中美清洁能源研究中心
清洁煤技术联盟
US-China Clean Energy Research Center

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- 背景意义
  Background
- 工作成果
  Achievements
- 二期标志
  Phase II Planning

中美气候变化公报

U.S.-China Historic Joint Announcement on Climate Change

中国：2030年GHG达到排放峰值，非化石能源份额20%；

China: Peak CO_2 emissions in 2030. Non-fossil-fuel share 20%

美国：2030年之前碳排放比2005年减少26~28%。

U.S.: Cut net GHG emission by 26-28% below level of 2005 by 2025.

中国要实现出现拐点，必须有**CCS**的贡献。

To achieve the turning point for China, CCS contribution is necessary.

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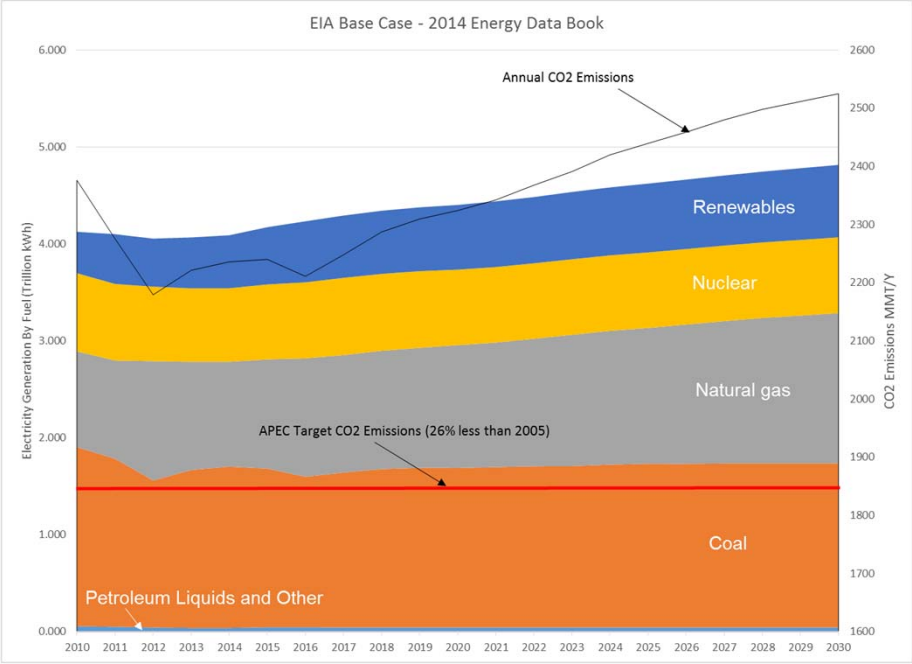
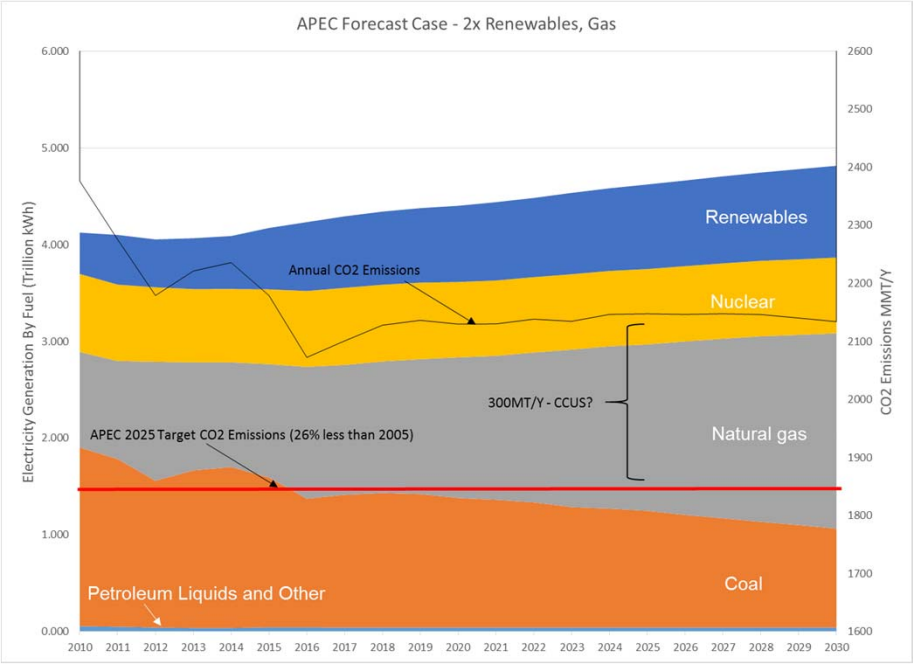
CERC-ACTC

为什么CCUS？ Why CCUS?

