Cooperative research efforts to reduce CO_2 emission

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- Prof. Yan Jinyue, KTH and MdU (CCS)
- Prof. Dahlquist Erik, MdU (BL Gasification)
- Prof. Jin Hongguan, CAS (Energy systems)
- Prof. Liu Honglai, ECUST (Physic chemistry)
- Prof. Wang Fucheng, ECUST (Coal Gasification)
- Prof. Ling Licheng, ECUST (Carbon materials)
- Profs. Yan Yongjie and Bao Jie, ECUST (Biomass)
- A/Prof. Yu Xinhai, ECUST (Biodiesel)

1. China-Sweden Program

Fundamental studies of thermophysical sciences for CO2 capture, Negative CO2 emission

2. ECUST Centered Cooperative Research Program

Clean coal technology, CO_2 Capture technology

3. Future Cooperation

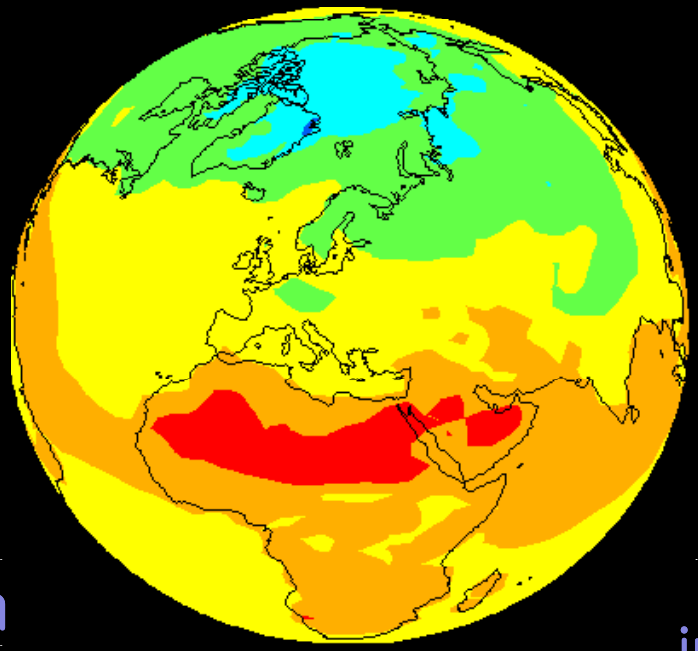
CO_2 Capture technology and Education

A 21st Century World full of Challenges and Opportunities……

Energy Crisis

Global warming

Disasters



New diseases

Population

Aging infrastructure

China-Sweden Research Program

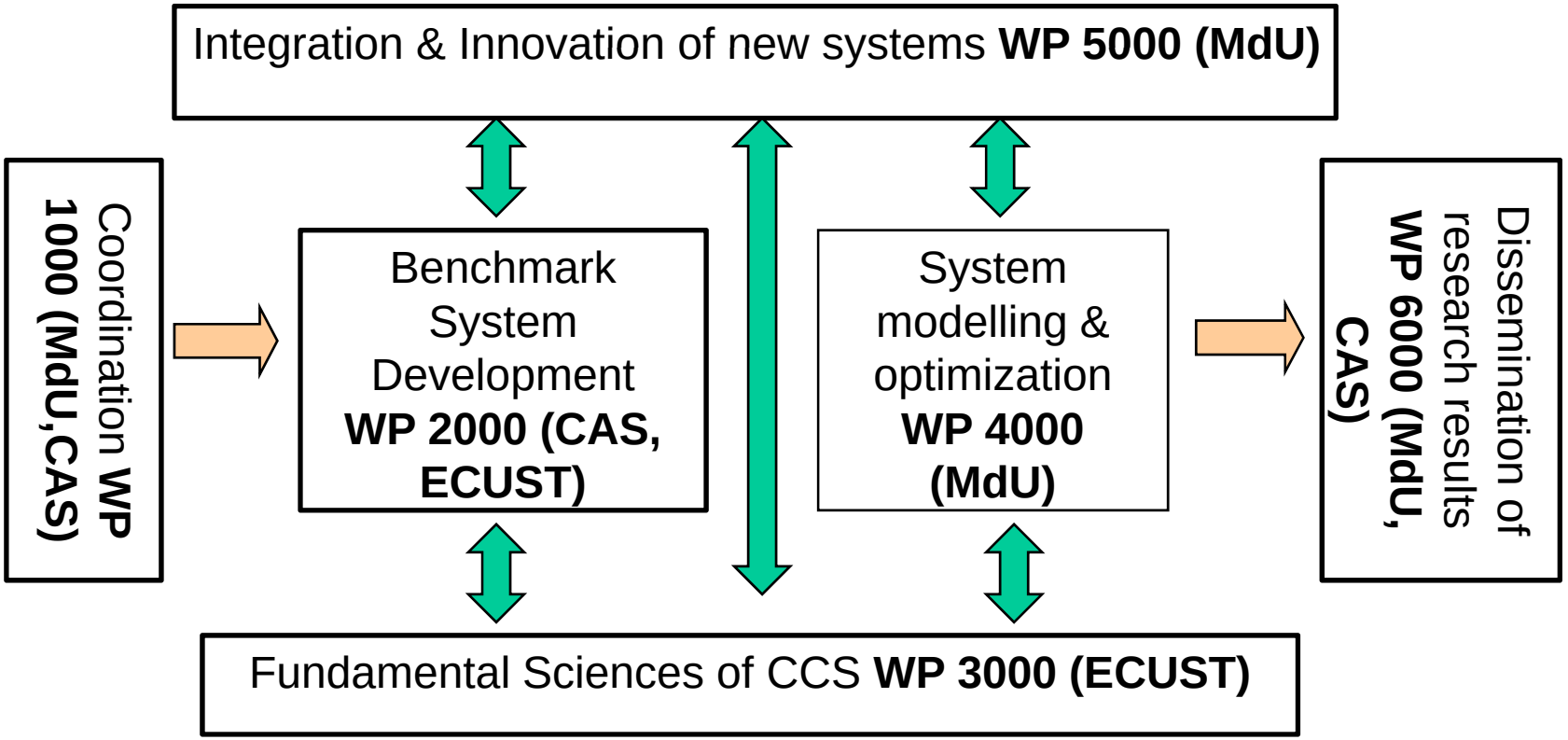
on fundamentals of CO2 Capture

- The goal is to develop innovative technologies for CO2 capture and storage (CCS) by using biomass and coal.
- We enhance and integrate cross-disciplinary competences from the partners to address the crucial gaps of R&D in CCS, such as CO2 chemistry and physics, key equipment development, system modelling and optimisation.
- A network will be established and workshops and conference will be organized to disseminate the research results to the industry and the public.

Research efforts needed

- All CCS technologies suffer from a **penalty in the energy efficiency** (8-10% points lower) and **cost** (30-50% higher), which is the major obstacle for the use of those technologies. How to improve the efficiency with lower cost forms the central tasks of the future research in CCS
  - **Fundamental sciences** of CO2 chemistry and physics: kinetic modeling, fluid dynamics, material synthesis, molecular modeling, surface modeling etc.
  - **Component technology**: solvents, adsorbents, gas-solid contactors, gas-liquid contactors, enhanced transport, etc.
  - **Technology platform**: absorption, adsorption, membranes, low-temperature distillation, gasification and reforming, and other novel concepts.
  - **Production technology system**: fuel production, power and/or heat production, and sequestration.

Project Work Packages



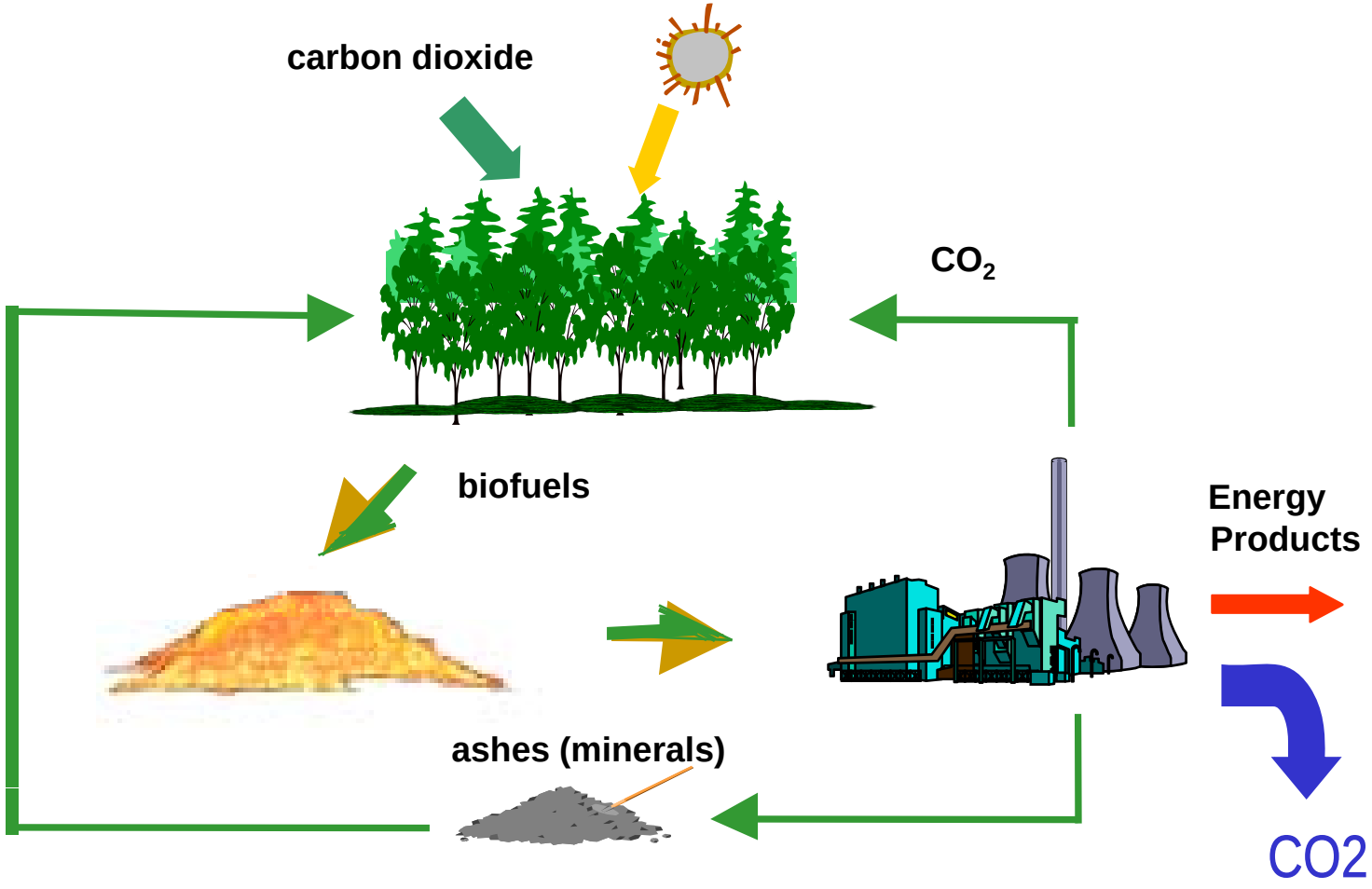
- **WP 1000 Coordination, Communication and Representation (WP Leader: MdU & CAS):** coordination and management of the project.
- **WP 2000 Benchmark System Development (WP Leader: CAS, ECUST):** to define a reference system consisting the major components and process for CO2 capture and storage. The benchmark system will provide a baseline against which new technologies can be compared with. Two variations of the fuel feedstock will be considered, biomass and coal with considerations of the applications of Sweden and China.
- **WP 3000 Fundamental Sciences of CCS (WP Leader: ECUST):** 1) Scientific problems such as kinetic of chemical reaction in the fuel conversion, material issues related to high temperature, molecular modeling of properties of CO2 and its mixtures, Database development; 2) component development of gasification, reforming, capture unit, heat exchangers etc.

