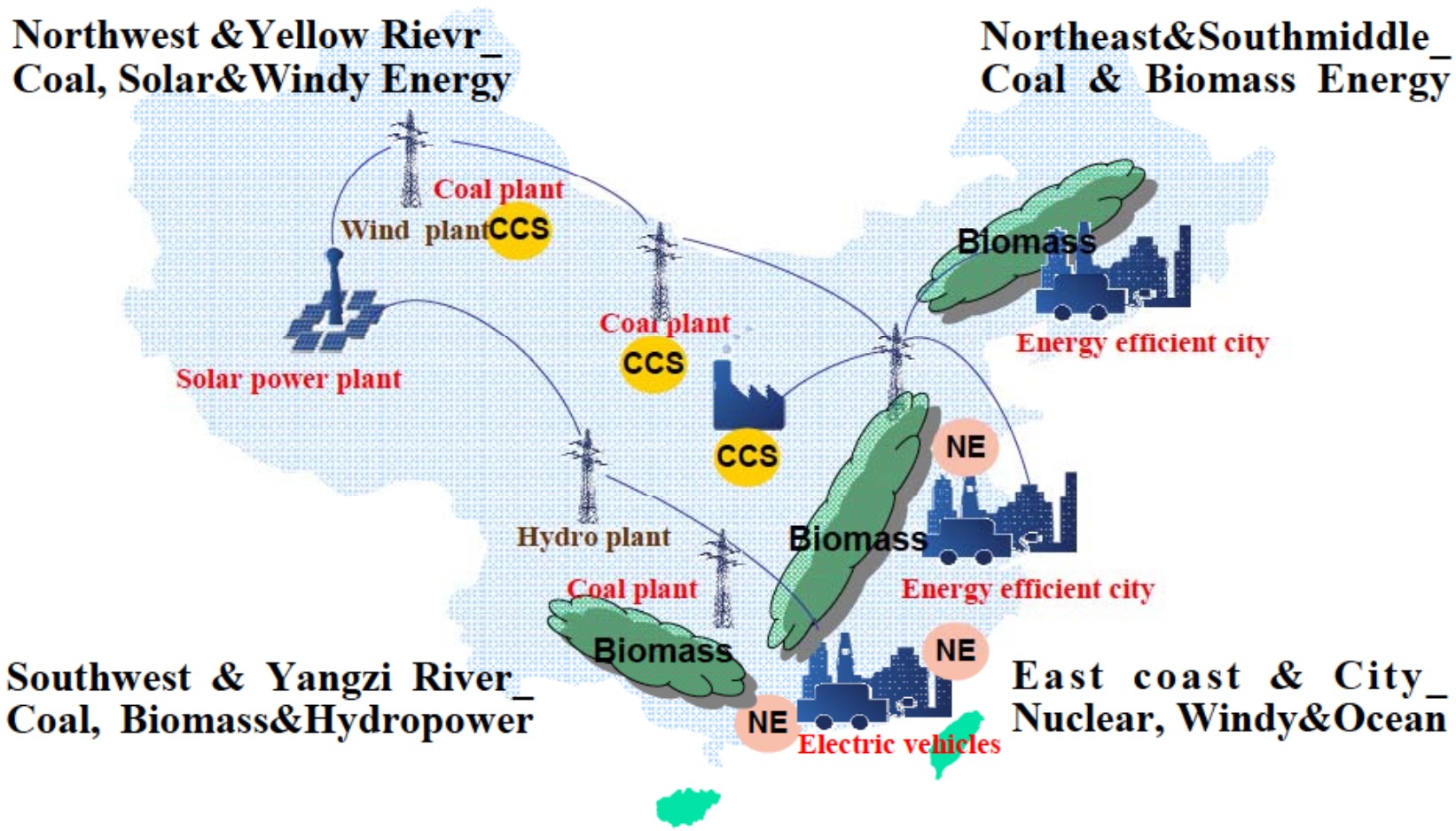
- China has 13 nuclear power reactors in commercial operation(10.8GWe, 1.4%) in 2010, 24 under construction (25.4GWe).

- Additional reactors are planned, including some of the world's most advanced, to give a sixfold increase in nuclear capacity to at least 60 GWe or possibly more by 2020(>5%), and then a further substantial increase to 200 GWe by 2030.