Even with aggressive growth in renewables and natural gas, significant CCUS required to meet U.S. APEC Targets

即使可再生能源和天然气积极成长，仍需要重视**CCUS**以满足美国**APEC**目标





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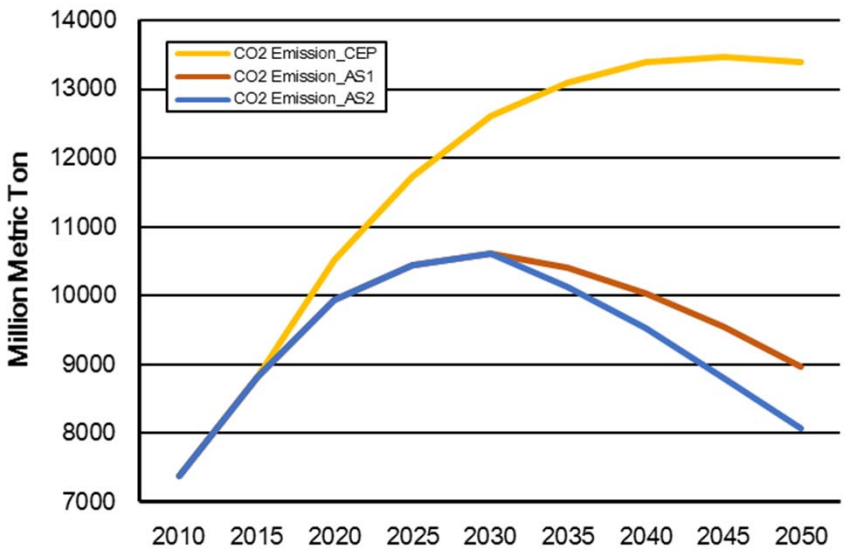
Recognition to CCUS

在中国，预测只有在能源领域使用CCUS技术（图中AS1和AS2），CO2排放才能在2030年达到峰值。

In China, the continued-efforts policy (CEP) scenario presents an annual reduction of carbon intensity of 3% from 2016 to 2050. An alternative scenario (AS1) assumes an annual reduction of 4% from 2016 to 2050.
While another alternative scenario (AS2) assumes an annual reduction of 4% during 2016-2030 and 4.5% during 2031-2050 with CCUS applications in the power sector.



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五年工作成果的总体描述/General Achievements of Phase I

五年来，通过中美两国科技人员富有成效的工作和紧密的交流合作，不仅取得了令人瞩目的研发成果，而且在CCUS领域的诸多方向上，引领和促进了该技术的发展，展示了良好的应用前景，为实现碳减排和应对气候变化，做出了我们的贡献。

In the past 5 years, through the effective work and close collaboration of the scientists in ACTC from the two countries, achievements have been obtained. ACTC leads the way in various areas of CCUS and promotes the development of this technology which shows bright future of application. ACTC has made great contributions to realizing carbon emission reduction and corresponding to climate change.

实质性合作 Virtual Collaboration To Success

- ACTC十分强调双方要开展实质性的合作(Collaboration)
  Collaboration between Chinese and US teams has been carried out since the foundation of the CERC-ACTC
- 采取访问、视频或音频会的形式，双方开展各种交流活动，仅2013年互访约90人次，视频会议约20次，有力推动了合作。
  Different forms of communication and exchanges between the two sides are involved, such as visiting, personal joint meeting, video meeting or audio meeting.

建成了大规模的CO_2燃后捕集装置
Built Large-scale Post-combustion CO2 Capture Pilot Facility

为了降低两国的燃烧后捕集技术的成本，CERC在类似项目之间的数据共享方面做了突破性的工作，这样使得支持同样方法的CO_2捕集成本分析通用模型得以建立。研究人员试图调和两个具有一定可比性的燃煤设施的分析报告中的成本，这两个设施一个在中国，一个在美国。在CERC的框架下，两个工厂以一种史无前例的方式向从事该分析的研究人员提供各自操作数据和成本数据。

To reduce the cost uncertainty of post-combustion capture technologies in both countries, CERC facilitated a breakthrough arrangement for data sharing between similar projects, enabling development of a consensus model that supports consistent cost analysis for CO_2 capture. The researchers sought to reconcile the reported costs for two comparable coal-fired facilities, one in China and one in the United States. In an unprecedented step, under CERC's framework, both plants provided operating and cost data to researchers engaged in the analysis.