- **WP 4000 System Optimization and Process Modeling (WP Leader: MdH):** modeling and optimization of system to provide further improvement which will be used for the development in WP 5000. Simulation tools and modeling strategy will be developed in this work package.
- **WP 5000 Integration and Innovation of New Systems (WP Leader: MdH):** this work package will make further synthesis of the system based on the research results from WP3000 and WP 4000 to provide a new innovative energy system with higher efficiency, low cost.
- **WP 6000 Dissemination of Research Results (WP Leader: MdH and CAS):** The research results will be disseminated through this work package to reach to both public and reputable international conferences and journals. An active website will be established.

CO2 chemistry and physics

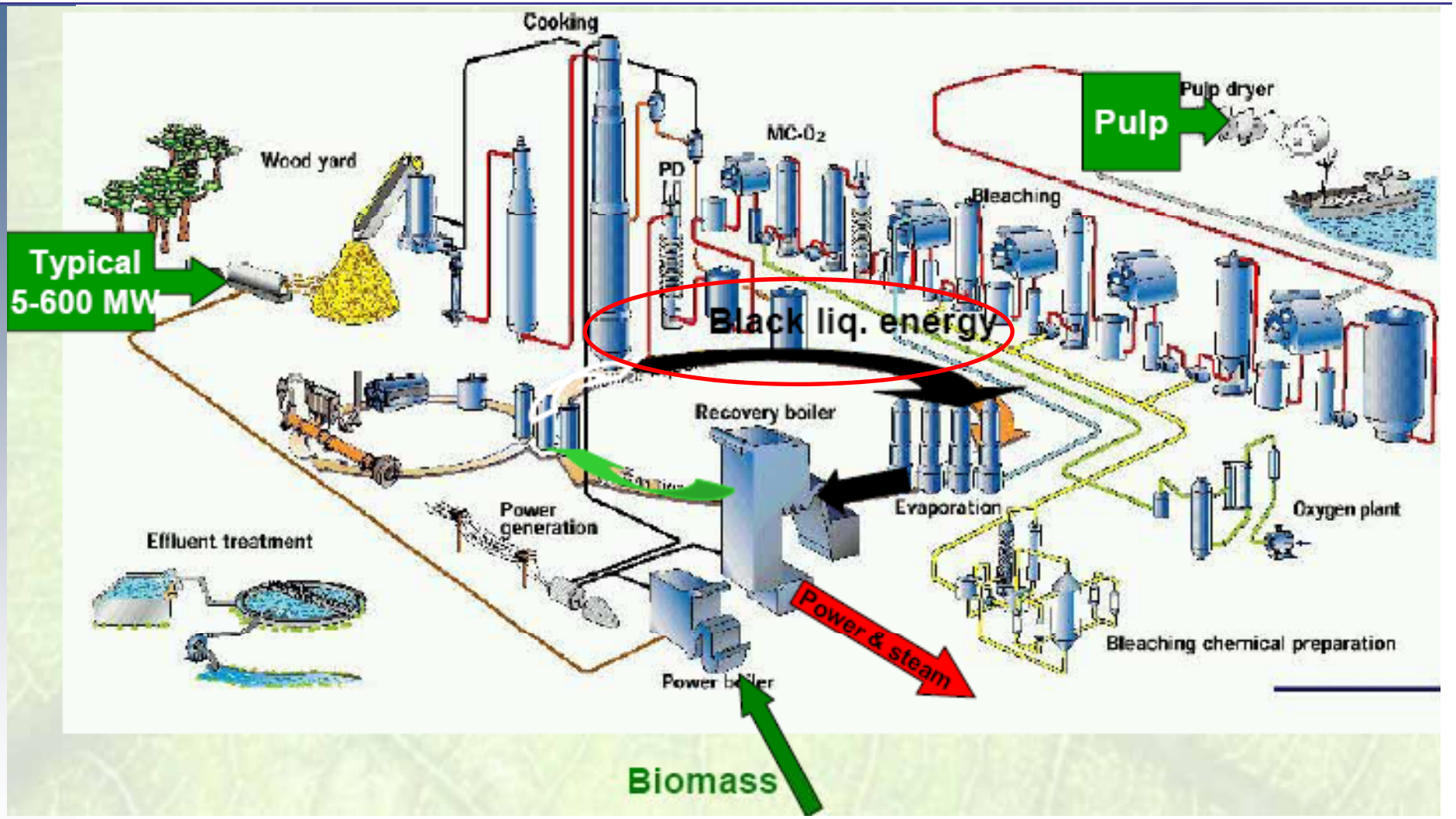
- Databases of Physic Chemistry Properties being developed for CO_2-H_2O and CO_2-H_2O-Mixture
- Experimental data at high temperatures and pressures are scarce
- Among the existing thermodynamic models, no models can represent the phase equilibria at high temperature and pressure quite well.
- Considering the injection of carbon dioxide into depleted hydrocarbon reservoirs, more experimental data and more accurate thermodynamic calculation are needed at high temperatures and pressures.
- Molecular simulation shows an unsatisfactory result.
- Further study: the phase equilibrium and the densities of the aqueous solutions with CO_2 and multi-ions under the geological conditions of a wide temperature and pressure range.

Negative CO2 emission system

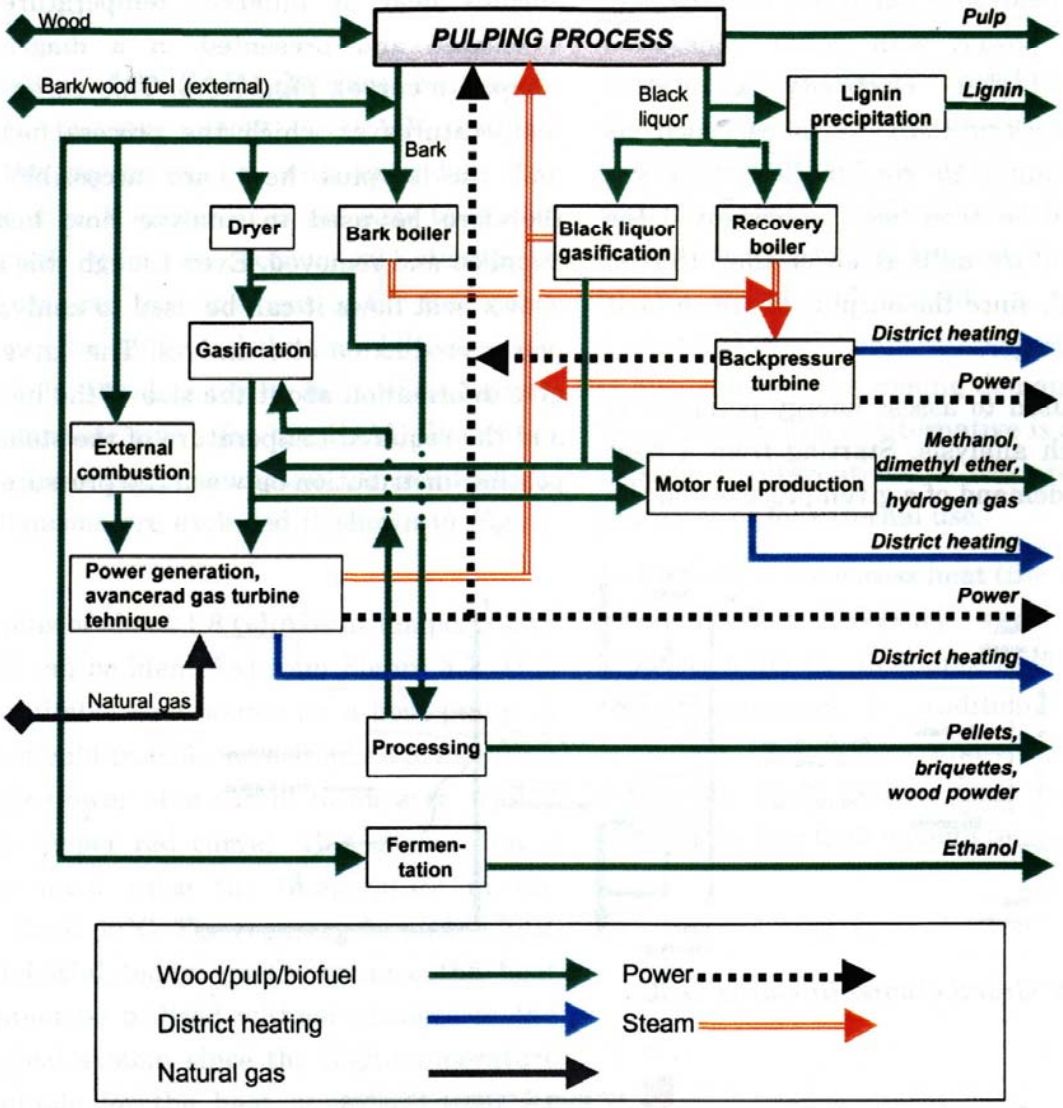


Obersteiner M, Azar Ch, Kauppi P, Möllersten K, Moreira J, Nilsson S, Read P, Riahi K, Schlamadinger B, Yamagata Y, Yan J, Managing Climate Risk, *Science*, 2001, 294(5543): 786-787