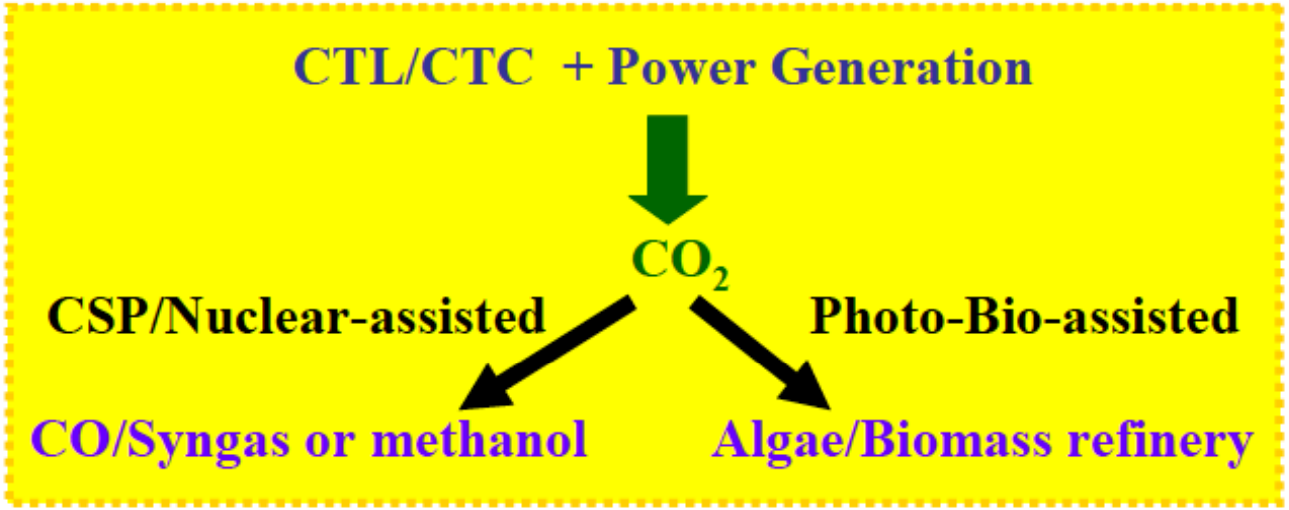
Renewable Energy — Solar



Localized Energy Resource in China

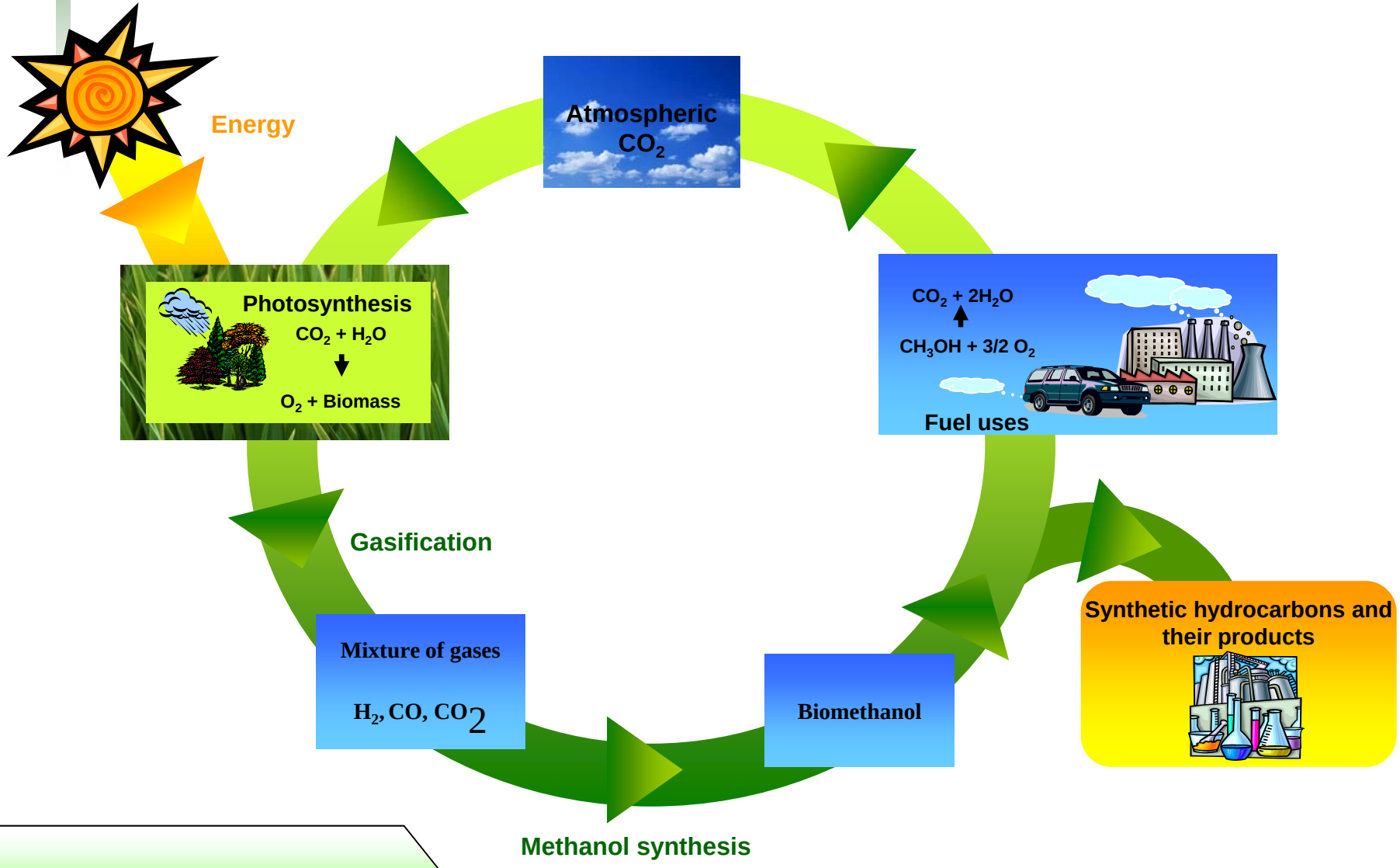


Low Carbon Energy System

