nzec carbon capture & storage

UK China NZEC Initiative Summary of Storage Results

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British Geological Survey
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NZEC Storage team

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Heriot Watt University – Mehran Sohrabi and Min Jin

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Outline

- Introduction – brief overview
- Geological storage potential in selected regions
- Conclusions
- Next steps

China/UK NZEC Initiative Scope of Phase 1 activities:

1. Energy use and Energy Intensive Industries with implications for CCS
2. CCS Options in China
   - CO_2 capture systems in coal-fired power
   - Storage options in NE China
   - Jilin Case study
3. Costs
4. Challenges and social issues

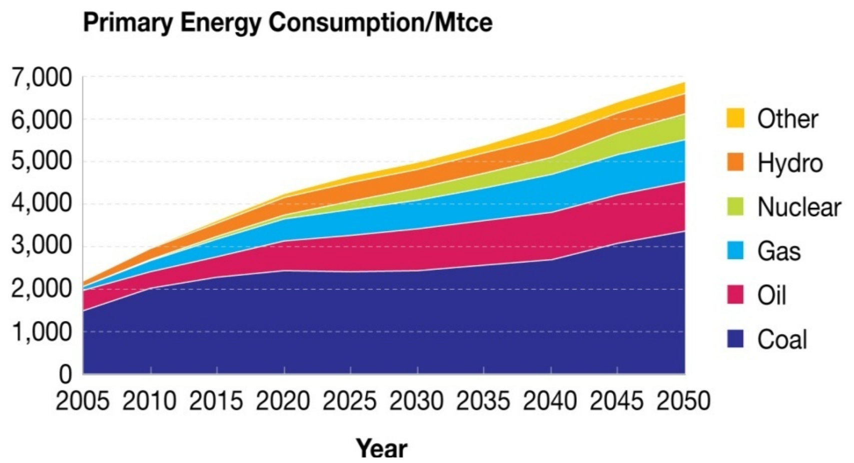
UK Government **DECC**	Chinese Government **MOST**
Project and UK lead: **AEA**	Chinese lead: **ACCA21**
Alstom Power **BGS** **BP** Cambridge University Doosan Babcock **Heriot Watt University** Imperial College Shell	Tsinghua-BP CEC Energy Research Institute 3E, Tsinghua University DCE, Tsinghua University DESE, Tsinghua University DTE, Tsinghua University **CUP (Beijing)** **CUP (Huadong)** CEEP, CAS IET, CAS **IGG, CAS** GreenGen TPRI **Jilin Oilfield** **PetroChina** **CUCBM Co Ltd** NCEPU WHU ZJU

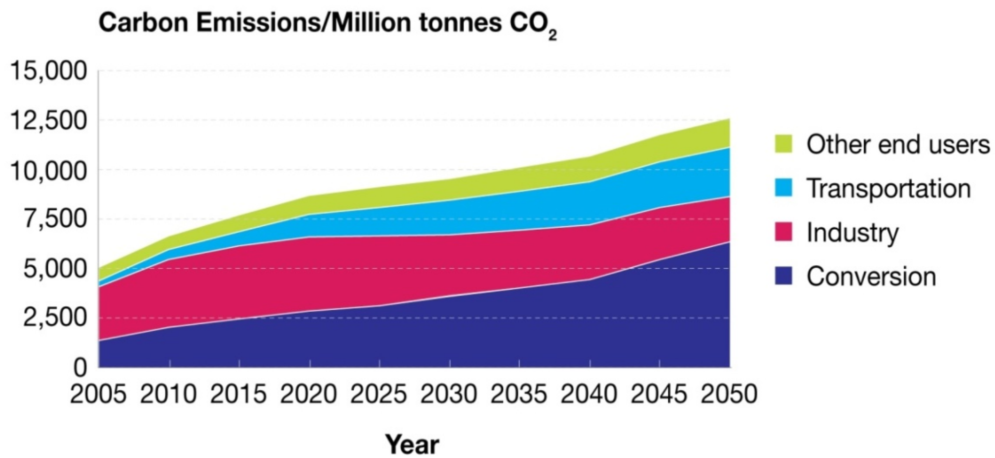
Coal will be the dominant energy type for the foreseeable future

- Coal in Primary Energy:
  - 70 % today
  - ca. 50% in 2050
- 70% of Power Generation uses coal
- Coal Gasification/liquefaction for fuels and chemicals
- Coal in Energy Intensive Industries
  - Iron & Steel, Cement & Ammonia

- <u>2006 </u>Total CO_2 Emissions 5,650 million tonnes
  - Coal >80% (4520 Mt CO_2)

