Current Status and Future Trends of the Post-Combustion Capture Technologies: "VIEWS FROM NORTH AMERICA AND ASIA"

Sept 19, 2013 for PCCC2 (Bergen, Norway)

by

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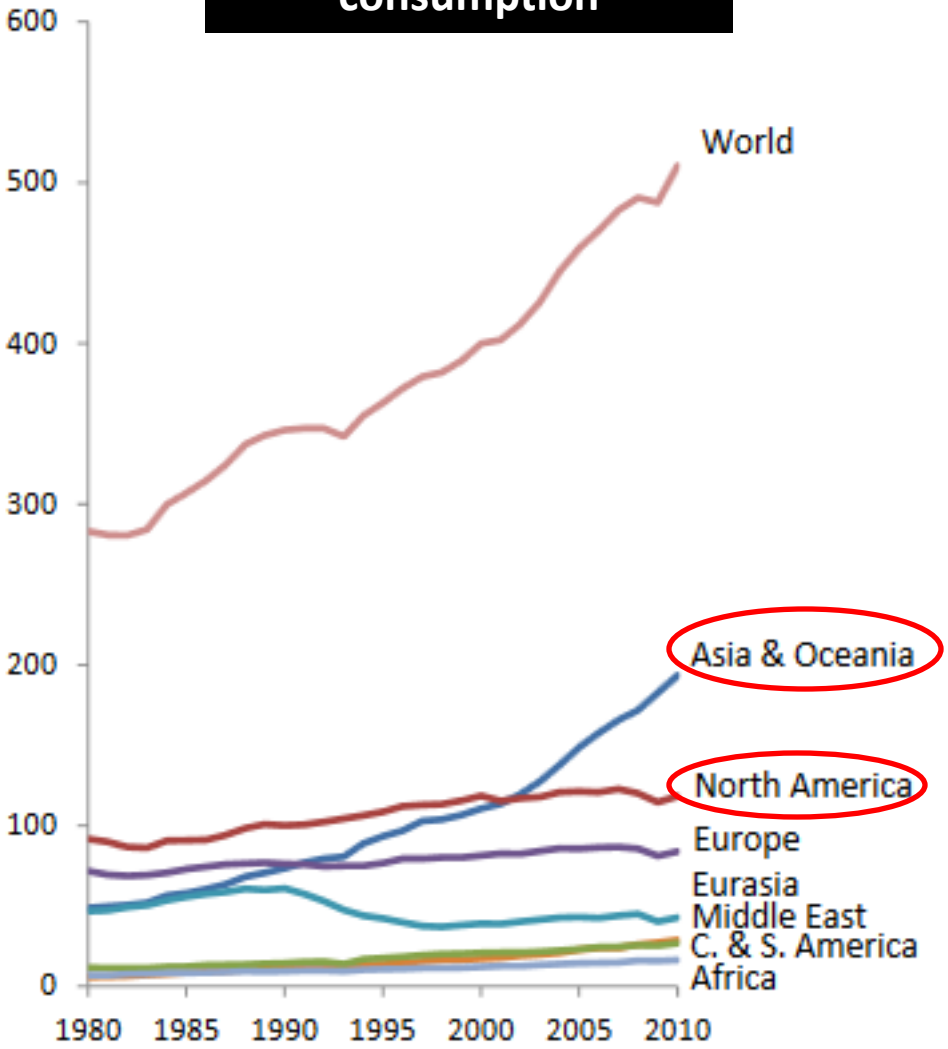
Presentation overview

- Background Post-Combustion Carbon Capture (PCC)
- Current status in ASIA (China, Japan, ASEAN)
- R&D at iCCS, Hunan University
- Current status in North America (USA, AB, SK)
- RD&D initiatives by ITC, University of Regina
- PAST, PRESENT & FUTURE OF PCC

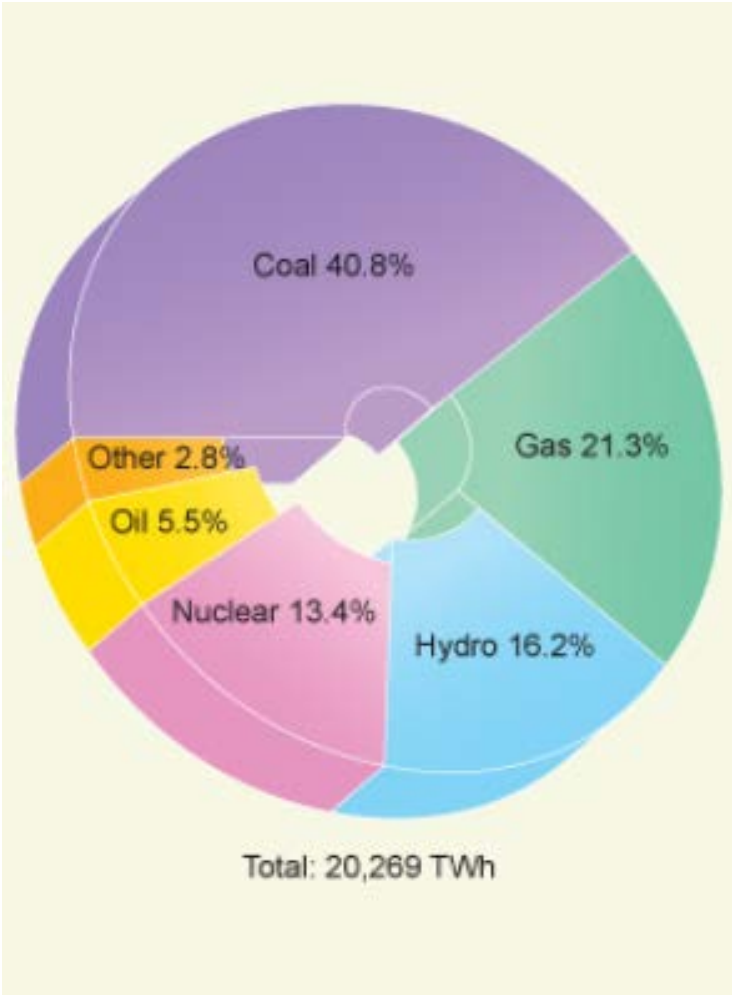
Key Global Events that Changing CCS

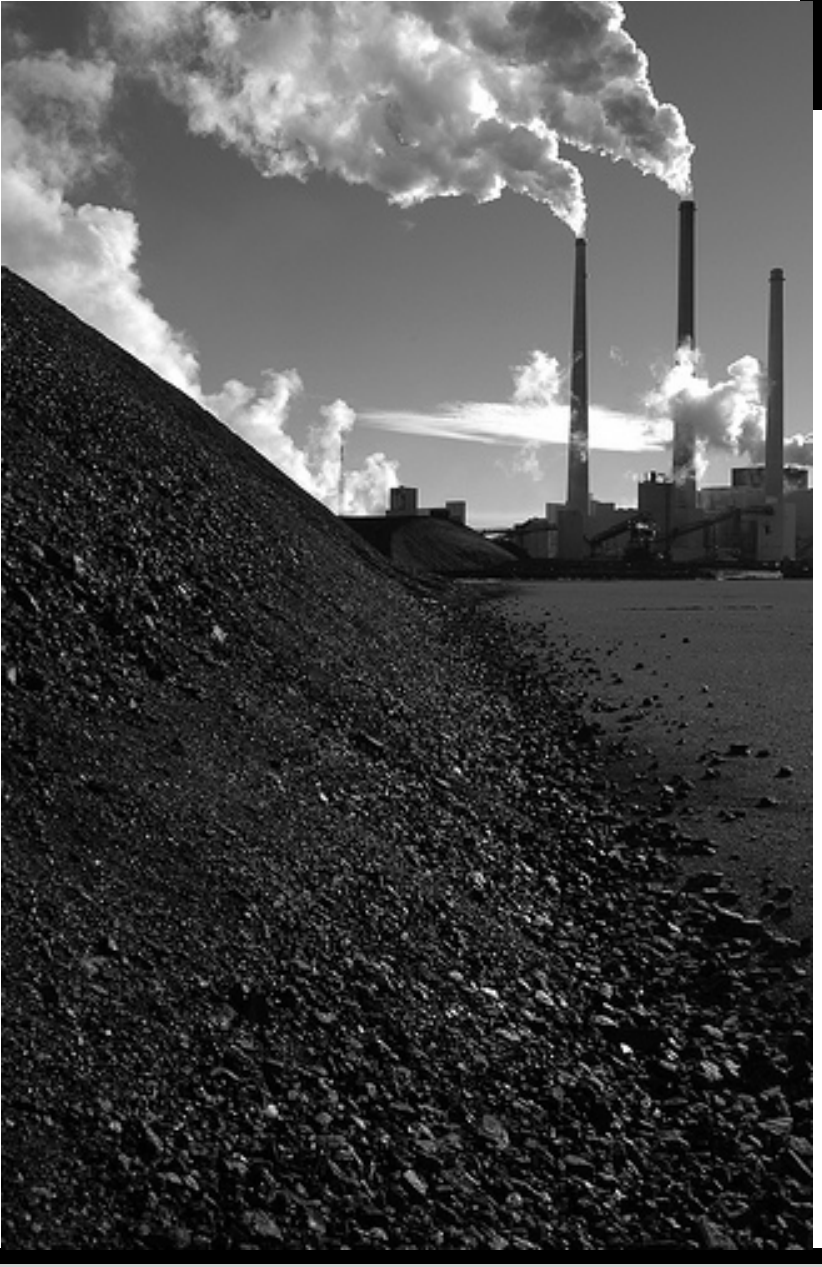
- Financial Crisis in 2008
- Tsunami and Nuclear Power Plants at Fukushima
- Carbon Intensity Issues about Oil Sands in North America (e.g. Keystone Pipeline (?)
- CO2 Concentration has passed 400 ppm level!