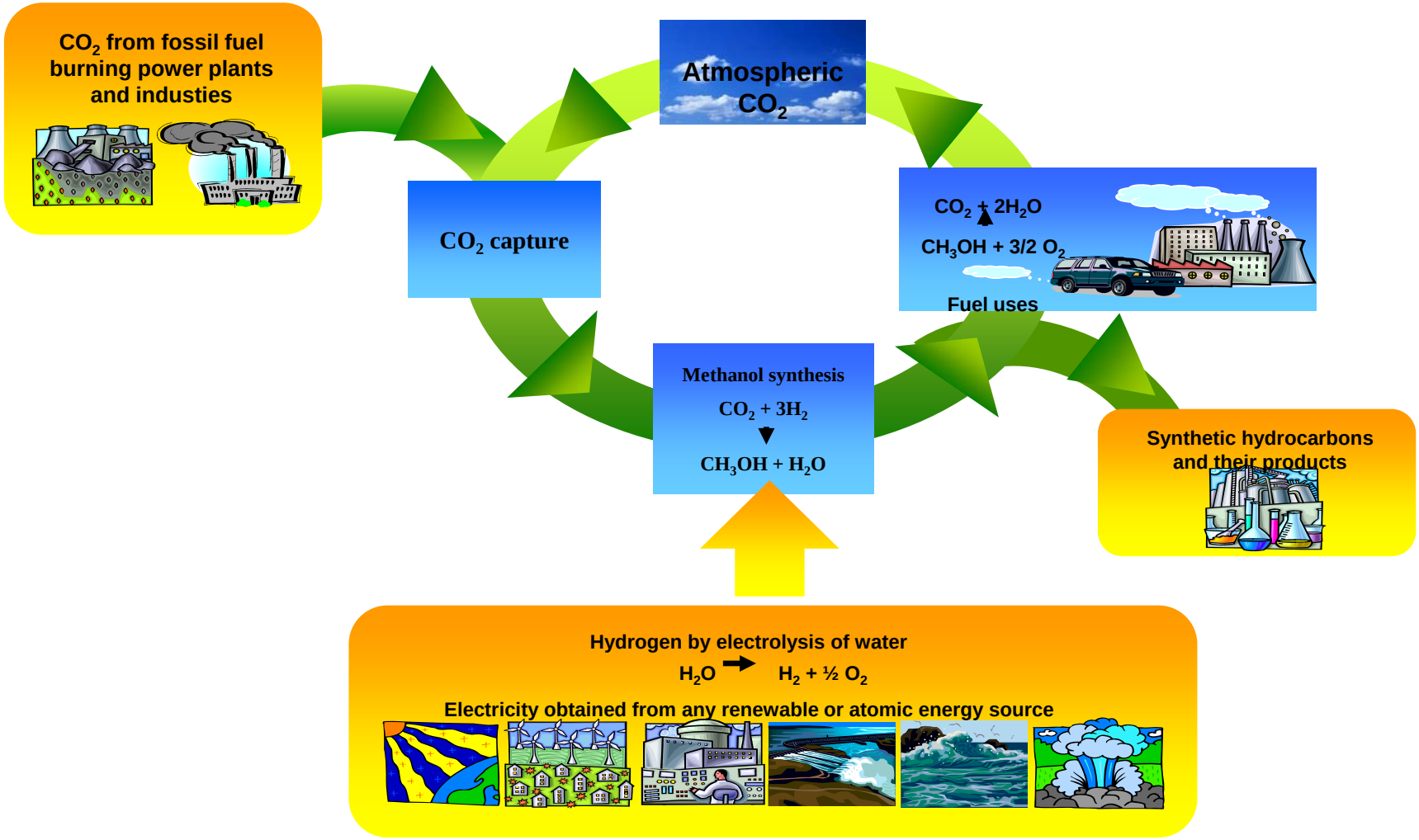


- Nuclear-assisted Hybrid Energy System
- Photo-assisted CO_2 Biochemical Fixation
- Solar/CSP-assisted Carbon Recycle Sytem

