二氧化碳捕集利用与封存的技术及实施
Carbon capture, use and storage: technology and implementation in the China context

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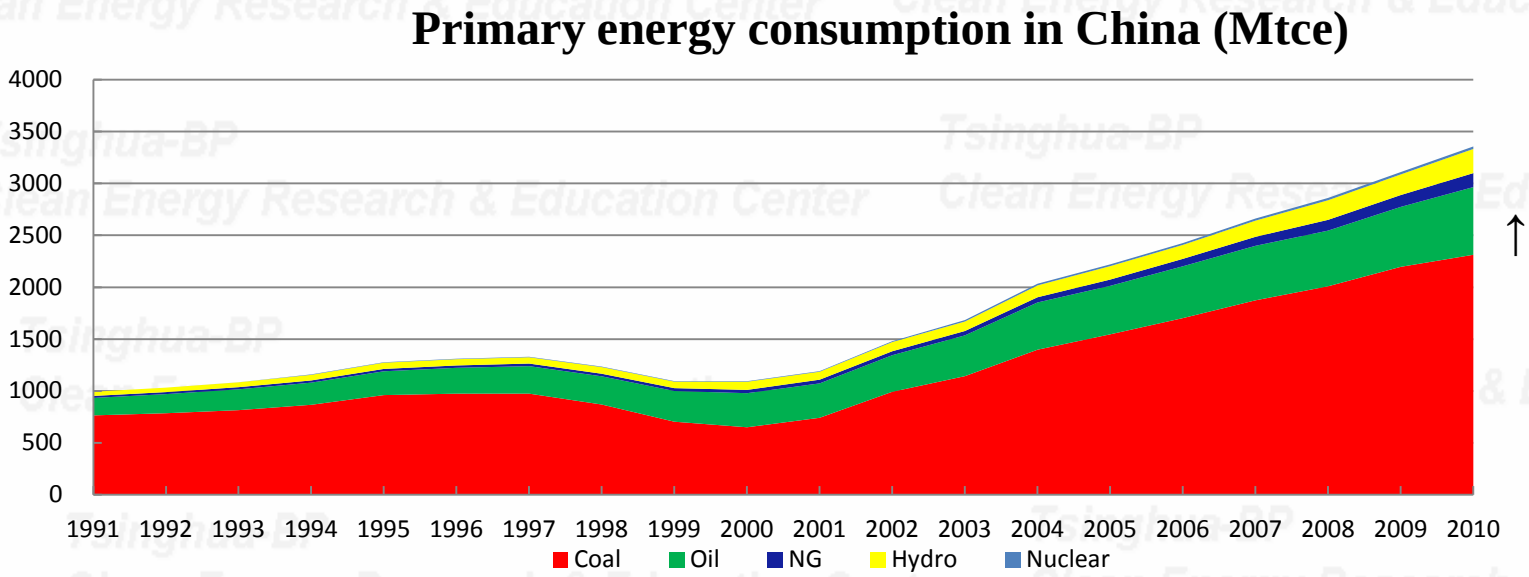
Outline

- CCS in Chinese context
- Tsinghua-WRI joint program
  - Program information
  - Defining goal, scope, and working approaches
- Highlights of the coming book
  - 7 chapters providing up-to-date knowledge points across CCS technical chain and chronological project chain
  - 19 sets of guidelines giving recommendations for important issues in conducting a safe and effective CCS project

Challenges: energy supply and carbon emission



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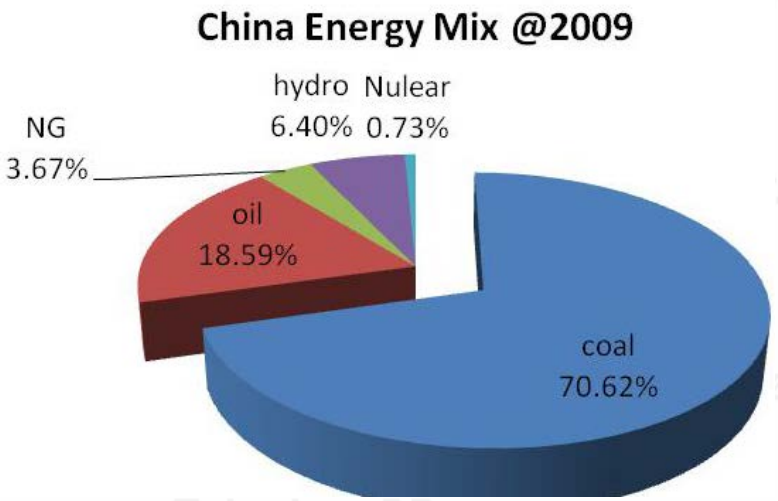
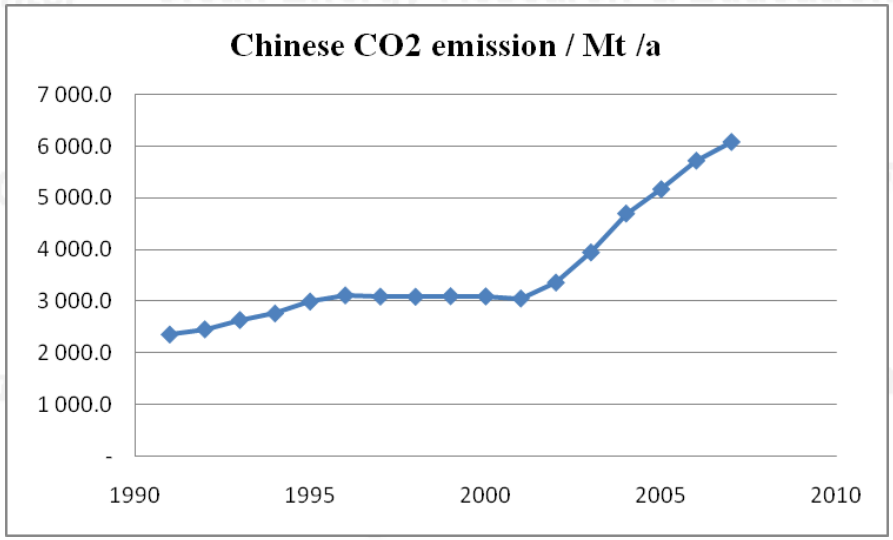




