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Experiences and lessons from CCS demonstration in China

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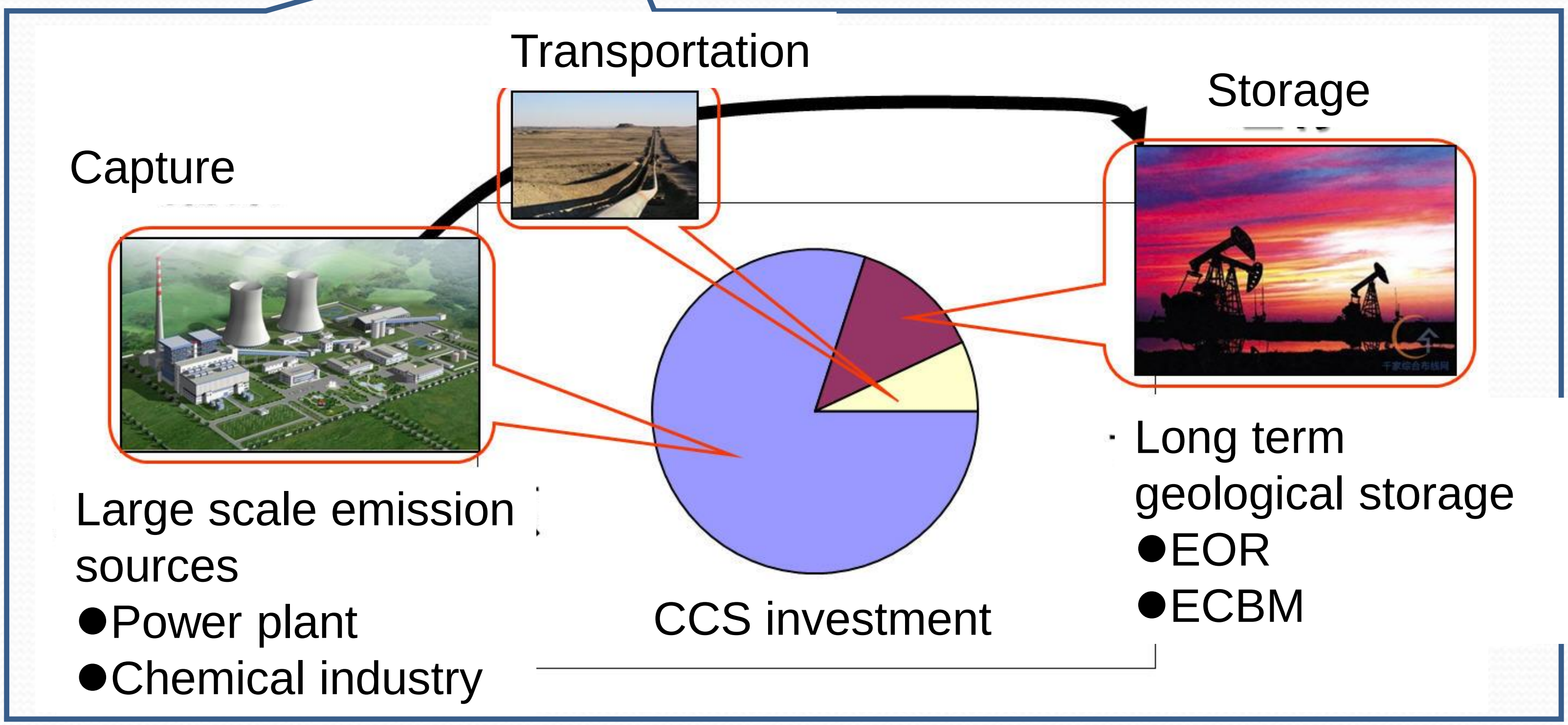
1. Progress of CCS demonstration in China

Technologies to reduce CO_2 emission

- Improve the efficiency of energy use
- Utilize renewable energy

} Less Fossil Fuel

- CO_2 Capture Storage (CCS) Low carbon Use of Fossil Fuel



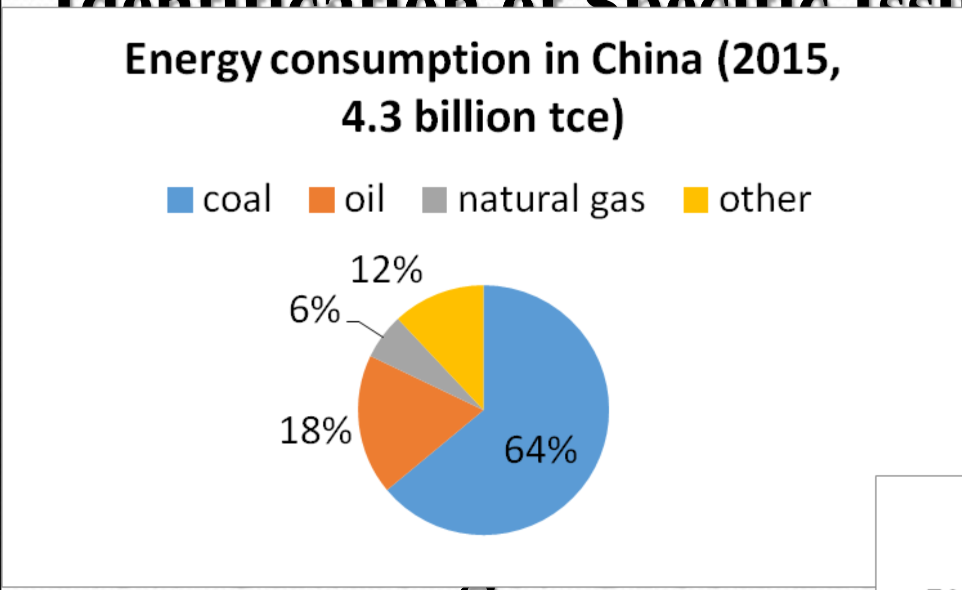
CCS contributes 1/6 of CO_2 emission reduction (IEA)

Challenges of Coal-relied China

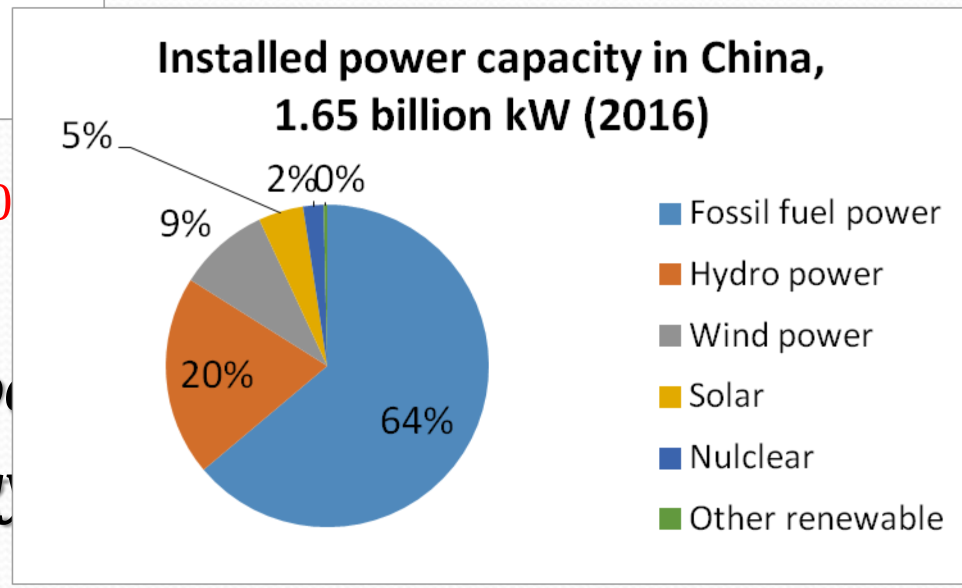
Identification of Specific Issues of China:

ower than Natural Gas (55%~60%)

Coal



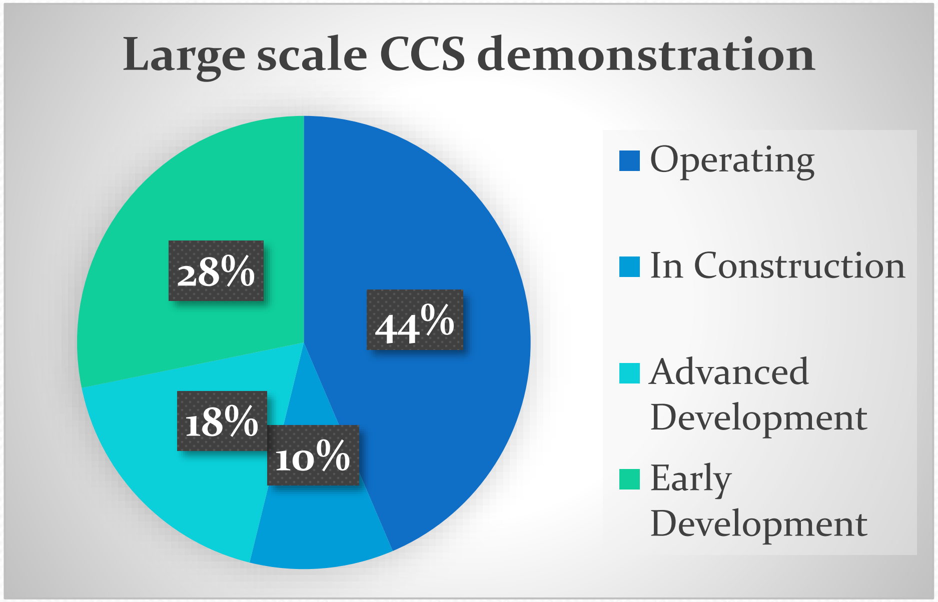
Coal power plants accounts for 40



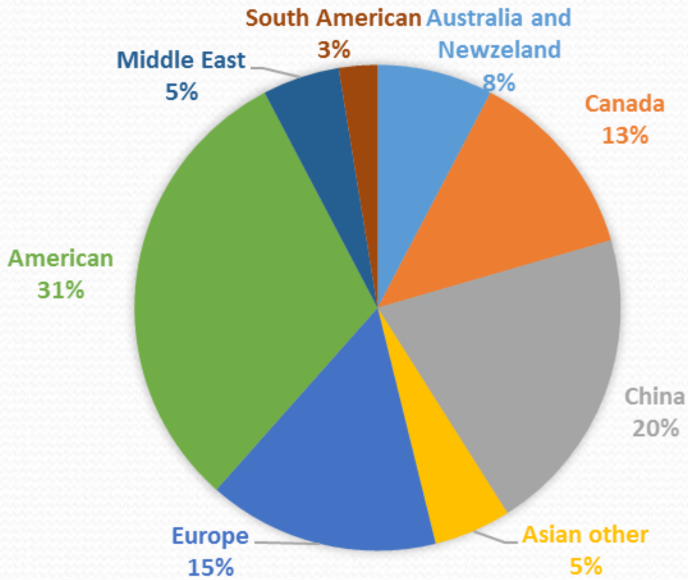
China need solution of co ***ly***

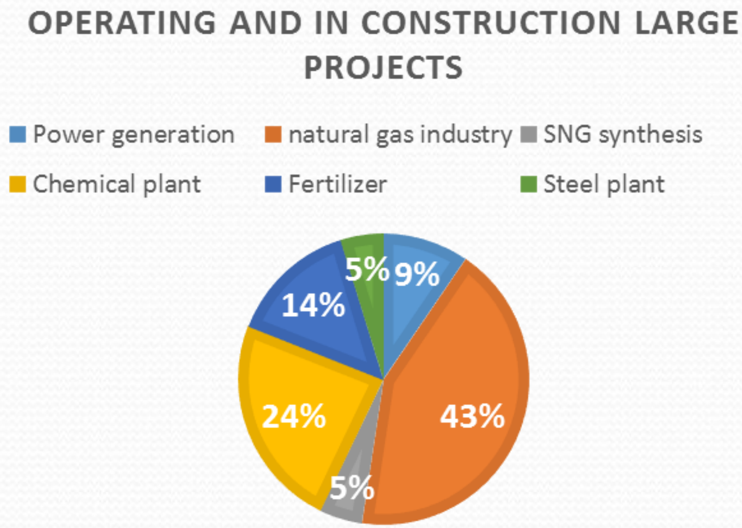
save energ

Overview of CCS demonstrations—Large scale projects

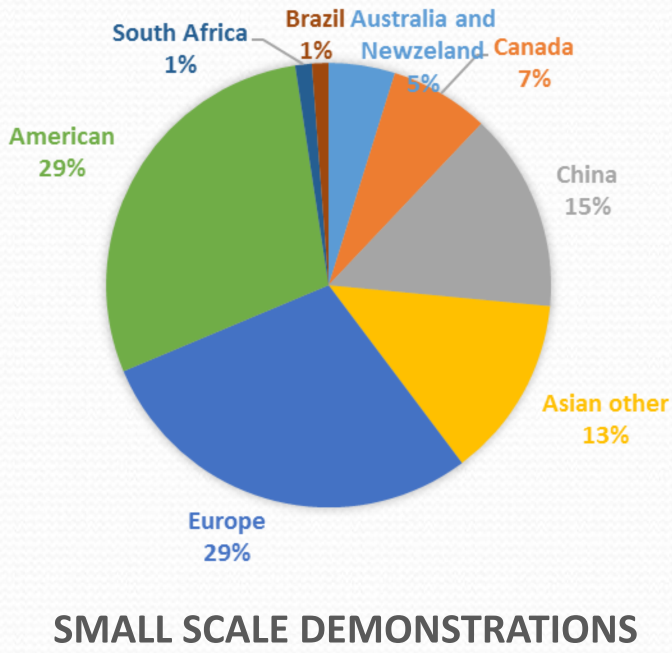


- 39 large scale demonstrations, and most located in North American, China, and Europe
- 17 in operation and 4 in construction (37 Mta)
- Operating and in construction large projects are mostly in natural gas and chemical industry, only 2 in power generation