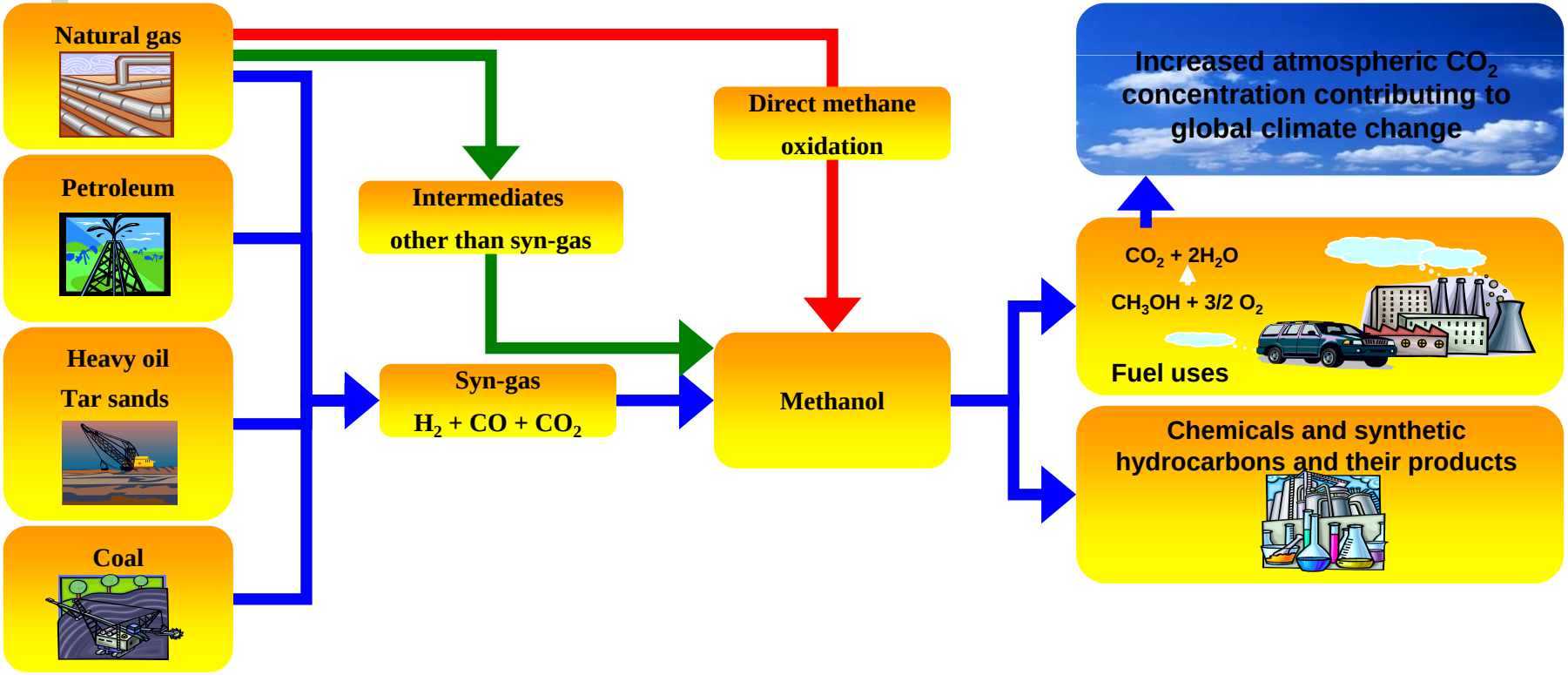
Carbon neutral cycle of biomethanol production and uses