Joint project on post-combustion capture processes at Shidongkou plant in Shanghai (top), and at the Duke Gibson plant, U.S. (below)

燃后捕集 Post-Combustion CO_2 Capture

Highlights

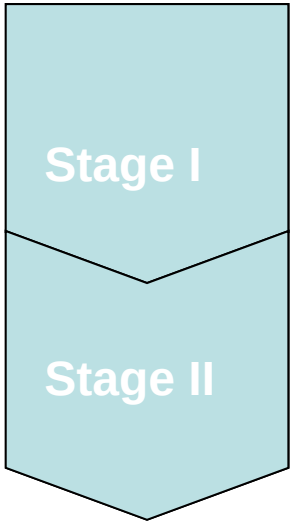
杜克与华能、**LLNL**合作，在美国印第安纳州欧文斯威尔进行一项分两阶段的燃烧后二氧化碳捕获项目。

Duke Energy cooperates with Huaneng and LLNL to implement a two-stage, post-combustion capture dynamic model.

杜克在其下属的**Gibson**电厂三号发电机组启用本项目

Duke Energy provided operating data on unit 3 at its Gibson Station, Owensville, IN facility for this PCC project.

Gibson Power Plant



Shidongkou Carbon Capture Demonstration

富氧燃烧示范 Oxyfuel Combustion

主流捕获技术

HUST和B&W的数据共享

Data Share between HUST and B&W

- **True collaboration via open information exchange**

  通过公开信息共享达到真正的合作

  - **Early creation of data exchange mechanism**

    早期建立的数据交换机制

  - **MOU between HUST and B&W signed in June 2012**

    华中与巴威在2012年六月就签署了谅解备忘录

- **Monthly teleconference and regular visits**

  每月的电话会议和常规性的互访

- **Cooperation extends to outside CERC**

  合作延伸到中心之外

3 Joint paper
1 B&W Technical Paper

3 MW FCS

数据共享
Data Sharing

基础反应数据库	中试台架数据及CFD模型	中试试验动态及仿真	大型示范经验共享
Coal Reaction Kinetics Database	Pilot Facilities and CFD	Pilot Facilities Dynamics and Process Model	Knowledge Sharing on Large Demo

1.8MW SBS

采油与埋存 EOR & Storage

Highlights

场地适宜性评价和优先级确定

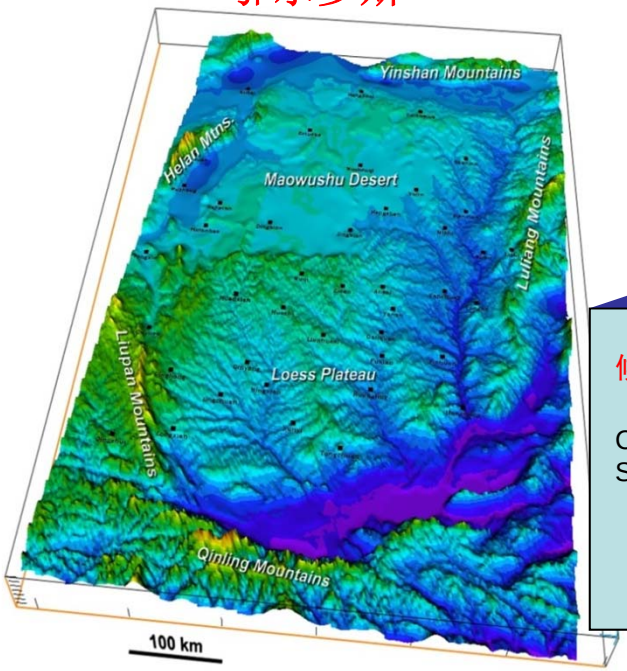
Site suitability and priority evaluations by the site screening methodology.