Current arguments regarding CCS development in China

- Supporting opinions:

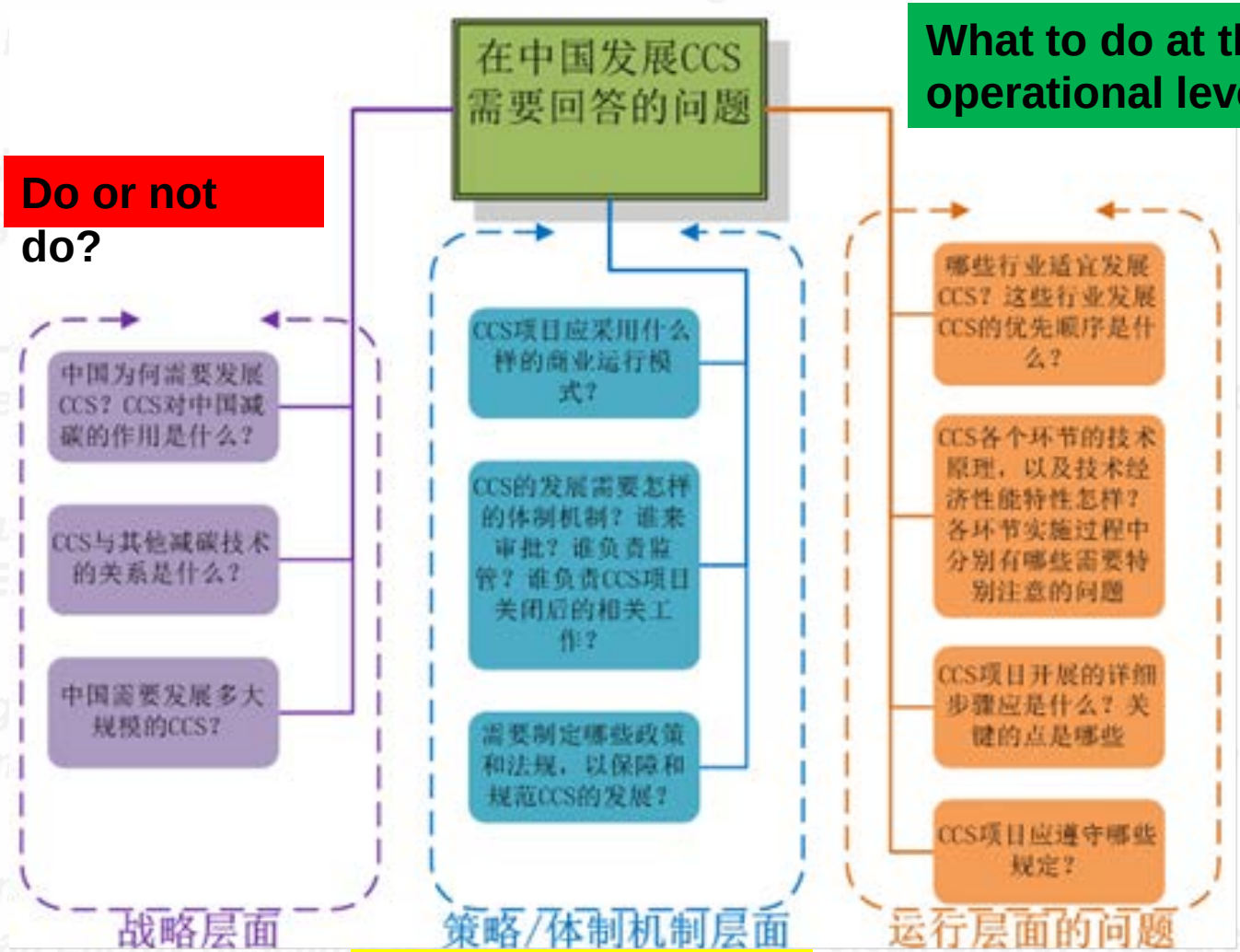
1. CCS is a key bridging technology to be deployed on a large scale to reduce the burgeoning CO_2 emissions from China's large number of major point sources and achieve the sustainable development of China's energy industry (Chen et al., 2009; Liu and Gallagher, 2010; Ma et al., 2010; Ou et al., 2010).
2. China can position itself as a leader in CCS technology and equipment manufacturing and make it a point of economic growth by becoming an exporter.
3. CCS is the only technology shown possible to directly reduce CO_2 emissions from fossil fuel use.

- Dissenting opinions:

1. Capture equipment operation imposes a large (~30%) energy consumption increase, and this energy penalty is contradictory with China's fundamental policy of energy conservation (Xu, 2009);
2. The cost for CCS is too high for China and CCS should not be considered right now (Xiao, 2010);
3. Technologies for CCS are almost all possessed by developed countries, whose instigation for China to deploy CCS in large scale is an attempt to "swindle" China and suppress its future development through CCS' high cost and energy penalty. China must not be fooled (Chen, 2010);
4. CCS projects can greatly threaten the safety and health of local residents, especially for a country as densely-populated as China, so extreme prudence is required before deployment (Wang, 2010); and,
5. China has extremely complicated geology, and whether or not long-term and effective CO_2 storage can be achieved in China still needs to be demonstrated through extensive research (Zhang et al., 2010).
6. While the component technologies already exist, CCS as an integrated technology is not yet mature

- **However, neither the supporting nor opposing voices currently have foundations that are based soundly enough on comprehensive knowledge of CCS in China.**

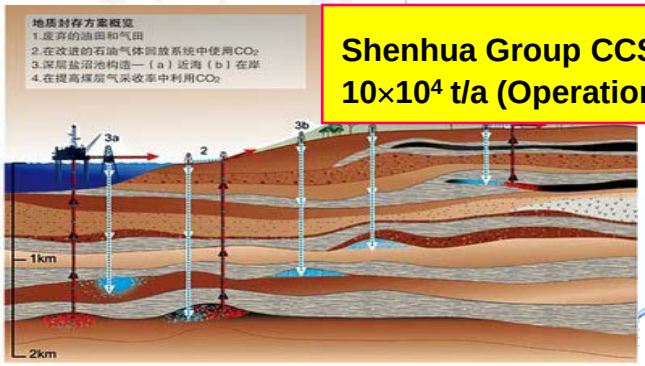
CCS has strategic, tactical and operational level questions to be answered
我国发展CCS尚有多层次的问题需要回答



How to plan at the tactical level?