CO_2 Recycling for methanol and synthetic hydrocarbons production

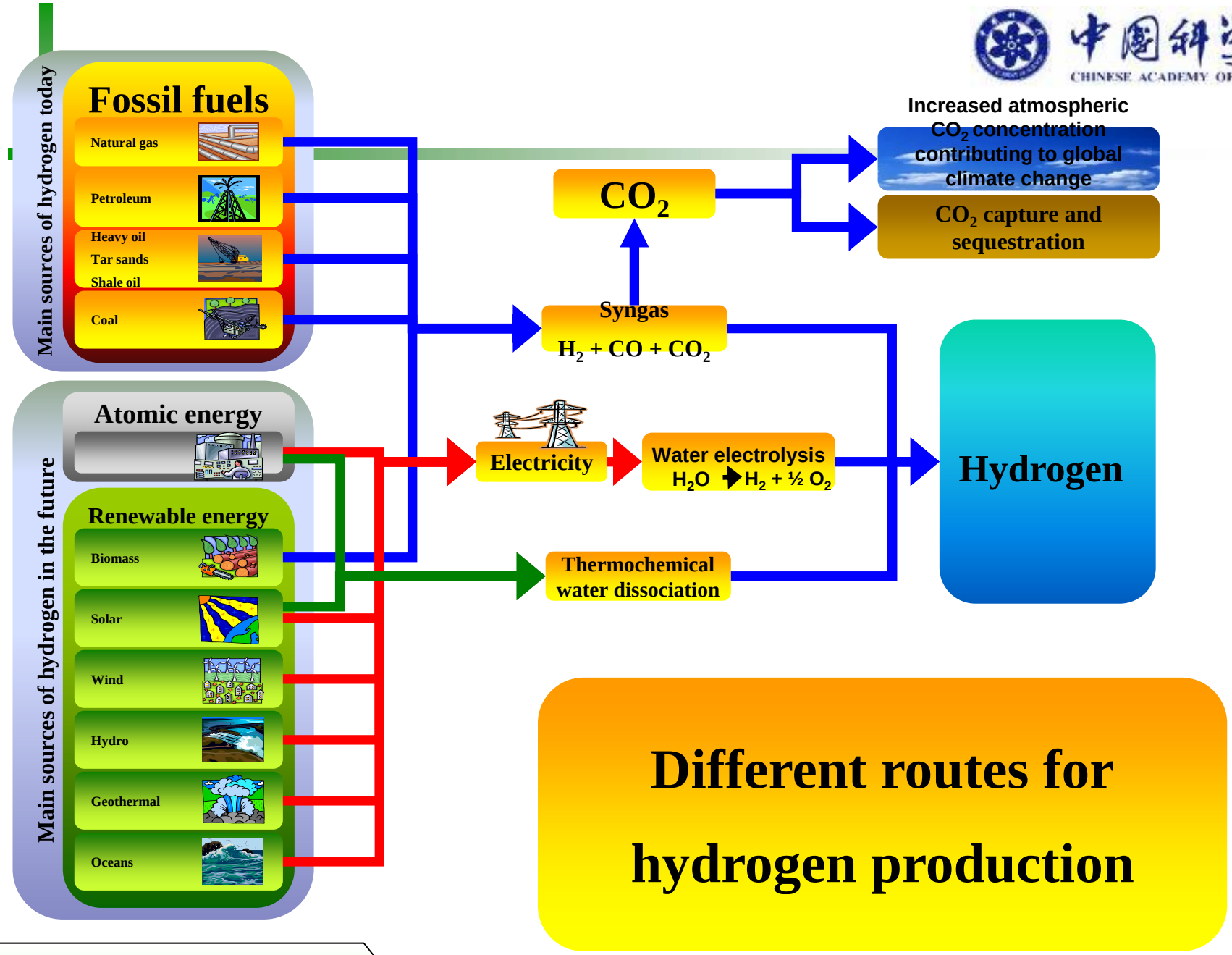


Methanol from fossil fuel resources



Technologies to be developed

Using current technology

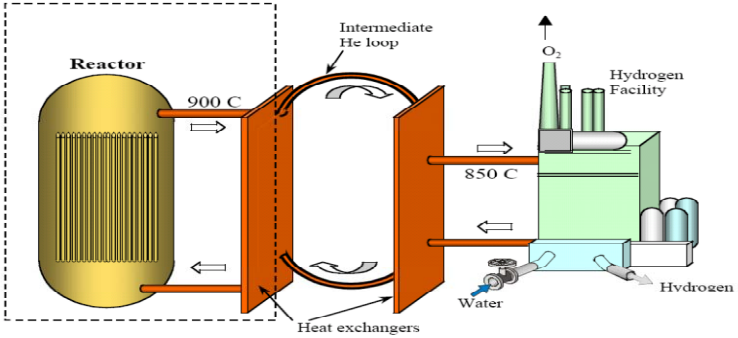


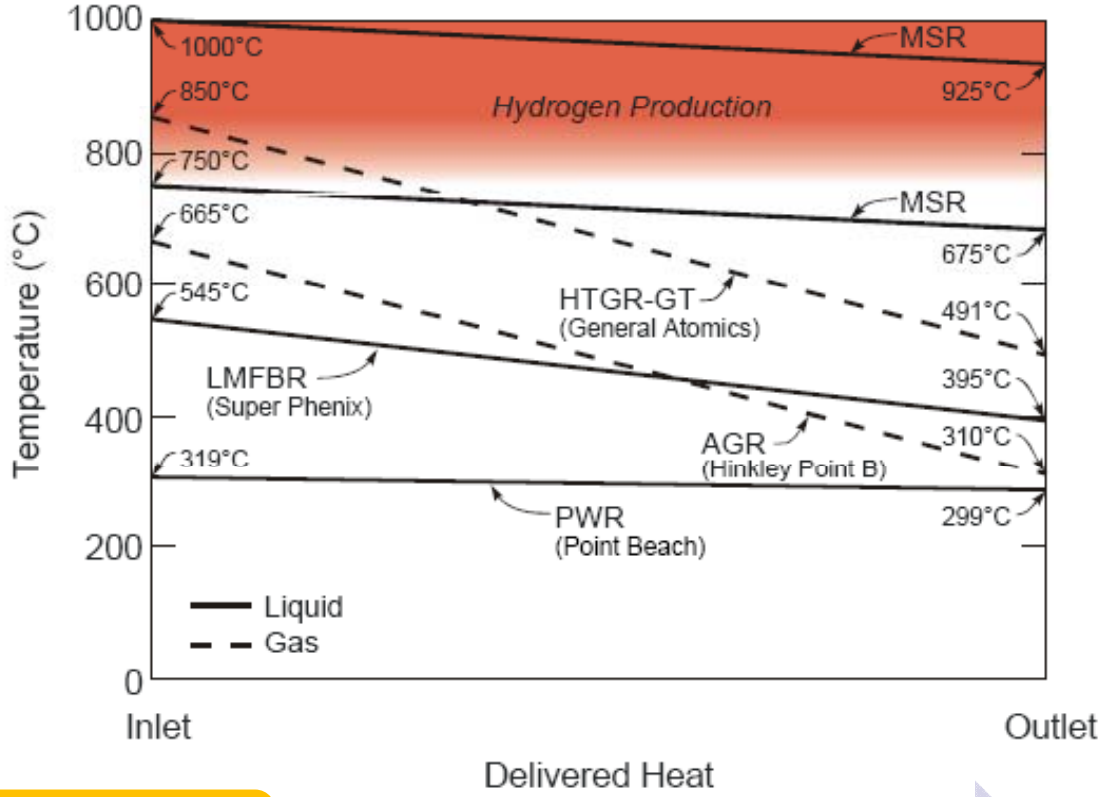
Different routes for hydrogen production