World energy consumption



World source of power generation





Energy by COAL

- Available for foreseeable future
- Affordable for long-term
- Reliability source of energy
- Safety to store in a power plant

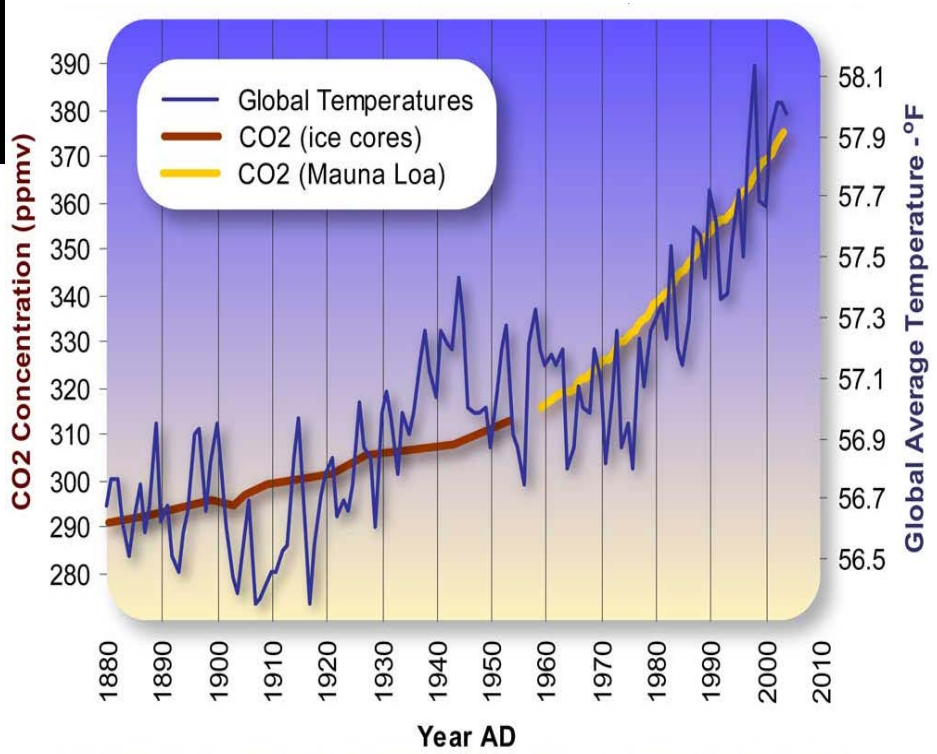
“However”

Energy by coal contributes to **42% of the global CO_2 emission**

Carbon content per unit of energy generated

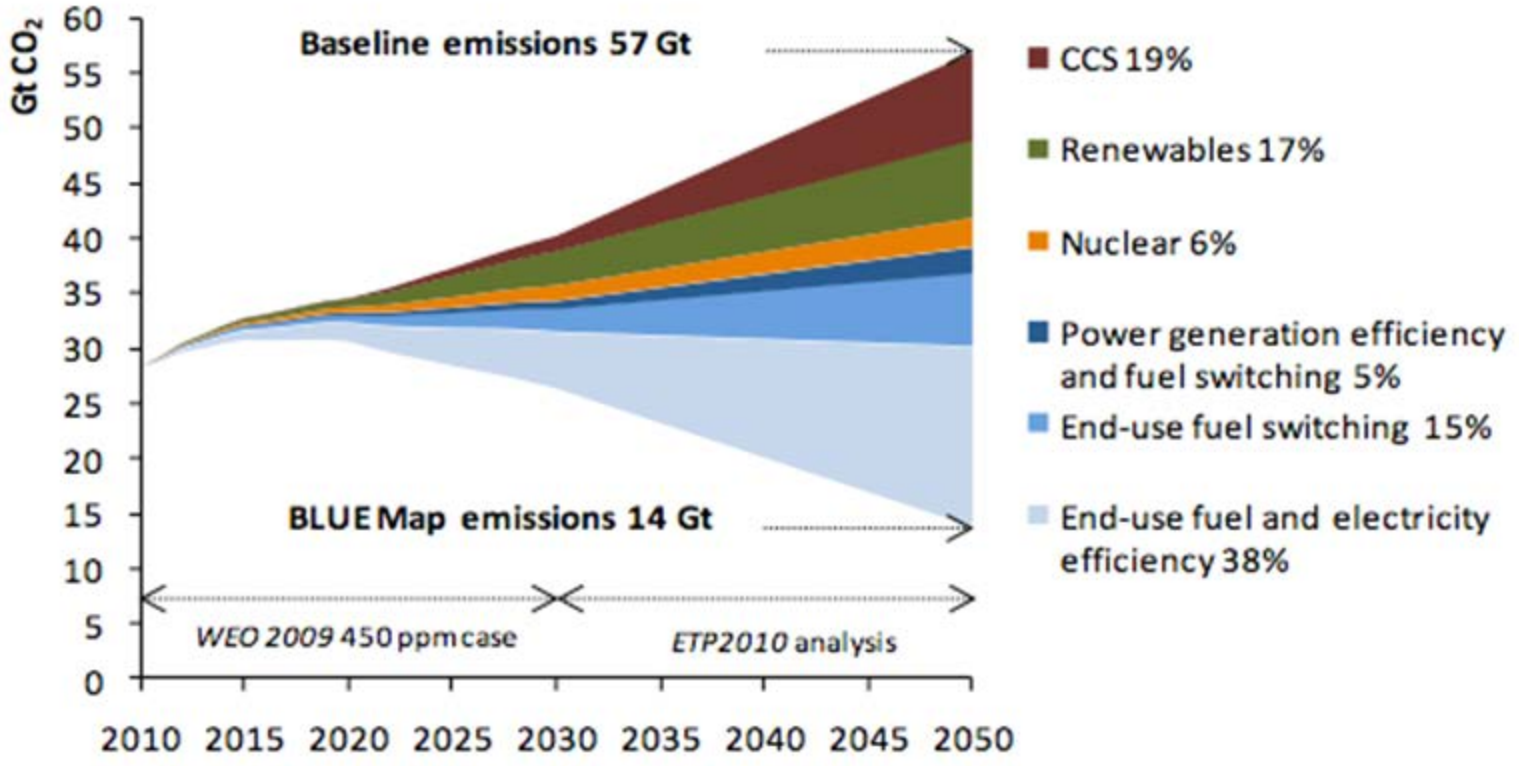
Fuel	g CO_2/kWh
Anthracite	870
Coking coal	710
Bituminous coal	840
Sub-bituminous coal	930
Lignite	950
Crude oil	640
Natural gas	380

Source: IEA. CO_2 Emission from Fuel Combustion (2009).



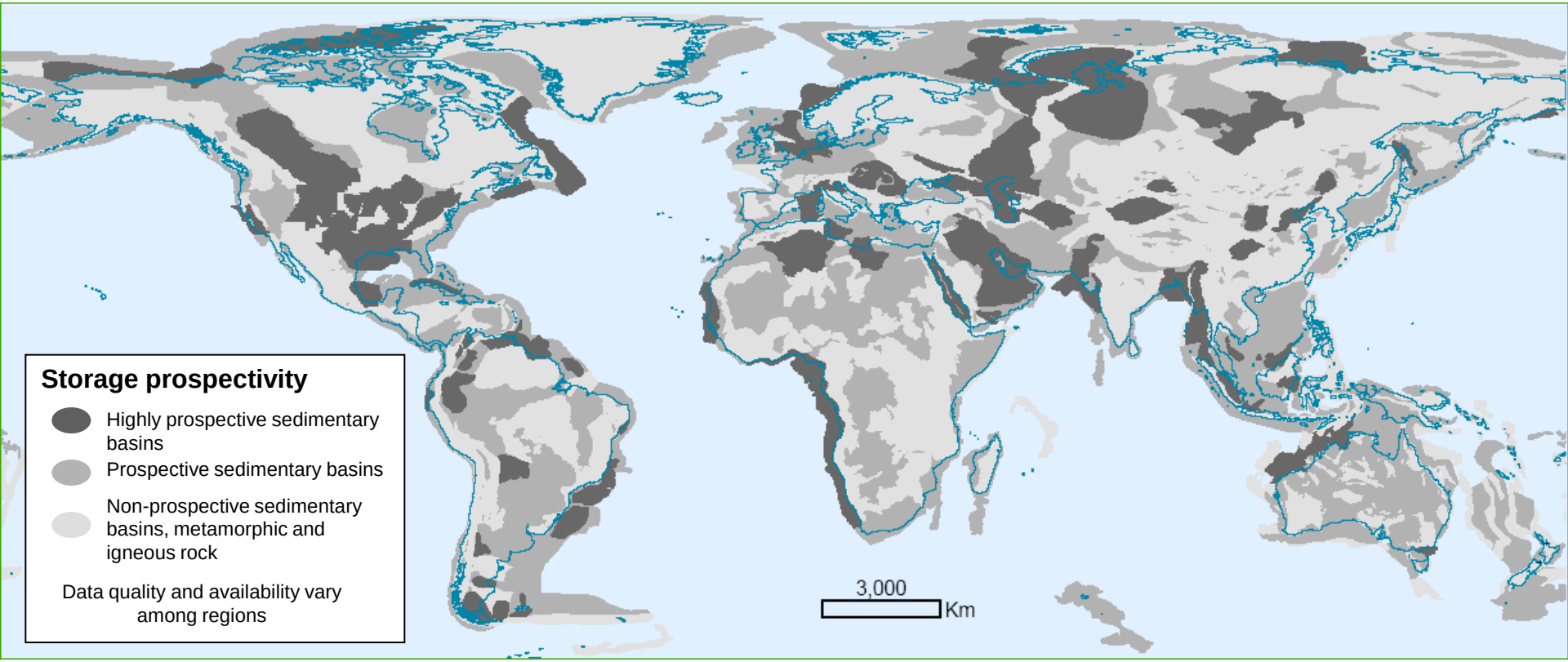
Data Source Temperature: ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/annual_land.and.ocean.ts
Data Source CO2 (Siple Ice Cores): http://cdiac.esd.ornl.gov/ftp/trends/co2/siple2.013
Data Source CO2 (Mauna Loa): http://cdiac.esd.ornl.gov/ftp/trends/co2/maunaloa.co2