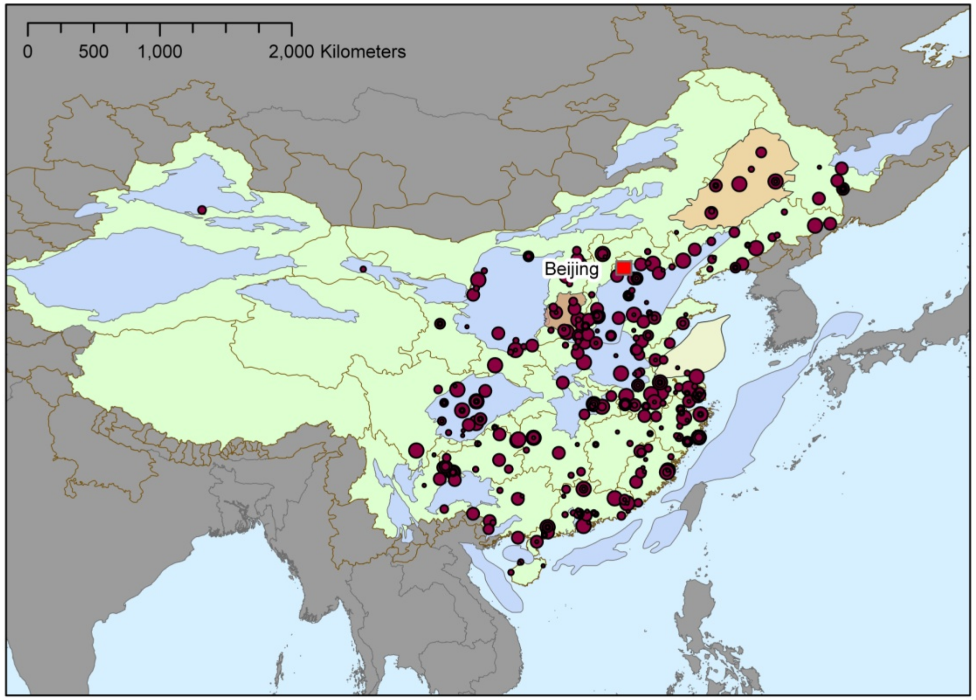
- <u>Baseline projection</u>
- Slower growth than recent years
  - 2%/year
  - Progress on energy efficiency and clean energy
- => Total emissions double by 2050





Options for CO_2 Storage

- Injection of CO_2 into underground rock formations in sedimentary basins for long term containment
- Major Storage Options are:
  – Enhanced Oil Recovery (EOR) with CO_2 storage
  – Depleted Oil and Gas fields
  – Saline Aquifer Formations
- Assessing storage potential:
  – Capacity - how much?
  – Integrity - how safe?
  – Injectivity - what cost?



IEA Greenhouse gas database (2008)
CO2_Mt
0.1- 0.8
0.8- 2.0
2.0 - 3.5
3.5 - 5.5
5.5 - 11.0
11.0 - 55.0

Songliao Basin
Qinshui Basin
Subei Yellow Sea Basin
Major sedimentary basins

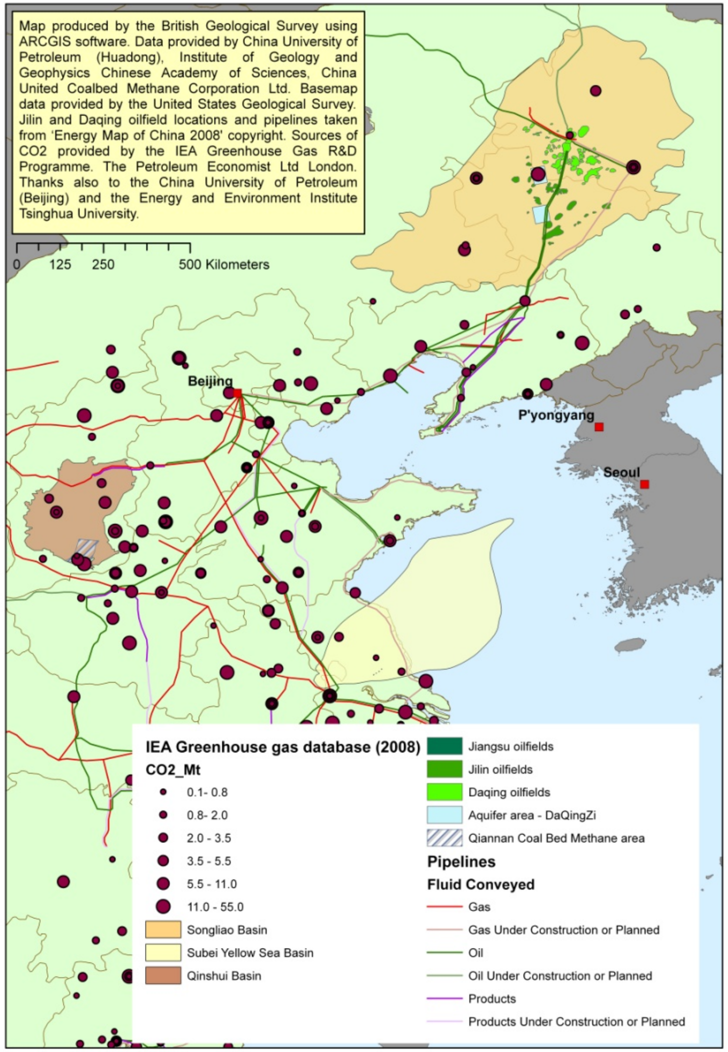
Map produced by the British Geological Survey using ESRI ARCGIS software. Basemap data provided by the United States Geolgical Survey. CO2 sources data provided by the IEAGHG R&D programme. Major sedimentary basins as identified in Asia Pacific Economic Cooperation 2005. Assessment of geological storage potential of carbon dioxide in the APEC region - phase 1. CO2 storage prospectivity of selected sedimentary basins in the region of China and south-east Asia. APEC Energy Working Group project 06/2003) and Watson, M. P., Hayward, A. B., Parkinson, D. N. and Zhang, M. Zh. 1987. Plate tectonic history, basin development and petroleum source rock deposition onshore China, Marine and Petroleum Geology 4 (August) 202-225

Overview – geology

- Targets for storage prospecting are the Late Palaeozoic to Early Tertiary sedimentary basins.
- However, sediments dominated by continental, fluvial-lacustrine deposits
  - Heterogeneous, lower permeability & porosity and limited lateral extent
  - Compartmentalised due to later tectonics
- Early desk-based studies (APEC Report) indicated that Songliao, Bohai and Subei-Yellow Sea Basins had highest ‘prospectivity’ in eastern China.
  - Storage space in hydrocarbon fields was estimated at only ~4.5 times annual CO2 emissions in 2000 (IEA 2000 – 2792Mt/yr)