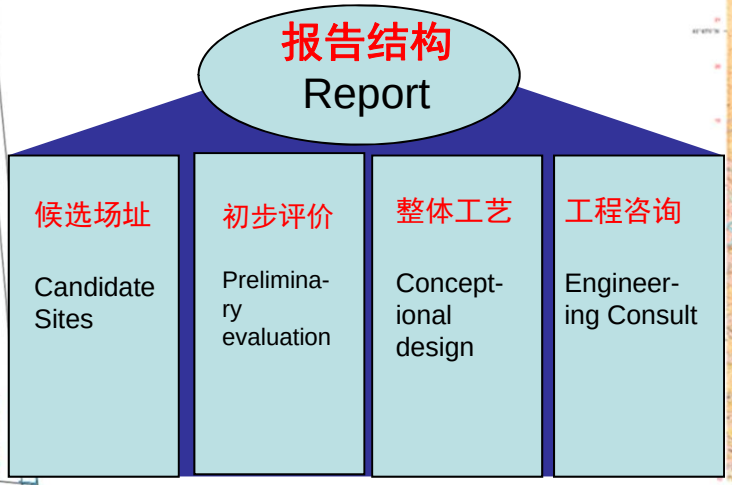
神华与LLNL 、WVU的CO_2封存合作

Collaboration Between Shenhua，SPIERCE，and UWY, WVU, LLNL on CO_2 storage

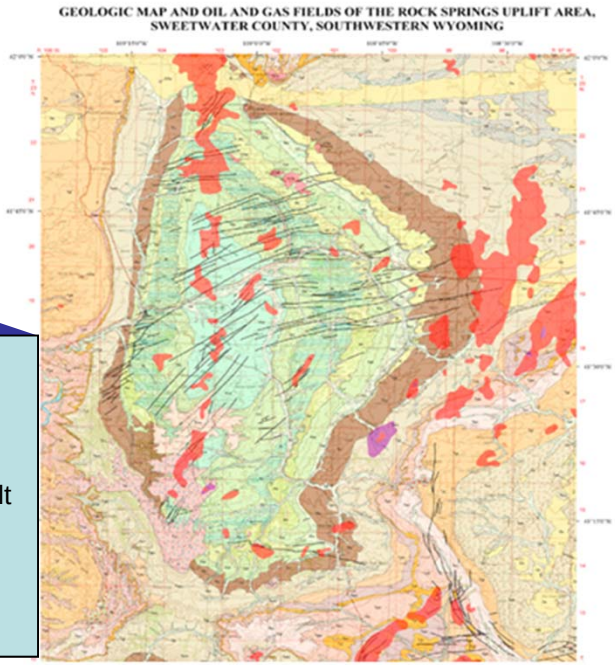
Ordos Basin, China

鄂尔多斯





Rock Springs Uplift, USA



采油 EOR

CO_2-EOR先导试验区：开展2口井CO2注入试验
CO2-EOR pilot test region: Conduct CO2 injection test in 2 wells
(延长石油和怀俄明大学，Shaanxi Yanchang Petroleum and UWy)

Surface infrastructure

CO_2储罐

注气井口

注气泵房

延长石油CO_2驱油先导试验 Shaanxi Yanchang Petroleum CO_2-EOR test

CO_2利用 CO_2 Utilization

利用

二氧化碳资源化利用------可持续发展的解决方案

CO_2 Utilization with Microalgae - A Sustainable Approach

通过检验中美两国许多种类的藻株在不同条件下的CO2利用情况，ACTC研究人员发现一种很有前景的菌株，它比大多数藻类生长快15%，并且能够轻松适应极端环境。

After examining various reactor designs and the utilization of CO2 by a number of U.S. and Chinese algae strains, ACTC researchers identified a promising strain that grows 15% faster than most and is remarkably tolerant of extreme environments.

杜克能源微藻项目现场

Duke Energy's Microalgae Project at East Bend Power Plant

新奥集团的开塘种植微藻示范基地，中国廊坊

Growth System Optimization in China

发电与转化Generation& Conversion

提高效率

超700℃超超临界锅炉特性研究 Research on issues related to 700℃ USC boiler

煤热解气化分级转化多联产技术 Staged Coal conversion poly-generation system

- **煤中矿物质在燃烧过程中的迁移转化机制**

  Migration and transformation mechanisms of mineral during coal combustion process.

- 在**1MWth**试验装置上验证煤炭热解燃烧分级转化技术的可行性，具备工业示范能力

  Coal conversion poly-generation technology combined pyrolysis, gasification and combustion is verified on 1MWt pilot plant and may be demonstrated in industry.

结渣、积灰行为对受热面热阻特性的影响

Effect of slagging and fouling behavior on heating surface thermal resistance characteristic.

热解煤气燃烧火炬

Torch of pyrolysis gas

1MWt煤热解燃烧分级转化试验装置

1MWt coal stage conversion pilot plant

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下5年项目建议 Proposals for Next 5 Years

设置的原则 / Principles:

- 示范项目 / Large pilot projects
- 合作深化 / Deepening collaboration

  (more private sector participation)
- 项目延续 / Project extension(build on phase I)
- 可实现性 / Realizable (outcomes)
- 可对接性 / Interrelated (system integration)

未来五年工作标志的描述/Highlights of Phase II

在已有的基础上，我们坚信再经过五年的共同努力，会为CCUS现有技术的完善和成熟，特别是在CCUS的规模化放大和商业化应用方面奠定更加坚实的基础；并为新一代CCUS技术的发展和推进展现出新的亮点。

Based on the work done in phase I and under the common effort of ACTC in the next five years, we believe much more solid foundation will be laid to make CCUS technology more mature, especially in the aspects of scaling up and commercialization of CCUS technology. Highlights of novel CCUS technology will emerge.