Candidate for Gen IV nuclear energy system

Reactor	Neutron spectrum	Coolant	Temperature(℃)	Cycle way	Application	Required R&D
Very High Temperature Reactor(VHTR)	Thermal	He	900-1000	Once-through	Electricity/hydrogen production/thermal disposal	Fuel, material, Hydrogen product
Super Critical Water Reactor (SCWR)	Thermal/Fast	H2O	510-625	Once-through/ closed	Electricity/hydrogen production	Material, thermal hydraulic design
Gas-cooled Fast Reactor (GFR)	Fast	He	850	Closed	Electricity/hydrogen production/Actinium waste treatment	Fuel, material, thermal hydraulic design
Lead-cooled Fast Reactor (LFR)	Fast	Lead	480-800	Closed	Electricity/hydrogen production	Fuel, material
Sodium-cooled Fast Reactor (SFR)	Fast	Sodium	550	Closed	Electricity/Actinium waste treatment	Selection of advanced recycle system, fuel
Molten Salt Reactor (MSR)	Thermal/Fast	Molten salt	700-800	closed	Electricity/hydrogen product/Actinium waste treatment	Fuel reprocessing, material, reliability

Demand of Heat by Hydrogen Production





Nuclear energy is a good choice of Primary energy for hydrogen production

High efficiency ← High temperature • VHTR，AHTR，MSR，LFR

Stability of catalyst efficiency ← Stability of temperature • Coolant：Molten Salt

Charles W. Forsberg . 2004, The Advanced High-Temperature Reactor (AHTR) for Producing Hydrogen to Manufacture Liquid Fuels

Advanced High Temperature Reactor

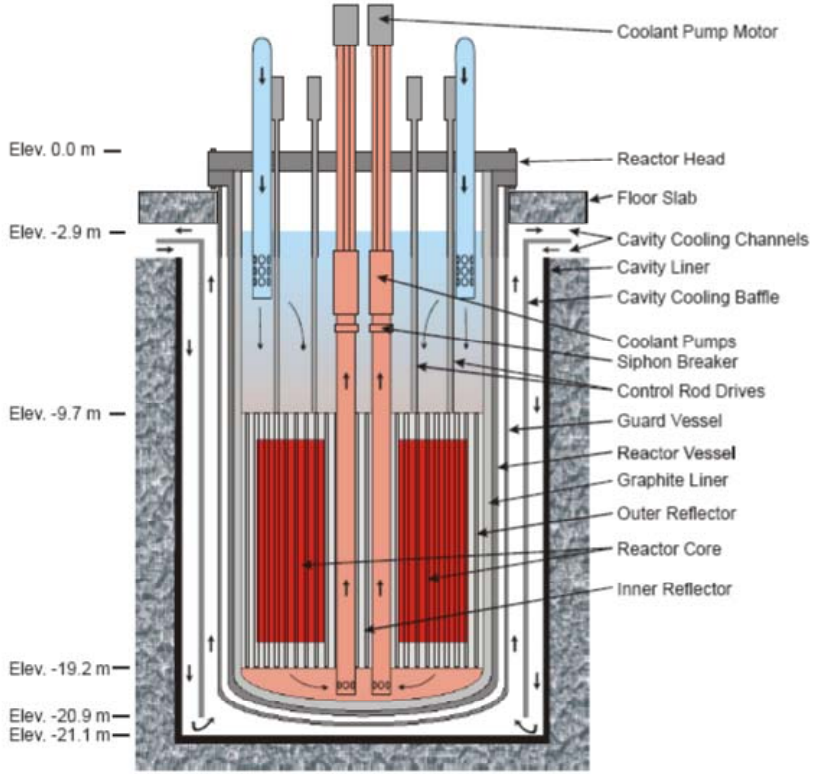


Fig. 2.6. Elevation view of AHTR core, vessels, and internals.