Key technologies for reducing global CO_2 emissions under Blue Map scenario



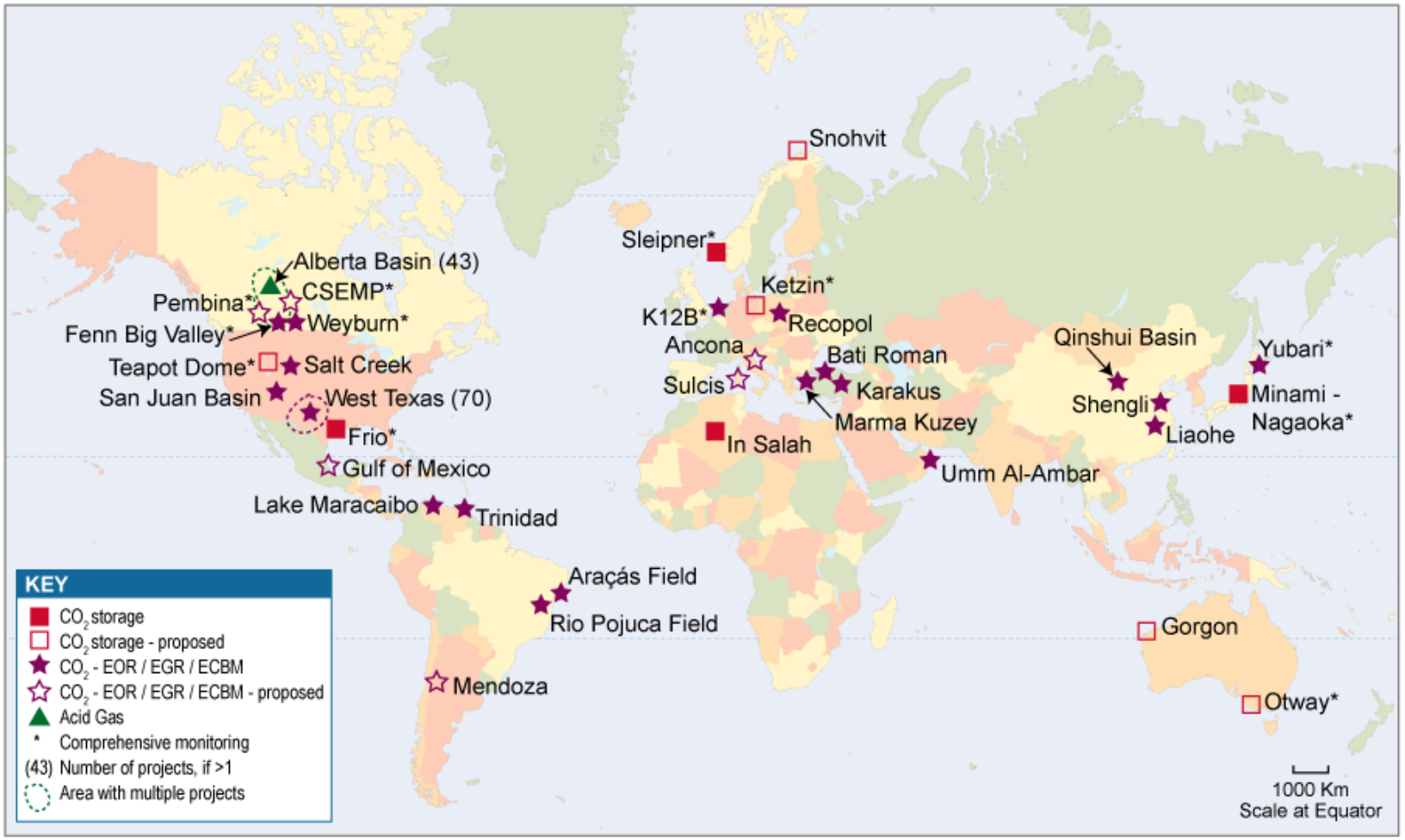
A wide range of technologies will be necessary to reduce energy-related CO_2 emissions substantially.

Geographical relationship between sources and storage "*opportunities*"



Prospective areas in sedimentary basins where suitable saline formations, oil or gas fields, or coal beds may be found. Locations for storage in coal beds are only partly included. Prospectivity is a qualitative assessment of the likelihood that a suitable storage location is present in a given area based on the available information. This figure should be taken as a guide only, because it is based on partial data, the quality of which may vary from region to region, and which may change over time and with new information (Courtesy of Geoscience Australia).

Planned and current locations of geological storage



Post-combustion capture

- Amine-based
- Chilled ammonia
- Catalyst-based
- Membrane separation
- Enzyme-based

Why post-combustion capture with amine

- Relatively,
  - Cheaper
  - Simpler
  - ~5-10 years closer to deployment
  - Can be used to retrofit existing conventional coal-fired power plants

“VIEWS FROM ASIA and NORTH AMERICA”

CHINA

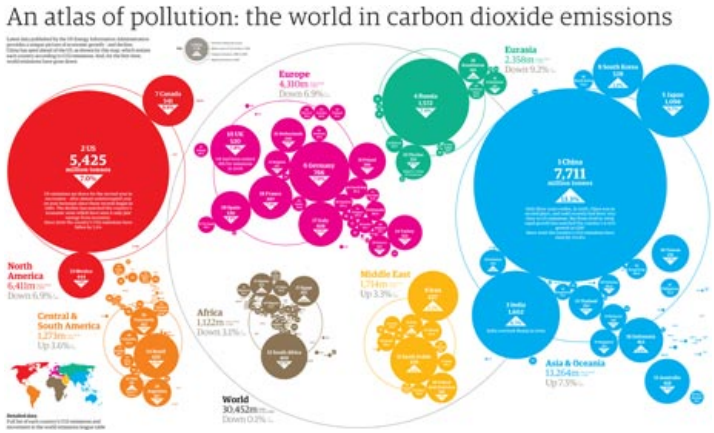
Why CHINA

- World's most populous country
- World second largest economy
- World largest contributor to CO_2 emission (7,700 Mt = over 25%)
- Chinese CO_2 emission mostly from:
  - ELECTRICITY AND HEAT (50%)
  - Manufacturing/Construction 30%
  - Industrial Processes 10%
- Governmental Policy on Carbon Capture
  - National Medium and Long-term Science and Technology Development Plan Towards 2020 (2006-2020)
  - The 12th Five-Year Work Plan on Controlling GHG Emissions (2011-2015)
  - Promoting Carbon Capture , Utilization and Storage Pilot and Demonstration (Department of Climate Change)

Global CCS Institute

Present situation of CO_2 emission in CHINA

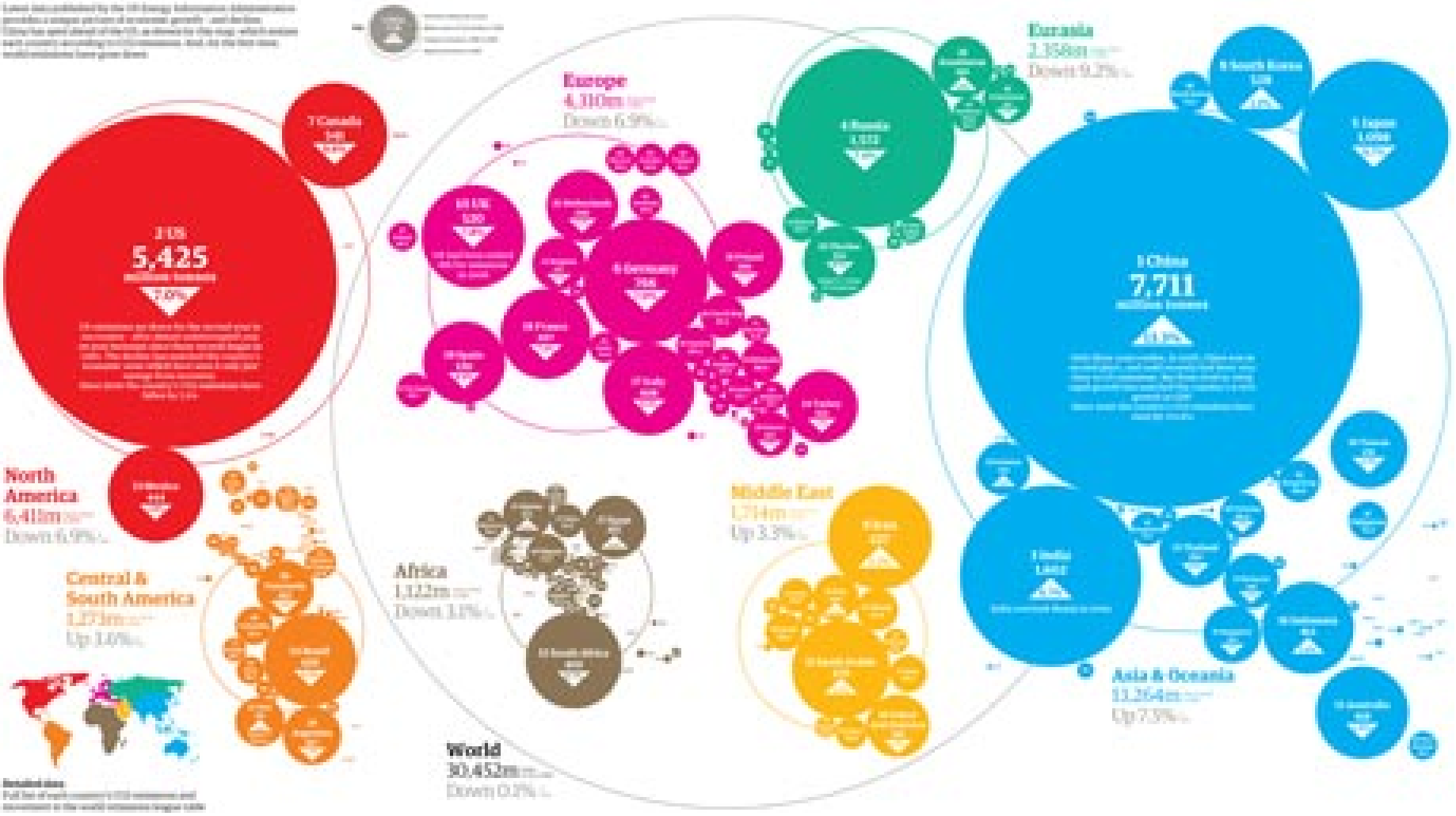
- World large carbon emitting country (7.7 billion tons per year)
- Coal is the main energy source (70.4 %)
- Mostly used in power generation industry (75% of power production is from coal).