设置5个任务 / 5 Themes Determined

与美方交流后，下一阶段拟设置5个任务：

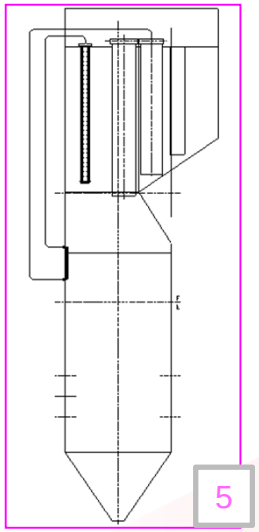
1）先进发电技术；
2）大型示范项目合作与知识共享；
3）CO_2利用与埋存；
4）清洁转换；
5）系统分析与建模。

ACTC proposals are grouped into five categories:

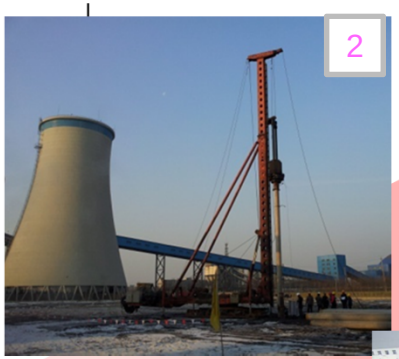
1) Advanced power generation;
2) Collaboration and knowledge sharing on large scale demonstration projects;
3) CO_2 Utilization and storage;
4) Advanced coal conversion;
5) System analysis and Modeling.

亮点-路线图 Highlights & Roadmap

USC挂件试验
USC Test



燃前捕集30MW
30 MW Pre-Comb.

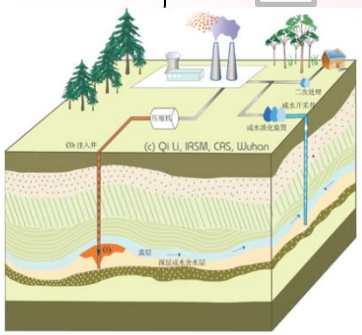


富氧燃烧
Oxy-Comb.

300MW分级转化
300MW poly-gen.
demo plant

微藻规模化养殖
Large Scale
Algae cultivation

驱水
EWR



埋存与驱油
EOR

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延长油田EOR示范工程 Yanchang CO_2-EOR Demo

- 延长油田与Wyoming大学达成合作协议，共同开发针对鄂尔多斯盆地内适宜低渗高非均质性油藏的CO_2-EOR技术；
- Yanchang Co. agreed with Wyoming Uni. in CO_2-EOR project in Ordos.
- 神华集团、延长油田、石油协会等机构计划开展40万吨/年规模的CO_2-EOR示范工程，并计划未来逐步扩大规模。
- A 100 kt/y CO_2-EOR demonstration project is planned by Shenhua Group, Yanchang, and Petroleum Association and will be scaled up gradually.

神华煤制油厂CO_2捕集设施
Shenhua CO2 capture facility

合作内容
Collaboration

规划中的 延长CO_2-EOR工程
CO_2-EOR in Yanchang Co.

神华 Shenhua

延长 Yanchang

中美CERC

怀俄明大学与中方多家机构共同研发低渗非均质的CO_2-EOR技术，提高石油采收率。
Wyoming Uni. Collaborates with China in CO2-EOR.

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CO_2提高石油采收率
CO_2 Enhanced Oil Recovery (CO_2-EOR)

Injection well index: 60
Pipeline index:200-300km
Capture index 80000-400000 tons

Reservoir study
- Reservoir screening
- Geological model
- Reservoir simulation

Site construction
- Increase injection well groups (60)
- Injection station construction
- Pipeline construction(200-300km)

Capture device Construction (80-400kt)
- Device construction
- Capture process innovation

Reservoir study → Construction of injection station and pipeline → Construction of capture device