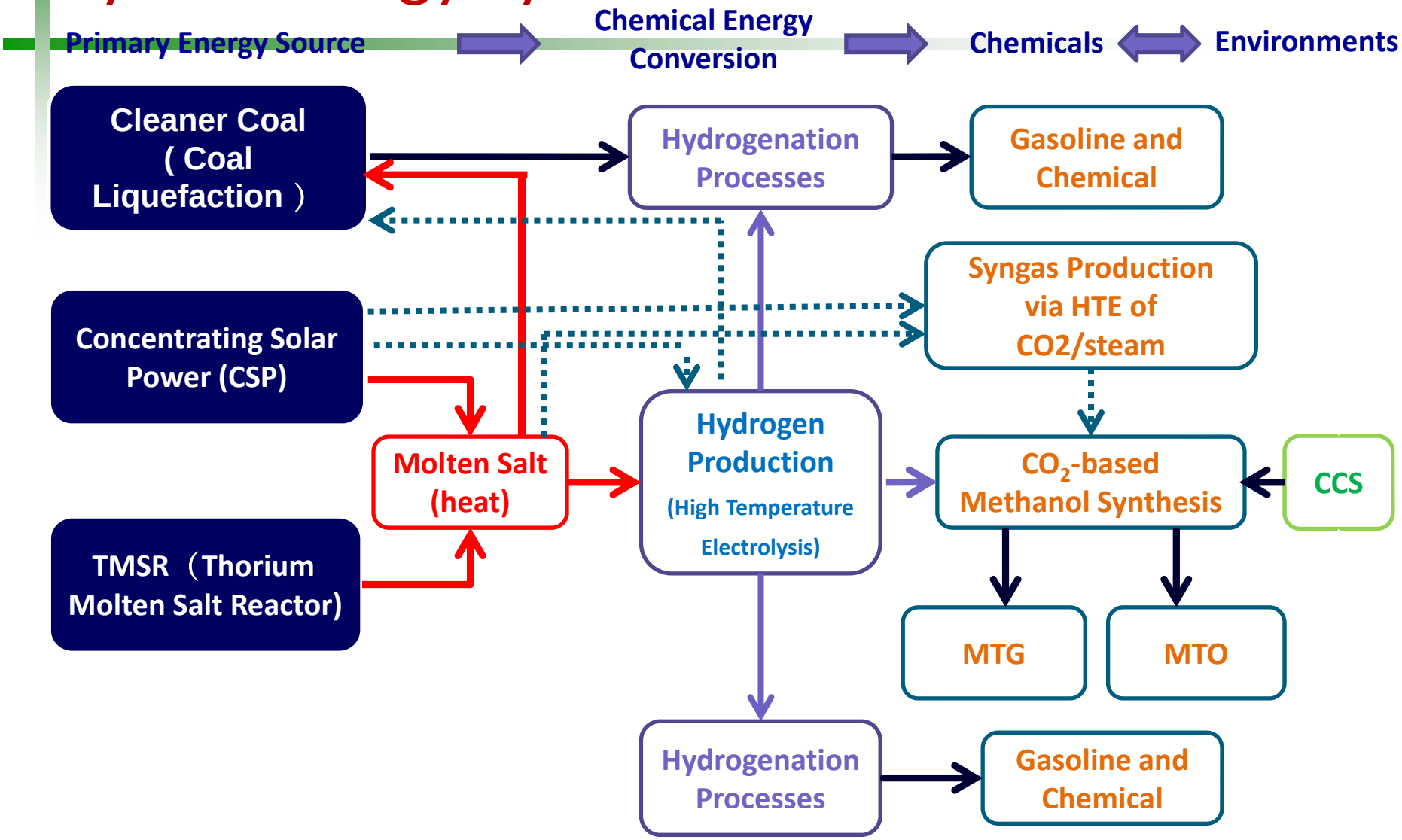
	Very high temperature AHTR-VT	Intermediate temperature AHTR-IT
Thermal power	2400 MW(t)	2400 MW(t)
Electrical power	1300 MW(e)	1145 MW(e)
Number of PCUs	3	3
PCU working fluid	Helium	Helium
Primary maximum temperature	1000° C	800° C
Intermediate maximum temperature	920° C	770° C
Intermediate minimum temperature	860° C	715° C
Intermediate flow rate	8.9m^3/s	9.7 m^3/s
Turbine inlet temperature	900° C	750° C
Compressor inlet temperature	35° C	35° C
PCU pressure	10 MPa	10 MPa
IHX power density [m3/MW(t)]	120 MW(t)/m^3	45 MW(t)/m^3
Heaters/steam generator/recuperator power density	100 MW(t)/m^3 (heater)	82 MW(t)/m^3 (heater)
Overall cycle efficiency	0.54	0.48
PCU power density	360 kWh(e)/m^3	305 Wh(e)/m^3

Coolant：LiF-BeF2-ZrF4-NaF-KF-RbF etc.

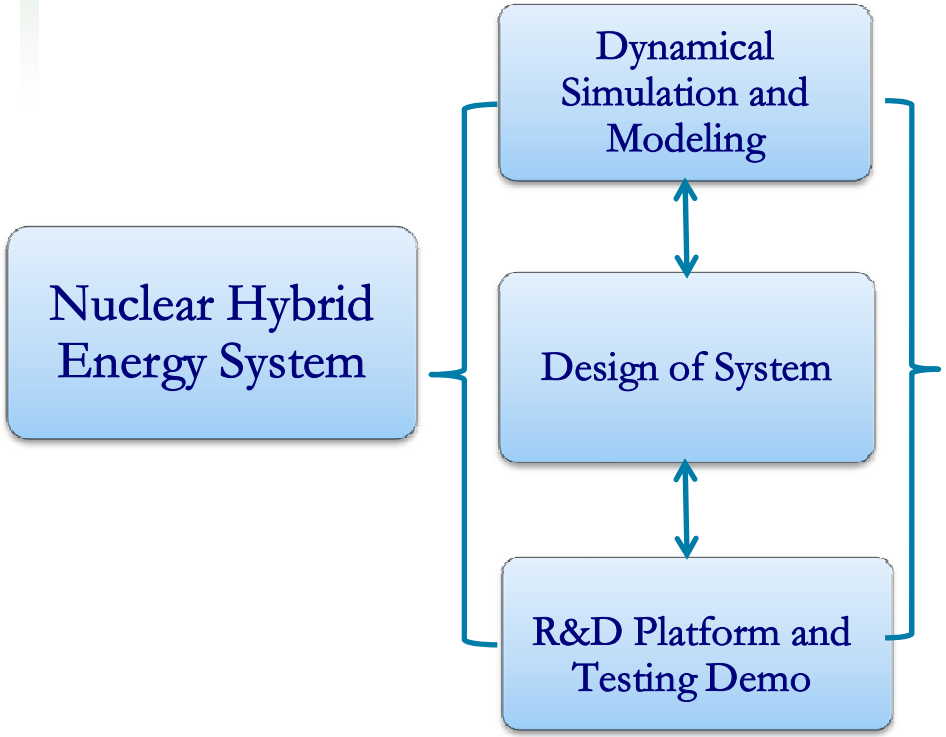
Structural Materials：High temperature alloy，C/C composite，SiC/SiC composite