UK NZEC storage capacities

- 30 Major Sedimentary Basins in China
- Two basins studied in UK NZEC project:
  - In Songliao: storage capacities estimated in hydrocarbon fields and a saline aquifer
  - In Subei: storage capacities in hydrocarbon fields
- Storage capacities have been estimated at two scales: Basin-(regional) scale and at the 'site-specific' scale



Reasons for selecting sites in UK NZEC

- Large, onshore, active, mature oil and gas fields where relevant information is available in the public domain.
- The presence of oil and gas fields, where hydrocarbons have been naturally trapped on geological timescales, provides confidence that CO_2 may be permanently stored in these or similar structures.
- The Chinese partners have experience of working in these oilfields.
- Tertiary recovery is increasingly being sought to improve declining production and there is consequently great interest in these regions for enhanced oil recovery including via CO_2-flooding.
- Pilot CO_2 flooding tests have been carried out in Jilin and Jiangsu oilfields.
- In mature oil provinces, depleted oil and gas fields can be used for dedicated CO_2 storage fields once production ceases.
- These regions were selected to complement those being studied within the COACH and Geocapacity projects which evaluated onshore fields in the Bohai Basin.

Calculating storage capacities

Volumetric estimates for oilfields

$$M_{CO_2D} = V_{oil(STP)} \times B_o \times pCO_2 \times S_{coeff}$$

Where

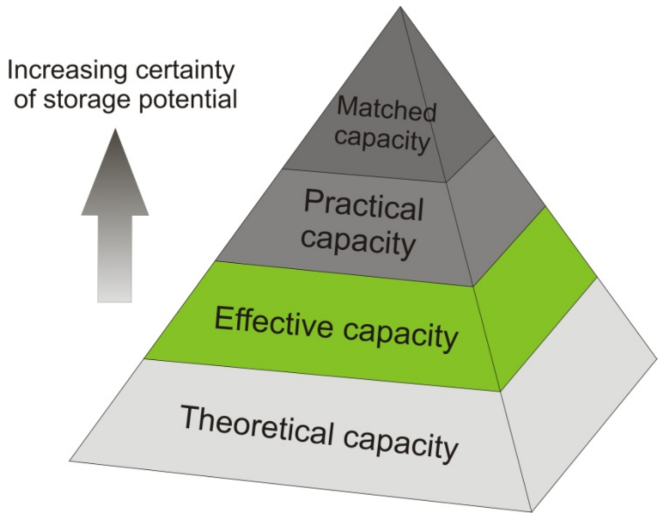
M_{CO2D} = estimated storage capacity (Mt)

$V_{OIL(stp)}$ = Volume of oil at standard temperature and pressure (Mt converted to m3 using API value of oil which is typically 33API in the Jilin oilfield)

B_o = Formation volume factor (Assumed to be 1.1)

ρCO2 = Density of CO2 in the reservoir (0.6 t/m3)

S_{coeff} = storage coefficient to discount for water invasion etc is assumed to be 0.4



Volumetric estimates for aquifers

$$M_{CO_2C} = A \times h \times \Phi \times (1 - S_{wirr})$$

Where

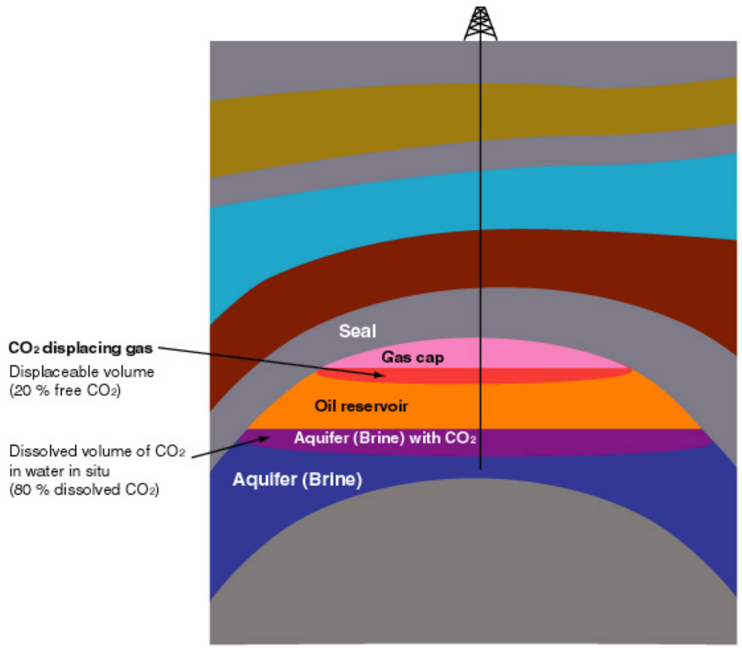
M_{CO2C} = estimated storage capacity (Mt)