2010 — CERC1.0 — 2015 — CERC2.0 — 2020

神华集团 SHENHUAGROUP

CHINESE ACADEMY OF SCIENCES

1905 延长石油

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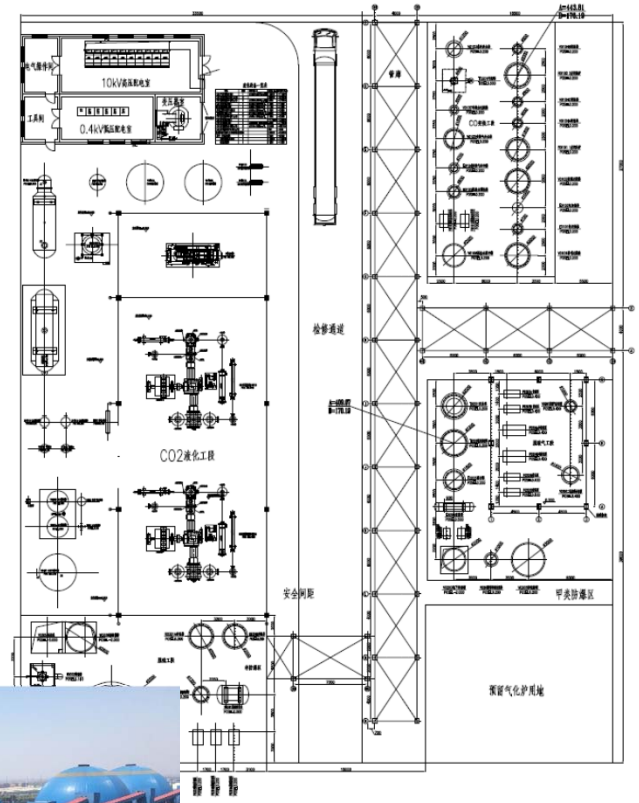
华能IGCC+CO_2捕集　IGCC+CO_2 Capture in Huaneng

- 华能在绿煤I期IGCC投运的基础上开展II期30MW燃烧前CO_2捕集项目。
- Based on the operation of IGCC, Huaneng is starting a 30 MW precombustion CO_2 capture project for syngas cleanup.

30MW$_{th}$ pre-combustion CO_2 capture system layout



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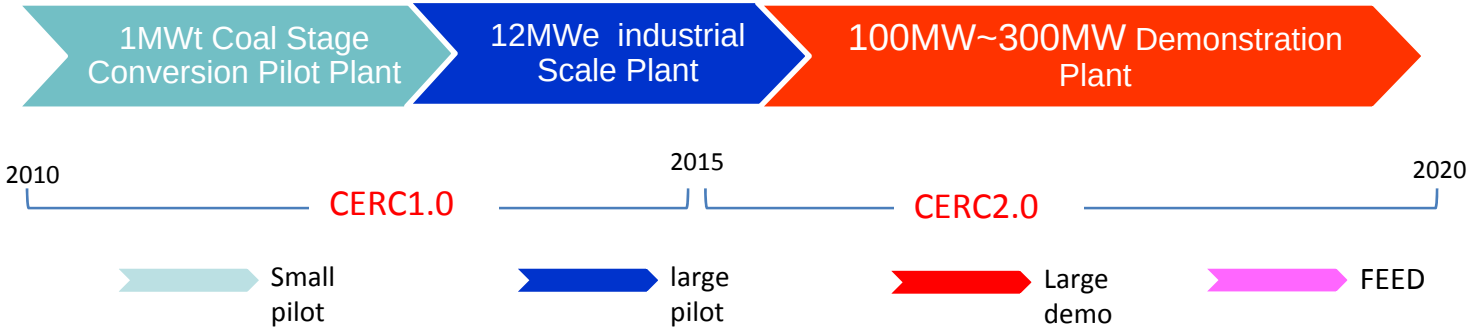
300MW分级转化 300MW Conversion

1MWt Pilot Plant

12MWe Industrial Plant

-Experiments on the key conversion processes
-New synthesis processes for pyrolysis gas
-Environmental technologies
-Simulation on poly-generation system
-Design Theory and methods
-Operating the demonstration plant with a capacity between 100MW and 300MW.