Pulp and paper black liquor gasification technology

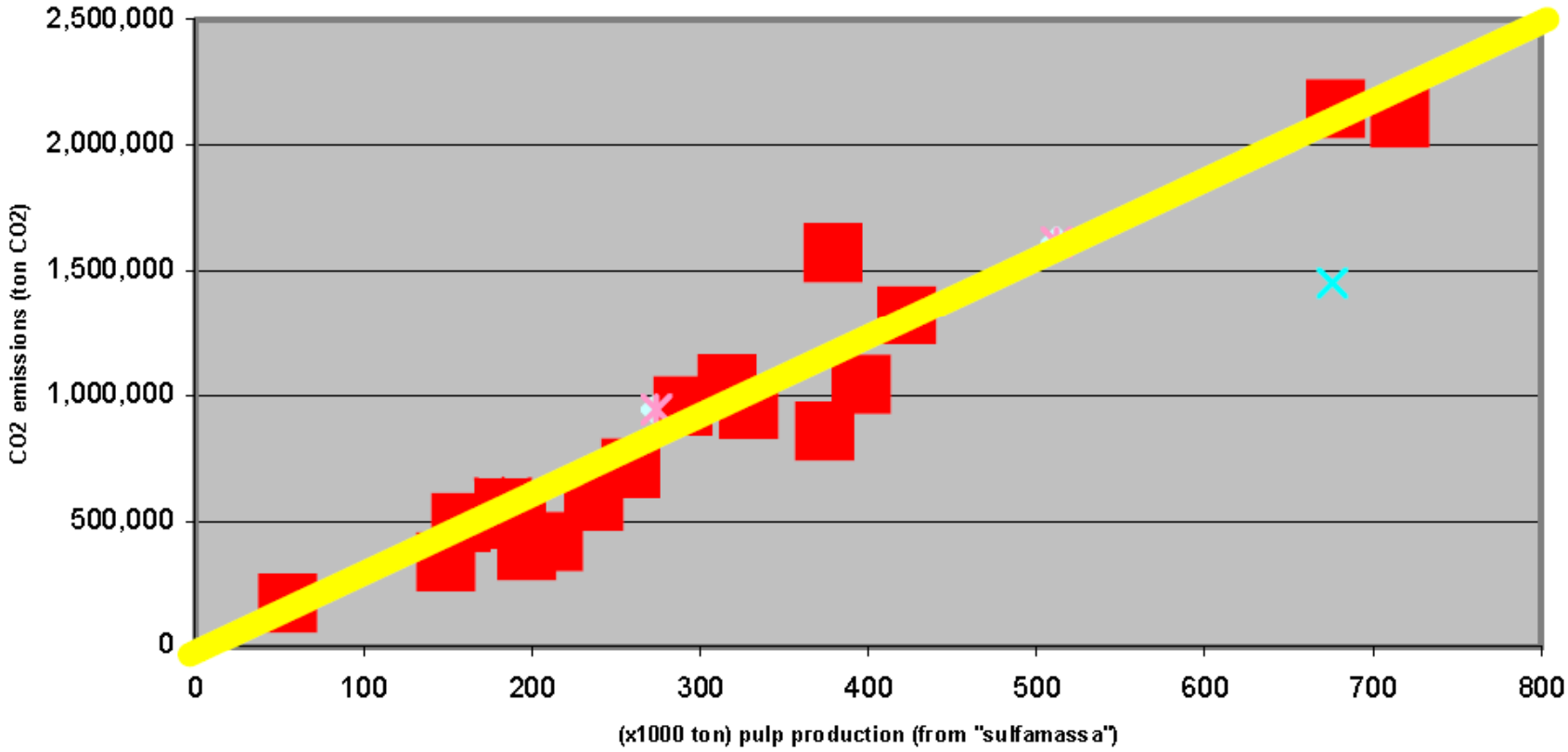


Integrate CCS with Poly-generation in Pulp and Papers Mills

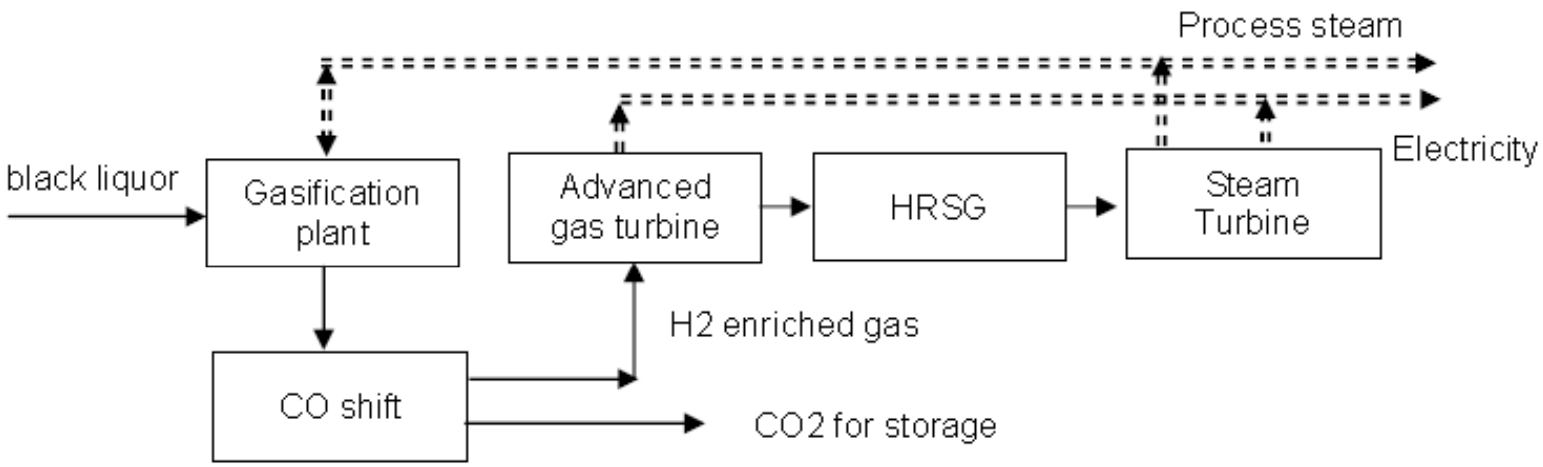


Maunsbach, 1999, STFI, 2003

CO2 emission vs. Pulp production



Worldwide total CO2 emission: 100Mt/yr

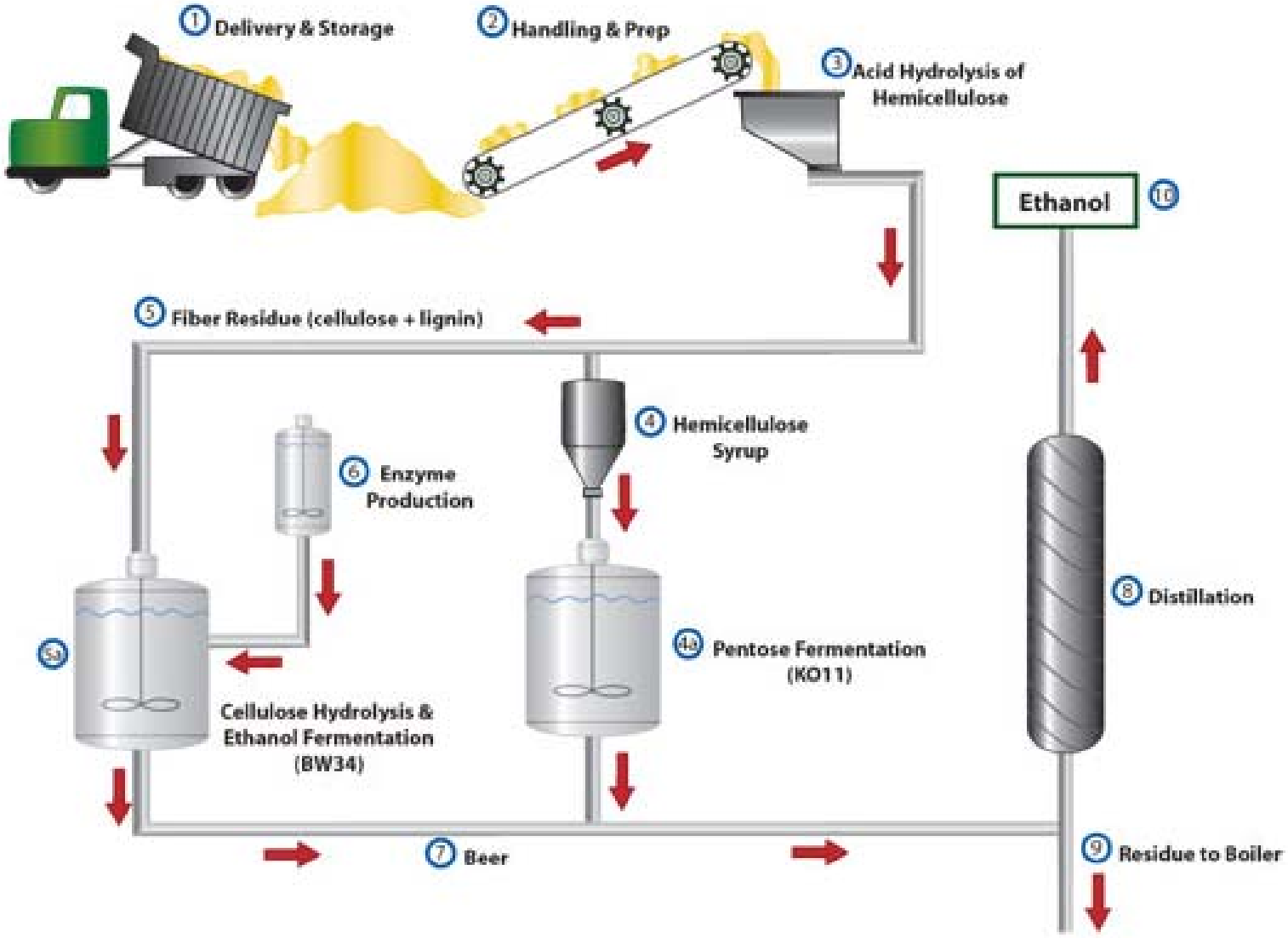


- The under-demonstrated black liquor gasification is the key technology for the successful implantation of the future bioenergy systems with CO2 capture and storage in the large pulp and paper industry.
- The inventory of CO2 emissions from Swedish pulp and paper mills shows the potential of the integration of CCS in the P&P industry.

Yan J, Dahlquist E. Jin H., Gao L., and Tu S., Integration Of Large Scale Pulp and Paper Mills with CO2 Mitigation Technologies. Proc 2nd Int Conf. Green Energy, June, Vastras, Sweden

- Currently, the majority of enterprises do not have matching recovery system. The alkali recovered through Recovery system is less than 5%. More than 95% caustic soda together with the organic matter was being dissolved into the water.
- The process of integrated gasification-combined-cycle power plants can produce electrical energy and higher efficiency with the possibility of recovering sodium and sulfur separately.
- Development of multi-nozzle gasifier for BL + Coal Mixture

Process for Converting Biomass to Ethanol

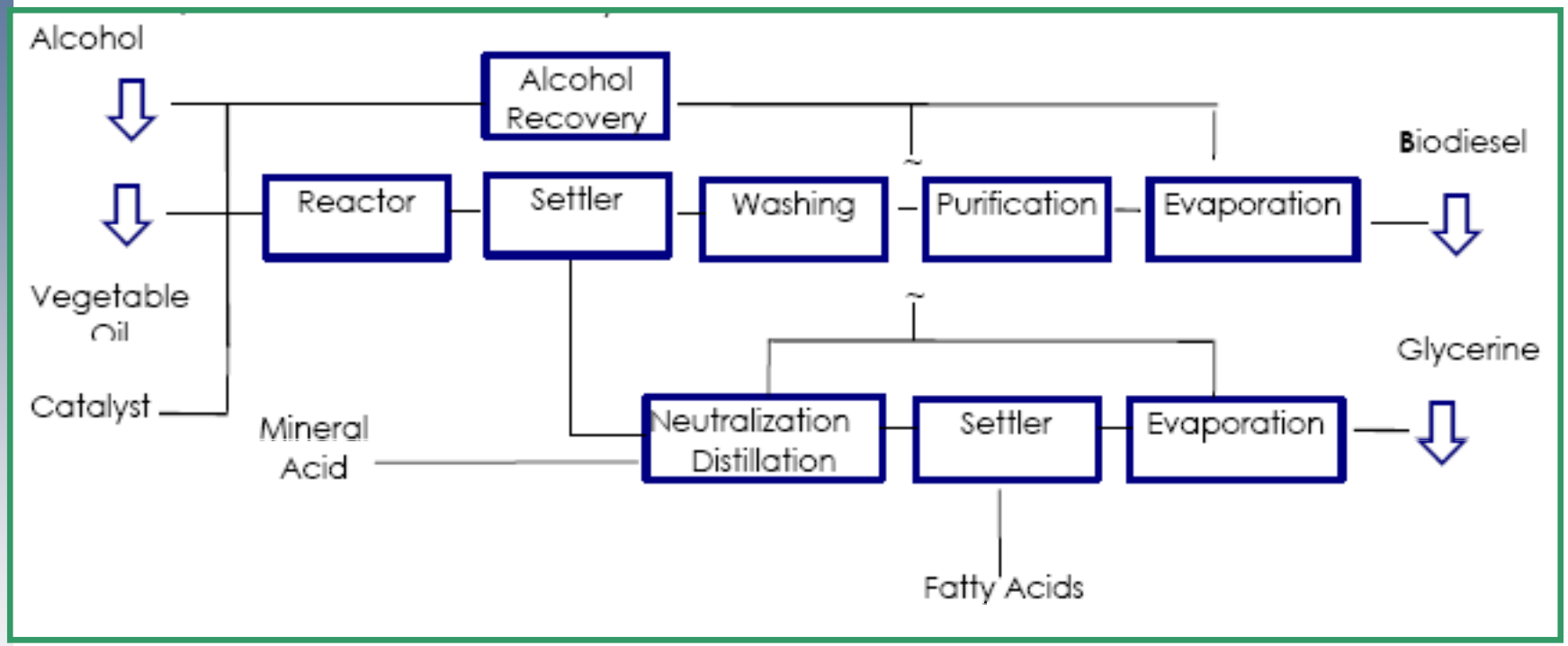


Lignocellulosic biomass producing fuel ethanol (ECUST)