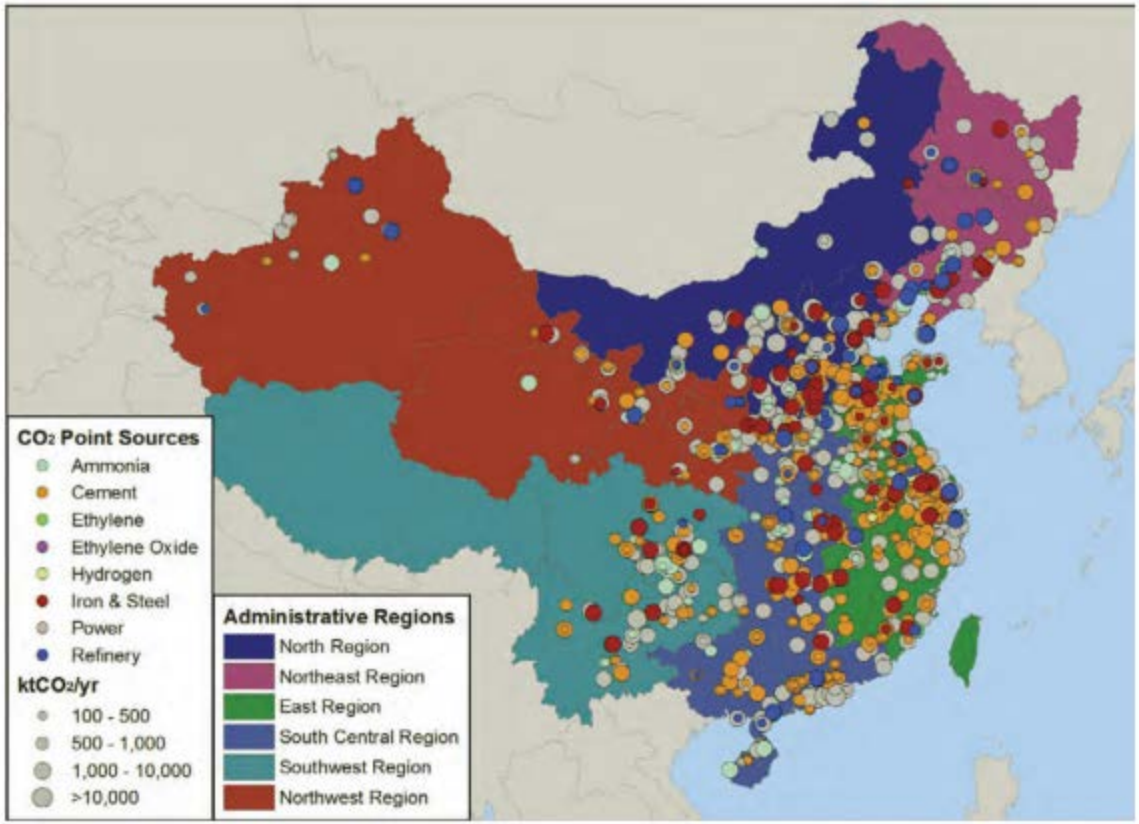
Carbon emission reduction in China is significant

The Guardian

An atlas of pollution: the world in carbon dioxide emissions



Why CHINA



- Large sources of CO_2 (>0.1 $MtCO_2$/year)
- Power & Non-power sectors
- 994 plants
- Total emission of 1081 Mt CO_2/year
- 73% Power Generation
- 27% from Cement, Iron, Steel, Refineries, Chemicals (e.g. ammonia, ethylene, ethylene oxide, hydrogen, etc.)

Centre for Low Carbon Futures report

Chinese leading companies working on carbon mitigation

- China Huaneng Group
  (Coal business & Electricity)

- CNPC Group
  (Oil & Gas business)

- Sinopec Group
  (Oil & Gas business)

- Shaanxi Yanchang Petroleum Group
  (Oil & Gas business)

China Huaneng Group

CHINA HUANENG

- Largest Power Generator in China
- First PCC project in China in 2008

  (Huaneng Beijing plant)
- Claim - carbon capture process at 30-35 USD/ton CO_2

Case study of The Shidongkou No. 2 Power Plant , Shanghai, China

CHINA HUANENG

- 1, 320 Mw coal-fired power plant
- 120,000 tons of CO_2 a year
- 30-35 USD/ton CO_2 (100 USD for first generation PCC)
- Claim as succeed in Technical design and Economic aspects
- High purity of CO_2 (99.5%) can be used in FOOD INDUSTRY
- Unrevealed technical details of plant design & solvent chemistry

Nature 469, 276-277 (2011)

China National Petroleum Corporation (CNPC)

CNPC

- 151 Mt of oil production
- 93 Gm^3 NG production
- Carbon capture for Natural gas processing & Clean coal
- Substituting NG for oil Project
- @ Inner Mongolia up to 100,000 ton CO_2 capacity demonstration plant (an ultimate aim of 3 Mt)
- CO_2 source: coal gasification

2012 CNPC annual report

China National Petroleum Corporation (CNPC)

- Captured CO_2 for storage project
- Up to 100,000 ton CO_2/year injection (2011-2014)
- CO_2 tank car transportation

CO_2 Capture System

Shenhua CCS project CO_2 storage area (storage tanks)

CCUS R&D in China 2011

China Petroleum & Chemical Corporation (SINOPEC)

中国石化 SINOPEC

- 328 million barrels of oil production
- 598 bcf NG production
- Largest refinery in ASIA (221 million ton)
- Low Carbon Development Strategy
- Carbon Capture project at Sinopec Shengli Oil Field, Dongying, Shangdong
- 14% CO_2 flue gas from Shengli Power Plant
- Currently capture 40,000 ton CO_2/year
- Ultimate aim of million ton CO_2 captured

2012 SINOPEC annual report

China Petroleum & Chemical Corporation (SINOPEC)

中国石化 SINOPEC

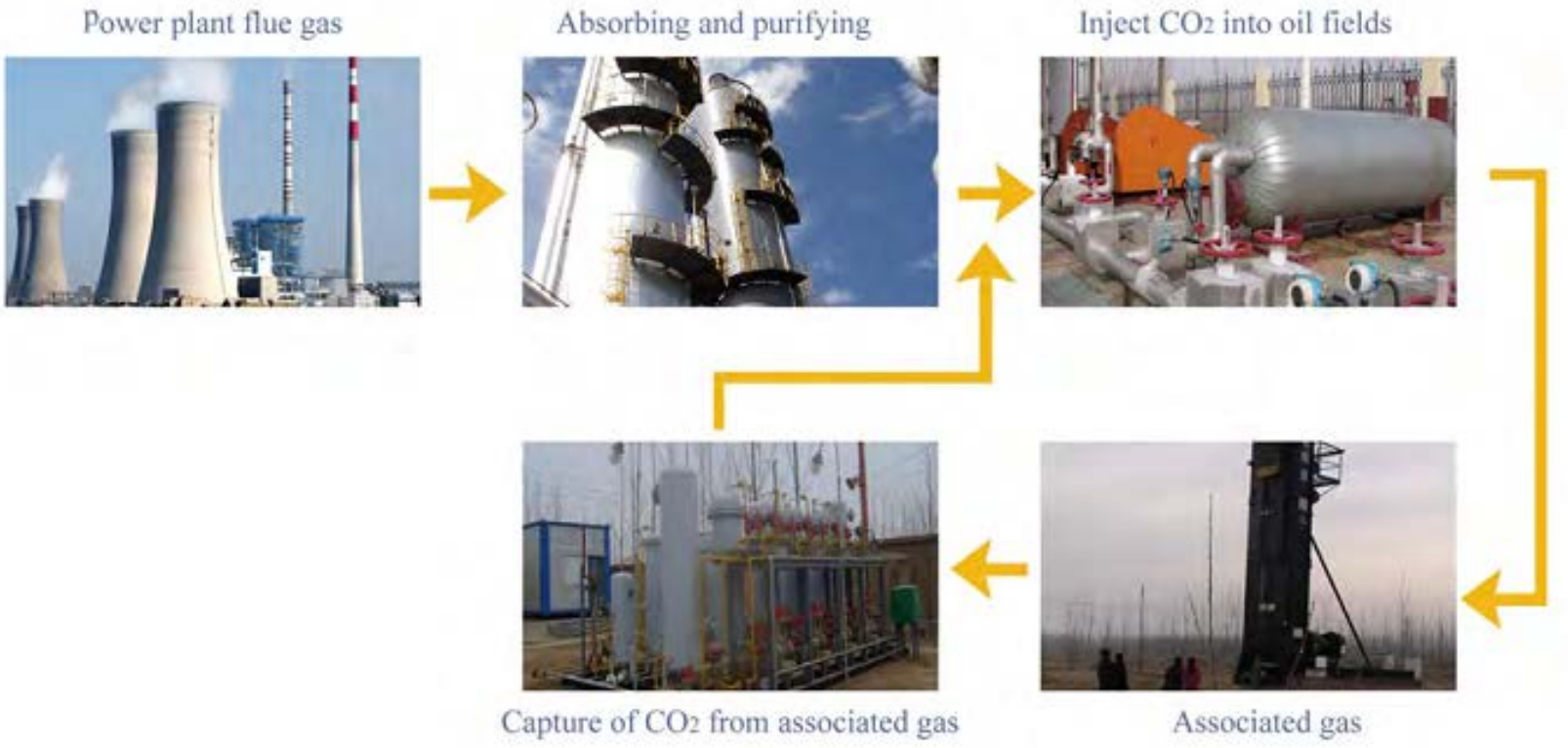
- Captured CO_2 (99.5% purity) will be used for CO_2-EOR
- Transportation
  - Tank car
  - Pipeline (51-100 km)
- Pre-feasibility studies in 2012/2013
- Investment decision in 2013/2014
- Will be launched in 2017