A = area of the aquifer

h = average height of the aquifer × net:gross ratio

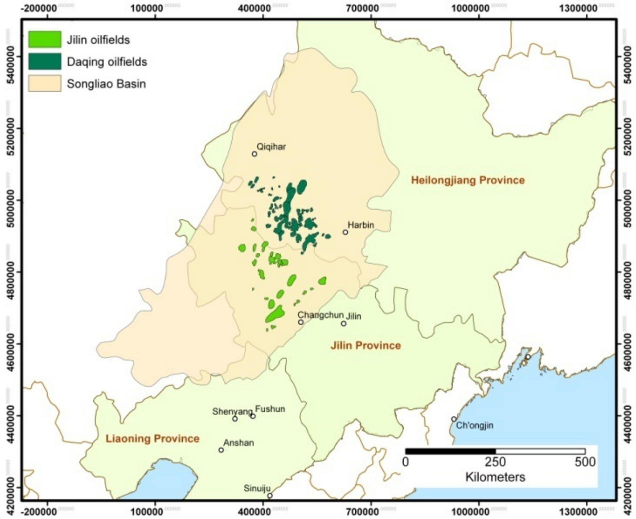
Φ = average porosity of the aquifer

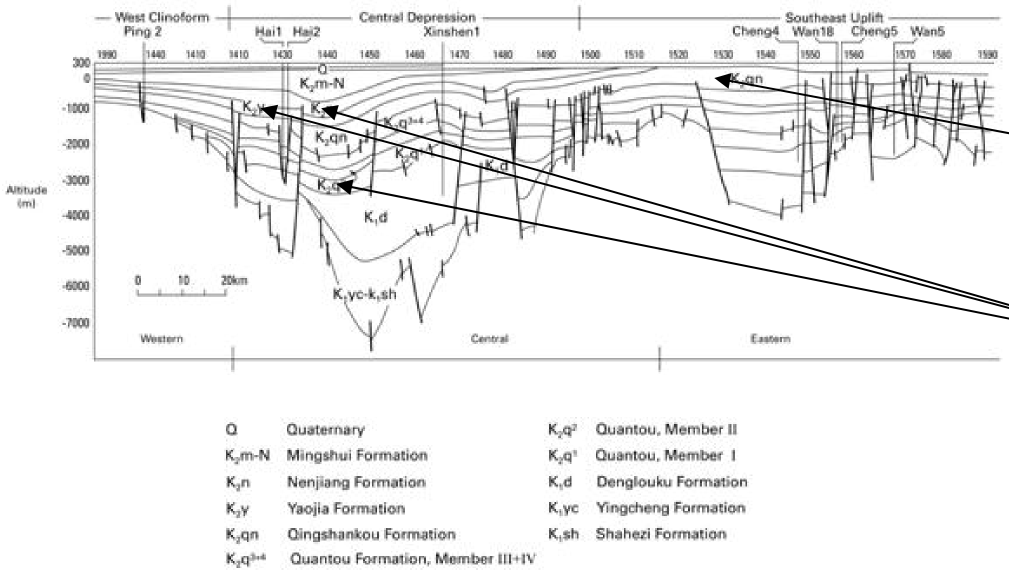
S_{wirr} = irreducible water saturation



Songliao Basin

- Storage capacity estimates made for:
  - Two oil provinces
    - Daqing
    - Jilin
  - Saline aquifer – Cretaceous Qingshankou Formation



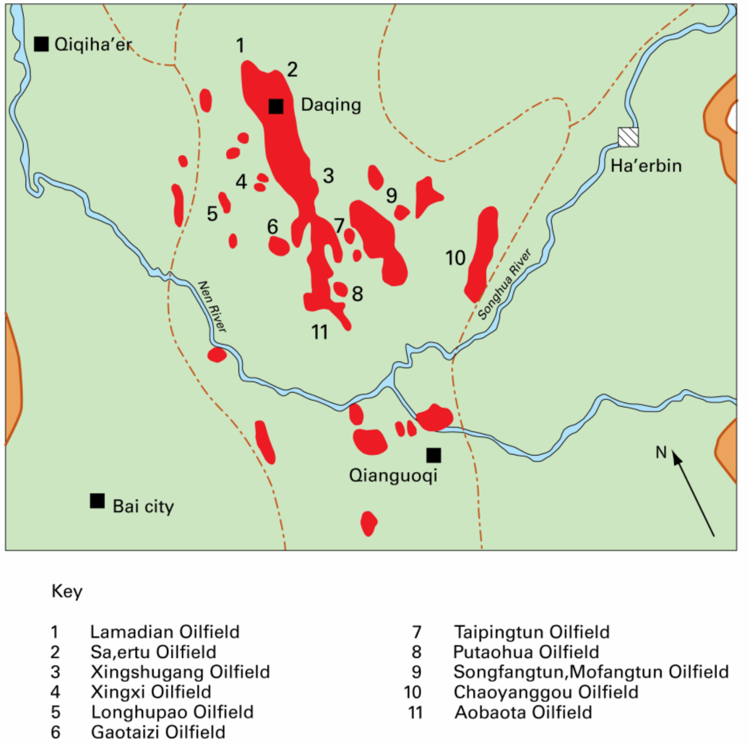


Saline aquifer

Main oil/gas-bearing reservoirs

Songliao Basin

- Basin-scale estimates:
  - Daqing – 593 Mt CO_2 in 7 hydrocarbon fields after depletion
    - Two fields account for 498 Mt (84%) of this capacity (Lamadian and Sa'ertu)
    - 269-1343 million barrels of additional oil using CO_2-EOR