600t/year fuel ethanol plant from waste biomass

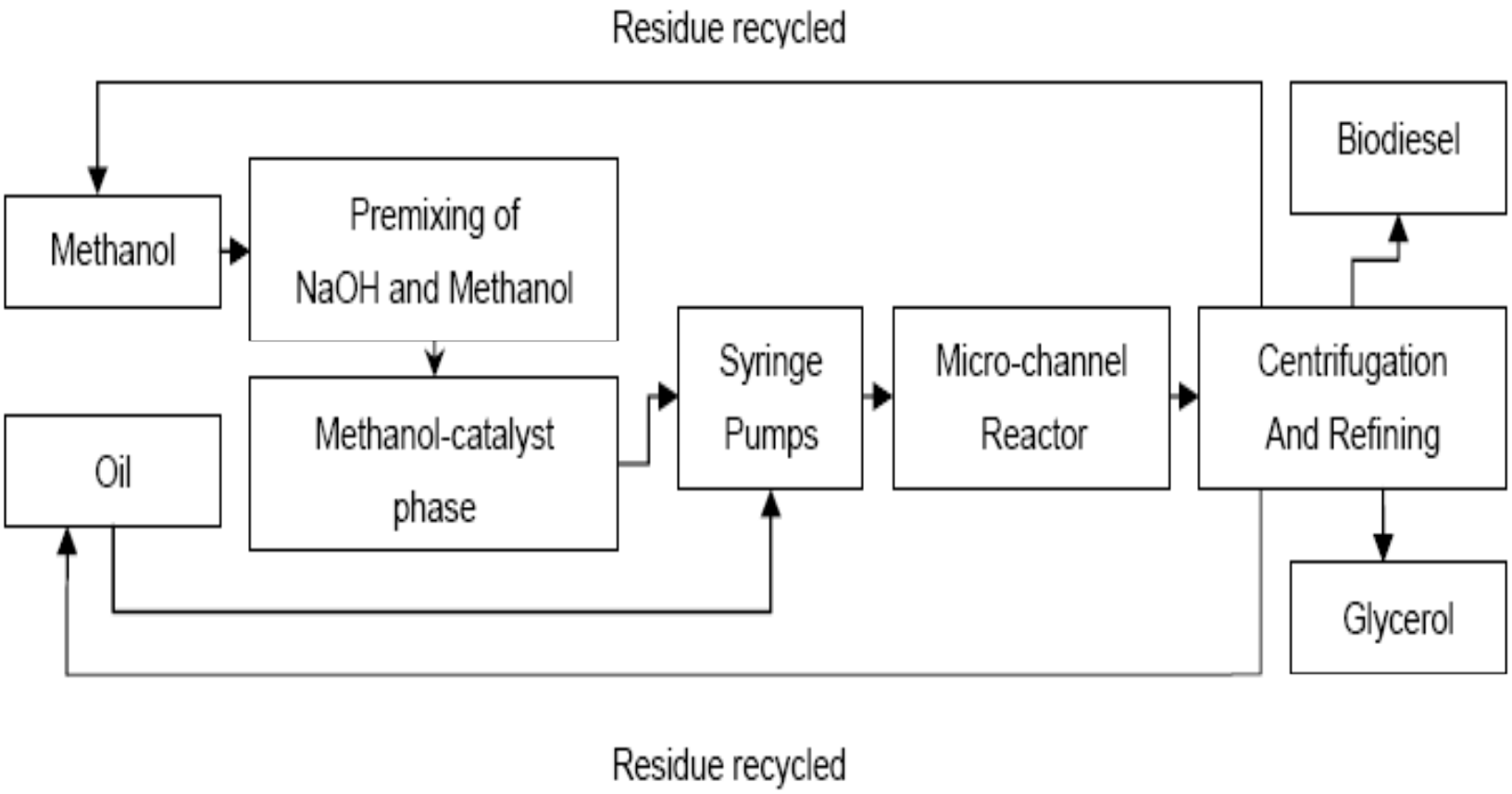
Cost: 5500 RMB/ton

Biodiesel production using a micro-channel reactor

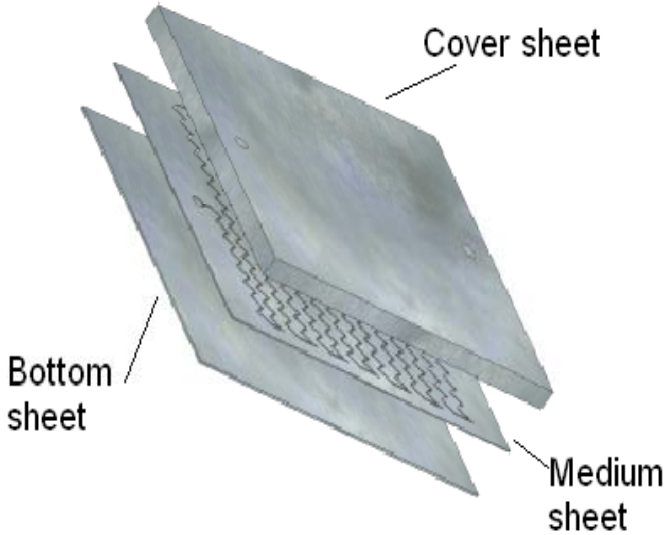


Flow diagram of process biodiesel production process

Biodiesel production using a micro-channel reactor



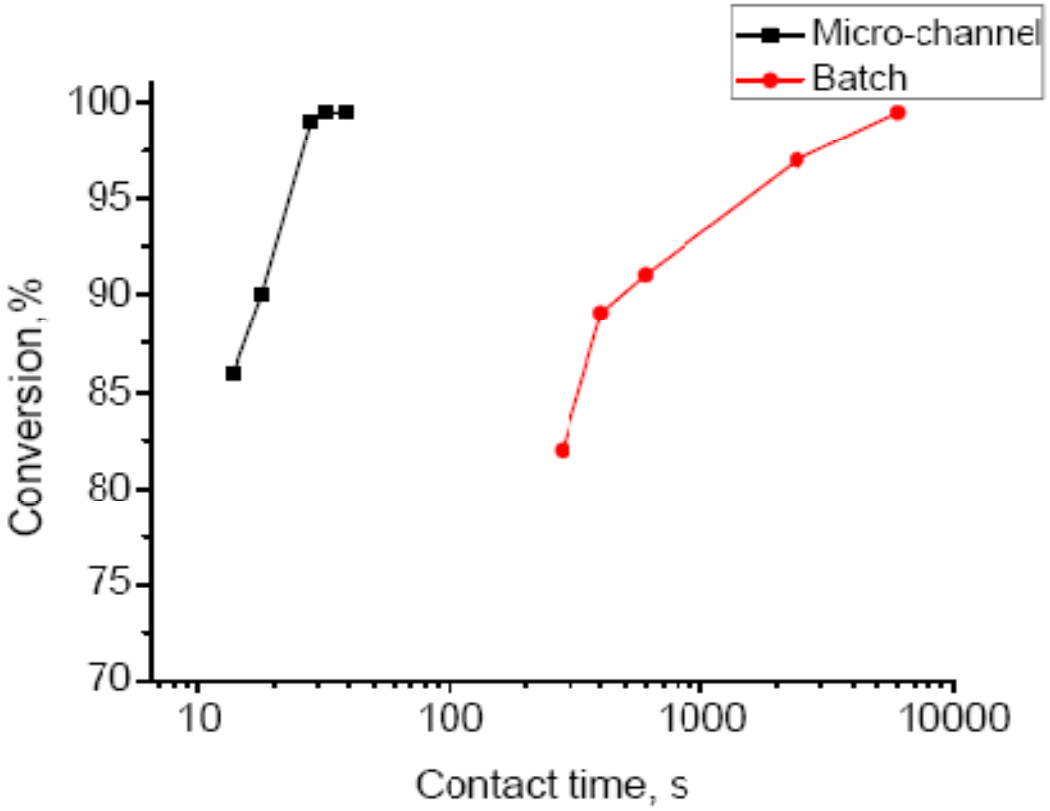
Micro-channel reactor



Dimension of micro-channel is 200 μm (W) × 300μm (D) ×1.07m (L)

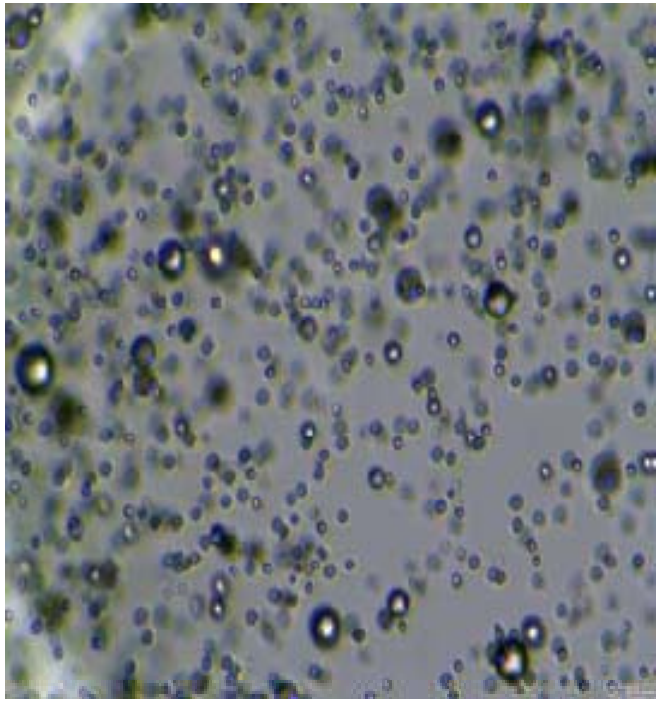
Flow path is a zigzag type.