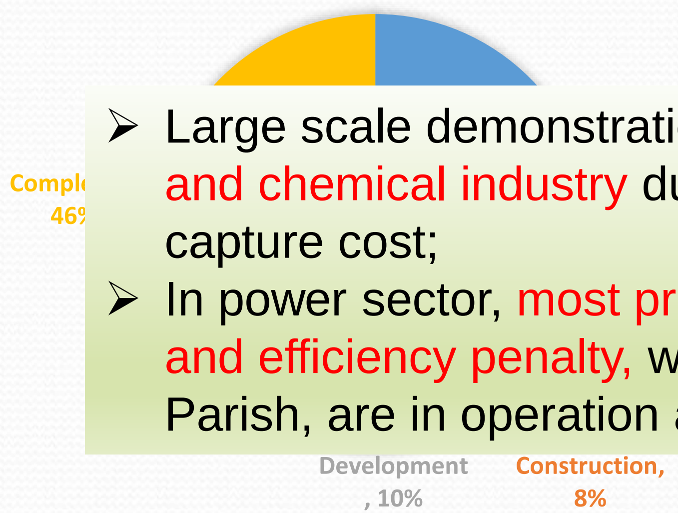


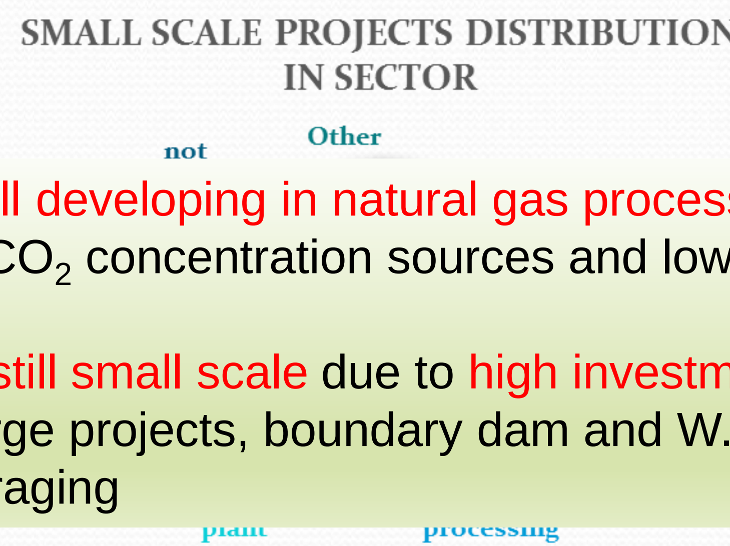


Overview of CCS demonstrations—Small scale projects



- ➢ 83 small scale demonstrations, and most located in North American, Europe and Asian
- ➢ Most projects are in operation, construction and completion
- ➢ 40% of the projects are in power generation plant





- ➢ Large scale demonstrations are well developing in natural gas processing and chemical industry due to high CO_2 concentration sources and low capture cost;
- ➢ In power sector, most projects are still small scale due to high investment and efficiency penalty, while two large projects, boundary dam and W. A. Parish, are in operation and encouraging

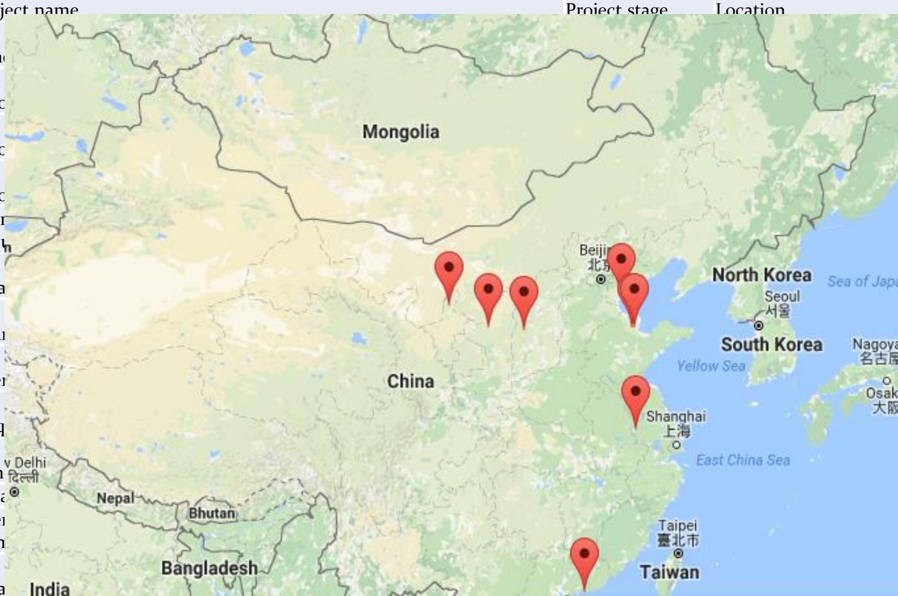
Overview CCS demonstrations in China

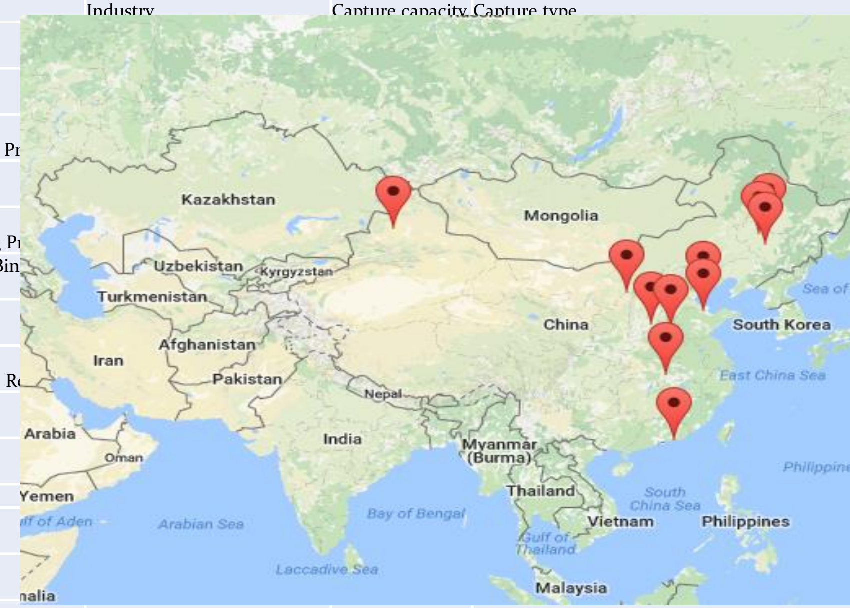
Capture:
~120 Mta

Transportation:
experiences over decades

Storage:
~120 Mta

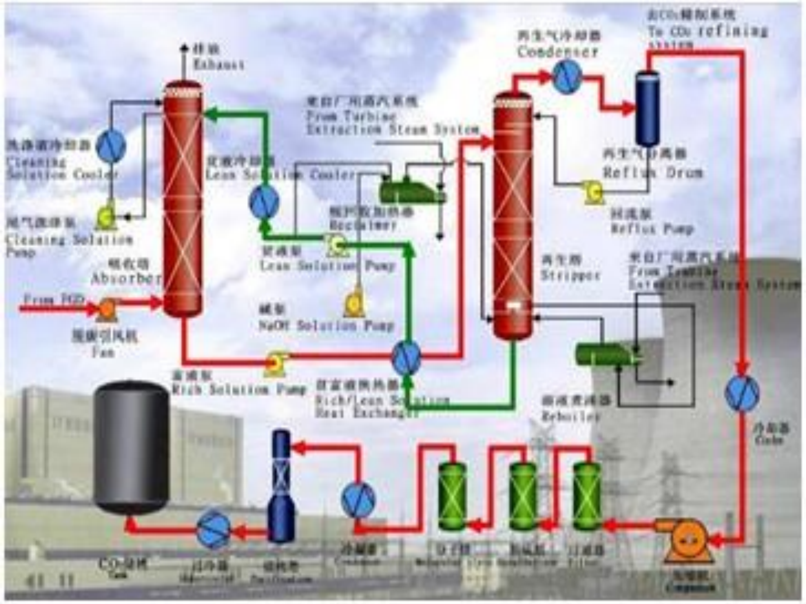
Project name	Project stage	Location	Industry	Capture capacity	Capture type
Sinopec Shengli Oilfield Carbon Capture Utilization and Storage Pilot				30,000 – 40,000	





- Capture covers post, pre and oxy combustion;
- Storage demonstration are mostly located nearby oil fields and coal beds;
- Three pilots in coal power plants are in operation, and one large scale full chain CCUS is in construction

Beijing Thermal Power plant post-combustion demonstration



Location: Beijing
Scale: 3000 tons/year, operated in 2008 and shutdown now
Investment: 28 million RMB

Flue gas components		
	N_2	65.6%
	O_2	5.7%
	CO_2	14.2%
	H_2O	14.5%
	SO_2	2×10^{-5}
Flowrates		2372 Nm³/h

CO2 product	
Capture rate	3000 tons/year
Pressure	1.3MPa
Purity	99.9%

Performance of CO2 capture unit	
Steam consumption	3.3~3.4GJ/tonCO_2 (1.3~1.5MPa 140~150℃)
Electricity consumption	150~200kWh/ton CO_2

Beijing Thermal Power plant post-combustion demonstration

	Base power plant	90% CO_2 capture
Fuel type	Shenfu bituminous	Shenfu bituminous
Ash	8%	8%
Sulfur	0.4%	0.4%
Heating value (lower)	23-24MJ/kg	23-24MJ/kg
Fuel input, MW	3945	3945
CO_2 capture rate		
CO_2 capture technology		MEA solvent absorption
CO_2 product pressure， MPa		10
Steam product, MW	1556[1]	1307-1315[2]
Gross power output, MW	845[1]	845
Net power output, MW	811[2]	811
Efficiency without capture,%	43.6[1]	
Thermal efficiency, %	60[1]	
CO_2 capture unit power consumption， MW		99-102
CO_2 compression work， MW		67-88
PC+CC power output， MW		621-645
Efficiency for PC+CC, %		31.1-32.3
Efficiency penalty for 90% CO_2 capture		11.3-12.5
CO_2 capture cost, RMB/ton		300-420

Efficiency penalty for 90% CO_2 capture: 11.3-12.5 percentage points

CO_2 capture cost: 44-62 $/ton

Shanghai Shidongkou post combustion capture demonstration

Location: Shanghai

Owner: Huaneng Group

Scale: 120000 tons/year

Investment: 150 million RMB

Flue gas treatment: 66000 Nm^3/h (4%)

CO_2 product	
CO2 capture rate	120000 tons/year
Pressure	1.3 MPa
Purity	>99.99%

Performance of CO2 capture unit	
Steam consumption	1.84 kg/kgCO_2, 3.0 GJ/ton
Power consumption	75 kWh/ton CO_2[2]
Solvent consumption	6 kg/ton-CO_2

Shanghai Shidongkou post combustion capture demonstration

	Base plant	90% CO_2 capture
Fuel input, MW	1573~1444	1444~1573
CO_2 capture rate		90%
CO_2 capture technology		Amine based solvent
Boiler type	Supercritical	Supercritical
CO_2 product pressure, MPa		10
Gross power output, MW	660	
Net power output， MW	634	
Efficiency, %	40.3%-43.9%[1]	
Power for CO_2 capture, MW		228.7
Power for CO_2 compression, MW		8.4
PC+CC net power output, MW		396.9
PC+CC efficiency, %		25.2-27.5
Efficiency penalty for 90% CO_2 capture		15-16
Investment, M$	396-462[2]	623-688[3]
Unit investment, M$/gross-kW	600-700	950-1050
CO_2 capture cost, RMB/ton		350-400

Efficiency penalty for 90% CO_2 capture: 15-16 percentage points
CO_2 capture cost: 51-59 $/ton

Chongqing Shuanghuai post combustion capture demonstration

Location: Chongqing, operated in 2010
Scale: 10000 tons/year

Flue gas treatment: 8400 Nm^3/h (1%)
Investment: 12.4 million

CO_2 product	
Capture rate	10000 tons/year
Purity	>99.9

Energy performance of CO_2 capture unit	
Steam consumption	3.9 GJ/ton CO_2
Power consumption	~150kWh/ton CO_2

Chongqing Shuanghuai post combustion capture demonstration

	Base plant	90% CO_2 capture
Fuel input, MW	1500~1544	1500~1544
CO_2 capture rate		90%
CO_2 capture technology		Chemical absorption
Boiler type	Subcritical	Subcritical
CO_2 product pressure, MPa		10
Gross power output, MW	2×300MW	2×300MW
Net power output, MW	576[1]	
Efficiency, %	37.3~38.4[2]	
Power for CO_2 capture, MW		90
Power for CO_2 compression, MW		50.6
Net power output for PC+CC, MW		435.4
Efficiency for PC+CC, %		28.2~29.0
Efficiency penalty for 90% capture		9.1~9.4
Investment, M$	459[2]	508~581[3]
Unit investment, M$/gross-kW	765	847~970
CO_2 capture cost, RMB/ton		400