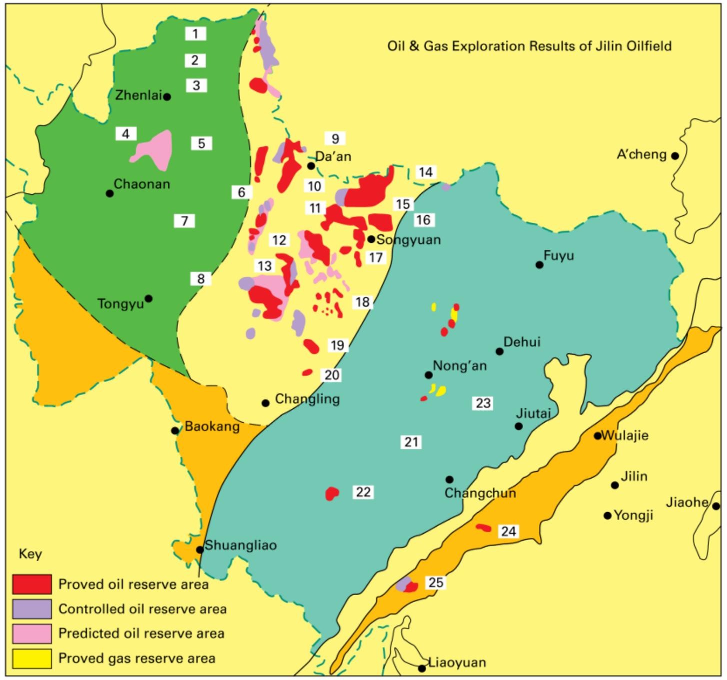


Songliao Basin - Daqing

Oilfield	Lamadian	Sa'ertu	Xingshugang	Gaotaizi	Taipingtun	Putaohua	Aobaota
Discovery year	1959	1959	1959	1959	1960	1959	1959.12.
Oil-bearing formations	Qingshankou, Yaojia and Nenjiang	Qingshankou, Yaojia and Nenjiang	Nenjiang, Yaojia and Qingshankou	Yaojia	Yaojia	Yaojia	Yaojia
Burial depth of oil-bearing reservoir (m)	920-1208	660-1200 (reservoirs with suitable T and P for storage considered only)	850-1190	1080-1115	1895-1165	916-1250	916-1250
Lithology of oil-bearing layer	Sandstone interbedded with mudstone	Sandstone interbedded with mudstone	Sandstone interbedded with mudstone	Sandstone interbedded with mudstone	Sandstone interbedded with mudstone	Sandstone interbedded with mudstone	Sandstone interbedded with mudstone
Total thickness of oil bearing interval (m)	390	30-60	300	65	60	65	
Number of oil-bearing layer	97	135	69	5	4	6 - 11	920~1230
Net thickness (m)	72	35-62	13-20	4.4	2.9 - 3.3	2.0 - 4.5	1.0 - 1.5
Area (10^6 m^2)	100	200	216	9.5	61	95.2	40
Porosity (%)	23.7 - 26.7	23-26.3	21.4-25.0	23	23	23 - 24	23
Permeability (Darcies)	0.23 – 1.3 D	0.15 – 3.65 D	204 – 569 mD	86 – 258 mD	135 – 506 mD	89 – 370 mD	115 (117 mD)
Original pressure (MPa)	11.33	11.1	11.49	11.98	10.5 - 11.7	10.7 - 11.6	11.57
Remaining reserves (Mt) (2000)	570.00	930.00	250.00	2.90	13.00	22.00	3.30
Storage capacity (Mt)	187.4	308.1	83.4	1.0	4.3	7.4	1.1

Songliao Basin

- Basin-scale estimates:
  - Jilin – 102 Mt CO_2 in 5 hydrocarbon fields after depletion
    - 46-230 million barrels of additional oil through CO_2-EOR

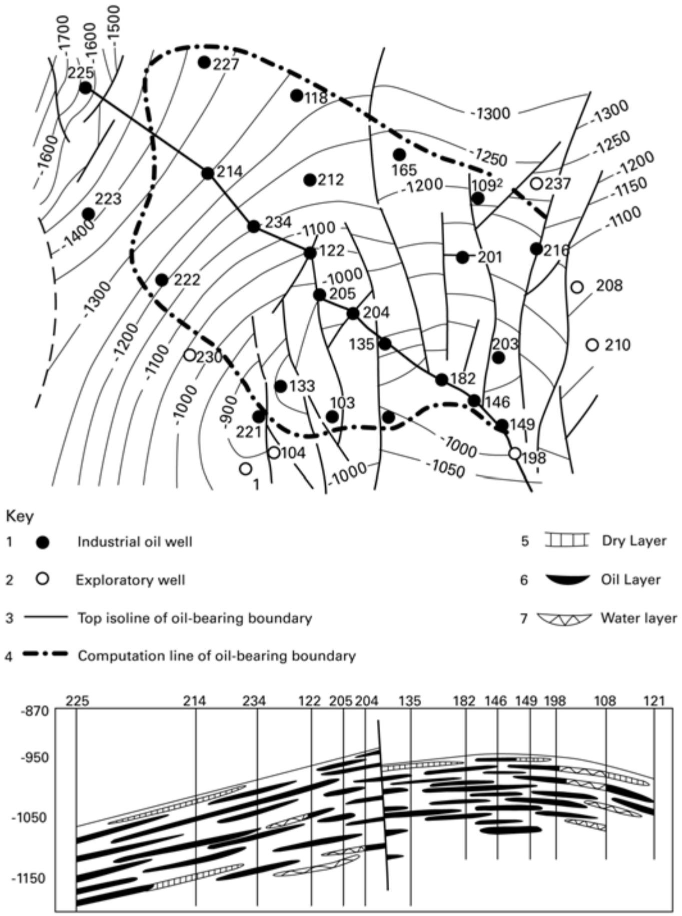


1	Yikeshu Oilfield	10	Xinbei Oilfield	19	Dalaoyefu Oilfield
2	Sifangtuozi Oilfield	11	Xinli Oilfield	20	Shuangtuozi Oilfield
3	Yingtai Oilfield	12	Liangjing Oilfield	21	Xiaohelong gas field
4	Taobao Oilfield	13	Qian'an Oilfield	22	Siwujiazi Oilfield
5	Honggang Oilfield	14	Xinmin Oilfield	23	Buhai Gasfield
6	Da'an Oilfield	15	Xinmiao Oilfield	24	Changchun Oilfield
7	Haituozi Oilfield	16	Fuyu Oilfield	25	Moliqing Oilfield
8	Daqingzijing Oilfield	17	Mutou Oilfield		
9	Da'anbei Oilfield	18	Gudian Oilfield		