2012 SINOPEC annual report

China Petroleum & Chemical Corporation (SINOPEC)

中国石化 SINOPEC

Carbon Capture project at Sinopec Shengli Oil Field



CCUS R&D in China 2011

Shaanxi Yanchang Petroleum Group

Yanchang Petroleum

- Oil and Gas business
- E&P, Refinery, petrochemicals
- 12.6 Mt of crude oil
- Carbon Capture and Utilization
  - Non-power sector
  - CO_2 Capture from Yulin Coal-Chemical Company in Shaanxi (50,000 ton CO_2 per year)
  - CO_2 EOR at Yanchang's Jinbian Qiaojiawa CO_2 injection site

2012 Yanchang Petroleum annual report

Shaanxi Yanchang Petroleum Group

Yanchang Petroleum

- Great Opportunity in Shaanxi (CAPTURE & EOR)
- China major coal base with highly developed coal-chemical industry
- Chemical plants: ammonia, methanol, hydrogen, ethanol, dimethylether
- Highly suitable for CO_2-EOR

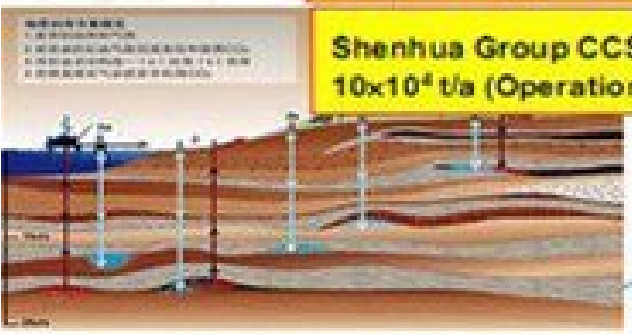
Centre for Low Carbon Futures report

Challenges and Opportunities for PCC in China

- Rapid China's economic growth resulting in a largely increase of CO_2 emission → Carbon Capture is CRUCIAL
- Several demonstration projects are now operating; under construction and planning
- Good support from governmental policy/programs
- Everything is cheap in CHINA, large scale PCC can be deployed
- China is now in early stage of demonstration phase; need Technology Improvement and Market Development
- Social awareness and acceptance are important
- Commercial gap for profitable PCC
- PCC + EOR/Coal-to-Liquids

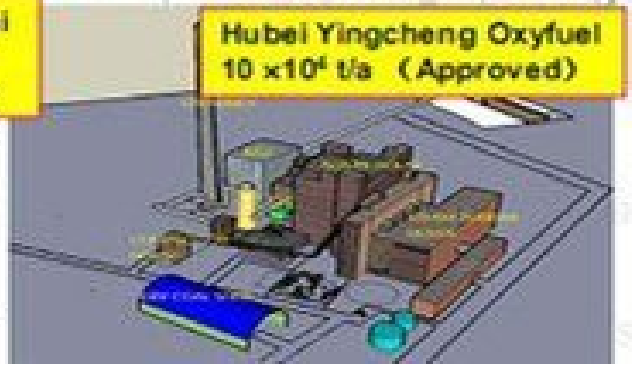
CCS Demonstration Projects in China
中国已建成和在建CCS示范项目

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



Shenhua Group CCS
10×10^4 t/a (Operation)

Chongqing Shuanghuai power station
1×10^4 t/a （Operation）



Hubei Yingcheng Oxyfuel
10×10^4 t/a （Approved）

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

Huaneng Shidongkou Power Station
10×10^4 t/a (Operation)

Wuhan 3MW oxyfuel 1×10^4 t/a
（under construction）

Joint International Center for CO_2 Capture and Storage (iCCS)
Hunan University, China

University of Regina | Faculty of Engineering & Applied Science

College of Chemistry and Chemical Engineering
Hunan University

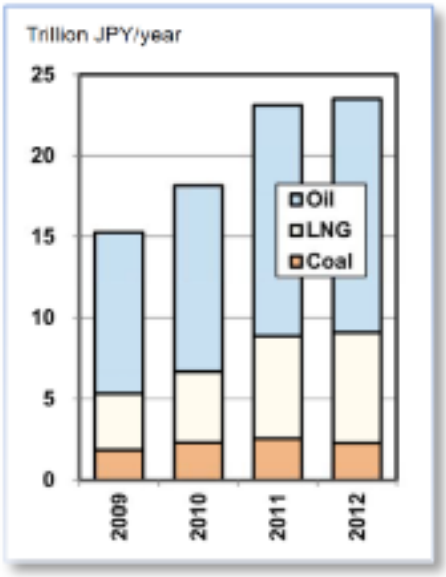
PCC in JAPAN

- World third largest economy (after US and CHINA)
- 1,258 Mt CO_2 was emitted in 2010
  (90% from Energy sector)
- 1997 KYOTO Protocol
- 2007 COOL EARTH policy by PM Abe
  → 50% GHGs reduction by 2050
- March 11, 2011: Nuclear Accidents
  → Nuclear Power Stations have been shut down
  (lost 25-30% electricity capacity)

JEPIC; Global CCS Institute; CCUS R&D in JAPAN by GASSNOVA

PCC in JAPAN

- Revision of the Energy Master Plan
- Largely increase in a fossil-fired power generation dependency
- In order to meet the target, Carbon Capture is crucial
- KEY Players: MHI, TOSHIBA, HITASHI,RITE, POWER Industry (TEPCO; KEPCO)
- Advanced Carbon Capture Technology in JAPAN
- Presently, 52.5 USD/ton CO_2
- Targets at 25 USD (2015) & 12.5 USD (2020s)