Comparison between the micro-channel reactor and batch impeller reactor

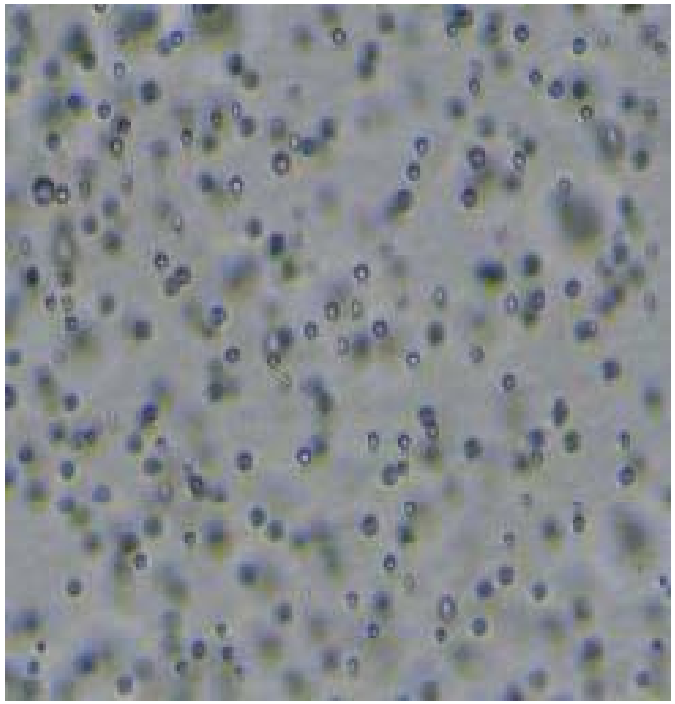


Experimental conditions: Methanol/oil molar ratio 9:1, temperature 56 °C
1wt % NaOH

Droplets in the emulsion



batch impeller



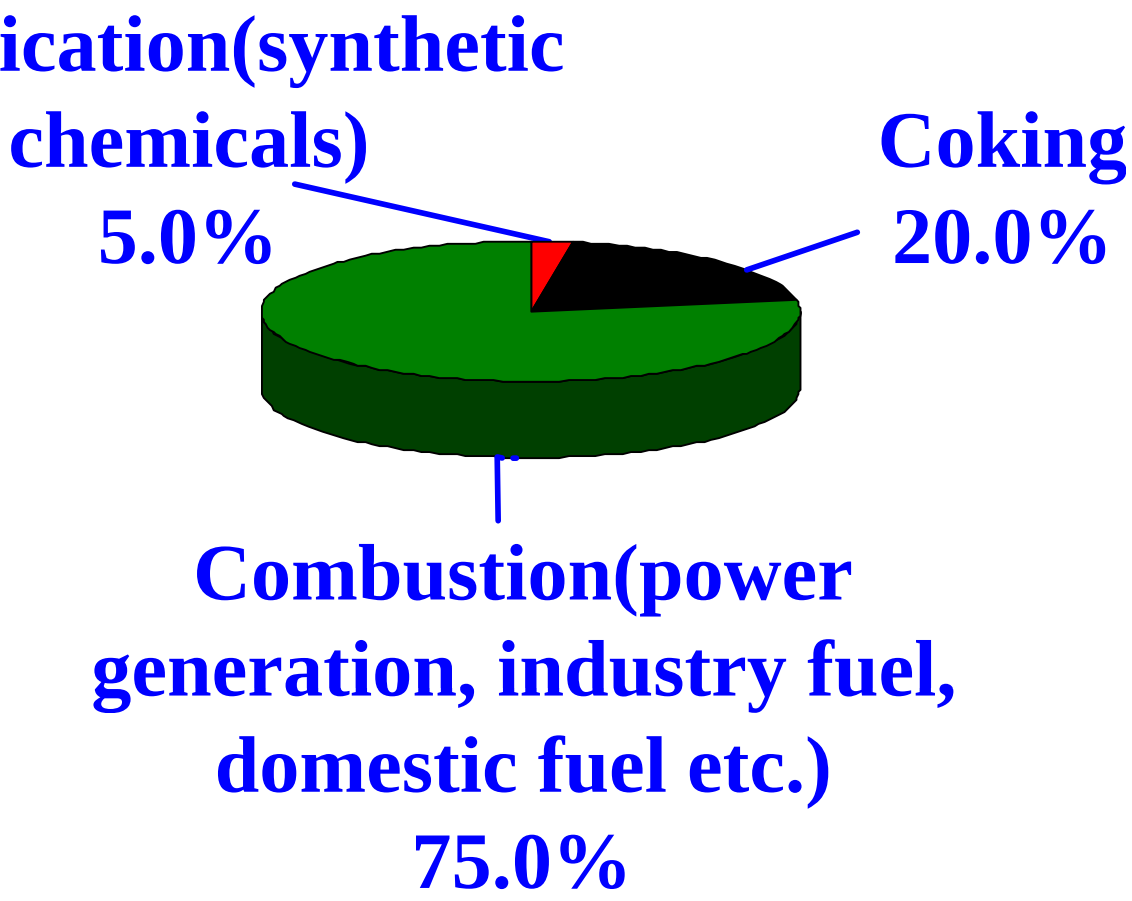
zigzag micro-channel reactor

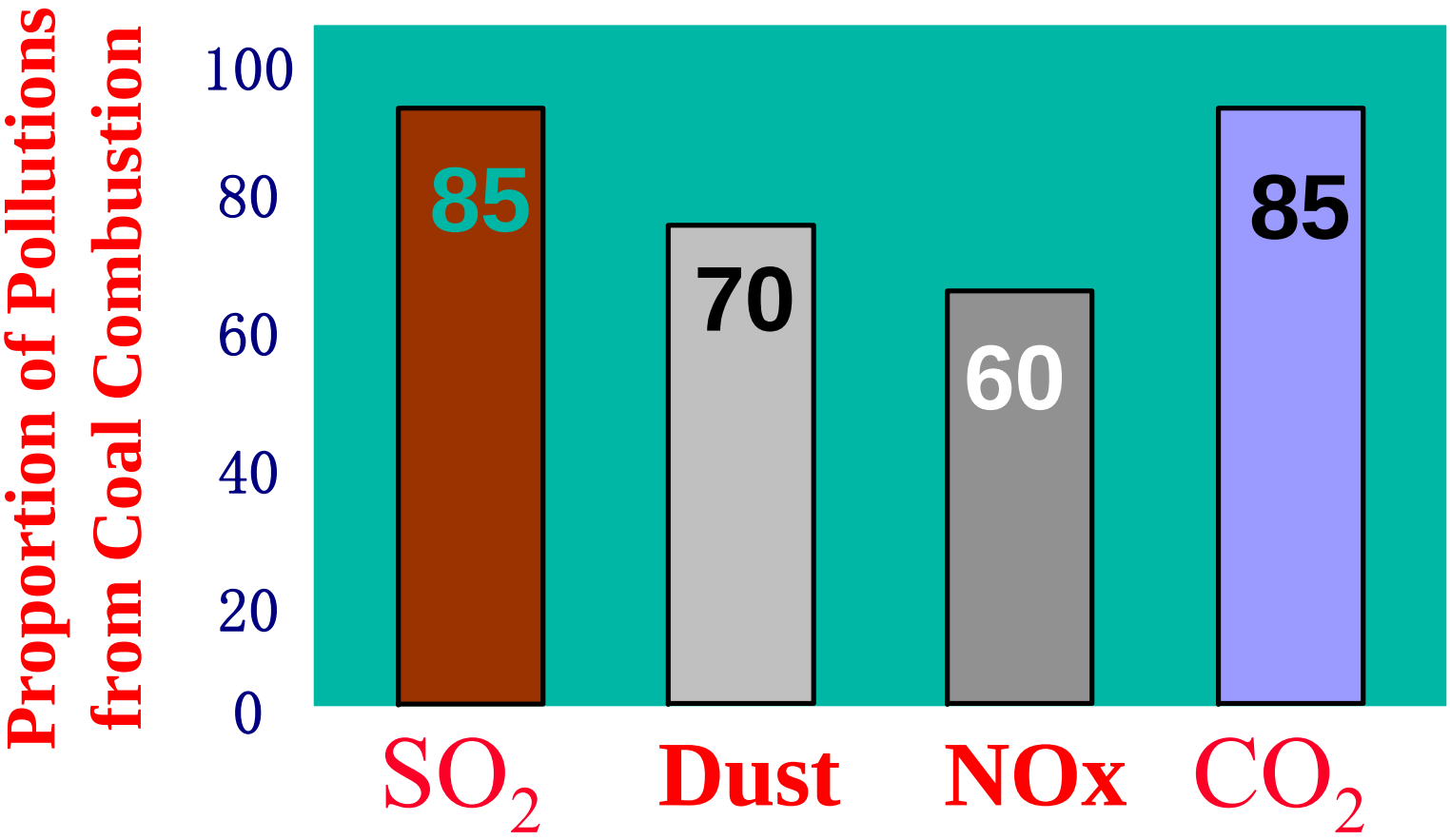
Experimental conditions: Methanol/oil molar ratio 9:1, temperature 56 °C, contact time of batch was 280s, and micro-channel was 28s

ECUST Coal gasification technology

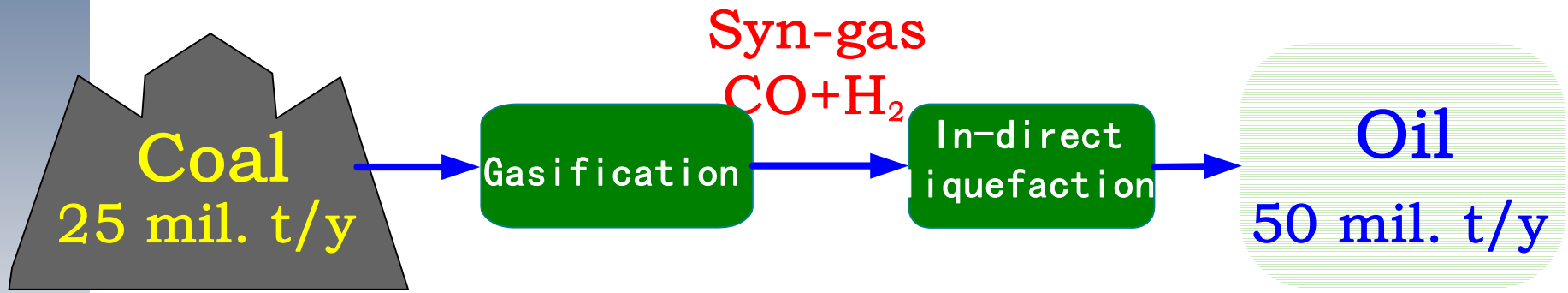
In cooperation with a number of companies and universities

Out-of-date technologies for coal utilization, mostly direct combustion




Proportion of Pollutions from Coal Combustion
100
80
60
40
20
0
85
70
60
85
SO_2
Dust
NOx
CO_2

Large-scale equipment is a requisite for the development of related technologies

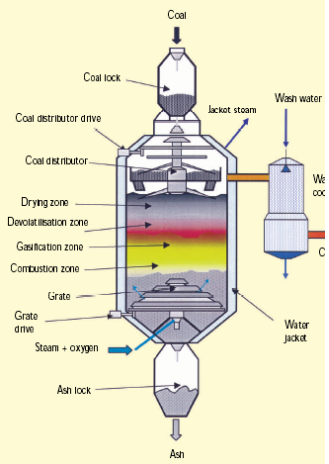


- Around 25 units of 3,000t/d gasification facility are needed
- Gasification takes 55%-60% of total investment

Entrained Bed

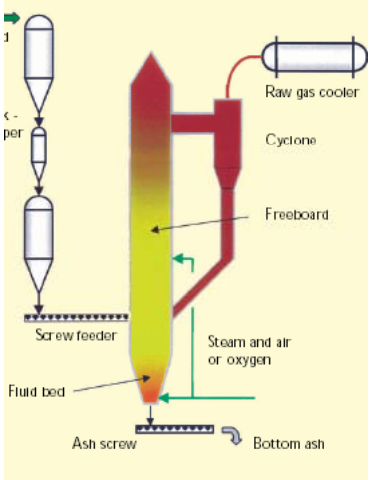
Fixed Bed

Lurgi

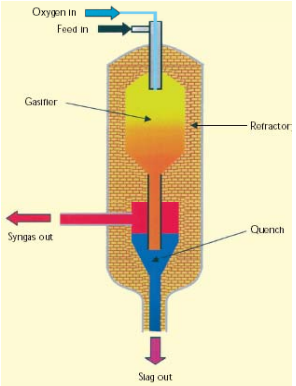


Fluized Bed

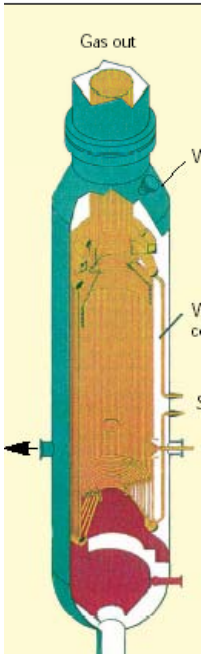
HTW



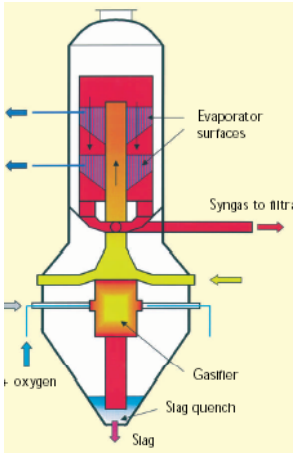
Texaco

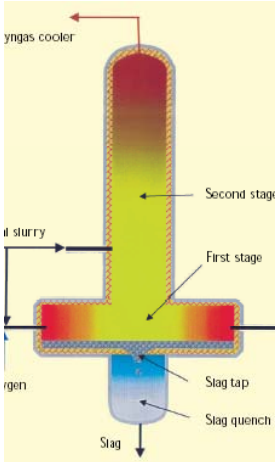


Shell



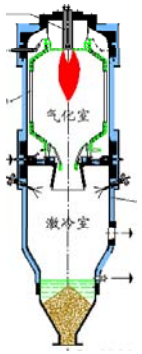
Prenflo





Conoco Phillips

GSP



Entrained bed is the trend of coal gasification technology.