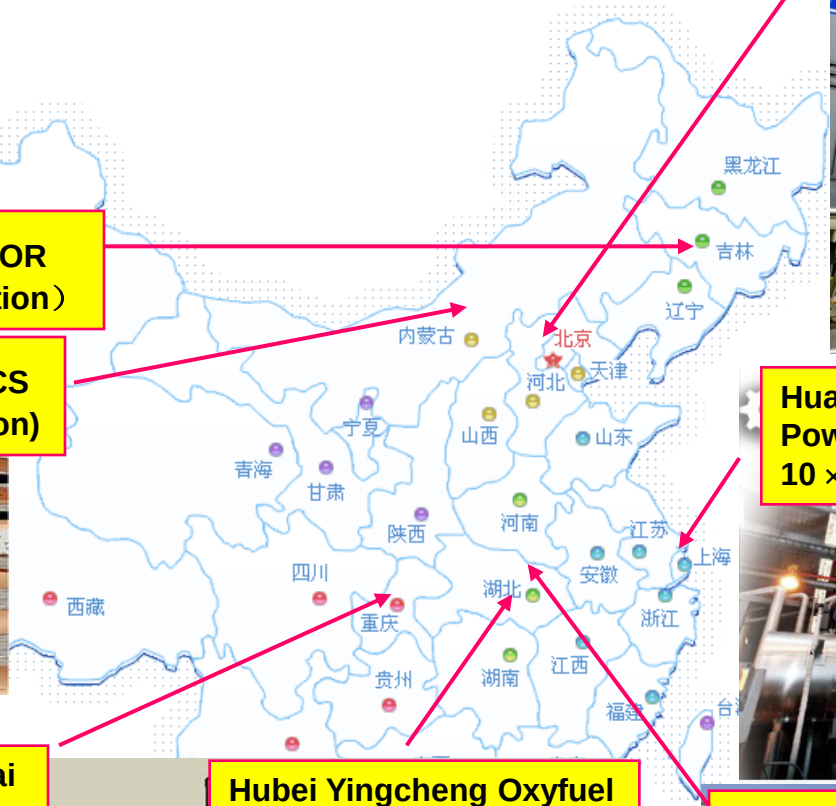
CCS Demonstration Projects in China
中国已建成和在建CCS示范项目

Jilin Oil field CO_2-EOR
300-400 t/d（operation）



Shenhua Group CCS
10×10⁴ t/a (Operation)

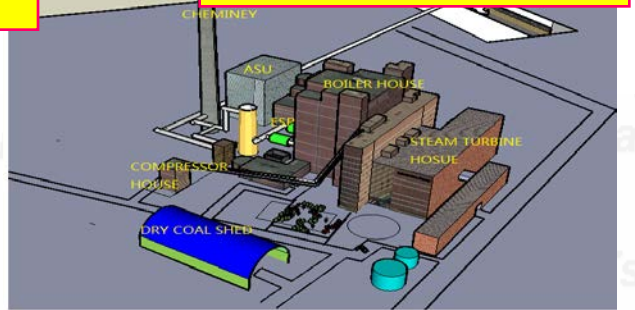
Chongqing Shuanghuai power station
1 ×10⁴ t/a （Operation）



Huaneng Beijing Thermal Power Station
3000 t/a（Operation）

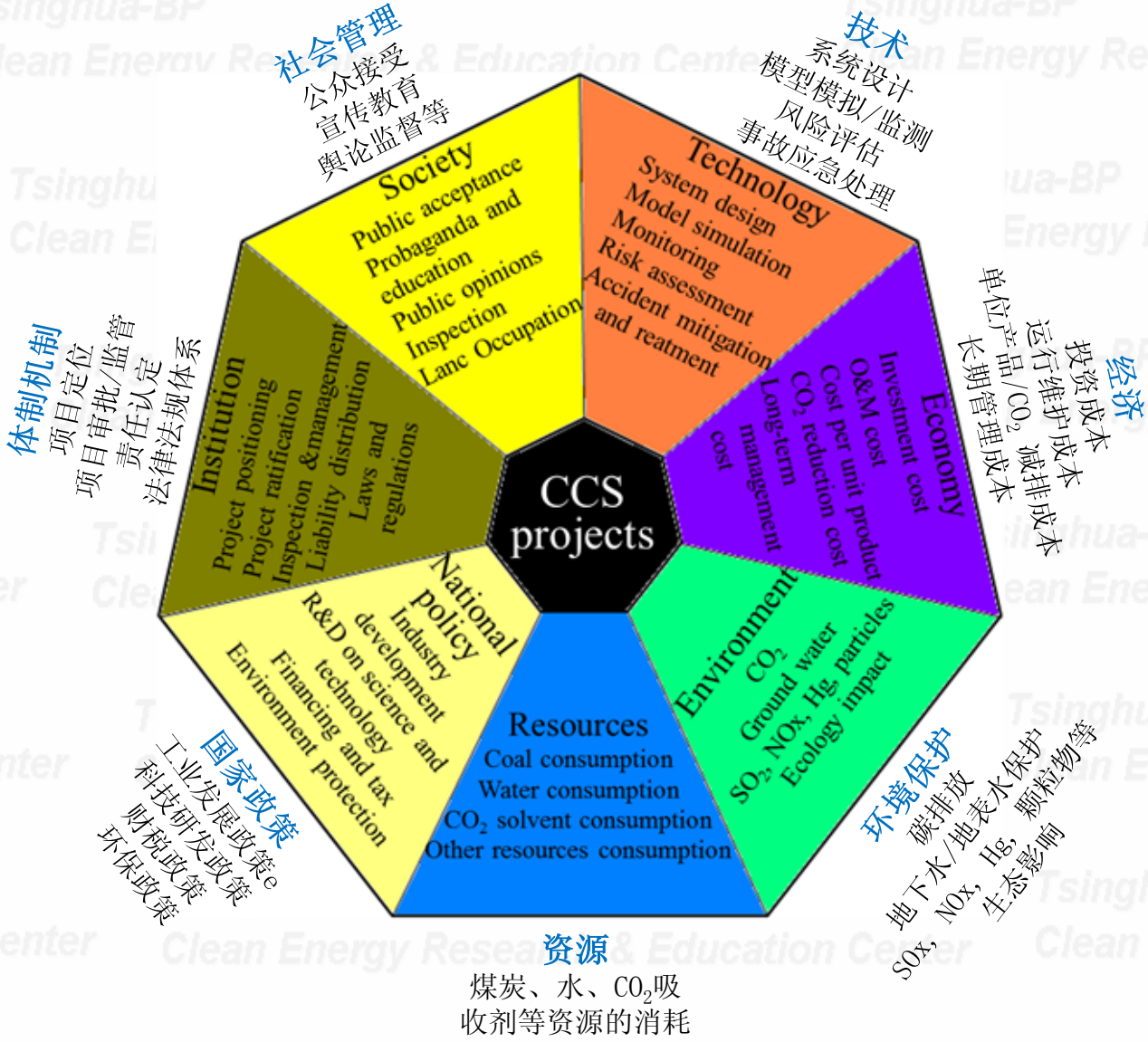
Huaneng Shidongkou Power Station
10 ×10⁴ t/a (Operation)