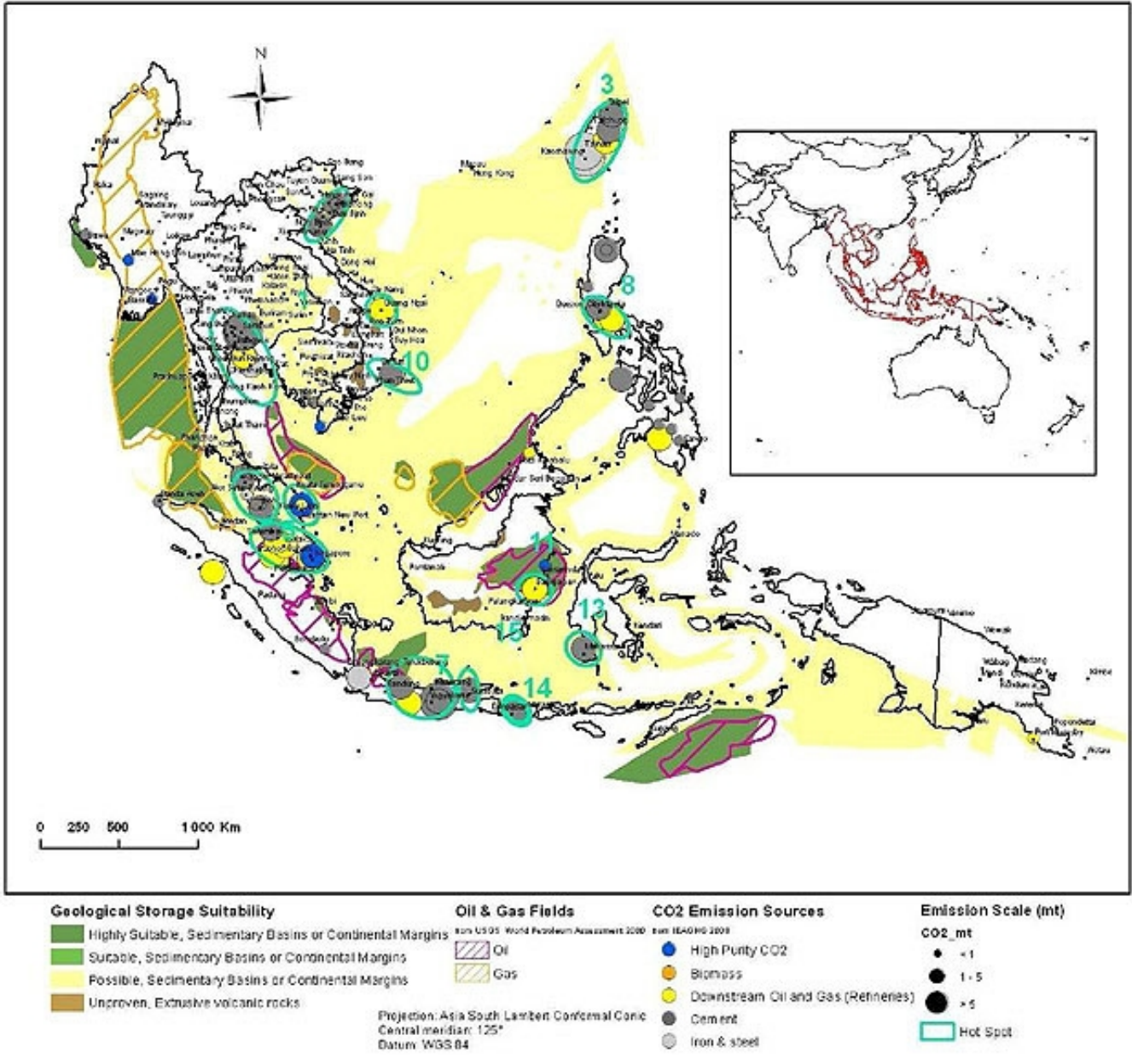


JEPIC; CCUS R&D in JAPAN by GASSNOVA

CCS in Southeast Asia

- **ASEAN** (Brunei, Burma, Cambodia, Indonesia, Laos, Malaysia, the Philippines, Singapore, Thailand, Vietnam)
- 600 M people; 2 Trillion GDP
- **Energy demand** will be increased by **76% (2007-2030)**
- Especially; **Coal**, **Oil&Gas**

Asian Development Bank (ADB); Global CCS Institute



CCS in Southeast Asia

- Southeast Asia **short term** Carbon Capture on **Natural Gas Processing**
- Southeast Asia **Medium term** Carbon Capture on **Coal Fired Power Plant**
- Asian Development Bank **(ADB)** initiated **Regional capacity Development Technical Assistant Program** (R-CDTA) to promote **Clean Coal Technology associated with CCS**
- Focused countries: Indonesia, Malaysia, Thailand, Vietnam
- Key Partners: China, India, Korea, Europe
- Due to the increase of **electricity/coal consumptions**

Asian Development Bank (ADB)

CCS in Southeast Asia

- Recently, CCS projects are rarely operated; especially for environmental reason
- Lacks of Legislations, Regulations, Governmental Support, Social Awareness
- Potentially a great area for CCS investments
- High purity CO_2, CO_2 conversion, EOR & Storage

Asian Development Bank (ADB)

Present situation of CO_2 emission in the USA

- World third largest population (313 M)
- World largest economy
- World second largest carbon emitting country (5.4 billion tons per year) → 18% of world wide emission
- Mostly from power generation (37%)
- CO_2 mitigation target of 17% (2005-2020)
- At about 7.5% CO_2 emission was reduced (2006-2011)

Congressional Research Service: Carbon Capture and Sequestration: RD&D at the DOE. 2013

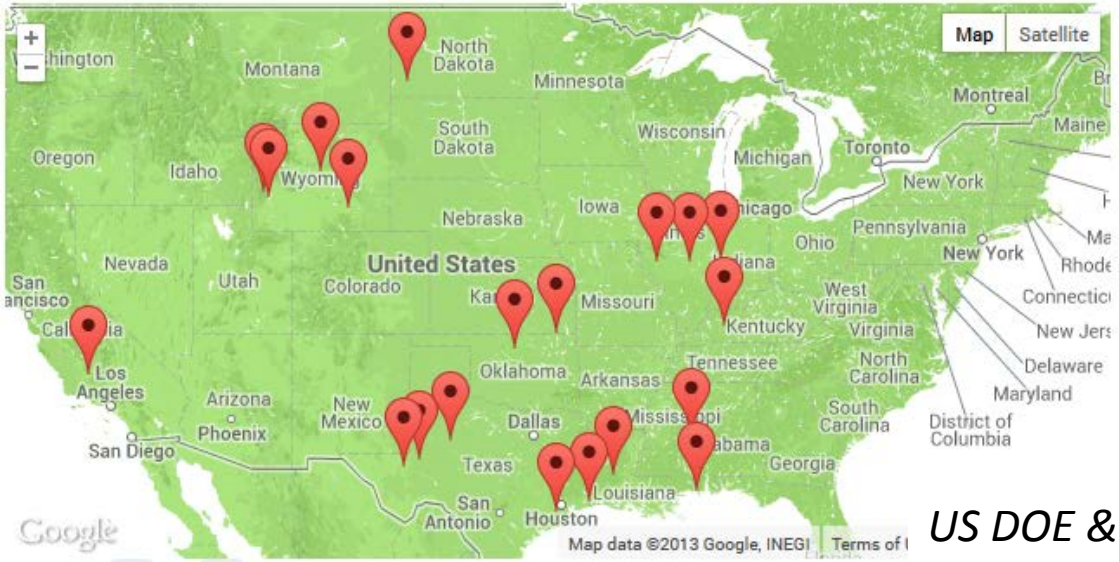
US Environmental Policy

- From US Environmental Protection Agency (EPA), a NEW rule that limits CO_2 emissions to be **no more than 1,000 lb CO_2/MWhr** (issued in MARCH 2012).
- Option of using 30 yrs average CO_2 emissions to meet the standard.
- The New RULE (section 111; Clean Air Act) applies for **NEW fossil-fired power plants**. But not for existing plants.
- Those **new COAL fired-power plants** will DEFINITELY **need PCC**.
- According to this policy, PCC in US will be crucial.
- Natural Gas!

US DOE & Global CCS Institute

US Current PCC Status

- Over **20 large scale Carbon Capture Projects** (> 1 Mt CO_2 /yr) in US.
- 5 Projects are defined; and will be executed during 2014-2017.
- 6 Projects are under evaluations; and may be executed during 2015-2018)
- **Great potential for CCUS**; over 40% of coal generating sources located above potential geological sequestration sites.



US DOE & Global CCS Institute

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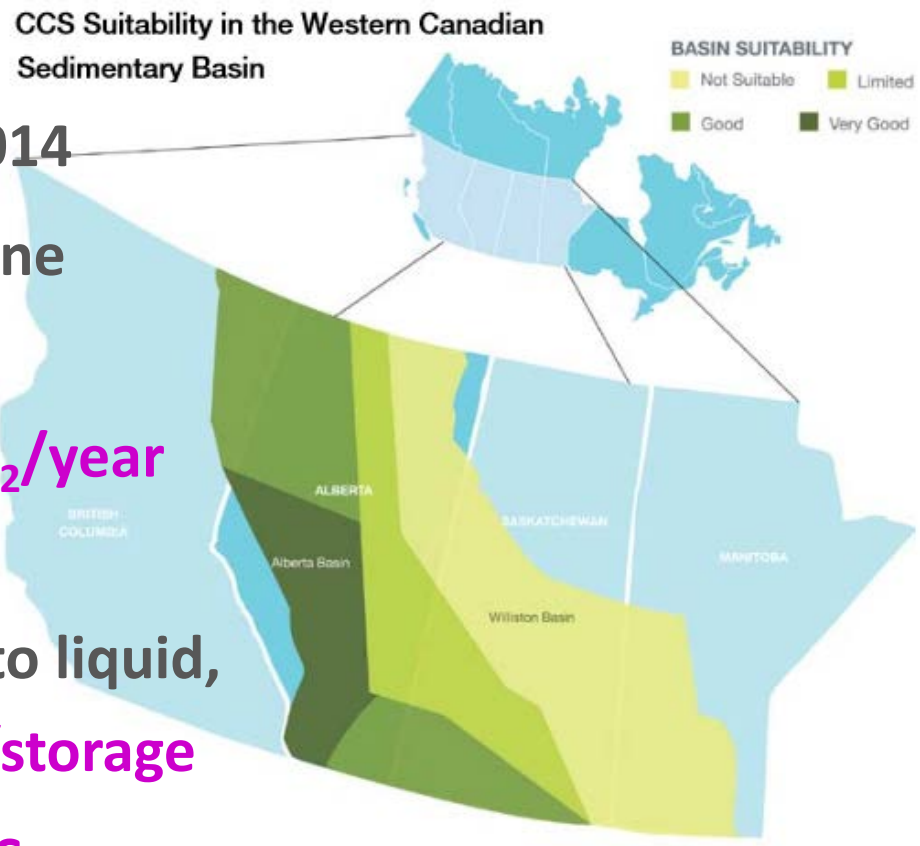
US DOE

CCS in Alberta, Canada

- Alberta has committed total of **1.5 billion** CAD for 15 years
- **170 million** CAD for CCS in 2013/2014
- 2 projects: Alberta Carbon Trunk Line & Shell Quest
- Total GHG reduction of **2.76 Mt CO_2/year** (in 2016)
- CO_2 will be captured, converted into liquid, transported, injected for **CO_2-EOR/storage**
- Alberta's geology is **suitable for CCS**