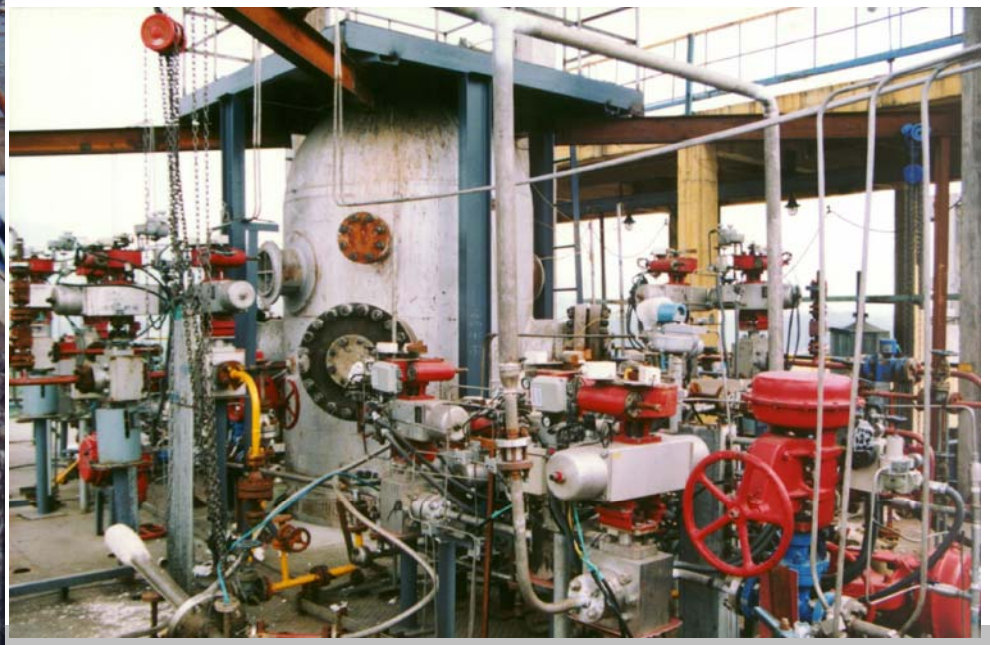
Pilot plant

1) Coal slurry OMB gasifier

Time: 2000

Capacity: 22 t/d

Pressure: 1.0-4.0MPa



2) Pulverized coal OMB gasifier
Time: 2004

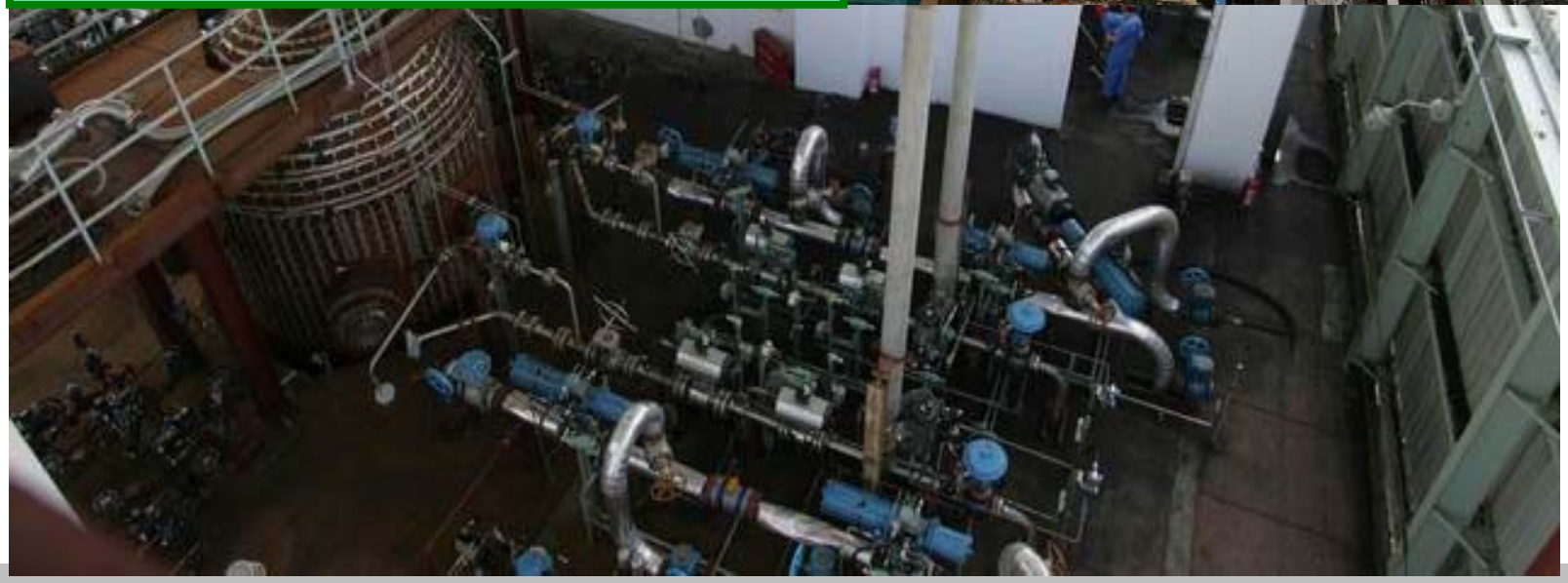
Throughput of pilot trial:
15~45 ton coal/day (625~1875 kg/h)
Operating pressure: 2.0~2.5MPa
Operating temperature: 1300~1400℃
CO+H2: 89~93%
Carbon conversion rate: 98~99%
O2 consumption:
300~320Nm^{3}O2/1000Nm^3(CO+H2)
Coal consumption:
530~540kg coal/1000Nm^3(CO+H2)
Cold gas efficiency: ≥84%

Demonstration plant (1)

Hualu Hengsheng Chemical Co.
1 gasifier
Capacity: 750 t/d
Pressure: 6.5 MPa
Products：Ammonia
Startup: July, 2005

Demonstration plant (2)

Yankuang Cathy Coal Chemical Co.
2+1 gasifiers
Capacity: 1150 t/d
Pressure: 4.0 MPa
Products：0.2 Mt/a Acetic acid,
80MW IGCC power generation
Startup: First stage Oct. 2005



The first coal-based polygeneration plant in China

The first patent owned large-scale coal slurry gasifier in China

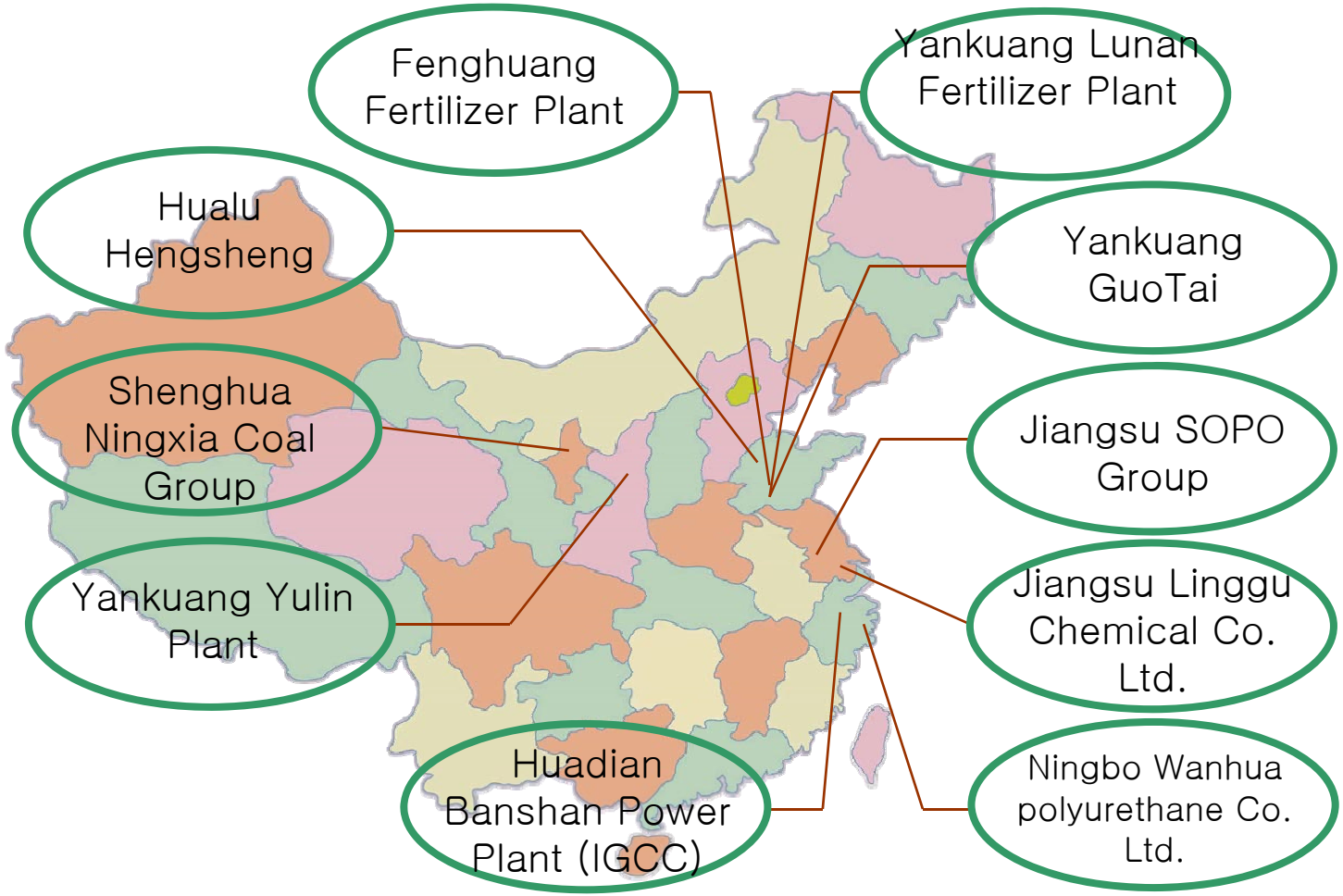
168 h Practical Assessment by China Petro Chem Association in Dec 12–19, 2005

		capacity	Effiective gas	Oxy consump	Coal consump	Carbon conver	PS
		t/d	$(CO+H_2)$%	Nm_3O_2 /1000$(CO+H_2)$	kg coal /1000$(CO+H_2)$	%	
Yankuang guotai OMB Gasifier		1000	84.9 ↑2-3 point	309 ↓7.9 point	535 ↓2.2point	98.8 ↑2-3point	Beisu coal
GE CWS Gasification Technology	Lunan fertilizer plant	~400	82-83	~336	~547	96~97	Beisu coal
	Shanghai coking plant	~500	81	412	638	~95	Shenfu coal
	Weihe fertilizer plant	~750	78	415	627	~95	Huating coal
	Anhui huaihua group	~500	77	425	708	~95	Huating Yiwu mixture