Efficiency penalty for 90% CO_2 capture: 9.1-9.4 percentage points

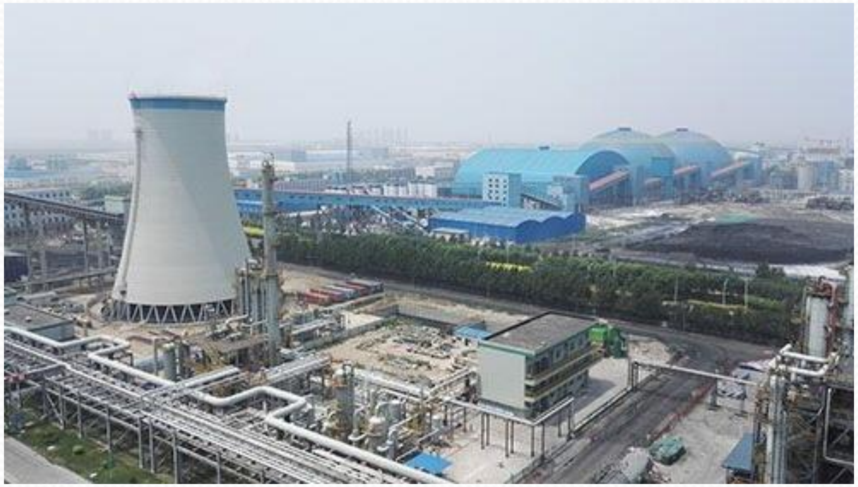
CO_2 capture cost: ~59 $/ton

Performance of China post-combustion projects

	Beijing thermal power plant		Shidongkou		Shuanghuai	
	Base plant	90% CO_2 capture	Base plant	90% CO_2 capture	Base plant	90% CO_2 capture
Coal input, MW	3945	3945	1444-1573	1444-1573	1500-1544	1500-1544
Boiler type			Supercritical	Supercritical	Subcritical	Subcritical
CO_2 product pressure, MPa		1.3		1.3		
Heat, MW	1556[1]	1307~1315[2]				
Gross power of ST, MW	845[1]	845	660		2×300MW	2×300MW
Net power output for base plant, MW	811[2]	811	634		576[1]	576
Power efficiency, %	43.6[1]	31.1-32.3	40.3%~43.9%	[illegible]	[illegible]	28.2-29.0
Efficiency penalty, %		11.3-12.5		[illegible]		9.1-9.4
COE $/MWh			***42.94-47.81***	***80.88-88.61***		
CO_2 capture cost, $/ton		44-66		52-62		59
Total investment, M$			396-462[2]	623-688[3]	459[2]	508-581[3]
Unit investment, $/kW			650-730	1570-1734	796	1167-1335

COE rises from ￥0.26~0.292/kWh to ￥0.493~0.54/kWh, CO_2 capture cost ranges from 44-66 $/ton

Tianjin IGCC pre-combustion capture demonstration



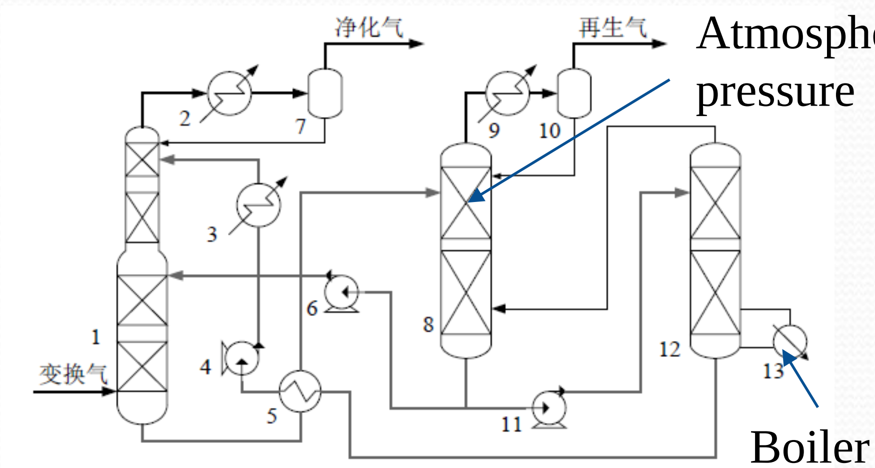
Location: Tianjin

Plant: 250 MW

Capture technology: MDEA absorption

Efficiency: ~41%

Scale: 100000 tons/year



Performance of sulfur and CO_2 removal unit				
	WGS	Sulfur and CO_2	Sulfur removal	CO_2 regeneration
Steam, t/h (0.57 Mpa, 163.2)		4.5	0.1	
Steam, t/h (4.85 Mpa, 263)	1.5			0.15

Tianjin IGCC pre-combustion capture demonstration

	Base plant	5% CO_2 capture	50% CO_2 capture	90% CO_2 capture
Fuel input, MW	595.2	595.2	595.2	595.2
CO_2 product pressure, MPa		10	10	10
Gas turbine power output, MW	191	190.1	182.2	175.0
Steam turbine power output, MW	94.74	93.3	79.9	68.0
Gross power output, MW	285.74	283.5	262.1	243
Net power output, MW	244.0	241.3	215.5	192.5
Efficiency, %	41	40.5	36.2	32.3
Efficiency penalty, %	-	**0.5**	**4.8**	**8.7**
Investment, M$	**~580**			
Unit investment, $/gross-kW	**~2030**			
CO_2 capture cost, RMB/ton				

Efficiency penalty for 90% CO_2 capture: 8.7 percentage points

CO_2 capture cost: ~59 $/ton

Large scale full chain project in construction

Location: Shaanxi Province, China

Scale: 0.41 Mt/year

CO_2 capture start date: started construction in 2017 for CO_2 captured from gasification facilities of the Yulin Energy Chemical Co. Ltd (0.36 Mtpa); operational in 2012 for CO_2 captured from gasification facilities of the Yulin Coal Chemical Co. Ltd (0.05 Mtpa)

CO_2 capture source: 50,000 tonnes per annum of CO_2 from gasification facilities of the Yulin Coal Chemical Co. Ltd, Yulin City, and 360,000 tonnes per annum of CO_2 from gasification facilities of the Yulin Energy Chemical Co. Ltd, Jingbian Industrial Park

Capture method: Absorption physical solvent-based process - Rectisol

Transportation: Tanker trucks plus pipeline (in planning)

Storage: Enhanced oil recovery, Primary injection site is the Jingbian producing unit of the Yanchang oil field (>100 kilometres southwest of Yulin city and in close proximity to Jingbian Industrial Park), Additional test volumes have been injected into the Wuqi producing unit (southwest of the Jingbian producing unit), and Injection is planned for the Xingzichuan oil field (105 kilometres southeast of Jingbian)

CO_2 storage activities in China

- Jilin Oil Field EOR Demonstration has been researching CO_2-EOR operations for a decade and has injected over one million tonnes of CO_2 into the Jilin oil complex.

- The Ordos Basin was the subject of a large demonstration scale project that injected around 300,000 tonnes of CO_2 over a three-year period.

- The Jingbian Qiaojiawa pilot test started in September 2012 and

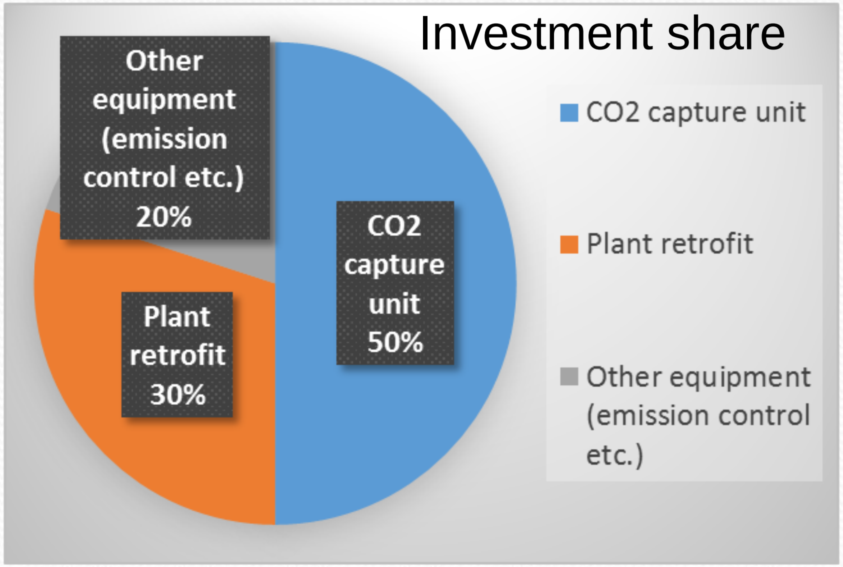
as of July 2014, the cumulative injected CO_2 reached 17,000 tonnes. After

expansion, the injected CO_2 may reach 200,000 tonnes per year, whereas stored CO_2 will reach 120,000 tonnes per year. Furthermore, Yanchang Petroleum started the second CO_2 storage and flooding test area in 2014 in Wuqi Shaanxi to carry out miscible-phase flooding experiments

Boundary Dam post-combustion CO_2 capture project

Operation in 2014. 10

- Location: Boundary Dam
- Capacity after retrofit: 160 MW
- Capture rate: 1 Mt/year
- CO_2 utilization: EOR in Weyburn
- Final investment: $1.5 billion



Boundary Dam post combustion demonstration

Parameters before retrofit	
Fuel type	Saskatchewan lignite
Fuel input, MW	397.1
Boiler type	Subcritical
Steam turbine	150MW
Steam	12.5Mpa/538℃/538℃
Gross power, MW	150
Net power, MW	139
Net efficiency, %	35.5
CO_2 emissions, Mt/y	110
COE, $/kWh[4]	0.091-0.125

Parameters after retrofit	
Fuel type	Saskatchewan lignite
Fuel input, MW	397.1
Steam turbine	Hitachi 160MW
Steam	29Mpa/593℃/621℃
Gross power, MW	162
Net power, MW	150
Net efficiency, %	37.8
CO_2 emissions, Mt/y	110

Retrofit plant with CO2 capture	
Fuel type	Saskatchewan lignite
Fuel input, MW	397.1
CO_2 capture rate	1 Mta
CO_2 capture technology	Cansolv amine-based
Steam parameter w/o retrofit	12.5MPa/565℃/565℃
Net power w/o retrofit, MW	95
Net efficiency w/o retrofit, %	23.9
Steam parameter w retrofit	29 MPa/593℃/621℃
Net power w retrofit, MW	110
Power for CO_2 compression，MW	9
Power for CO_2 capture， MW	14
Net efficiency for retrofit plant， %	27.7
CO_2 storage	Weyburn EOR
Total investment	1.50 billion
Unit investment, $/kW- gross	9375
Unit investment, $/kW- net	13636
Annual investment, M$	180[1]
Annual O &M cost, M$	60[2]
Annual fuel cost, M$	8.6[3]
COE, $/kWh	0.303
CO_2 capture cost, $/t	100-155

Performance comparison between post-combustion projects

Project	Capture scale, Mt/y	Efficiency penalty	Investment cost $/kW-net	CO_2 Capture cost $/t
Boundary Dam	1.0	10-14	~13636	100-155
W.A. Parish	1.6	12.4-13.2	4887-5253	110-120
ROAD	1.1	10.7	2190-2339	52-61
Trailblazer	5.1	13.2-14.5	2422-2886	50-60
China (estimated)	1.3	9.1-16.0	1200-1750	44-66

Efficiency penalty: 10.0-14.5 percentage points

Unit investment: 2200-13636 $/kW, Capture cost: 50-130$/t

Energy penalty from engineering projects agree well with literature review, but the investment is high beyond

Kemper County IGCC demonstration

Approved in 2006, construction began in 2010

Canceled in 2017

- Location: Kemper county
- 582MW;
- 67% CO_2 capture rate:

  300 Mta CO_2
- CO_2 storage: EOR
- Total investment until 2017:

  ~7.5 billion

Techno-economic evaluation of Kemper IGCC project

Kemper County IGCC+CC				
	50% capture	65% capture	67% capture	90% capture[1]
Fuel type	Lignite	Lignite	Lignite	Lignite
CF	0.85	0.85	0.85	0.85
LHV, kJ/kg	10736.8~13228.7	10736.8~13228.7	10736.8~13228.7	10736.8~13228.7
Fuel input, MW (LHV)[2]	1868.38	1907.44	1912.59	2059.45
Syngas LHV, MW	1181.75	1230.2	1209.71	1302.60
Cold gas efficiency (LHV), %	63.25	63.25	63.25	63.25
Net output, MW[3]	582	582	582	582
Net efficiency (LHV), %	31.15	30.51	30.43	28.26
Efficiency penalty		5.0-6.3		7.2-8.5
Total investment, M$[4]		7500		
Unit investment, $/kW		~12886		

Technical and economic performance of pre-combustion capture

Project name	Scale, Mt/y	Efficiency penalty (90% capture)	Investment $/kW
Kemper County	3.5	7.2-8.5	12886
Huaneng IGCC	2.0	8.7	~2000 (without CO_2 capture)