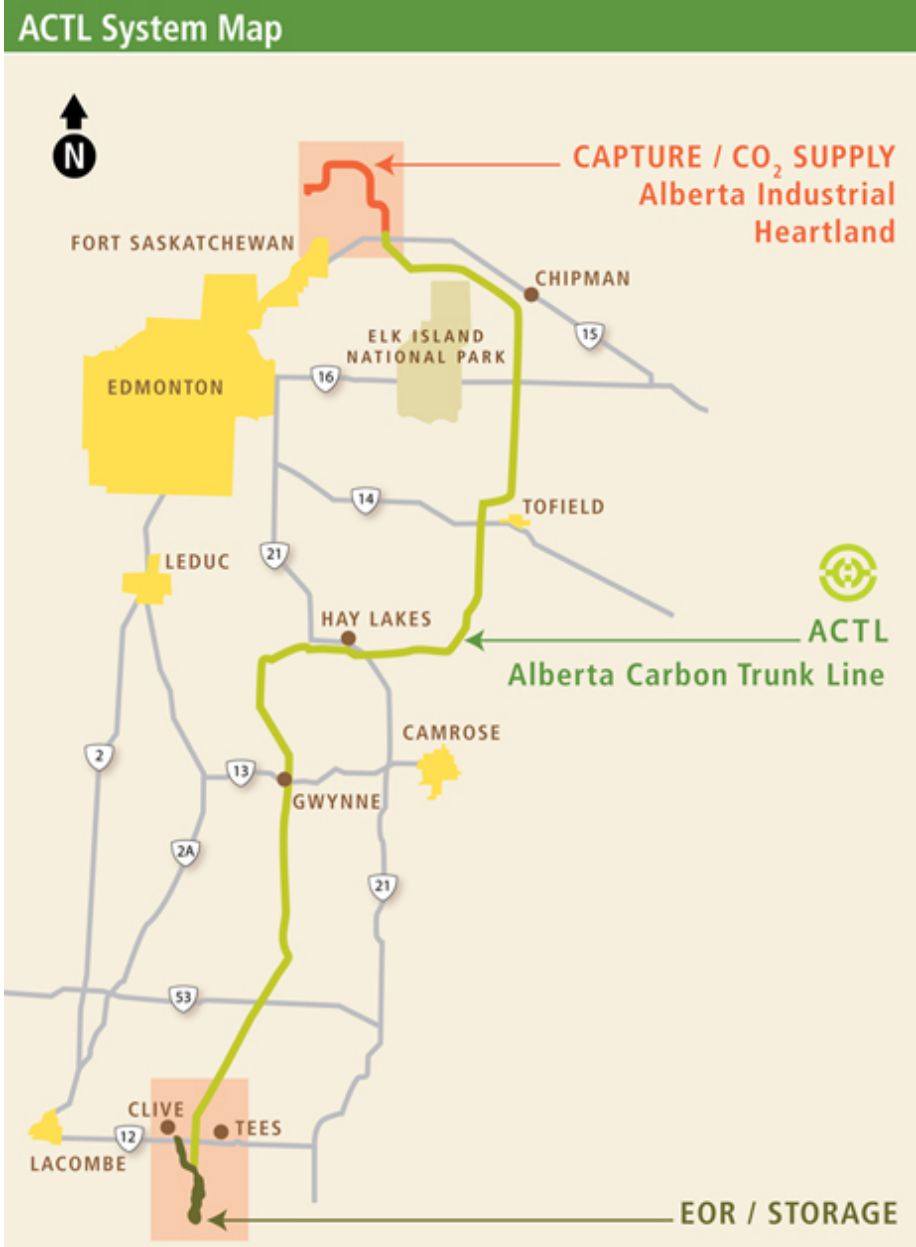
Alberta Energy

Alberta Carbon Trunk Line

- 495 million CAD for 15 years (2011)
- Carbon Capture from a **Fertilizer Plant** & an **Oil Sand Bitumen Refinery**
- 240 km pipeline transport
- For **EOR & Storage**

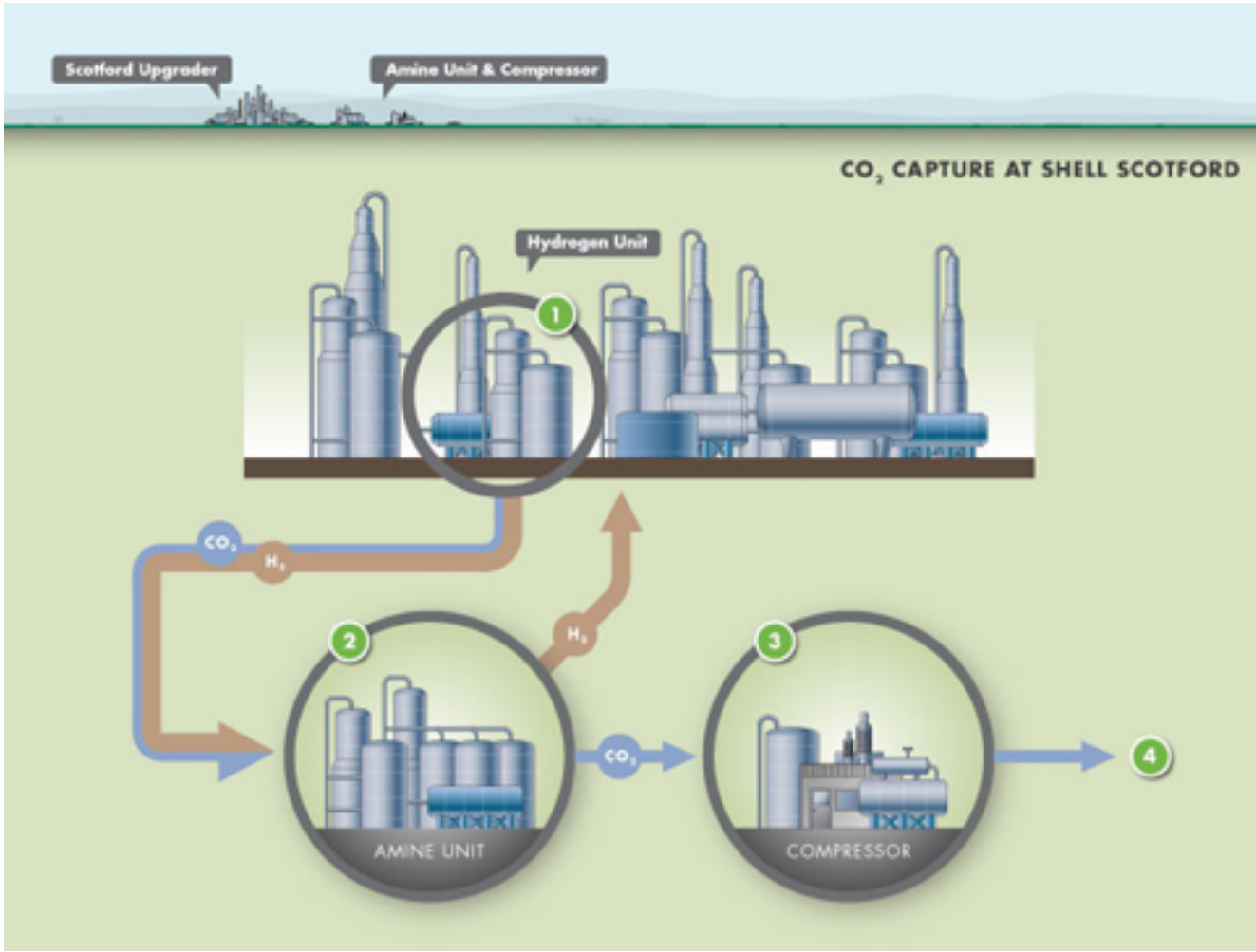
Alberta
Canada

Alberta Energy



Shell Quest

- **745 million CAD** for 15 years (2011)
- **1.2 Mt CO_2**
- From Shell's Scotford oil sand upgrader & expansion
- **80 km pipeline** transport
- For **EOR & Storage**



Alberta Energy

CCUS R&D in Saskatchewan, Canada

- IEA Weyburn-Midale CO2 Storage and EOR
- SaskPower BD3
- ITC

IEA GHG Weyburn-Midale CO2 Monitoring & Storage Project

Field size
- **70 square miles**

Original oil in place:
- **1.4 billion barrels**

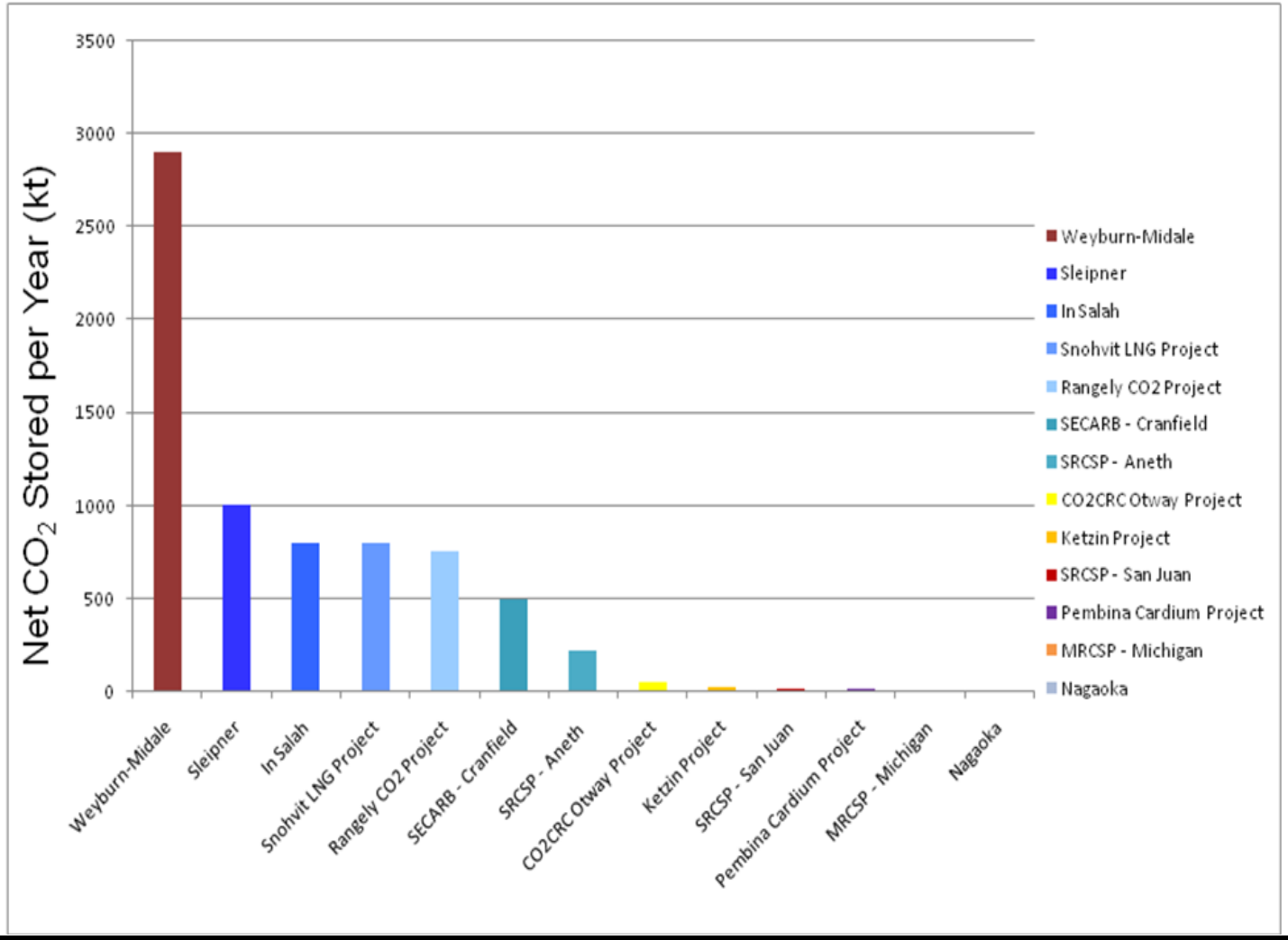
Oil recovery (pre-CO_2-EOR):
- **370 million barrels**