Songliao Basin - Jilin Province

Oilfield	Honggang	Xinli	Qian'an	Yingtai
Discovery year	1961	1973	1979	1982
Oil-bearing formations	Yaojia	Quantou. No gas cap or edge aquifers. Large difference in oil-water contact across the reservoir.	Qingshankou. No gas cap or underlying aquifer.	Yaojia and Qingshankou. Gas cap and underlying aquifer present.
Burial depth of oil-bearing reservoir (m)	1200	1200-1500	1820	1384-1440, 1550-1690
Lithology of oil-bearing layer	Siltstone interbedded with argillaceous layers	Siltstone, fine sandstone and argillaceous siltstone	mudstone, siltstone and coarse siltstone	Siltstone, fine sandstone
Total thickness of oil bearing interval (m)	120	240+	360 - 410	16
Number of oil-bearing layer	16			
Net thickness (m)	4.6	7.9	8.8	30
Area (10^6 m^2)	49.4 km2	120.6 km2	170.5 km2	51.7 km2
Porosity (%)	22	16.3	15	22, 21.4-22.5
Permeability (Darcies)	132 – 172 mD	20 mD	5 – 11 mD	37 – 86, 249 – 275 mD
Original pressure (MPa)	12.25	12.2	19.29	
Remaining reserves (Mt) (2000)	17.53	49.36	121.39	100.17
Storage potential (Mt)	11.2	13	40.5	33.3

Songliao Basin - Xinli



- Fault-bounded, compartmentalised with little communication (different OWC depths)
- Thin reservoir layers: fine sandstones to siltstones
- Caprock is regional mudstone seals within overlying Qingshankou Fm
- Site-specific estimates Xinli:
  - 24 boreholes in this field

Stratum	Mean Porosity %	Permeability Md	Capacity using CSLF based methodology (Mt)
Fu-Yang	12.2	7	4.7
Putaohua	16.6 – 24.6	0.2-14	6.6
Total			11.2

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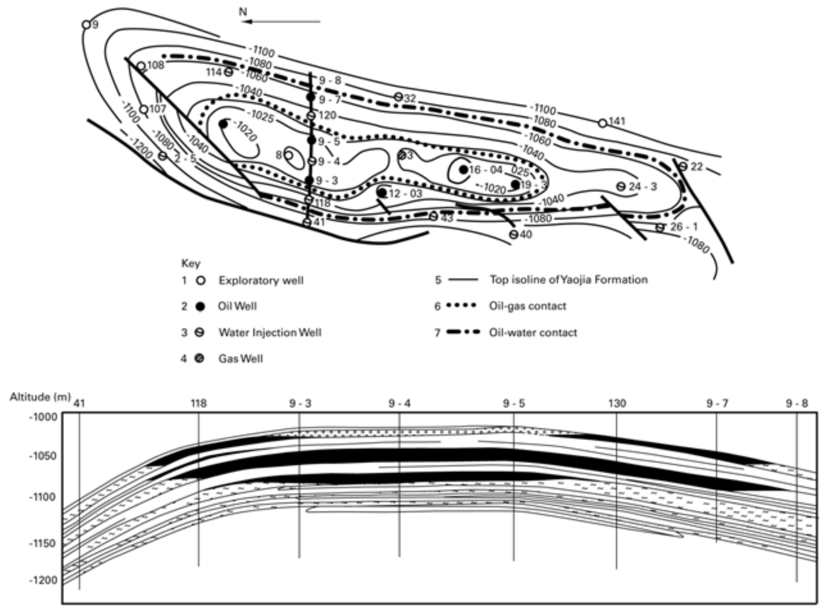
Songliao Basin - Honggang oilfield

- Honggang storage capacity - 13 Mt CO_2
- Fan delta sands
  - Poor connectivity (different OWC depths)
  - Multiple reservoir zones will require several perforations to maximise injection
- Mudstone caprock which traps gas