Features

- High carbon conversion and low oxygen/coal consumption because of proper flow pattern in the gasifier
- Easy to scale up (like 2000-3000 ton coal/day) because of multi-burner
- High efficient of syngas primary purification section, low process pressure lost and low flyash in syngas(1mg/Nm3 syngas) because of “Step-by-Step” concept
- High heat recover efficiency and stability in slag water treat section because of direct heat exchange between grey water and vapor from high pressure flash of slag water

Till now, 20 gasifiers are applied in10 projects



A Concerted effort in Basic Research

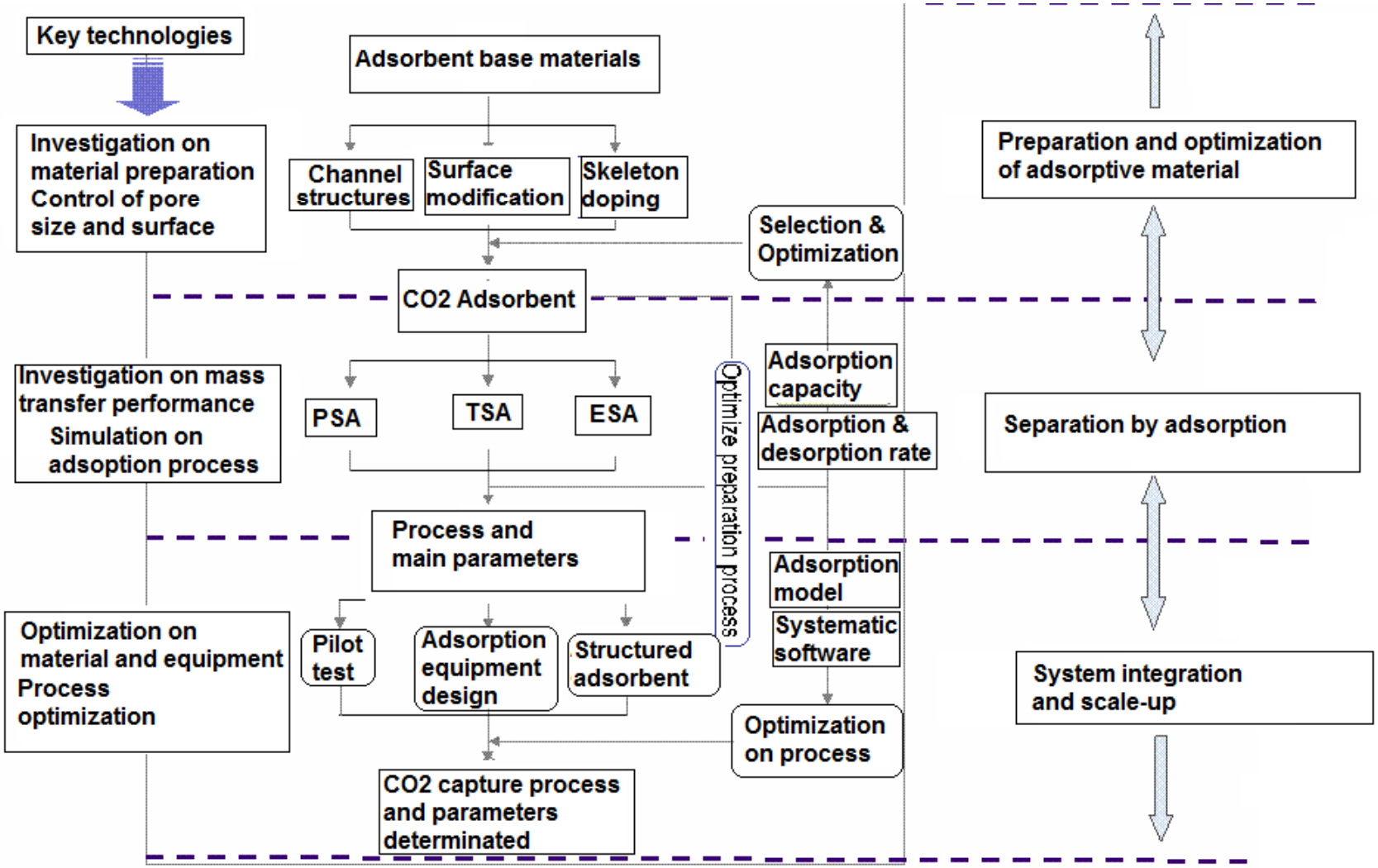
Supported by National 973 Program

- The main task packages:
  - Fundamentals of gasification reactions at high temperature and pressure
  - Fundamentals of multi-phase turbulent flow, mass and heat transfer in gasifier at high temperature and pressure
  - Super-high concentrated solid-gas phase flow pattern and non-Newtonian fluid flow and atomization under high pressure
  - Effective treatment of the complex gasification products
- Partners: ECUST, Zhejiang Univ., Southeast Univ., Tsinghua Univ., Institute of Coal Chemistry-CAS, Xi'an Thermal Power Research Institute.

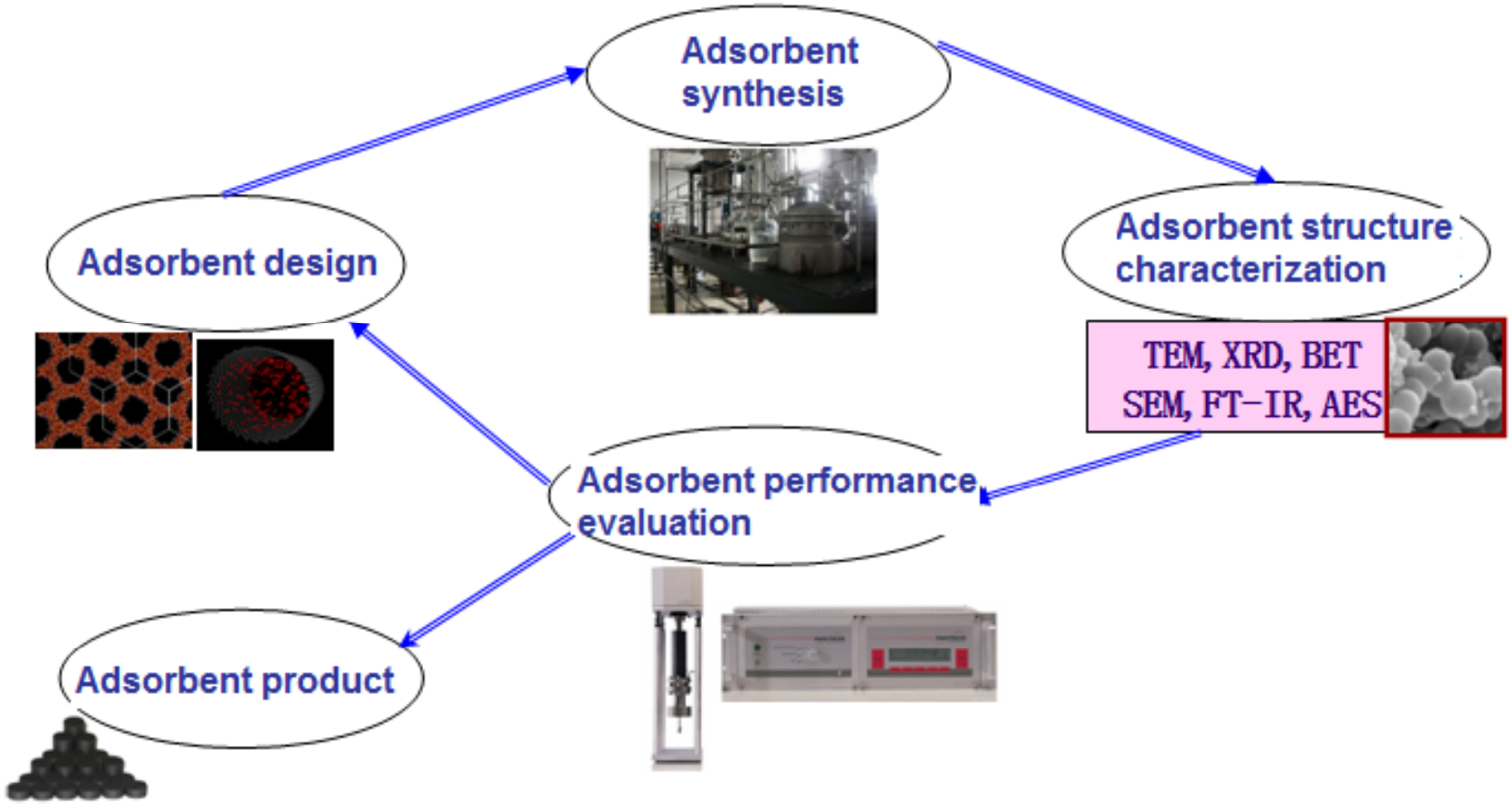
A Newly Initiated Program

CO2 Adsorption and Separation Technology
In Cooperation with Tianjing University and
Zhejiang University

Technical roadmap to be adopted



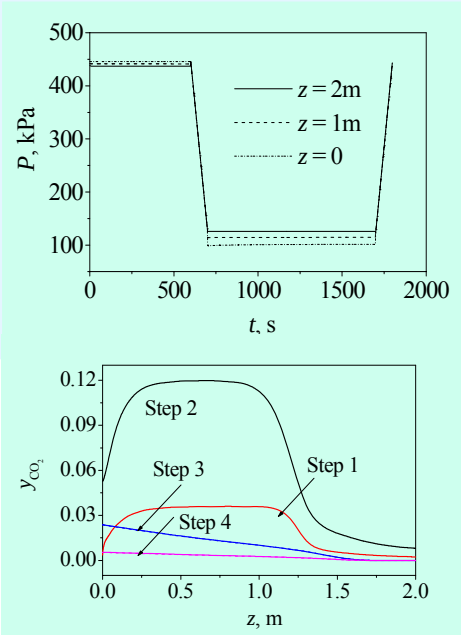
Task phase I: Adsorbent Development based on Super Active Carbon



Task Phase II: Adsorption separation process research and modeling optimization

Adsorption separation technologies:
Vacuum pressure swing adsorption (VSA)
Temperature swing adsorption (TSA)
Electric swing adsorption (ESA)
VSA/TSA integration process
VSA/ESA integration process

TSA Test Instrument



$$\frac{\partial}{\partial t}\left[\varepsilon_t C_i + \rho_{b(ad)}\bar{q}_i\right] = \varepsilon_t \frac{\partial}{\partial z}\left(D_L C \frac{\partial y_i}{\partial z}\right) - \frac{\partial (uC_i)}{\partial z} + \rho_{b(cat)} \sum_{j=1}^{III} v_{ij}\eta_j R_j$$