- Efficiency penalty: 7.2-8.5 for 90% capture, obvious lower than post-combustion
- Investment: 12886 $/kW (Tianjin IGCC is around 2000 $/kW without capture)
- CO_2 capture cost: 75-80 $/t

Evaluation results of DOE Future Electricity 2.0 Oxy-fuel demonstration project

	Base plant	Futuregen 2.0
Location	—	Meredosia, Illinois
Fuel type	PRB	60% Illinois 6 and 40% PRB
Fuel consumption	2346 ton/d	1149 ton/d and 766 ton/d
Capacity factor	85%	85%
Coal input, HHV, MW		460.5
Coal input, LHV, MW, MW[1]	543-576	426.4
CO_2 capture rate		1.1 Mta
Storage type		Morgan aquifers
CO_2 product pressure, MPa		14.5
Transportation pressure, MPa		8.3-14.5
Gross power, MW	200	168
Net power, MW[2]	190	99
Net power efficiency (LHV)[3]， %	33-35	23.2
Efficiency penalty		**9.8-11.8**
Total investment, M$	815-864	1202.5
Unit investment, M$/gross-kW	1500[4]	**7176**
Annual investment[5]， M$	98-104	144.3
Annual O&M [6]， M$	33-35	48.1
Annual fuel cost [6]， M$	13.8-14.6	13.9
COE, $/kWh	0.109-0.116	0.28
CO_2 capture cost， $/t		**109-114**

Technical and economic performance of Oxy-fuel technology

Project name	Capture scale, Mt/y	Efficiency penalty for 90% capture	Investment, $/kW	CO_2 capture cost, $/t
OXYCFB300 Compostilla	1.1	13		
Futuregen 2.0	1.1	9.8-11.8	7176	109-114
China oxy-combustion (based on Huazhong 35MW_{th} pilot)	1.0	8-12	-	35-50 (estimated)

Efficiency penalty: 9.8-13 for 90% CO_2 capture, slightly better than post-combustion

Investment: 7176$/kW

CO_2 capture cost: 109-114$/t-$CO_2$

2. Problems and lessons of current CCS demonstration

Problems and lessons from early CCS demonstration

1. For coal-relied China, CCS can make great contribution to CO_2 reduction.
2. The deployment of the CCS is behind expectation, and the cost of demo projects are far beyond the theoretical prediction. Rather high cost is the main barrier for CCS deployment.
3. The cost of domestic projects are much lower than that of international projects. Even so, the additional energy consumption and cost are unacceptable to key stakeholders.
4. To the present, there is no success international demo that China can follow. China has to find it’s own path.

Problems and lessons from early CCS demonstration

5. Without public funding, the first large scale demonstration in power plant in China is hard to start, while the policy makers are getting negative effects from current operational projects.

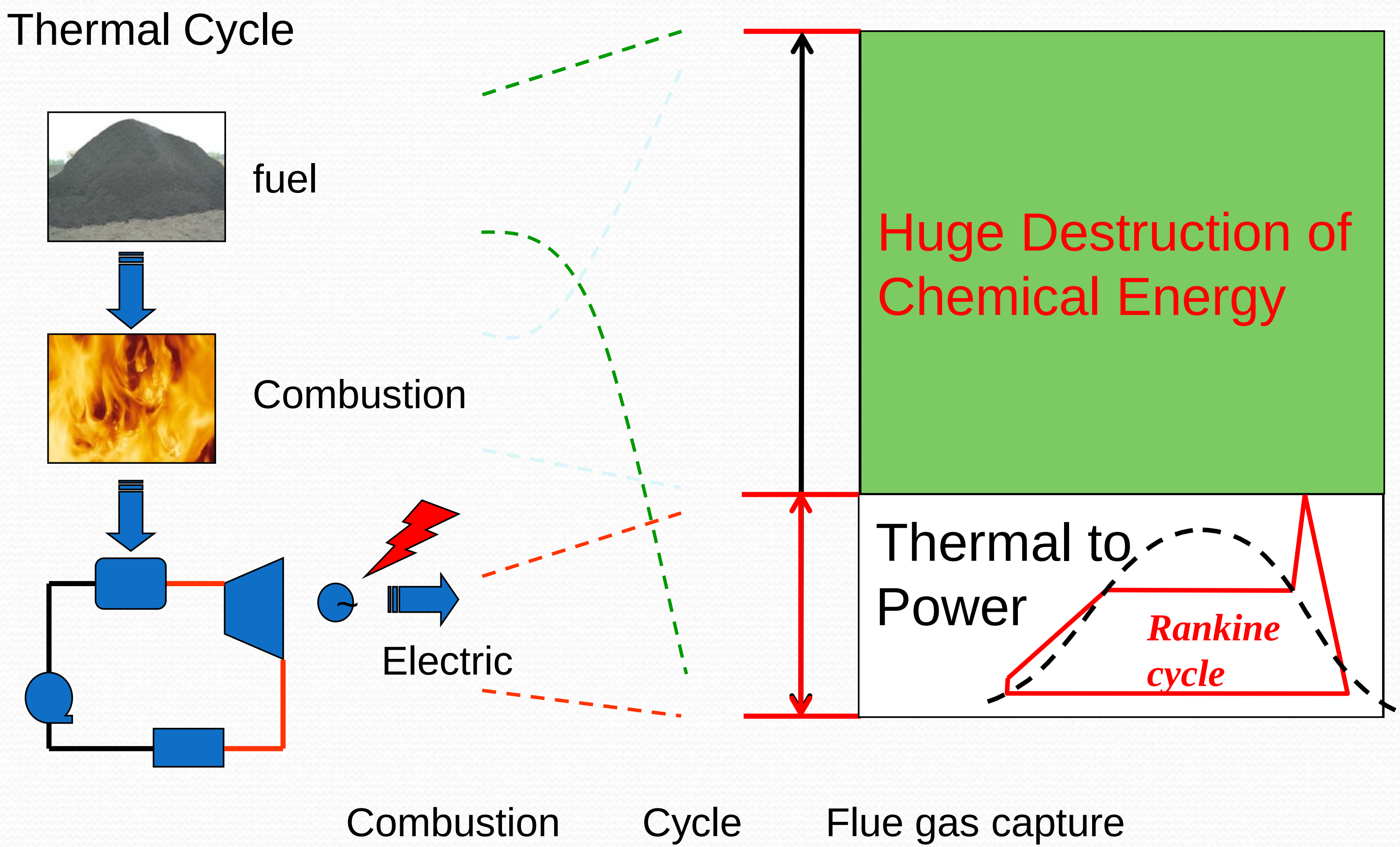
6. To avoid the situation of Demo to Death, low cost should be the main criterion for early demo selection. Early opportunities combining high purity sources and utilization sink should be demonstrated first and then followed by power plant.

7. CCS demonstration should distinguish technology investment and non-technology investment, the addition of non-technology investment may make the total CCS cost extremely high and keep the stakeholders away.

3. Technical Path Suitable for China

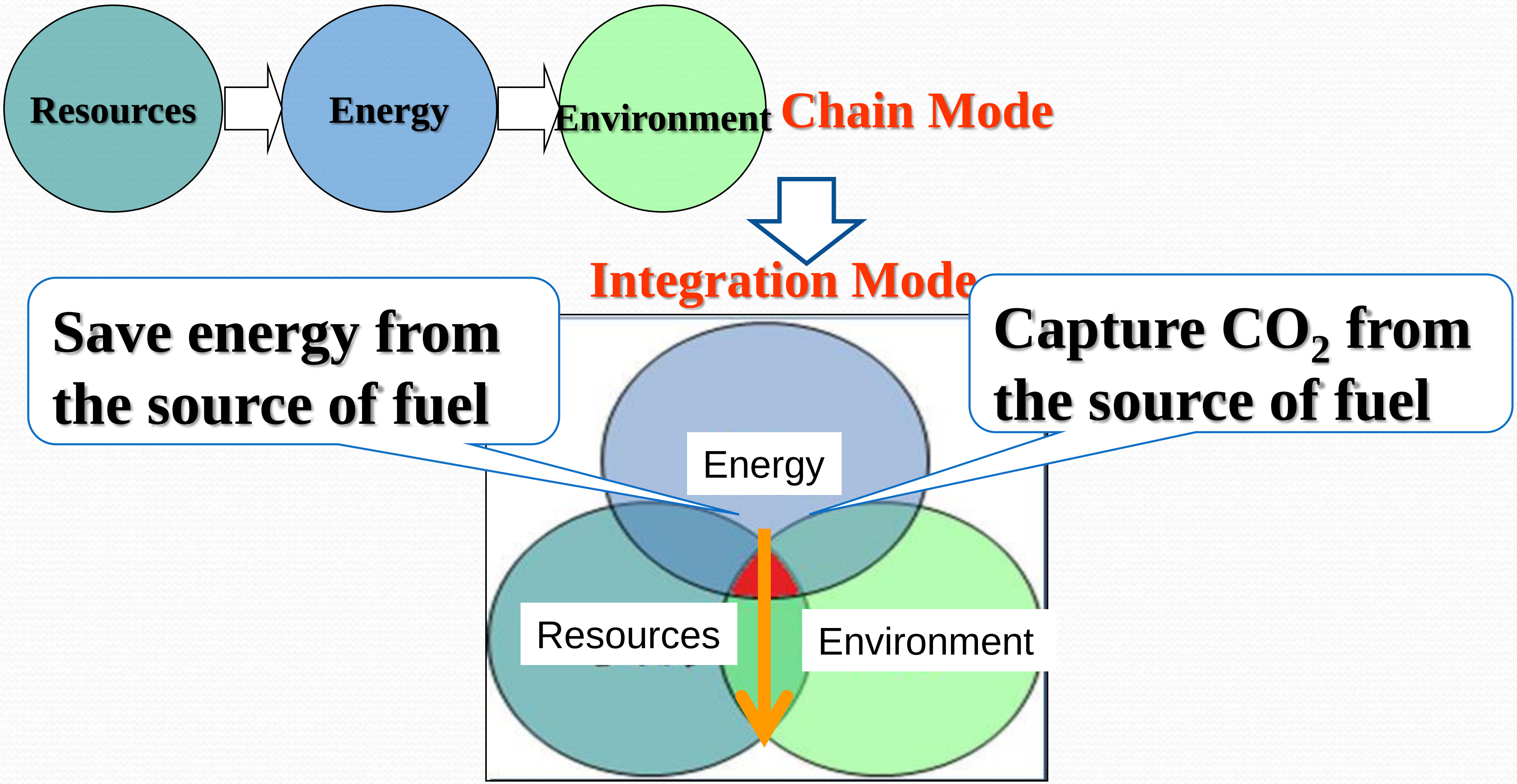
1. The internal problem of existing CCS technologies
2. Revolution of low-carbon utilization of coal
3. New generation CCS technologies suitable for China