Data from ORNL/TM-2004/104. Status of Preconceptual Design of the Advanced High-Temperature Reactor (AHTR)

Hybrid Energy System Based on TMSR



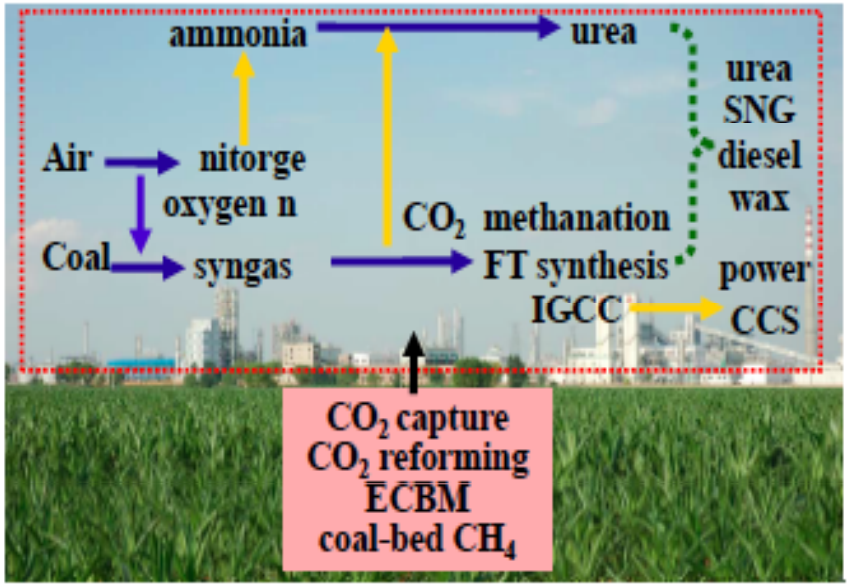
Framework of WBS



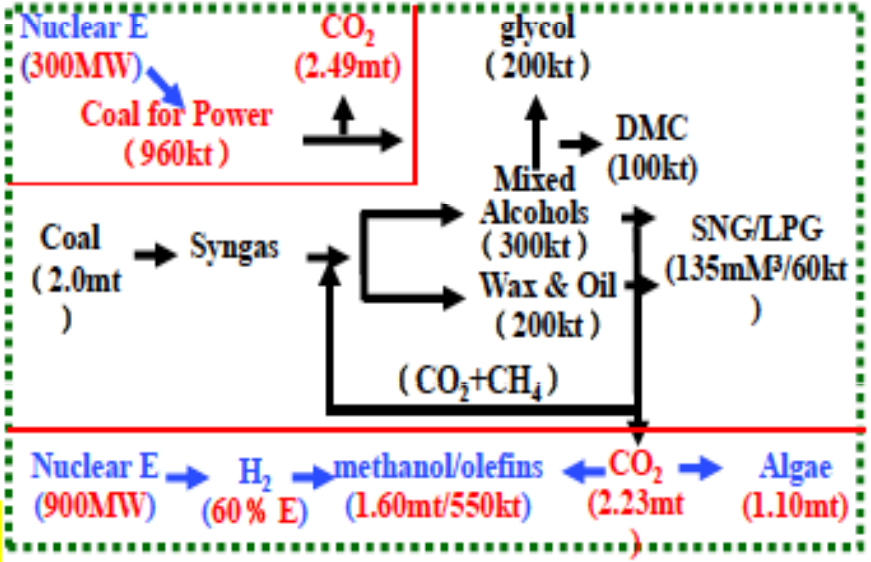
- Analysis and simulation of the complex flows and system
- Study of fundamentals for conversions and utilizations of different kinds of energy and mass
- R&D of hydrogen generation by High Temperature Electrolysis
- Solar-Hydrogen system and hydrogen production
- Safety and economics of system

Nuclear-assisted Coal-based Hybrid System

--Clean Energy for the Future China



Lu'an low Carbon CTL Polygen Park
coal ming, power generation, gasification, FTS, urea and IGCC, and 1/3 CO_2 has been reduced at the moment.



Case Study: *coal to gas & chemicals along with either nuclear power or CO_2 algae.*

Thanks for your attention.