Hubei Yingcheng Oxyfuel
10 ×10⁴ t/a （Approved）



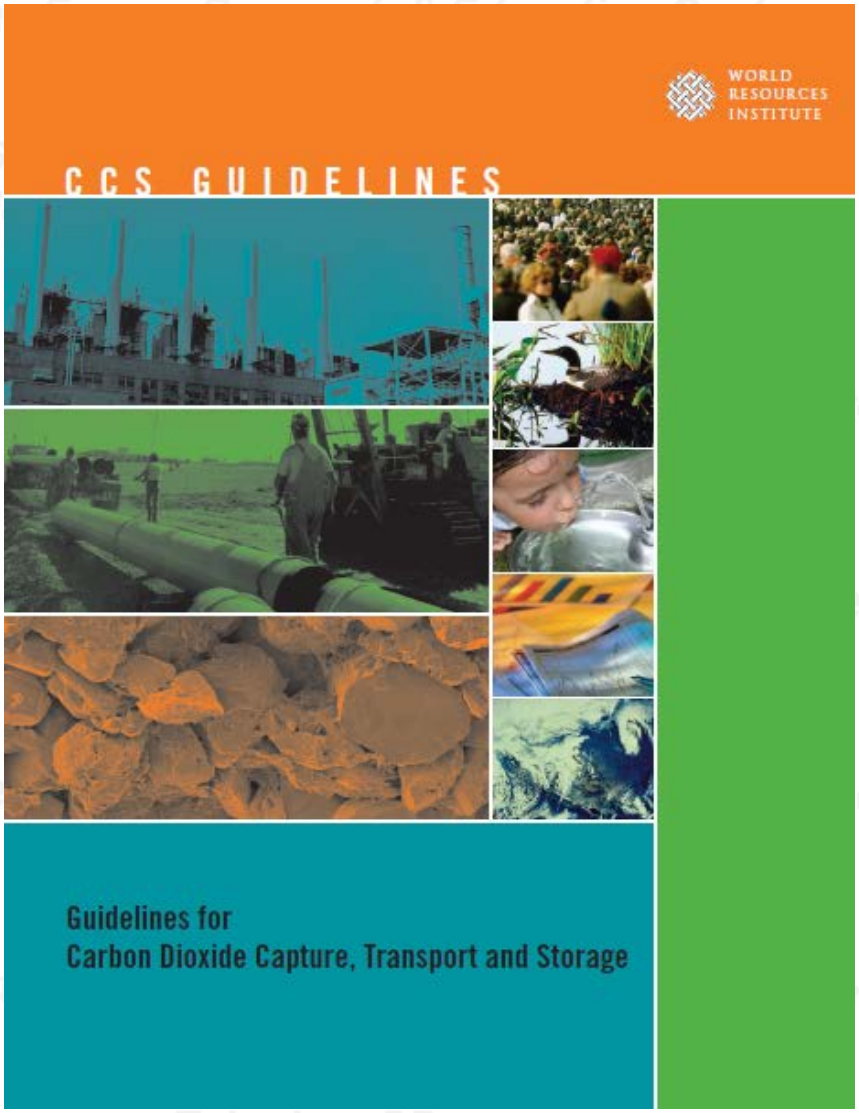
Wuhan 3MW oxyfuel 1 ×10⁴ t/a
（under construction）

Multidimensional issues relating to the implementation of CCS



Studies on CCS system level as well as on multi-dimensional issues are not sufficient → our mission