The Internal Problem of capturing CO_2 from Power cycle



fuel chemical energy → thermal → power → sacrifice as penalty

Integration mode of resources, energy and environment

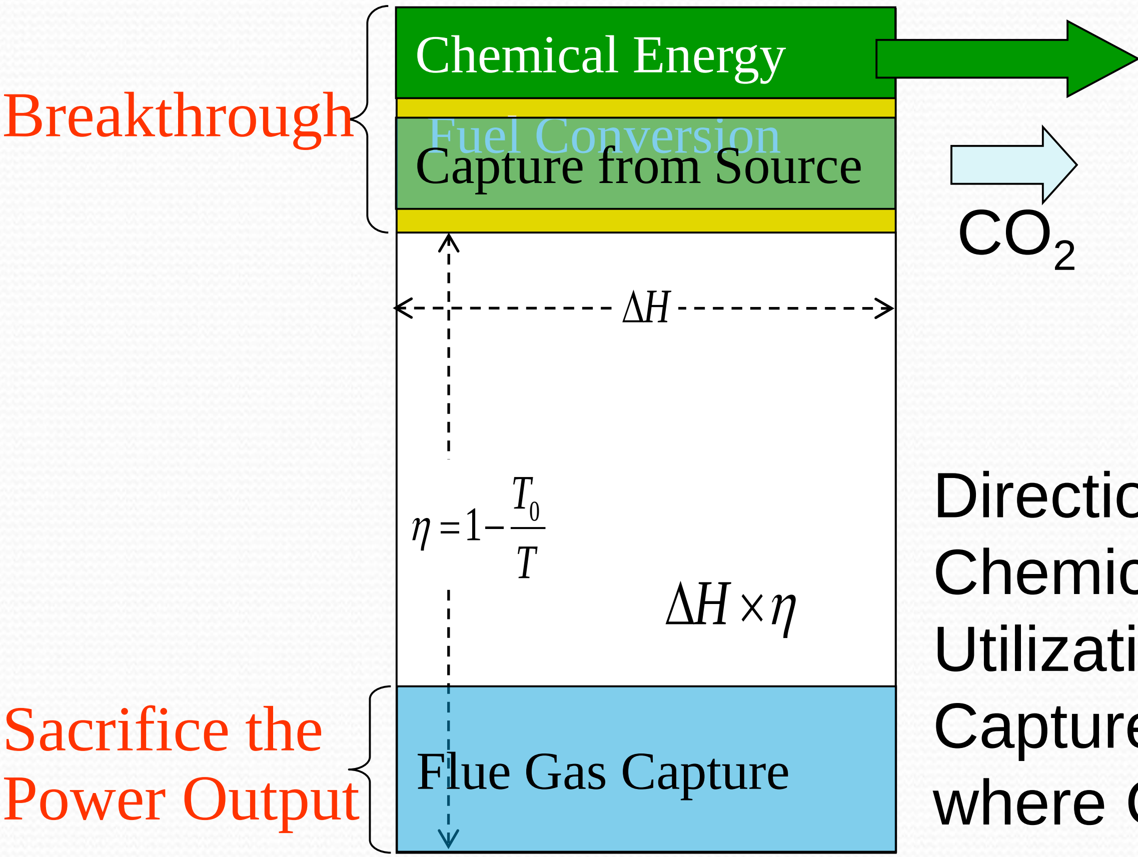


China need revolutionary mode

integrating resources, energy and environment

From Chain mode to Integration mode

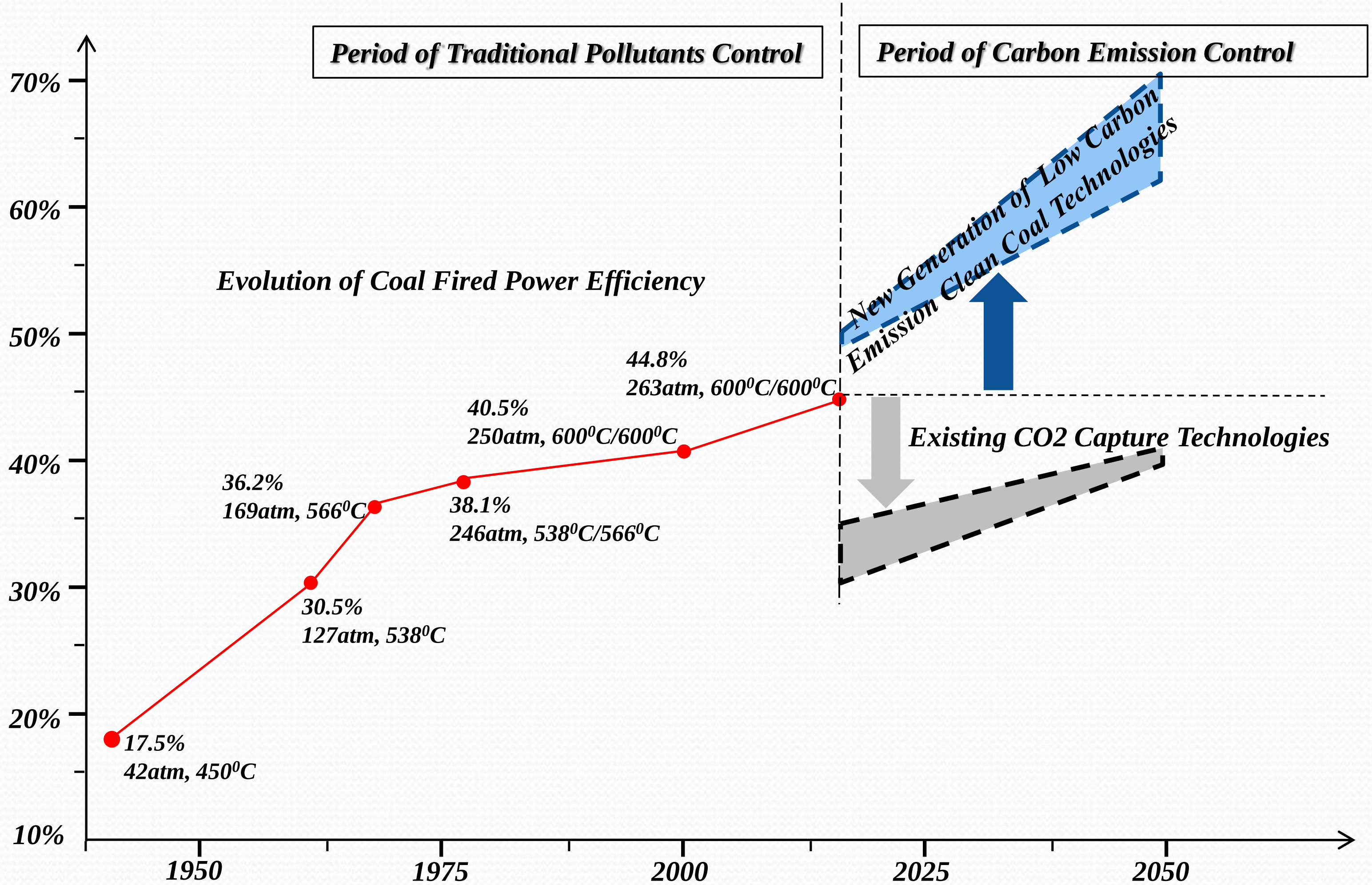
from Flue gas to Fuel source



Capture CO_2 from fuel source with chemical energy as driving force

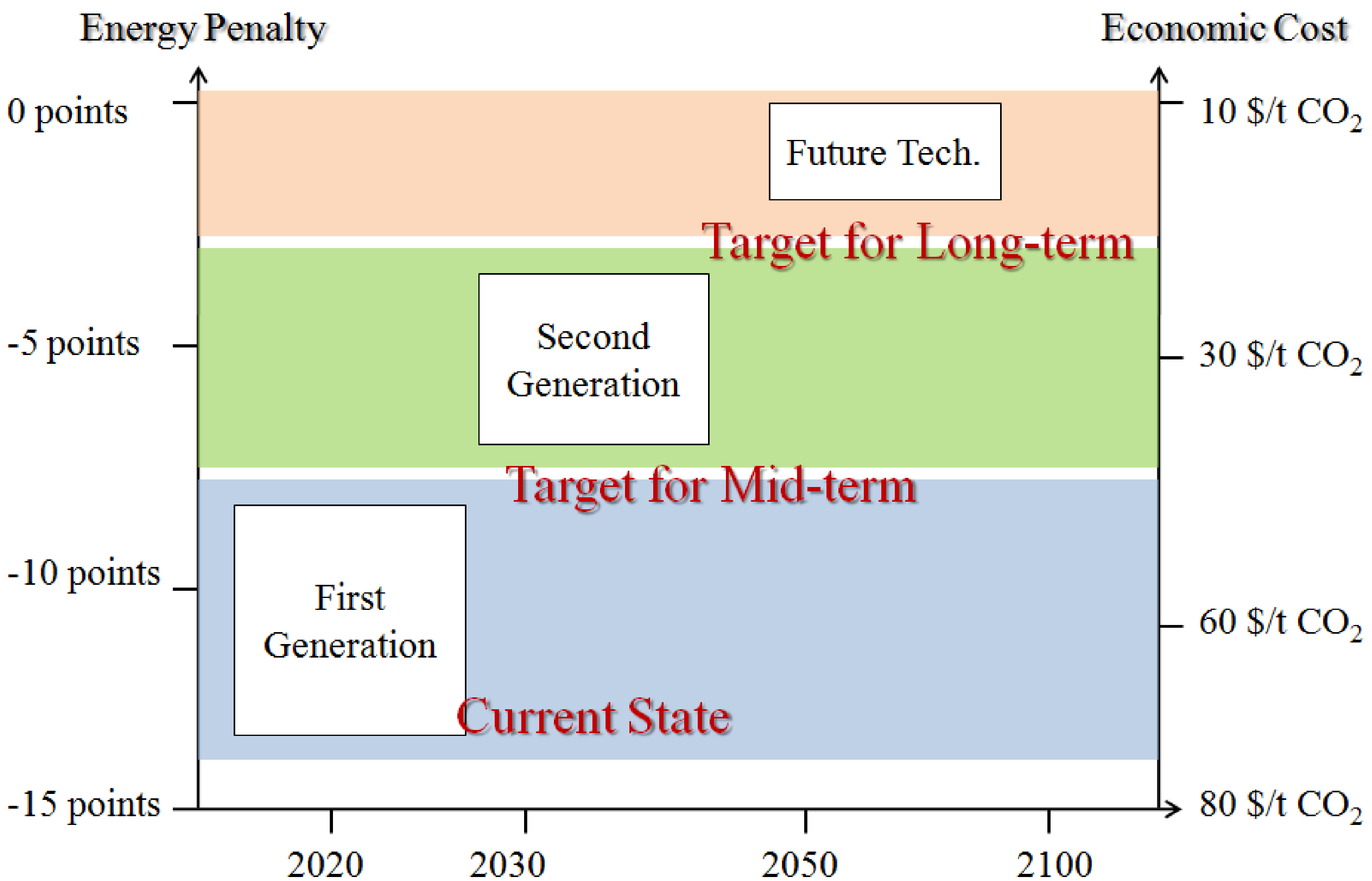
Direction:
Chemical Energy Cascade Utilization before combustion
Capture CO_2 from the fuel source where CO_X is concentrated

New generation of Low-carbon coal technology

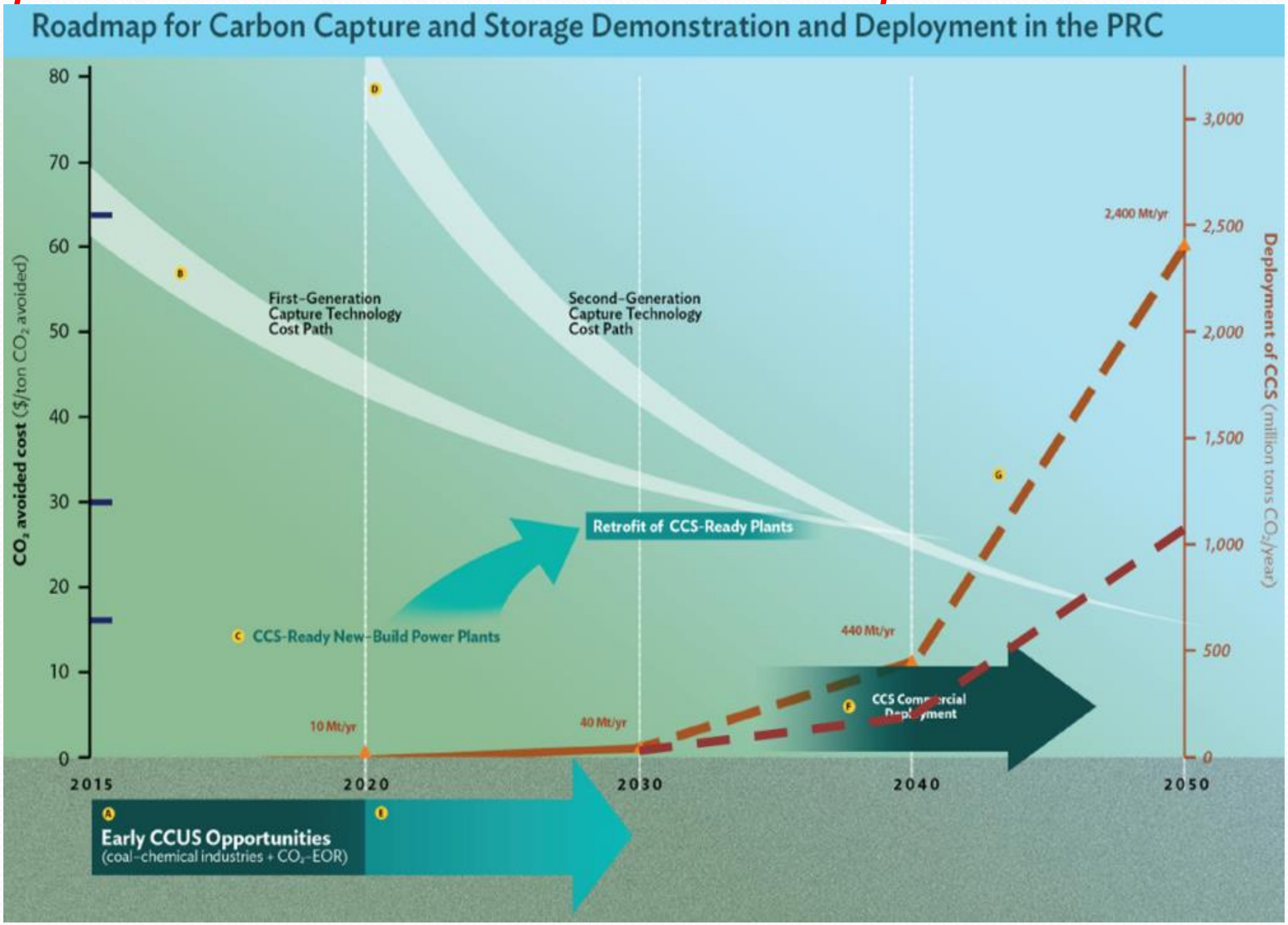


Solve the conflict between CO_2 capture and efficiency

The techno-economic targets for future CCS projects



Proposal of National CCS Roadmap for China



Supported by NDRC and ADB, Issued in COP21 Paris

Concluding remarks and recommendations

1. CCS should not just be recognized as the specific technology for climate change mitigation. It should also be the breakthrough to promote technology revolution and upgrade of energy industry.
2. High cost is still the main barrier of CCS demonstration, and the cost of demo projects are far beyond the theoretical prediction. The internal reason for the high cost should be revealed before more demo projects are built.
3. Post combustion is essential for existing power plant retrofit with CO_2 capture, but for the new power plant, it calls for new generation of CCS technology.