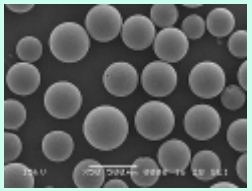
$$\left[\varepsilon_t \rho_g C_{pg} + \rho_p C_{ps}\right]\frac{\partial T}{\partial t} = \varepsilon_t \frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right) - \rho_g C_{pg} u \frac{\partial T}{\partial z} - \rho_{b(ad)} \sum_{i=1}^{n}\left(H_{adi}\frac{\partial \bar{q}_i}{\partial t}\right)$$

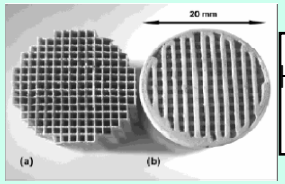
$$+ \rho_{b(cat)} \sum_{i=1}^{5}\sum_{i=1}^{III} v_{ij}\eta_j R_j H_{Rj} + \frac{4U_0}{Dr}(T_w - T)$$

Typical PSA mathematic model and simulation results

Task Phase III: Adsorbent molding and adsorption equipment optimizing design

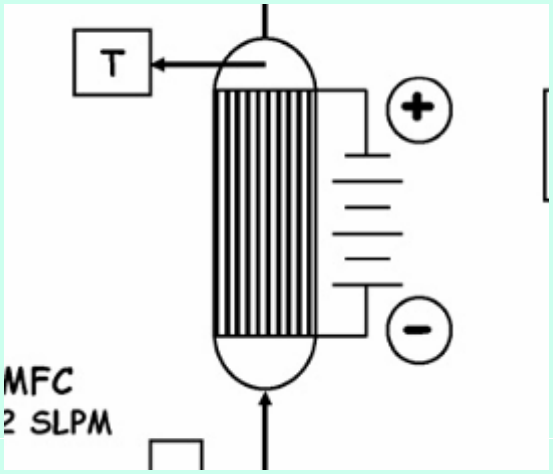
1. Breakthrough of adsorbent molding technology



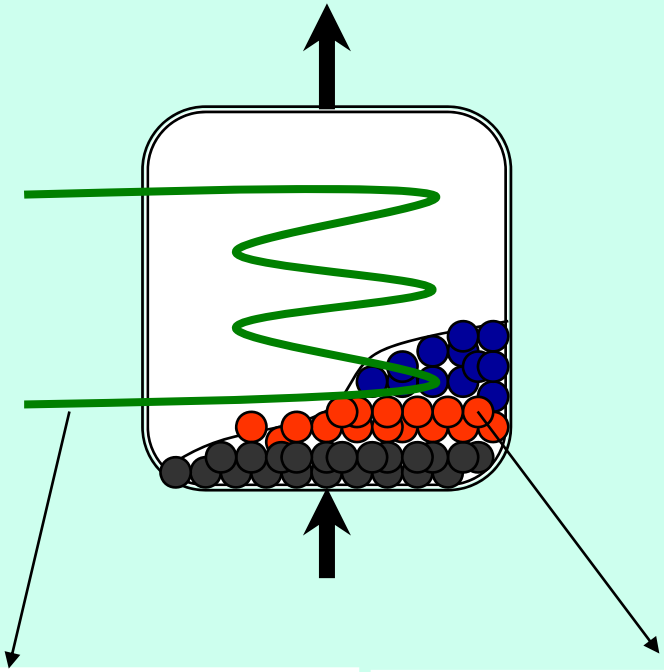


Honeycomb adsorbent

2. Good adaption of adsorbent and equipment; Achieving VSA/ESA integration technology



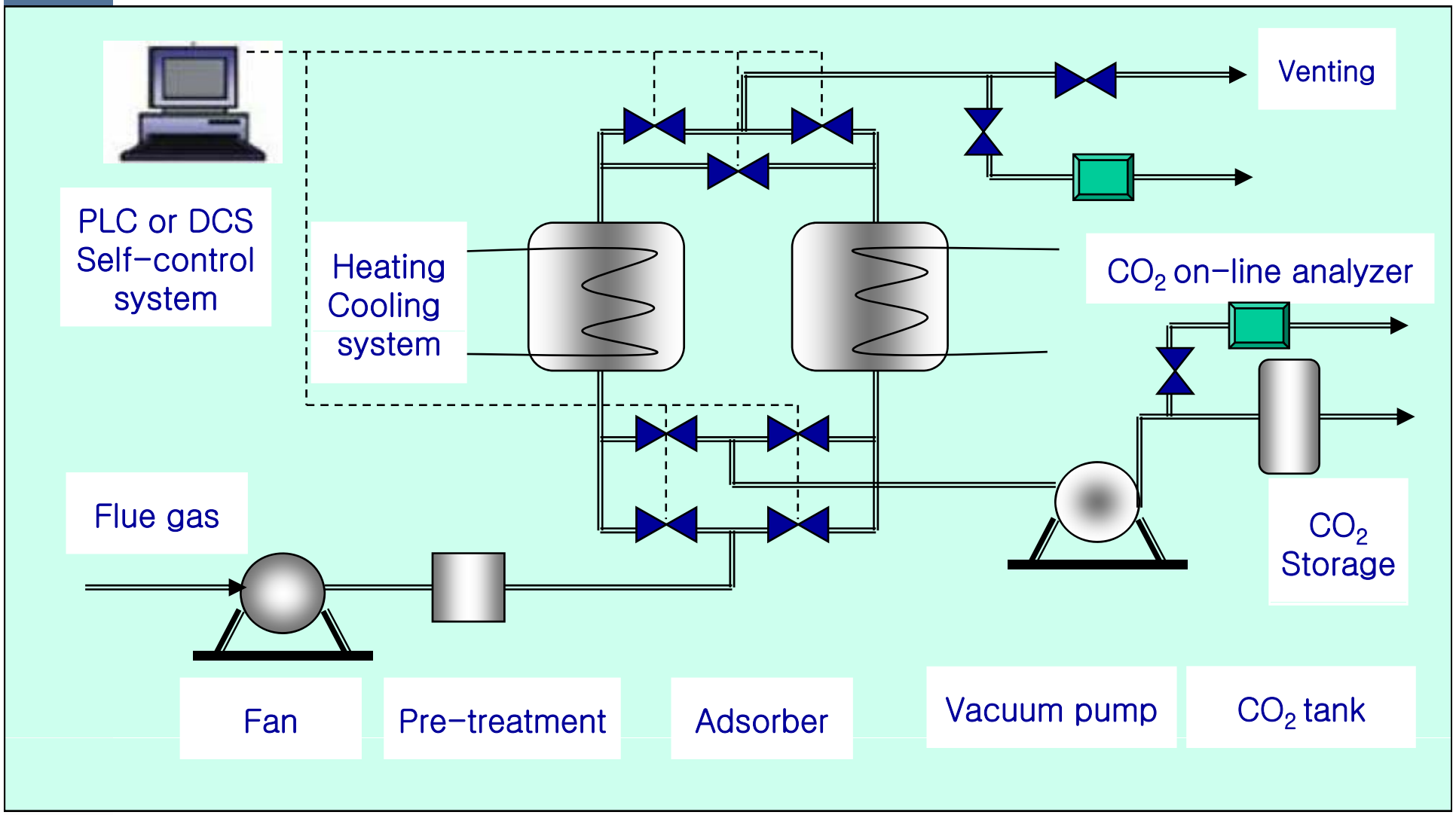
3. Optimizing design of adsorption equipment



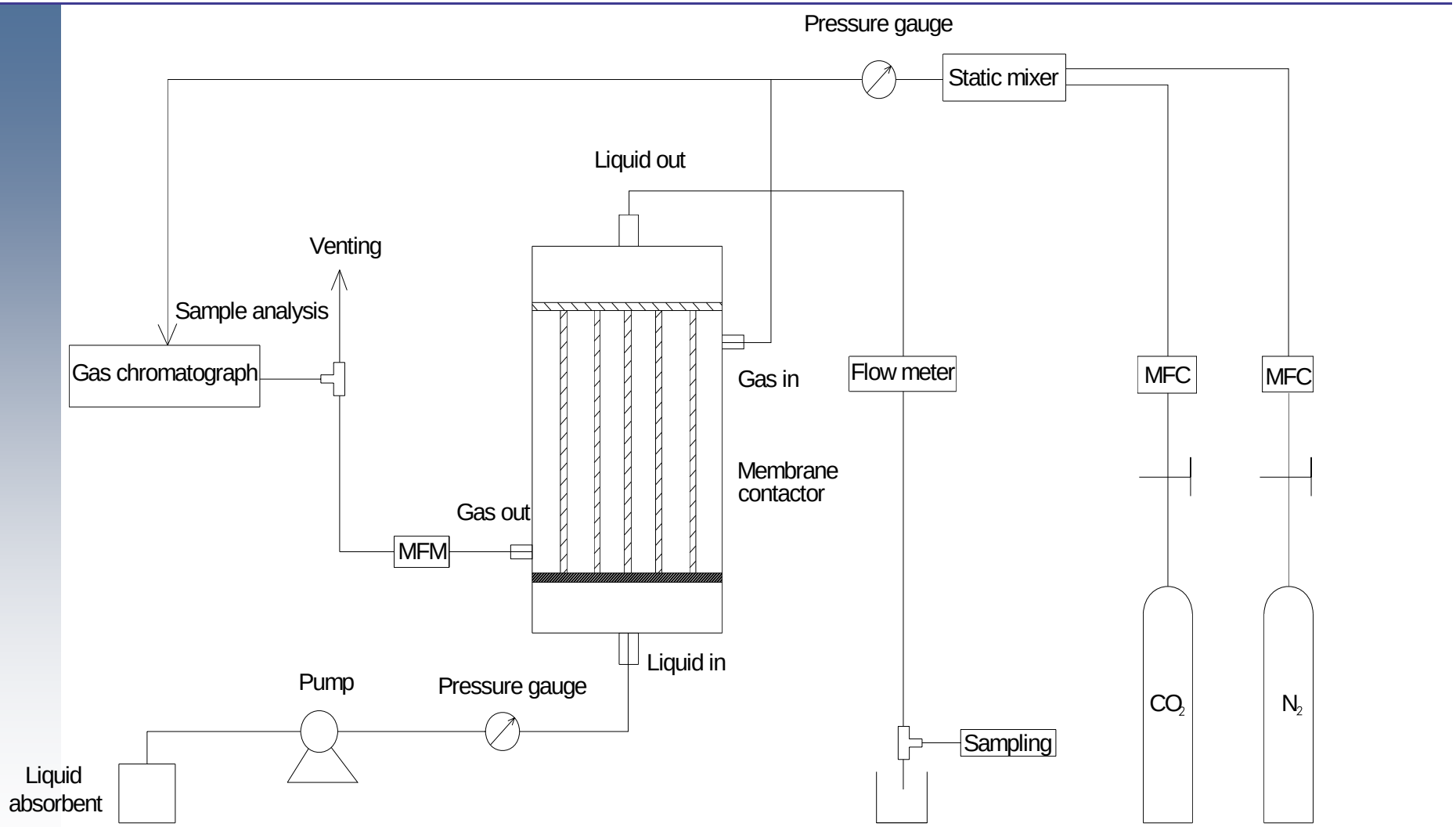
Replace heat element in the tower, make use of factory residual heat for TSA process; improve VSA/TSA process efficiency.

Filling of multi-layer absorbents With different functions, reduce impurities disturbance

Task Phase IV: Pilot test and economic evaluation



Membrane gas absorption (MGA)



Experimental setup

Hollow fiber membrane module

Control panel

Peristaltic pump

Global warming is a global business.
More cooperative and
concerted efforts should be taken.