WRI: CCS Guidelines

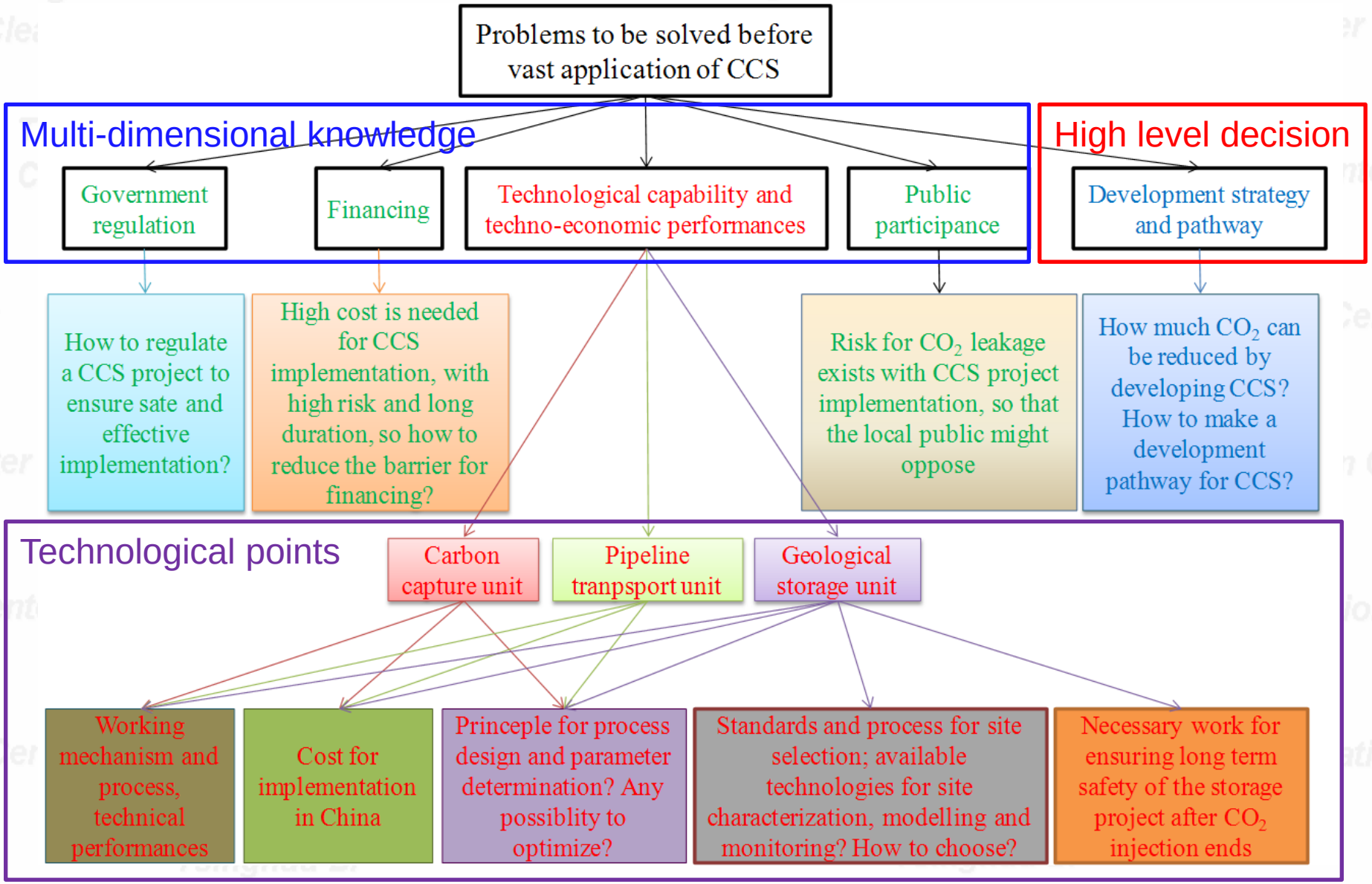


- A good example to refer to
- Generated thru stakeholder discussion—the approach to follow
- Dedicated mainly to regulatory issues-but less technical messages to facilitate reading, especially for Chinese readers
- Valid for US circumstances

Our strategies

- Do have WRI Guideline as the major template for framework design
- Populate the framework by examining all knowledge points in the Chinese context
- Adapt the stakeholder approach to ensure fitting to concrete China situ
- Effort in accommodating Chinese reading habits

Defining the study scope thru understanding three-layer questions to be answered for large scale dissemination of CCS



Target audiences and contents design

- **Audiences**
  - Potential contractors of CCS /CCS项目的承担方(most critical)
    - Decision maker (决定CCS发展的决策者): overall behaviors in technical/ environmental/economic/risk/regulatory/policy aspects
    - Technical staff (技术人员): design/construction/operation
  - Governmental agencies / 政府监管部门
    - Overall information about CCS
    - Legal/regulatory/mechanisms
  - Investors / 可能参与CCS项目的金融机构
  - Public / 想了解CCS原理和技术经济性能的一般公众
- **Contents design**
  - Element 1: providing knowledge points across the CCS technical chain and chronological project chain with explaining and highlighting important issues based on domestic and international best practices
  - Element 2: Providing our recommendations on key issues for China to implement CCS---guidelines

Key working mode #1:

Stakeholder analysis and discussion 利益相关者讨论

- Steering committee composed of experts from both China and US
  来自中美两国的相关领域专家构成专家指导委员会
- Diversified backgrounds concerned with CCS research, industrial practice, and governmental regulation as well
  多样化的专业背景，涉及CCS相关研究、工业实践和政府监管
  - Senior managers or engineers from China's oil/power/chemical industries that are working on CCS related demonstrations 从事示范的石油/发电/化工企业负责人
  - Famous professors studying geology, coal mining, EOR, ECBM, etc.
    地质/采煤/EOR/ECBM等研究领域专家
  - Officials from NDRC closely related with CCS development in China 发改委官员
- The personal experience and feeling of the experts in their specific fields of CCS research and industrial practice resulted in lots of debates, which ensure the high quality of the knowledge points finally generated.
  中美专家在各自CCS研究和工业实践领域的实际经验和切身体会使得利益相关者分析的过程充满了思维的碰撞，但也大大提高了产出知识点的质量

Steering committee members from US and China

Key working mode #2:

Field study tours 实地的学习旅行

- First-hand knowledge and engineering experience gained through 4 series of study tours to CCS concerned institutes and demonstrations in both US and China

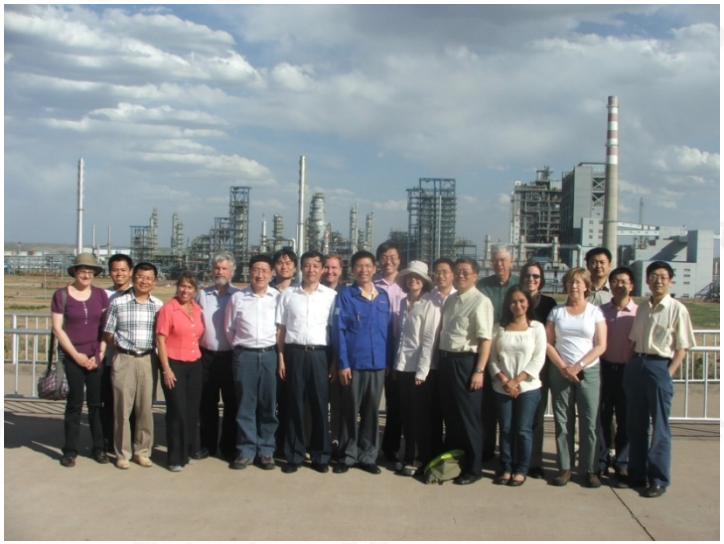
  通过4次精心规划的在美国和中国CCS相关研究机构和示范项目的学习旅行获得大量宝贵的第一手资料