Concluding remarks and recommendations

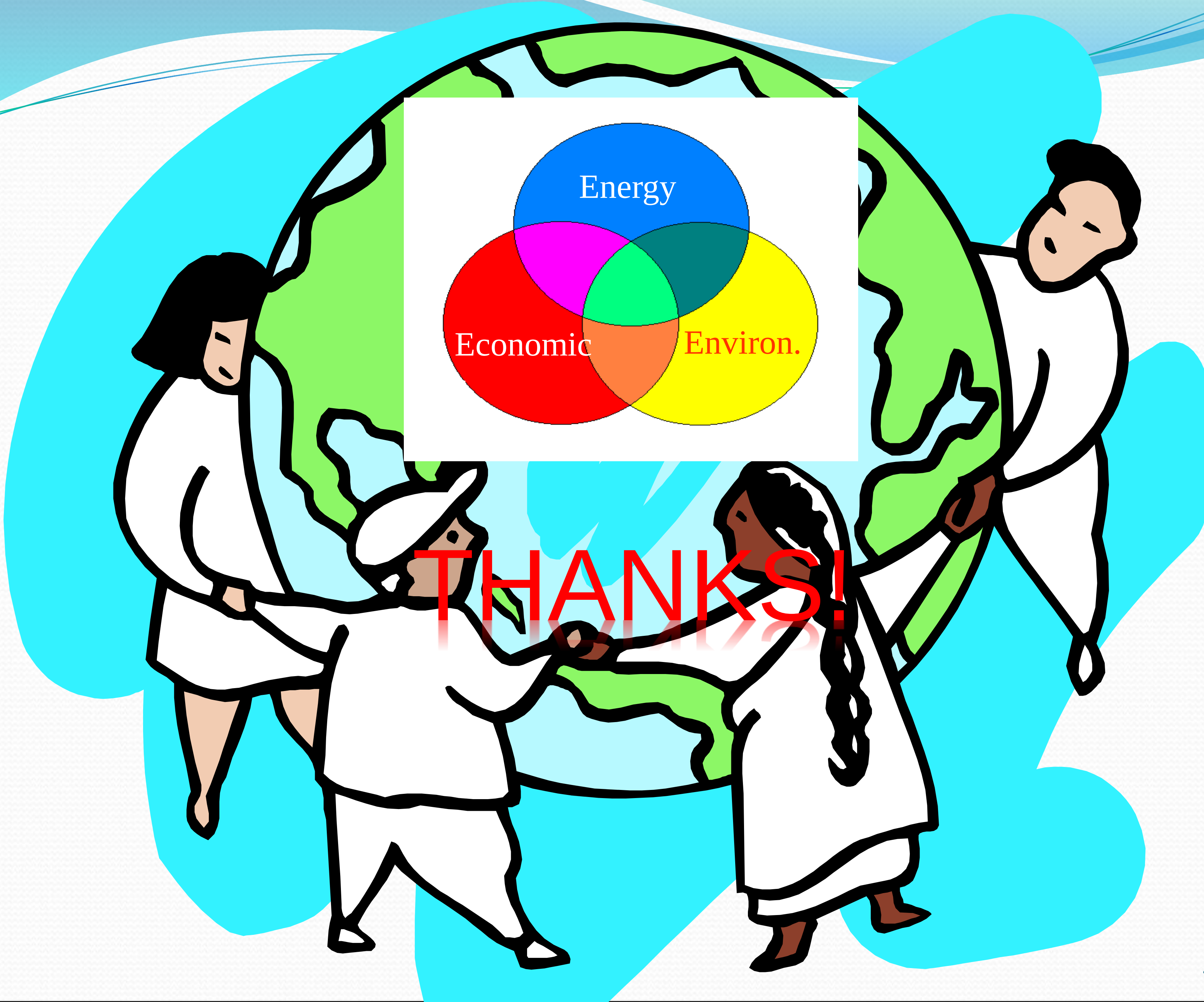
Near term demonstration projects:

- Build a national data base of current and planned CCS projects. Develop and publish principles for early demonstration projects assessment and support.
- Reinforce regulations and support policies. During 2020~2030, regulations, support policies, and technical standards for CCS projects and CO_2-EOR operations will need further refinement.
- Select and endorse priority regions, including the Ordos Basin, the Songliao Basin in Northeastern PRC, the Jungar Basin in Northwestern PRC, and the Tarim Basin.
- Provide fiscal and financial support for first-mover projects, like direct capital grants, resource tax relief specific for EOR, an electricity price subsidy and tax relief, government-supported contract-for-difference (CFD), etc..
- For the 2015~2020 period, the targeted outcomes should therefore be 5~10 CCS demonstration projects in the coal chemical sector and 1~3 projects in the power generation.

Concluding remarks and recommendations

Mid and long term deployment of CCS:

- Encourage international technology transfer. Set up a dedicated international fund to support research and development of key technologies of common international interest.
- Provide continuing national support for RD&D of technologies suitable for China. Revolutionary technologies such as chemical looping combustion and poly-generation system are expected to become commercially viable by 2030~2040.



THANKS!

Overview CCS demonstrations in China

Capture: ~120 Mta

Transportation: Experiences over decades

Storage: ~120 Mta

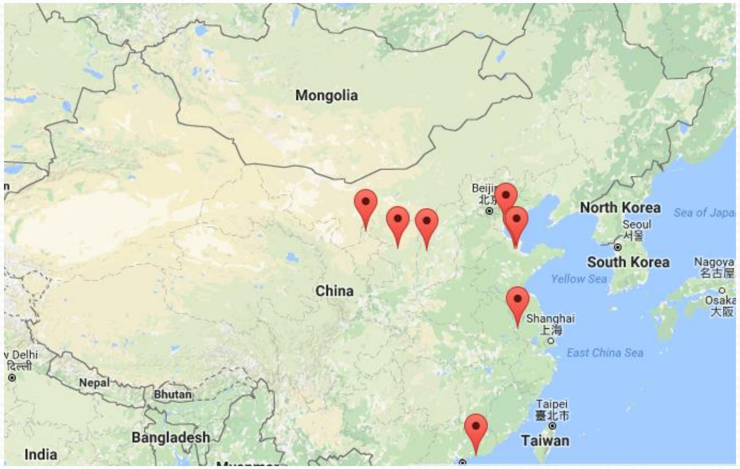
- Beijing thermal power plant post combustion capture
- Shanghai Shidongkou post combustion capture
- Chongqing Shuanghuai post combustion capture
- Tianjin IGCC pre-combustion capture
- Beijing Gaojing NGCC post combustion capture
- Hubei 30 MWth oxy-combustion capture
- Yanchang CO2 capture from chemical plant

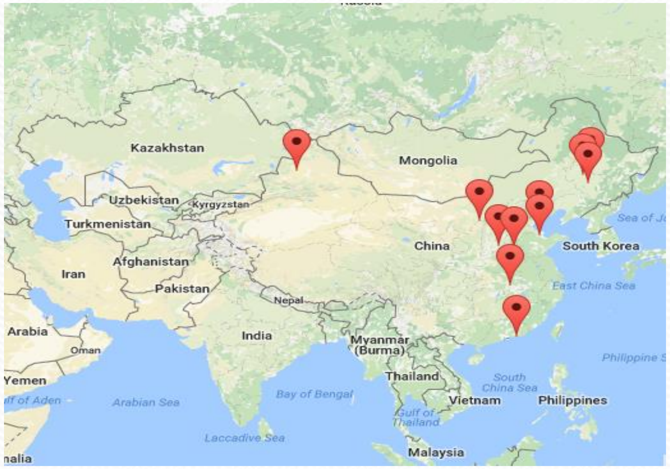
Storage activities:

- Jilin Oil Field EOR Demonstration has been researching CO_2-EOR operations for a decade and has injected over one million tonnes of CO_2 into the Jilin oil complex.
- The Ordos Basin was the subject of a large demonstration scale project that injected around 300,000 tonnes of CO_2 over a three-year period.
- The Jingbian Qiaojiawa pilot test started in September 2012 and as of July 2014, the cumulative injected CO_2 reached 17,000 tonnes. After expansion, the injected CO_2 may reach 200,000 tonnes per year, whereas stored CO_2 will reach 120,000 tonnes per year. Furthermore, Yanchang Petroleum started the second CO_2 storage and flooding test area in 2014 in Wuqi Shaanxi to carry out miscible-phase flooding experiments

Project name	Project stage	Location	Industry	Capture capacity	Capture type
Yanchang Integrated Carbon Capture and Storage Demonstration	In Construction	Shaanxi Province	Chemical Production	0.4 Mtpa	Industrial Separation
Sinopec Qilu Petrochemical CCS	Advanced Development	Shandong Province	Chemical Production	0.5 Mtpa	Industrial Separation
Sinopec Shengli Power Plant CCS	Advanced Development	Dongying City, Shandong Province	Power Generation	1 Mtpa	Post-combustion capture
Sinopec Eastern China CCS	Early Development	Jiangsu Province	Fertiliser Production	0.5 Mtpa	Industrial Separation
China Resources Power (Haifeng) Integrated Carbon Capture and Sequestration Demonstration	Early Development	Shanwei City, Guangdong Province	Power Generation	1 Mtpa	Post-combustion capture
Huaneng GreenGen IGCC Large-scale System (Phase 3)	Early Development	Lingang Industrial Park, Binhai New Area, Tianjin	Power Generation	2 Mtpa	Pre-combustion capture (gasification)
Shanxi International Energy Group CCUS	Early Development	Shanxi Province	Power Generation	2 Mtpa	Oxy-fuel combustion capture
Shenhua Ningxia CTL	Early Development	Ningxia Hui Autonomous Region	Coal-to-liquids (CTL)	2 Mtpa	Industrial Separation
Daqing Oil Field EOR Demonstration Project	Operational	Heilongjiang Province	Various, including natural gas processing	200,000 tpa	Pre-combustion capture (for natural gas processing capture component)
Jilin Oil Field EOR Demonstration Project	Operational	Jilin Province	Natural gas processing	300,000 – 330,000 tpa	Pre-combustion capture (natural gas processing)
Karamay Dunhua Oil Technology CCUS EOR Project	Operational	Karamay city	Chemical production	100,000 tpa	Industrial separation
Shenhua Group Ordos Carbon Capture and Storage (CCS) Demonstration Project	Completed	Inner Mongolia	Coal-to-liquids (CTL)	100,000 tpa	Pre-combustion (cryogenic)
Huaneng GreenGen IGCC Demonstration-scale System (Phase 2)	In Construction	Tianjin	Power generation	60,000 - 100,000 tpa	Pre-combustion capture (gasification)
Sinopec Shengli Oilfield Carbon Capture Utilization and Storage Pilot Project	Operational	Shandong Province	Power generation	30,000 – 40,000 tpa	Post-combustion
Sinopec Zhongyuan Carbon Capture Utilization and Storage Pilot Project	Operational	Henan Province	Chemical production	120,000 tpa	Industrial separation
Haifeng Carbon Capture Test Platform	In Construction	Guangdong Province	-	25550 tpa	-
Huazhong University of Science and Technology Oxy-fuel Project	In Construction	Hubei Province	-	100,000 tpa	Oxy-fuel combustion
Australia-China Post Combustion Capture (PCC) Feasibility Study Project	Advanced Development	Jilin Province	Power generation	1 Mtpa	Post-combustion
China Coalbed Methane Technology Sequestration Project	Completed	Shanxi Province	-	-	-
Huaneng Shidongkou post combustion	Operational	Shanghai	Power generation	120000 tpa	Post-combustion
Huaneng Beijing Thermal power plant	Operational	Beijing	Power generation	3000 tpa	Post-combustion
Chongqing Shuanghuai power plant	Operational	Chongqing	Power generation	10000 tpa	Post-combustion
Beijing Gaojing NGCC power plant	Construction finished	Beijing	Power generation	1300~1500 tpa	Post-combustion