LP AMINA 格盟国际

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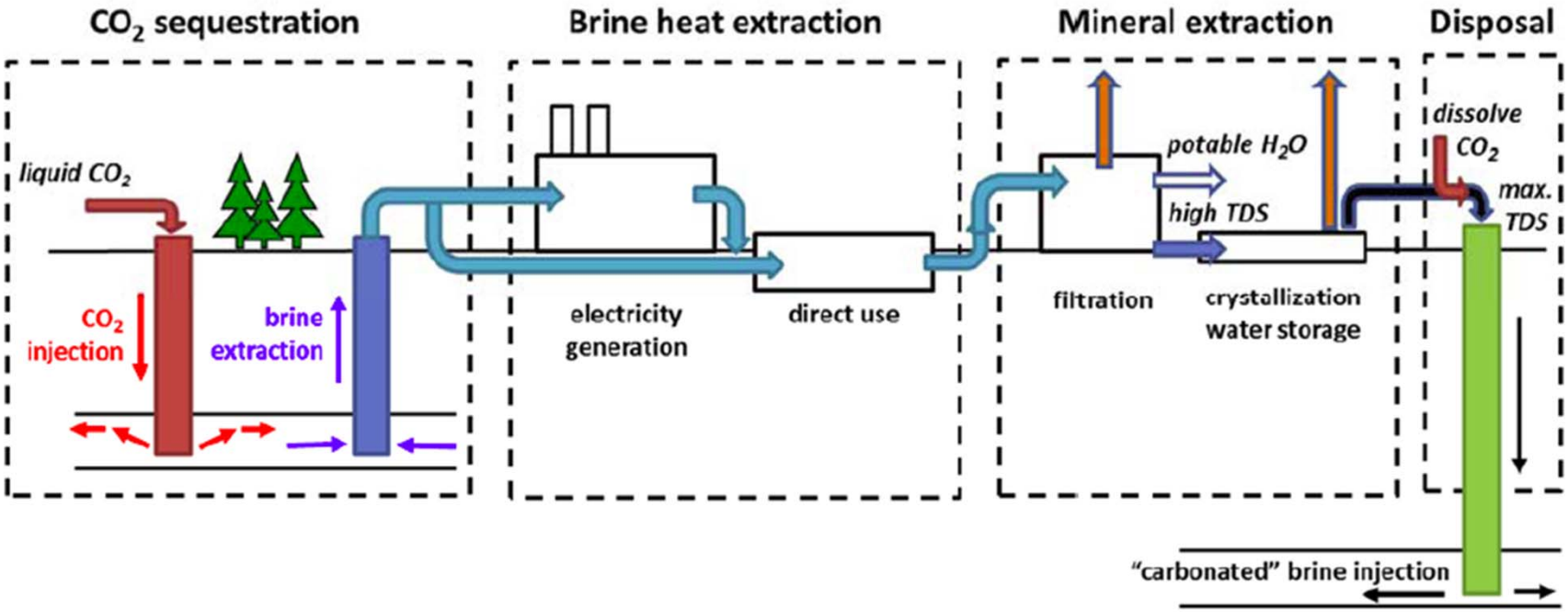
华能清能院与WVU合作EWR
Collaboration on EWR Between Huaneng-CERI and WVU

- 华能清能院与WVU签订合作备忘录，共同进行CO_2驱水技术研究。
- Huaneng-CERI and WVU signed an MOU to collaborate on the EWR project.



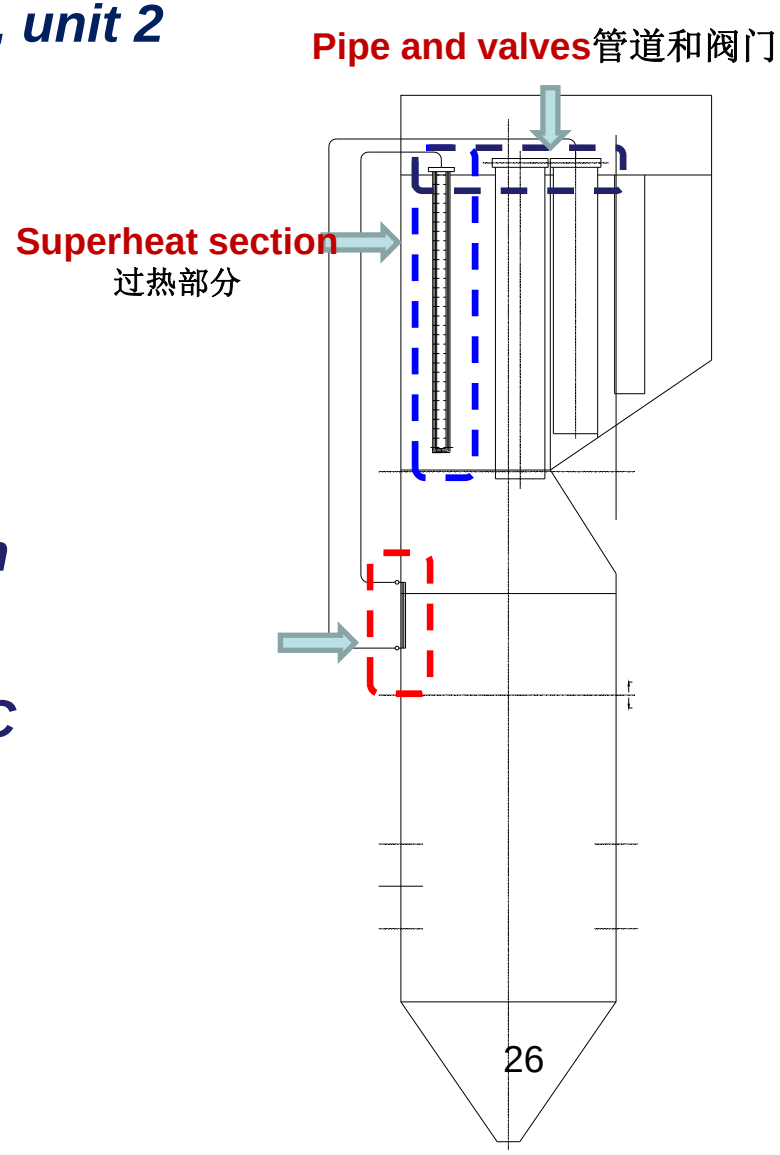
USC MATERIAL TESTING 材料测试

Host site 现场:

Huaneng Nanjing thermal power plant, unit 2

华能集团南京热电厂，2号机组

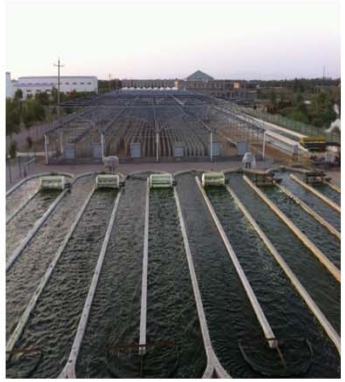
- **Boiler type** 锅炉类型: ***two pass boiler***
- **Steam capacity**蒸汽容量: ***1000 t/h***
- **Production capacity**生产能力: ***320 MWe***
- **Burner type** 锅炉类型: ***wall fired System***
- **Fuel** 燃料: ***bituminous coal***
- **SH steam temperature** 蒸汽温度: ***540° C***
- **SH steam pressure**蒸汽压力: ***25 MPa***



微藻碳捕集与生物固碳
CO_2 Sequestration and Fixation with Microalgae

微藻实验室与小规模室外实验

Lab and small scale outdoor experiments



1000平方米小型中试

1000m² small Pilot

- Achieve long term stable operation
- Obtain a CO_2 fixation rate at 30g/m²/d
- Improve biomass yield by 30% compared to SERC 1.0
- Separation and purification for product such as EPA
- Develop contamination control approaches

3英亩微藻养殖中试示范

3 acre large pilot demonstration

- Set up a 3-acre cultivation facility
- Biomass productivity 18 g/m²/d
- Conduct Techno-economic and lifecycle analyses of CO_2 capture and recycling
- Develop multiple high-value algal products

200平方米微藻养殖 200m² algae cultivation → 1000平方米微藻养殖 1000m² algae cultivation → 3英亩微藻养殖中试实验 3 acre pilot algae cultivation

2010 — CERC1.0 — 2015 — CERC2.0 — 2020

基础研究 Basic research → 室外试验 Outdoor testing → 小型中试 Small pilot → 大型中试 large pilot

ENN新奥 用我所能 善待明天

浙江大学 ZHEJIANG UNIVERSITY

DUKE ENERGY

清洁煤技术联盟 CERC-ACTC

Pressurized Oxy-PC 加压富氧燃烧

1MWt SOC Pilot 试点

10MWt POC demo 富氧燃烧示范

- Detail process modeling(Wustl)
  详细流程建模 （圣路易华盛顿大学）
- CFD simulation (WVU)
  CFD模拟 （西弗吉尼亚大学）
- System Improvement (WVU, Wustl)
  系统改进 （西弗吉尼亚大学，圣路易华盛顿大学）

100kWt POC small Pilot 小型中试

- Burner/boiler design (Wustl) 燃烧器/锅炉设计（圣路易华盛顿大学）
- Kinetics study (HUST) 动力学研究（华中科技大学）
- Ash deposition study (THU)火山灰沉积研究（清华）
- Sub-model development (WVU, Wustl)子模型开发 （西弗大，华盛顿大学）
- Experiments and CFD validation实验和验证
- Scale-up to 250kWt (Wustl) 规模达250kWt（圣路易华盛顿大学）

1MWt Staged Oxy-PC → 100kWt Pressurized Oxy-PC → 10MWe Pressurized Oxy-PC

2010 — CERC1.0 — 2015 — CERC2.0 — 2020

Small pilot | large pilot | Large demo | FEED

CERC-ACTC

富氧燃烧工业及大型示范 / Oxy Demonstration

- 华中科技大学与圣路易斯华盛顿大学将继续在富氧燃烧技术展开紧密合作；
  HUST and University of Washington in St. Louis will continue close collaboration on oxyfuel combustion.
- 华中科技大学等在应城建设35MW富氧燃烧工业示范装置，并对神木200MWe富氧燃烧大型示范开展预可行性研究；
  HUST leads the 35MW oxy demo project in Yingcheng and the 200MWe oxy plant pre-feasibility study in Shenmu.
- 采用化学链制氧与富氧燃烧耦合，使富氧燃烧的发电成本降低35%；
  Combine CLC oxygen production with Oxy-combustion to reduce the generation cost by 35%.

Thank you for your attention