  - Mont Simon demonstration for saline aquifer storage
  - Tinsley Oilfield of Denbury and Hess Oilfield for EOR industrial activities
  - Jackson Dome (natural CO_2 reservoir of Denbury) for CO_2 pipeline transport
  - Lawrance Livermore and Lawrance Berkeley National Laboratory, National Energy Technology Laboratory, Electricity Power Research Institute, for upfront CCS related research
  - Shenhua CTL+MTO, GreenGen IGCC, Huaneng post-combustion carbon capture in Beijing and Shanghai, Jilin Oilfield EOR, ENN algae oil, etc.
  - 神华鄂尔多斯煤制油+盐水层示范、神华上海煤制油中试、华能北京热电厂3000吨/年、上海石洞口第二电厂10万吨/年碳捕集示范、天津绿色煤电IGCC+CCS示范、吉林油田EOR示范、新奥微藻制油示范、上海电气等

Records of the study tours in China and US

Mont. Simon saline aquifer storage

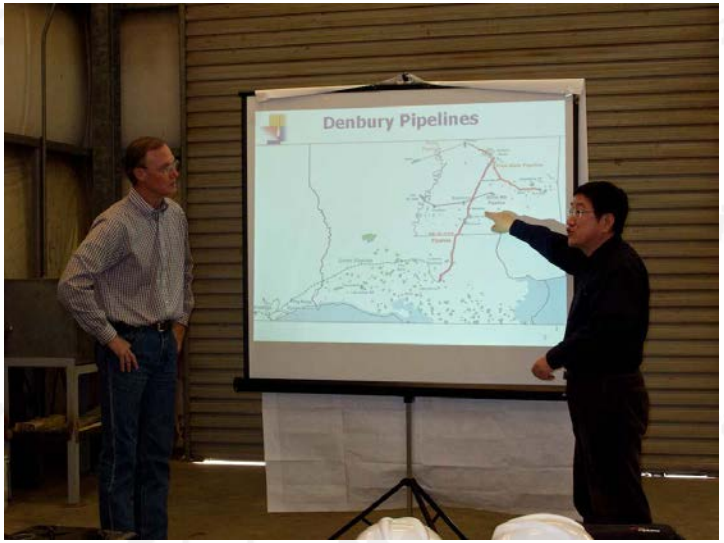
CO_2 separation unit for Tinsley



Shenhua Ordos Coal-to-Liquid

Gaobeidian 3000t/a CO_2 capture

CO2 transportation widely applied in EOR industry
-二氧化碳管道运输在石油强化开采中广泛应用



二氧化碳运输管道

生产井气液输出管

循环二氧化碳地面分离

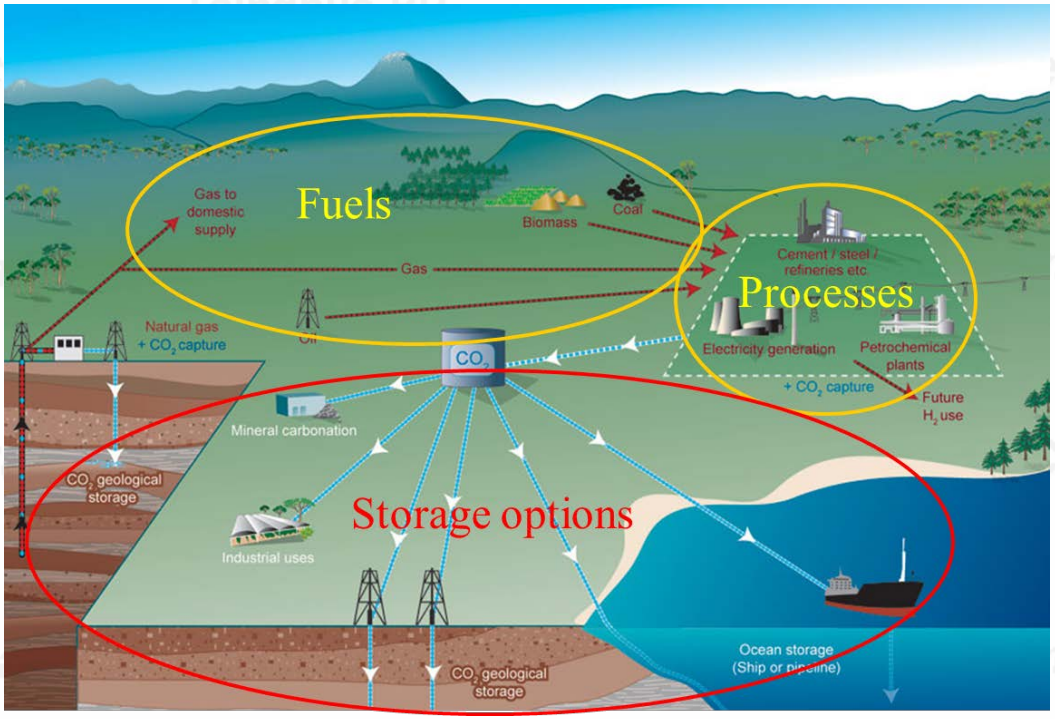
二氧化碳注入井井头

Chapters of the book 章节介绍

1. Introduction
   - Clarify CCS concept, describe the chapter structure
2. CO_2 capture
   - Technical mechanisms and performances, applicability analysis, etc.
3. CO_2 transport
   - Technical mechanisms and performances, engineering experience, etc.
4. CO_2 geological storage
   - Technical mechanisms and performances, issues to pay special attention to the whole project chain of CCS, other key issues for storage project operation, current disputes and doubts with geological storage, etc.
5. CO_2 utilization
   - Major utilization methods of CO_2 utilization, and priority analysis for China
6. CCS project management
   - Define 7 stages for the whole project chain of CCS, key actions summarized and proposed for potential operators and regulators
7. Summary of guidelines for different readers