Overview CCS demonstrations in China

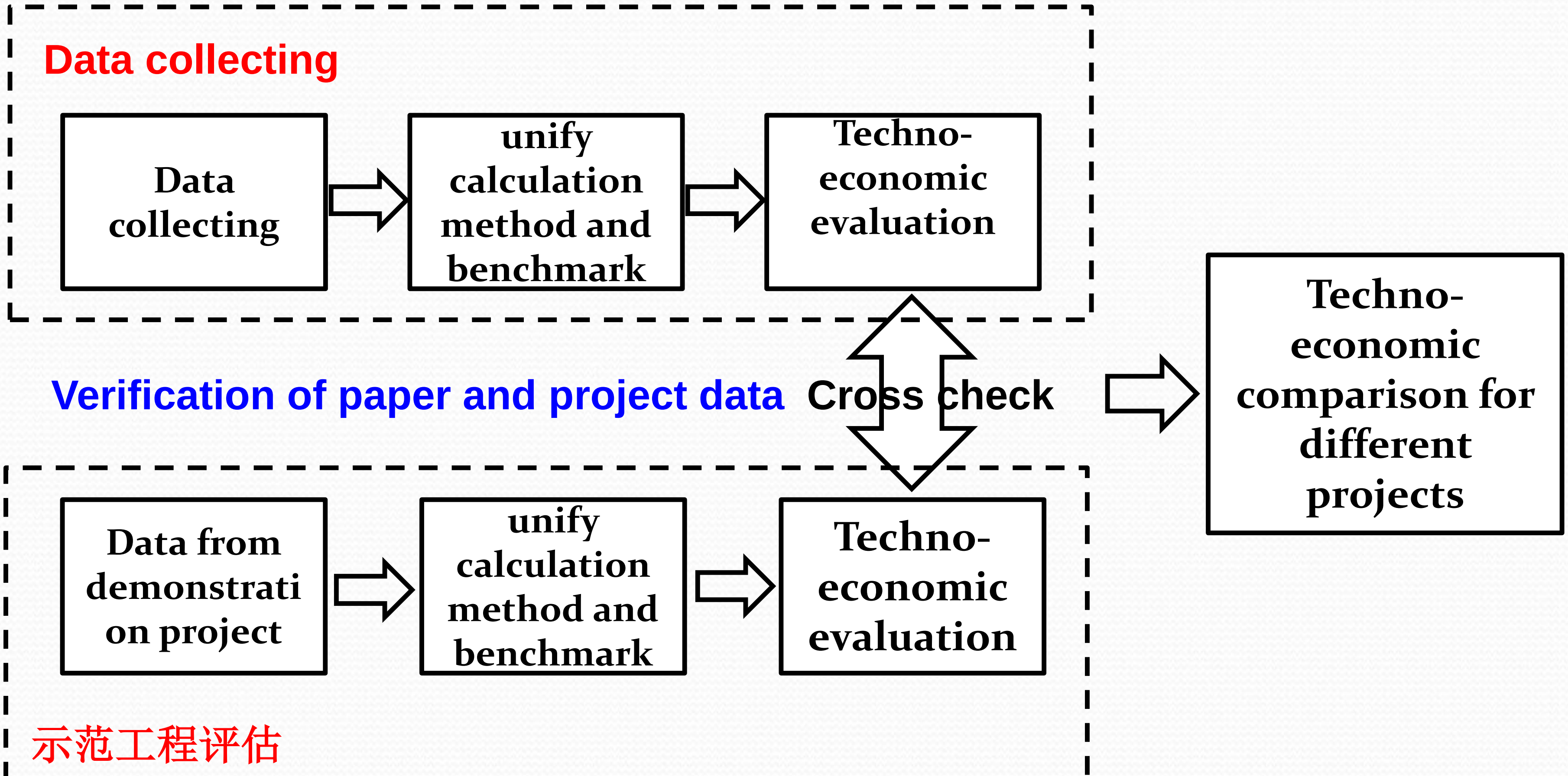




	Project name	Location	Scale, Mt/year	Stage	Industry	Capture type	Storage type
1	Yanchang Integrated Carbon Capture and Storage Demonstration	Yanan	0.41	In construction	Chemical production	Industrial separation	EOR
2							

Evaluation of energy consumption and CO_2 capture cost in power sector

Data from different sources or projects are hard to compare due to different plant scales, CO_2 capture rate, with or w/o compression, assumptions etc.



Comparable analysis and Identify of literature data

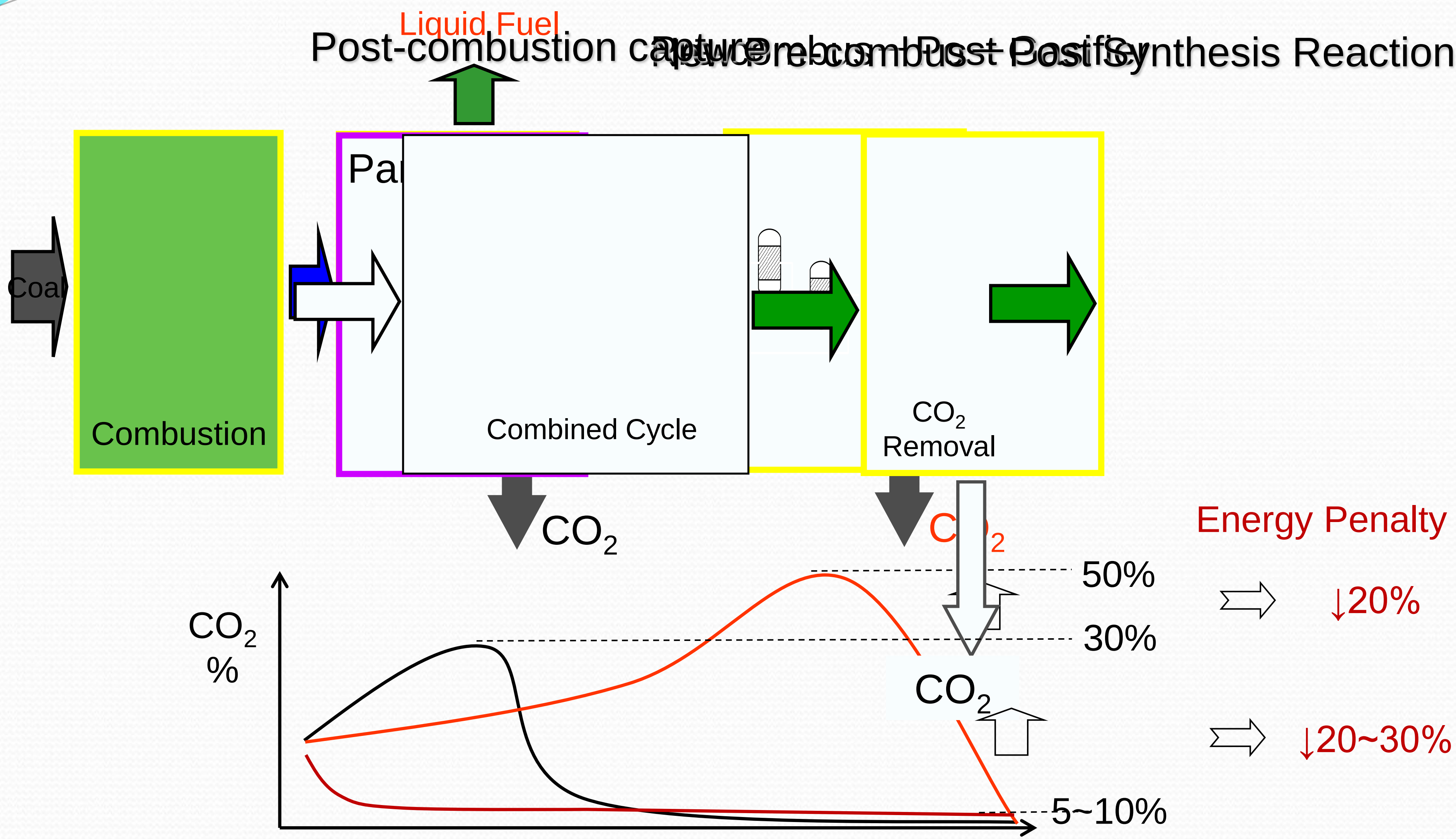
技术指标		可比性要求
发电技术	机组容量	同一捕集技术类型可比，不同捕集技术类型间规模需统一
	燃料种类	褐煤比烟煤的效率代价高 0.6~1.1 个百分点，不同捕集技术对比需统一
CO2 捕集技术	CO2 压力和纯度	统一为 100bar，98%的纯度
	分离工艺	根据最优化原则，燃烧后捕集采用 MEA，燃烧前捕集采用 Selexol
	捕集率	统一为 90%的捕集率
	系统集成水平	蒸汽系统热集成优化
评价方法	参比系统定义	改造机组以改造前机组额定工况为基准，新建机组以同级发电系统为基准
	效率计算方法	统一蒸汽、冷却水消耗等的折算方法

Comparison of efficiency penalty for different CO_2 capture technologies

Type	Post combustion			Post combustion (retrofit)			NGCC	IGCC Pre combustion			Oxy
	Subcritical	Supercritical	Ultra	Subcritical	Supercritical	Ultra		Shell	GE	E-GAS	
Capture technology	MEA			MEA			MEA	Selexol			—
CO_2 capture rate	90%			90%			90%	90%			90%
CO_2 pressure	10MPa			10MPa			10MPa	10MPa			10MPa
Efficiency decrease, %	**10.6—10.7**	**9.8—12.0**	**8.3—12.3**	**10.9—15.1**	—	—	**7.7—10.7**	**7.3—9.1**	**5.2—8.0**	**6.5**	**8.8**
Efficiency decrease, %	**10.2—11.5**	**10.0—12.1**	**9.0—12.4**	**—**			**6.1—10.9**	**8.8—11.7**	**5.7—7.8**	**9.3**	**7.7—12.5**

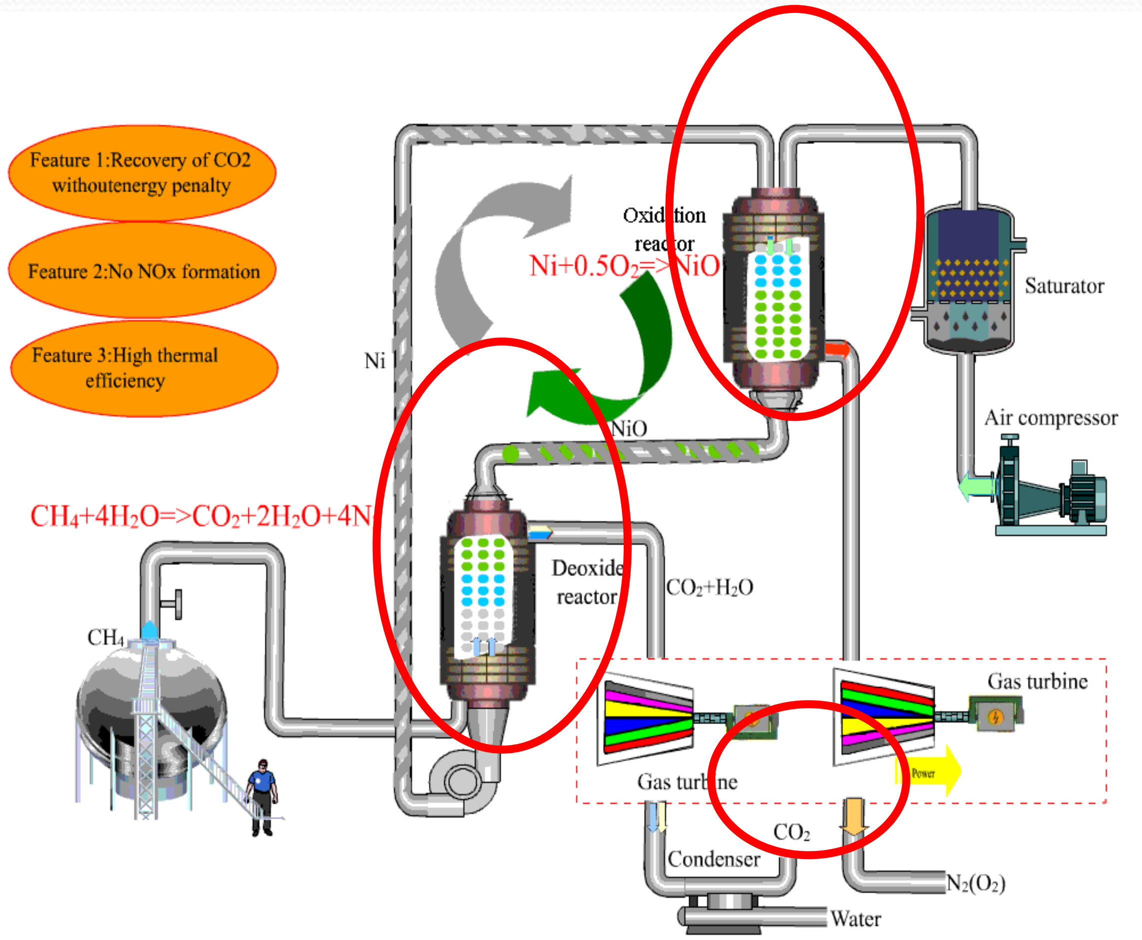
1. Original data source: IPCC special report, 2005
2. Original data source: IEA cost evaluation of CCS, 2012

Polygeneration system for alternative fuel and power with CO_2 recovery

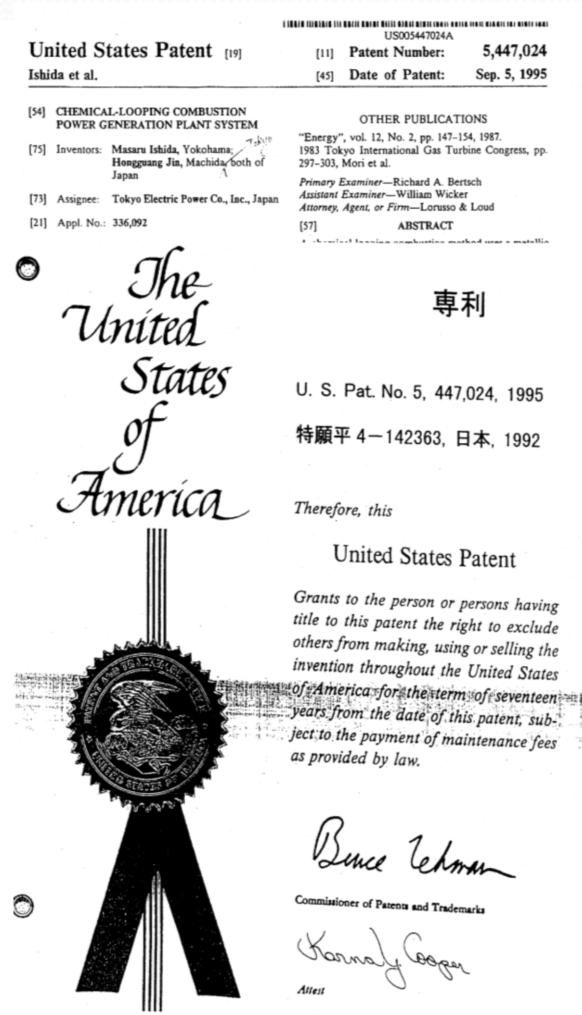


The energy efficiency has been increased 3~4 percent points, instead of losing 7~10 percent points.