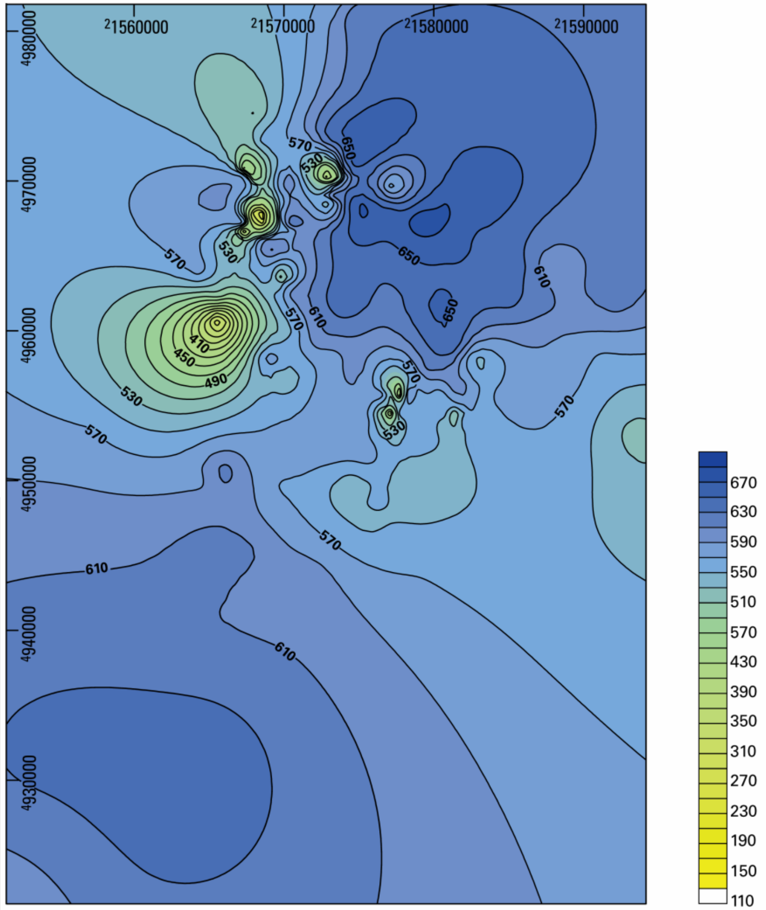


Payzone	Average Thickness (m)	Porosity %	Permeability (mD)	Reservoir T (°C)	Reservoir Pressure (MPa)	Total M_{CO2C} (using CSLF) (Mt)
Sa'ertu	5.1	24	165	55	12	8
Gaotaizi		17.9	16	40-73, (64 in middle of stratum)	13.78	5
Total						13

Songliao Basin

- The Qingshankou Fm saline aquifer basin-scale estimate - 692Mt CO_2 (S_{coeff} = 1%)
- Site-specific estimate for Qingshankou Fm saline aquifer in Daqingzi area – 288 Mt CO_2

Area of regional aquifer km2	260000		
Average height of aquifer m	380 (net:gross ratio 50 – 95%)		
Average reservoir porosity %	10		
Average permeability	20-30mD		
CO_2 density at reservoir conditions kg/m3	700		
Storage coefficient	1%	2%	10%
Effective CO_2 storage capacity Mt	691.6	1383.2	6916



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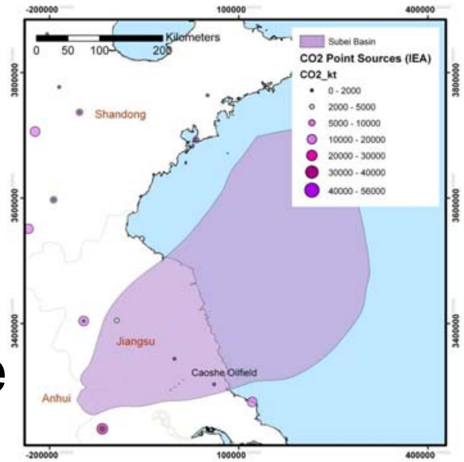
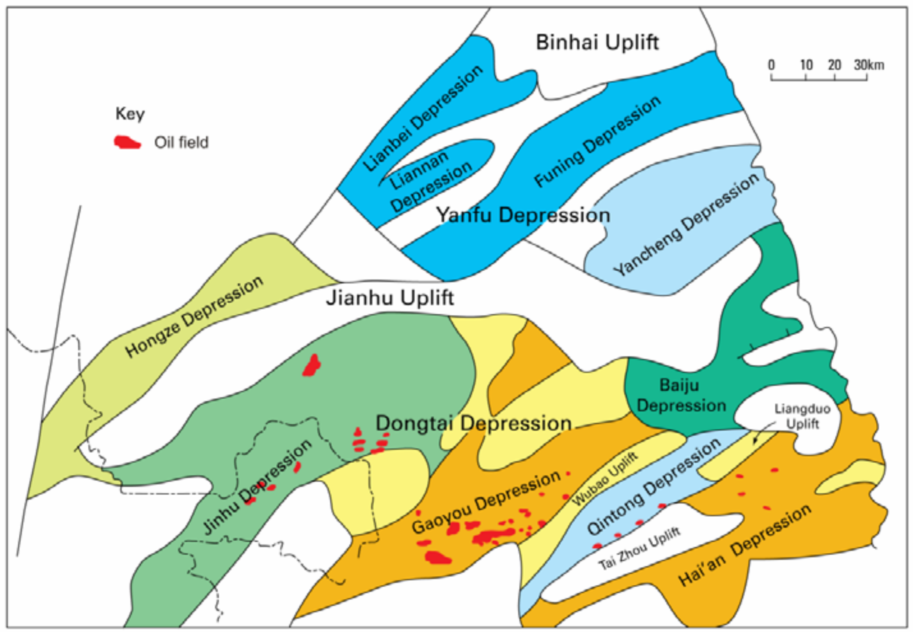
Sources of CO_2 in Jilin province

	Sources estimated		
	Number of sources	Capacity (GW) /Production (Mtons)	CO_2 ($MtCO_2$)
Power	55	7.57	47.68
Iron & steel	4	5.17	10.27
Cement	13	10.8	9.12
Oil refinery	2	8.21	0.62
Ammonia	4	0.54	1.73
Total	78	--	70.53

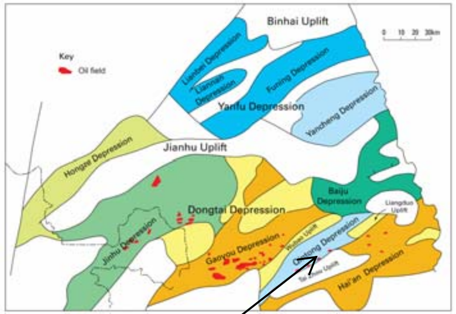
Subei Basin



- Mesozoic-Cenozoic Basin filled with fluvial sediments
- Jiangsu Oilfield complex basin-scale estimate
  - Storage capacity estimated at between 20 – 40 Mt CO_2.
    - Oil density - 0.86 g/cm3
    - CO2 Density - 0.7 g/cm3 at reservoir conditions
    - Formation volume factor - 1.1
    - OOIP - 993 million barrels
    - The average EOR by CO2 flood (miscible process) - 12%
    - The average recovery factor via water flood - 30%