Clarify CCS concept 代表三个概念或含义—澄清有助于解释和理解

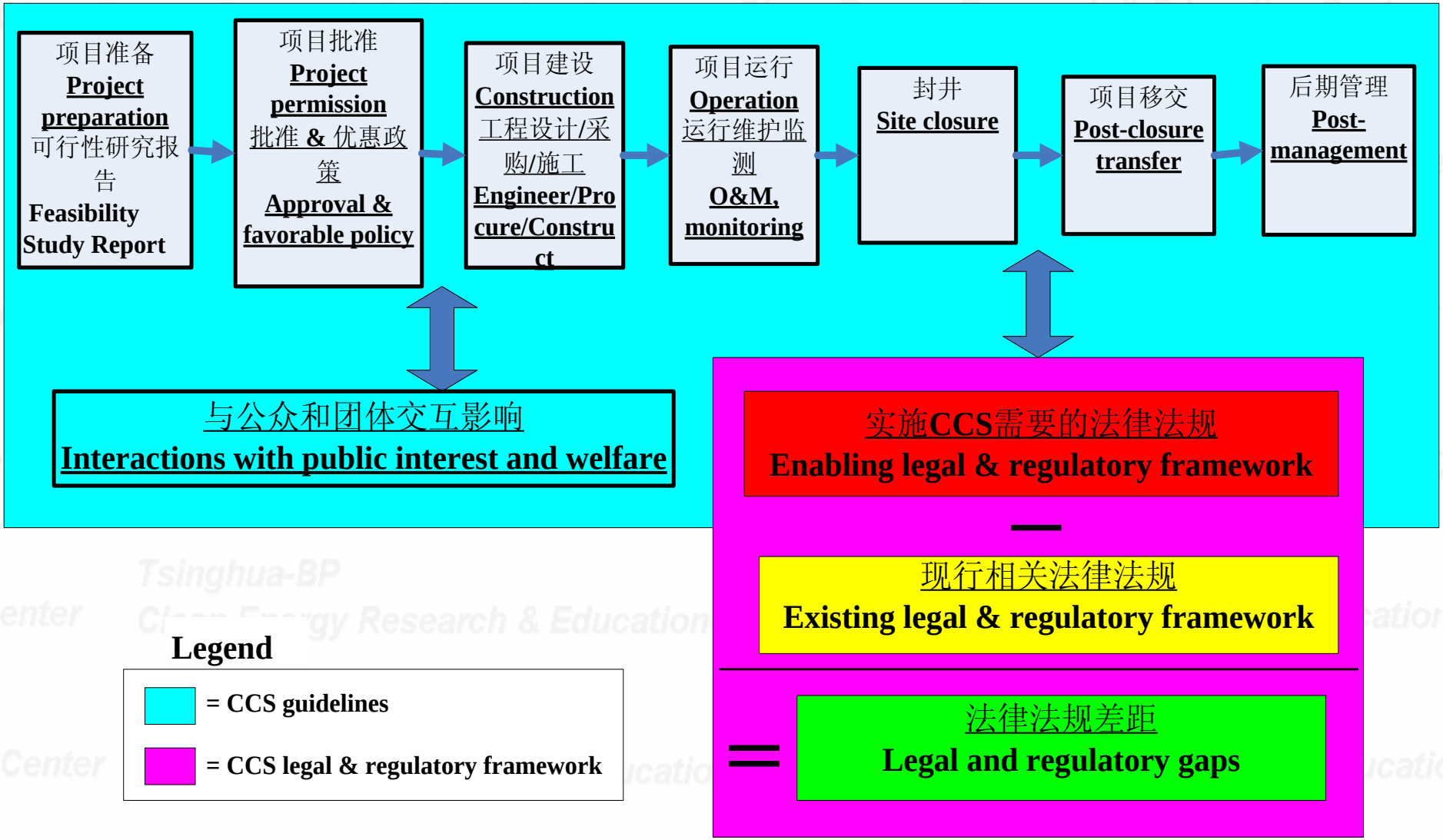
1. **想法/idea**：人为地把原本要进入大气中的二氧化碳搜集并封存起来，达到使其和大气长期隔绝的目的
2. **工业系统/engineering system**：由捕捉、运输和埋存三个环节组成的工程系统，它可以持续地把人为产生的二氧化碳封存到所设计的二氧化碳储存库中
   - 设备和建设问题不大



3. **CCS技术/CCS technology**：一套指导在哪儿建、怎么建CCS工程系统，且保证所处理的二氧化碳安全有效封存的工程技术和管理技术
   - CCS工业系统建设和运行技术
   - CCS专属技术：专门针对碳捕捉开发的单元及过程技术；封存地址的鉴定和选择技术；监测、风险评估及事故处理技术

Three main steps of a CCS system:
Capture—Transport—Storage
组成CCS的三个主要环节：
捕捉----运输----封存

Define the chronological stages for conducting a CCS project



Example：Chapter 2 Carbon Capture

- 2.1 Capture Technology: emission sources, separation process and equipment, compression and de-watering process, capture system
- 2.2 Capture performances: efficiency, economics, environment, resources consumption, maturity and applicability, comprehensive comparison
- 2.3 Project integration: carbon source selection, capture process selection, capture rate determination, specification of product stream
- 2.4 Multi-dimensional issues: economic, environmental, safety, legal and regulatory
- Guidelines: 1-carbon sources and capture technology, 2-plant integration,3-standards and regulation

- 2.1 捕集系统构成：二氧化碳排放源，分离设备，压缩与脱水设备，捕集系统
- 2.2 电厂捕集系统性能：技术，经济，环境排放，资源消耗， 成熟度和适用性，综合比较
- 2.3 捕集的实施流程：捕集源的选取，捕集技术的选取，捕集率的确定，二氧化碳混合物的成分含量限定
- 2.4 捕集的其他维度问题：经济，环保，安全，法律法规
- 指导意见: 1-排放源与捕捉技术，2-捕捉技术实施，3-法规和标准