Zero Penalty-Chemical Looping Combustion

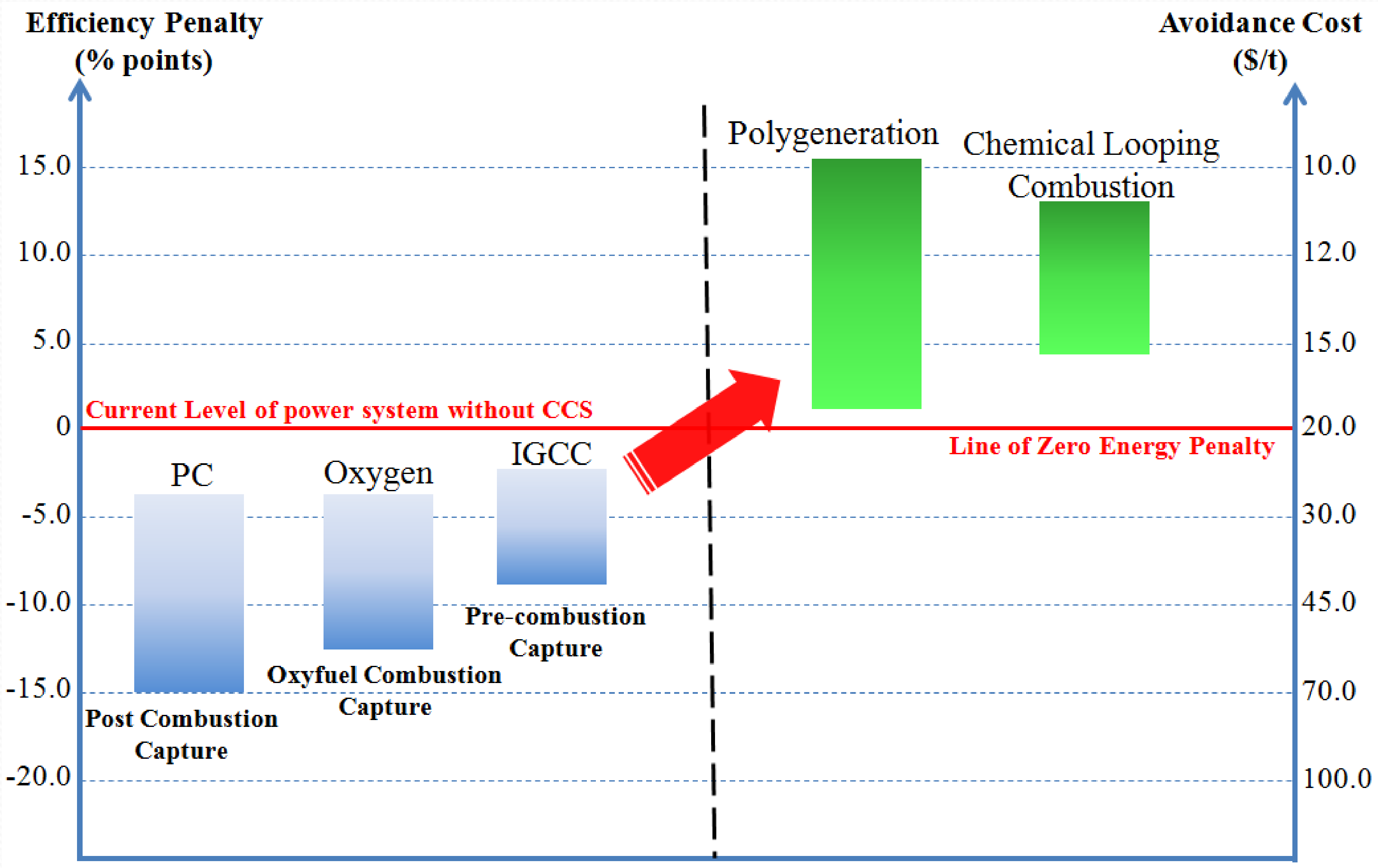


Concept flowsheet of gas turbine cycle with chemical looping combusiton



Patent by U.S.A and Japan

Revolutionary impact on Energy & Environment of China



Resolve the conflict between energy saving and CCS

20% for the sulfur removal unit investment, estimated

(数据来源：中电联发布《2016-2017年度全国电力供需形势分析预测报告》)。

2016年底，全国全口径发电装机容量16.5亿千瓦，同比增长8.2%,其中可再生能源电力总装机6.0亿千瓦。全年全国全口径发电量5.99万亿千瓦时、同比增长5.2%；发电设备利用小时3785小时、同比降低203小时。2016年全国净增发电装机容量1.2亿千瓦，其中净增非化石能源发电装机7200万千瓦。

2016年底，全国全口径火电装机10.5亿千瓦、同比增长5.3%，全口径火电发电量同比增长2.4%，自2013年以来首次实现正增长。设备利用小时4165小时、比上年降低199小时。净增火电装机5338万千瓦，其中煤电净增4753万千瓦。

2016年底，全国全口径水电装机3.3亿千瓦、同比增长3.9%。全国全口径水电发电量同比增长6.2%，设备利用小时3621小时。净增水电装机1259万千瓦，其中抽水蓄能电站366万千瓦。

2016年底，全国并网风电装机1.5亿千瓦、同比增长13.2%，占总装机容量比重为9.0%；并网风电发电量同比增长30.1%，设备利用小时1742小时、同比提高18小时,但西北、东北等地区弃风情况仍然突出。全年净增并网风电装机1743万千瓦，比上年减少1684万千瓦，其中东、中部比重过半，较前几年明显提高。

2016年底并网太阳能发电装机容量7742万千瓦（绝大部分为光伏发电），同比增长81.6%；并网太阳能发电量662亿千瓦时、同比增长72.0%；并网太阳能发电设备利用小时1125小时，西北地区部分省份弃光情况较为突出。全年净增并网太阳能发电装机3479万千瓦、同比增加一倍，超半数净增装机位于中、东部各省。

2016年底全国核电装机3364万千瓦、同比增长23.8%，发电量同比增长24.4%；设备利用小时7042小时、同比下降361小时。

2016年全国全社会用电量5.92万亿千瓦时、同比增长5.0%，比上年提高4.0个百分点。

4、未来战略

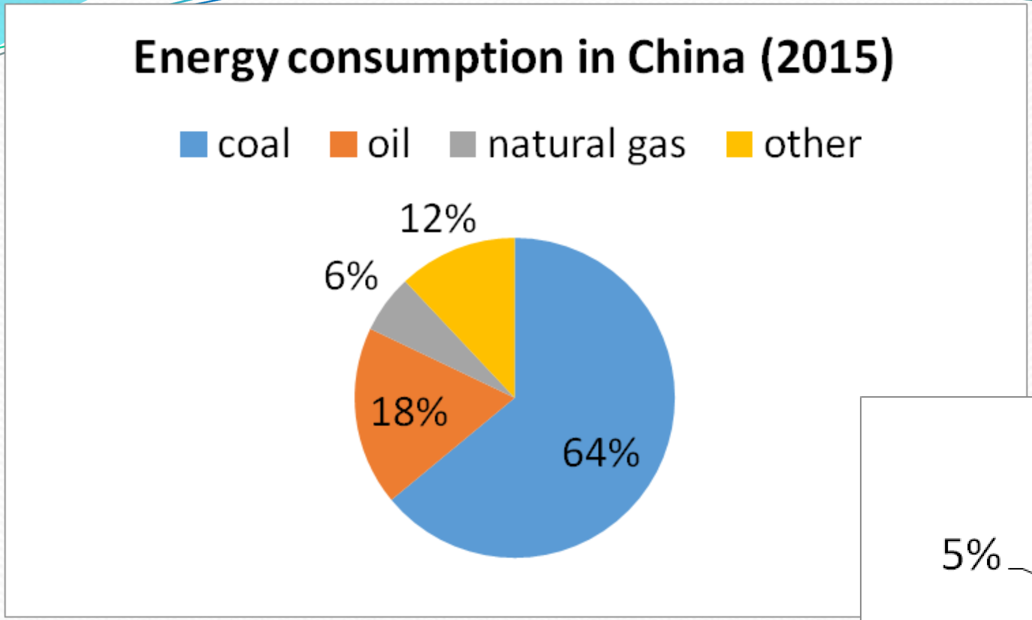
（1）“十三五”是我国能源转型发展的关键时期，要实现2020年非化石能源占一次能源消费比重达到15%，风电、太阳能等可再生能源从补充能源向替代能源转变。可再生能源发电总装机要达到7.5亿千瓦以上，占电力总装机超过40%，占总发电量超过30%，其中风电装机达到2-2.5亿千瓦，光伏装机达到1-1.5亿千瓦。

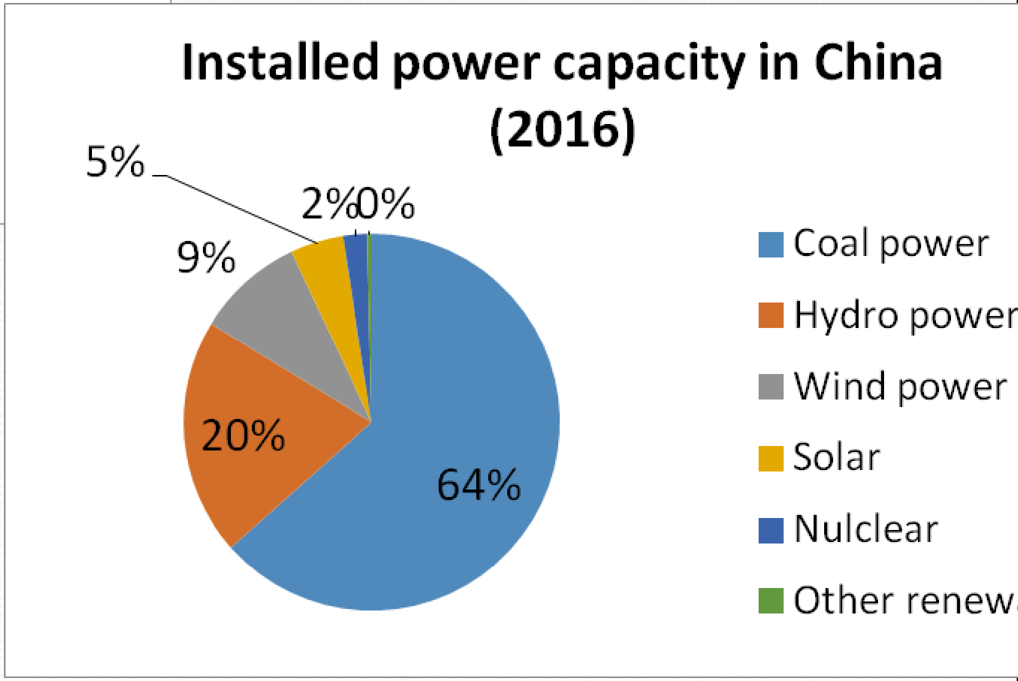
（2）提出“推动能源生产和消费革命”、“大力发展风电、太阳能等清洁能源”以及“加强生态文明建设”的战略部署。2015年6月我国发布《强化应对气候变化行动——中国国家自主贡献》，明确提出二氧化碳排放2030年左右达到峰值并争取尽早达峰、单位国内生产总值（GDP）二氧化碳排放比2005年下降60%-65%，非化石能源占一次能源消费比重要达到20%。

（3）提出“全球能源互联网”发展战略，建设以特高压电网为骨干网架（通道），以输送清洁能源为主导，全球互联泛在的坚强智能电网。将由跨国跨洲骨干网架和涵盖各国各电压等级电网的国家泛在智能电网构成，连接一极一道和各洲大型能源基地，适应各种分布式电源接入需要，能够将风能、太阳能、海洋能等清洁能源输送到各类用户，是服务范围广、配置能力强、安全可靠性高、绿色低碳的全球能源配置平台。

项目	2014年	2015年	2016年
电力总装机	13.75	15.2527	16.5
火电	8.9	10.0554	10.5
水电	3.0	3.1954	3.3
风电	0.9637	1.3075	1.5
光电	0.2805	0.4218	0.7742
核电	0.2	0.2717	0.3364
可再生能源电力	4.4	4.92	6.0

至于碳排放强度，中国政府2009年时曾经承诺，到2020年左右达到比2005年减少40%到45%的水平。李克强此次宣布了一个新的目标，到2030年左右，比2005年下降60%到65%。中国已经实现了早前承诺的很大一部分：政府数据显示，到去年底，碳排放强度比2005年的水平下降了33.8%。


Energy consumption in China (2015)
coal
oil
natural gas
other
12%
6%
18%
64%


Installed power capacity in China (2016)
5%
2%
0%
9%
20%
64%
Coal power
Hydro power
Wind power
Solar
Nulclear
Other renew