Caoshe Oilfield



Caoshe

- OOIP 10.7 million barrels
- Pilot CO2 test in 2006 by Jiangsu Oilfield Co
- 3 oil-bearing layers - Taizhou, Funing and Dainan (Palaeogene) at 3-4 km depth
- OWC depths vary across faults

Total wells	17	Cumulative liquid production (10^4 m^3)	55.12
Production wells in use	8	Cumulative oil production (million barrels)	2.07
Injection wells in use	4	Cumulative water injection (10^4 m^3)	54.08
The ratio of water well to oil well	1:2.25	Cumulative injection production ratio	0.98
Average well spacing (m)	260	Annual oil production rate (%OOIP)	1.02
Well spacing density well (km^2)	18.5	Current recovery factor (%)	19.44
Average single well controlled reserve of oil (million barrels)	1.18	Overall water cut (%)	50.2
Daily oil production (barrels)	465	Expected recovery (%)	24.00
Daily water injection (m^3)	137.76	Recoverable reserves (M)t	2.56
Daily oil production (barrels/well)	58	Remaining recoverable reserves (million barrels)	0.49
Average well water injection (m^3/day)	34.4		

Caoshe oilfield

- Caoshe oilfield
  - 108 separate oil ‘reservoirs’
  - 75 of these suitable for CO2-EOR and have total storage capacity of 16 Mt CO_2.
  - Remaining 33 reservoirs may be suitable for direct CO_2 storage with a capacity of 5 Mt CO_2.

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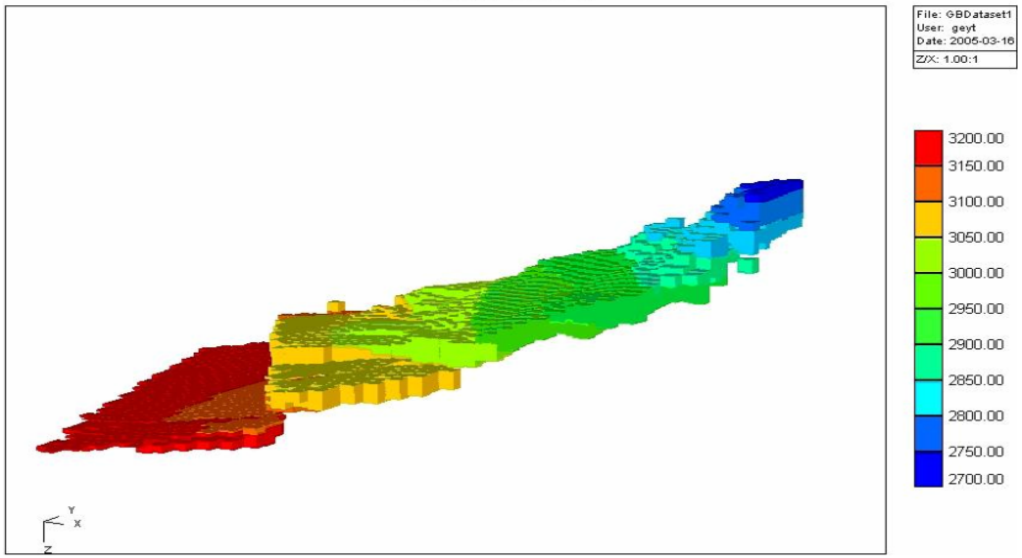
Coashe oilfield – Taizhou Fm

- Based on reservoir simulations CO_2 storage capacity was only 0.7 Mt
- Volumetric method estimated 1.3 Mt



Total Capture, Transport and Storage Costs for Coal fired power in China

Component	Basis	RMB/MWH
Capture Costs	Established Technology Cases	413-463 RMB/MWh
Transport Costs	200 km Pipeline	26 RMB/tonne
Storage	Storage with EOR (Caoshe Example)	6 RMB/tonne stored
TOTAL CCS Cost		440-493 RMB/MWh

Equivalent to 280 RMB per tonne of CO_2-avoided compared with the PC base-case

CO2 Storage - Main Findings

1. CO_2 EOR and Storage provides opportunity to gain experience with CCS and partially offset costs
   - Some potential for CO_2 EOR and Storage in the areas studied
     - Main opportunity in Songliao Basin; other fields very small
     - Reservoirs typically complex
   - Storage capacities of individual fields are generally small compared to annual emissions of Chinese power plants
2. Major aquifer identified in Songliao area
   - Aquifers likely to be important for large scale CCS and longer term
3. Older wells likely to be key area of risk
4. Further evaluation and data access required to confirm suitability and specific sites for storage
   - Additional exploration needed for Aquifers

Challenges for CCS

- Extra Cost and Energy Use
- Operational Uncertainties
- Safety of Storage
- Adapting Regulations to CCS
- Equipment Availability

Moving Forward : Research and Development requirements

- Storage – rigorous country-wide assessment is a priority, including
  - National and regional storage mapping, e.g. a CO_2 storage atlas for China
  - Detailed assessment and R&D on EOR, Depleted Fields and Aquifers
  - Assessment work on storage safety.
  - Gaining experience with site selection, site characterisation, monitoring and verification and overall risk assessment process.

Moving Forward : Considerations for Demonstration Activities

- Rationale and choices for demonstration are strategic considerations
- Portfolio of projects is likely to be required
- Leading options for demonstration with coal fired power focus by 2015 are:
  - Post-combustion capture
  - IGCC with Pre-combustion capture
- Choice of location critical to limit transport costs
- Availability and scale of storage site may be major constraint on early integrated projects

Conclusions

- Further R&D, capacity-building activities and outreach are required to reach the position where Chinese CCS stakeholders can be fully informed of the challenges and opportunities
- Continuation of the China-EU NZEC agreement in two further phases is important, since its objective is demonstration of an integrated CCS system, ideally by 2015.

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Thanks