Example：Chapter 3 CO_2 Transportation

- 3.1. CO_2 transportation briefing: principle, industrial experience
- 3.2. Pipe project integration: design, construction, operation
- 3.3. Safety issues: risk, legislation and regulation, public acceptance
- Guidelines:
  - Guidelines 4: pipe and system design；
  - Guidelines 5: construction；
  - Guidelines 6: operation and inspection；
  - Guidelines 7: safety and public publicity

- 3.1. 二氧化碳管道运输系统简介：原理，现有工程经验
- 3.2. 二氧化碳管道运输的实施流程：二氧化碳管道的设计，管道的建设，管道的运行
- 3.3. 二氧化碳管道的安全：安全风险，安全法规，公众安全宣传
- 指导意见 4-7
  - 指导意见4：管道及管道系统设计
  - 指导意见5：管道建设；
  - 指导意见6：管道运行和监管；
  - 指导意见7：管道安全和公共宣传

Guideline example

Set 1 The CO_2 capture system

a. China should start CO_2 capture from the industrial sectors with concentrated coal utilization, mainly including power sector, coal chemical sector, cement sector and iron & steel sector. Among these sectors, power is the largest single sector for CO_2 emissions. If China decides to achieve significant CO_2 reduction by implementation of CCS in large scale, then appropriate technologies are needed for capturing the CO_2 from the coal-fired power plants. (PM, R, O, GP)

b. Implementation of CO_2 capture projects should start from the easy ones to difficult ones, i.e. to start from sectors with large CO_2 emissions and high CO_2 concentrations, e.g. coal chemical industry, and then move to sectors with low CO_2 concentrations, e.g. power industry, cement industry, iron & steel industry, to help development of CO_2 capture technologies. (PM, O, R)

c. CO_2 capture from iron & steel industry should be combined with optimal utilization of coal gas from coke oven and blast furnace. (PM, O, R)

d. Among all CO_2 capture technologies, post combustion capture is one technology China must reserve, so much attention should be paid to R&D on it; pre-combustion capture and oxy-fuel capture technologies have advantages in respect of pollutants mitigation and water consumption, and more R&D effort should be provided. (PM, O)

e. China should also strengthen its R&D effort in industrialization, as well as reduction of cost and energy penalty, and decide key directions to implement industrialized demonstration of CO_2 capture. (PM, O)

Guideline example

Set 5. Construction of CO_2 pipelines

a. US has a niche targeting institute that is in charge of management of CO_2 pipeline construction and operation, i.e. the Office of Pipeline Safety (OPS). China might also establish some similar institutions. (R, O)

b. Route selection and land occupation for CO_2 pipelines can refer to the current practice of oil and gas pipelines in China. (O, R)

c. The route of CO_2 pipeline should as best avoid from areas with bad geological conditions (districts active in earthquakes, landslides, debris flows), and bad geographical conditions (mountains, rivers, deserts, marshes, etc), districts with dense population, and districts that are habitats important species, to reduce safety risk or transport cost increase. If a CO_2 pipeline has to get through these sensitive districts, special protection measures might be needed. Available measures include decreasing intervals between check valves along the pipeline, increase burying depth of the pipe, increasing the watertightness of pipeline, and increasing the frequency for monitoring and safety checking, etc. (O, R)

d. For onshore CO_2 pipelines, main body of the pipeline should be buried underground, except for the metering stations and boosting stations. Burying depths of the CO_2 pipeline can have small differences between projects, according to the specific conditions of the project, and a common choice is 1~1.2m. (O)

Guideline example

Set 5. Construction of CO_2 pipelines

e. If CCS can be included as key infrastructure projects that are supported by the government, ratification of land occupation would be prioritized, which can be then arranged and coordinated by governmental management departments of higher level. The working procedure can be referred from the current practice for land occupation for oil and gas pipelines. (R,O)

f. The route of CO_2 pipelines should as best avoid crossing rivers, freeways and railways, etc., or if avoiding is impossible, some specialized crossing technologies are necessary. If facing special situations such as valley rivers, where there might be too thick deposit on the river bed or the river bed fluctuate violently and it is too difficult to cross from downside the river, people can choose to bridge across the river. (O)

g. Monitoring instruments are necessary along the CO_2 pipelines, to help monitor and control CO_2 flow in the pipe. These instruments are normally installed in specialized metering stations or together with the boosting stations, and sometimes also next to the check valves. (O, R)

h. Protective measures are necessary for the surface facilities, e.g. boosting stations, monitoring stations, metering stations, etc., to protect them from destroyed by humans or animals. (O)

Guideline example

Set 19. Management of CCS projects

a. The whole CCS projects can be managed as 7 phases, including the planning and preparation phase, feasibility study phase, evaluation and verification stage, design and implementation phase, operation and monitoring stage, evaluation and site-closure phase, and long-term management phase after site-closure.

b. The operation and management of CCS projects can take the form of single entity operation, i.e. the CO_2 capture sub-system, CO_2 transport sub-system as well as the geological storage sub-system are all operated by a single entity, or they can also be operated separately, while obeying a unified commercial contract for the whole CCS project, including standards for flow rate, temperature, pressure and component composition of the CO_2 stream.

c. Before a large pipeline network for CO_2 transport is formed, partial CO_2 capture could be considered to implement, i.e. 20~60% capture. When the CO_2 reduction pressure of the company or the requirement for CO_2 injection or utilization increases, the capture ratio can then be increased by enlarging the CO_2 capture facilities.

Closing remarks

- Led by Tsinghua and WRI and with contributions from American and Chinese experts, we have successfully conducted a practice for CCS knowledge transfer in a systematic way.
- CCS is not purely a technical issue. Understanding its multi-dimensional characters is essential to ensure its final application.
  - Hopefully this process being enhanced by our work
- CO_2 capture projects should start from the easy ones to difficult ones, e.g. coal chemical industry. Utilization like EOR should be prioritized to ease early CCS development.
- Appreciate US Department of State, UK FCO and China NDRC
- Special thanks to our US partner, Sarah Forbes, for her wisdom and leadership in making all this happen.

Thank you!

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