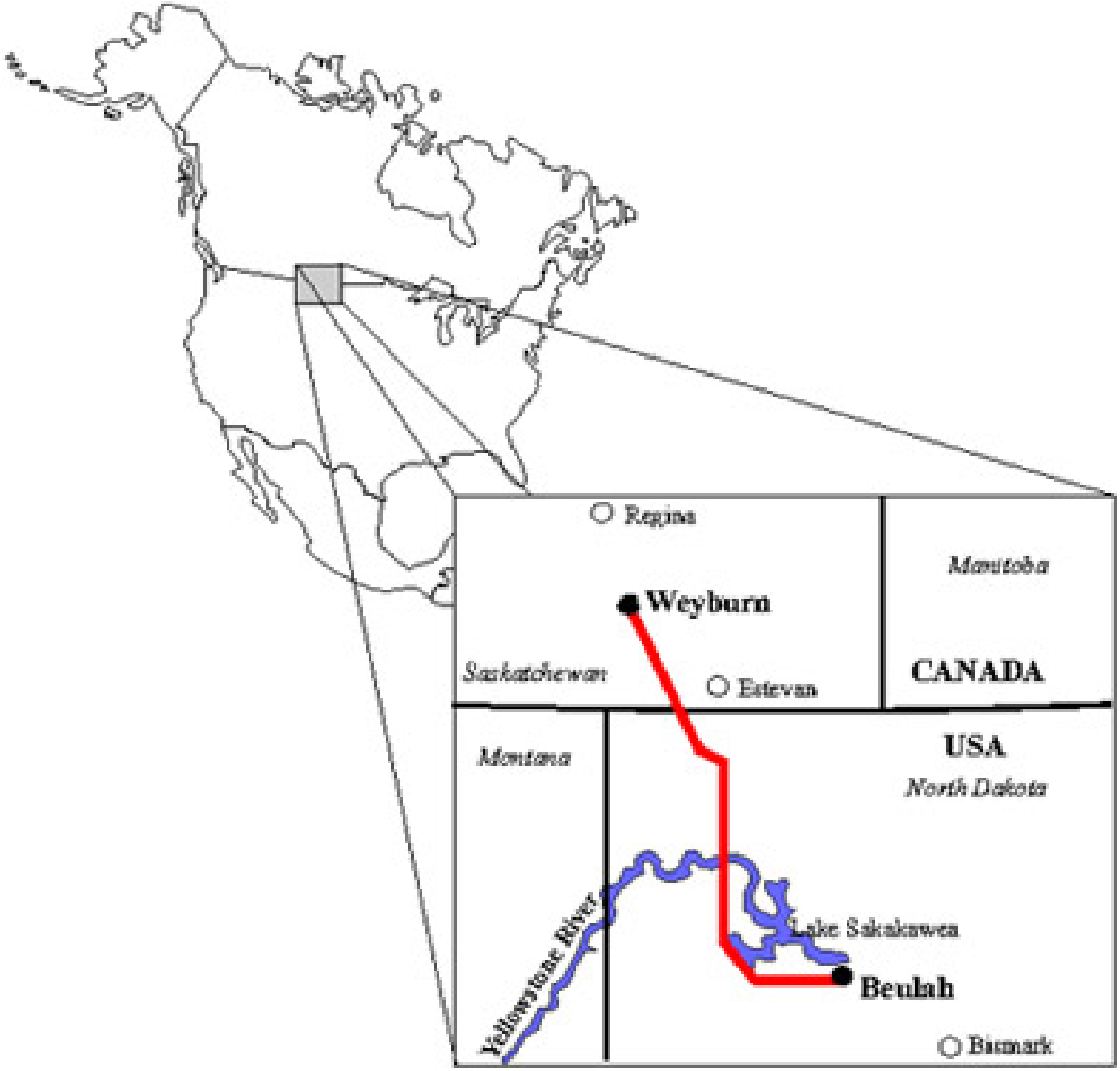
Projected CO_2 IOR:
- **155 million barrels**

Projected CO_2 stored:
- **30+ million tonnes* (gross)**
- **26+ million tonnes (net)**

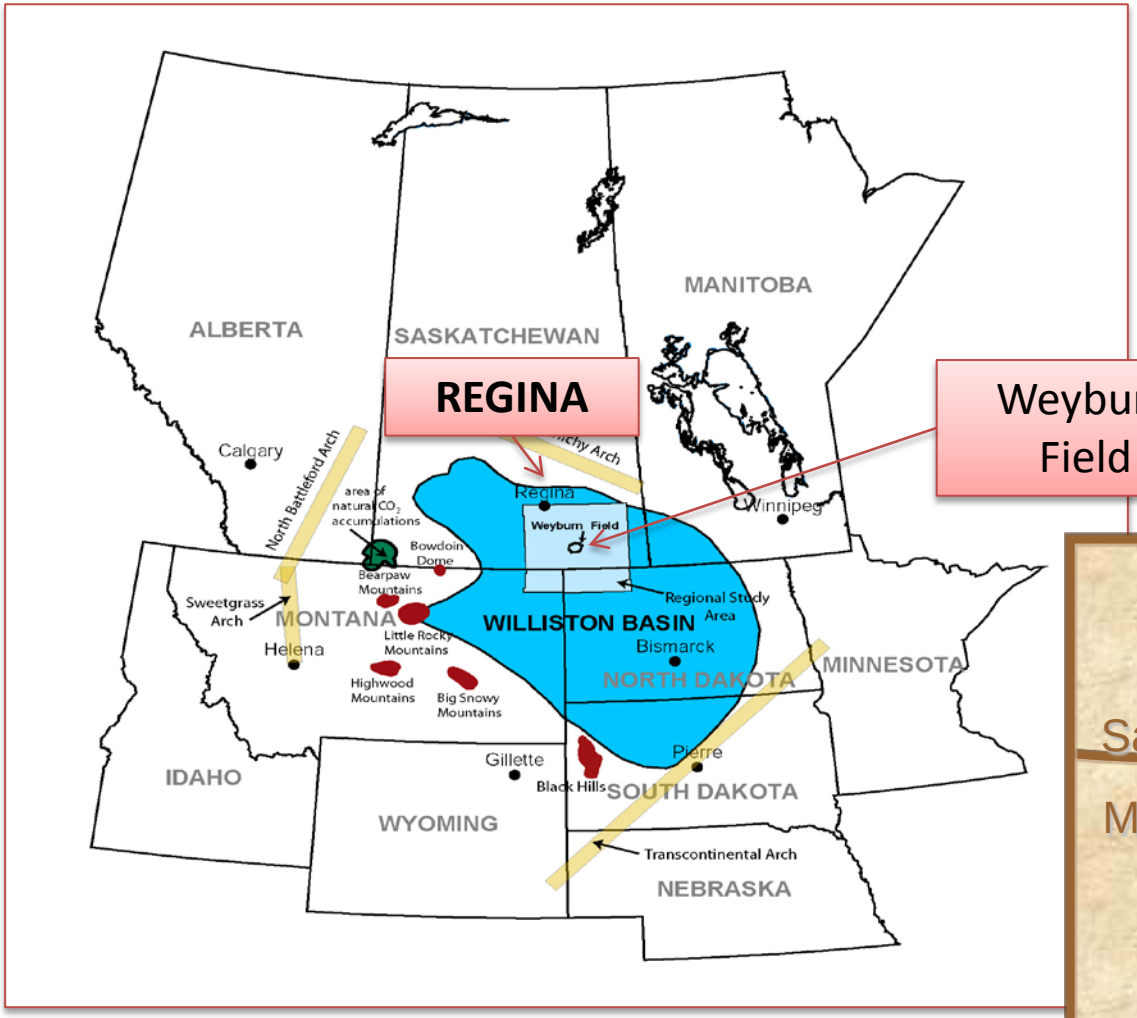
equivalent to removing* ***over 6 million cars* *from the road for 1 year*

IEA GHG Programme Large CCS Projects




Regina
Manitoba
Weyburn
Saskatchewan
Estevan
CANADA
Montana
USA
North Dakota
Lake Sakakawea
Yellowstone River
Beulah
Bismark

Project location: Williston Basin



Weyburn Pipeline

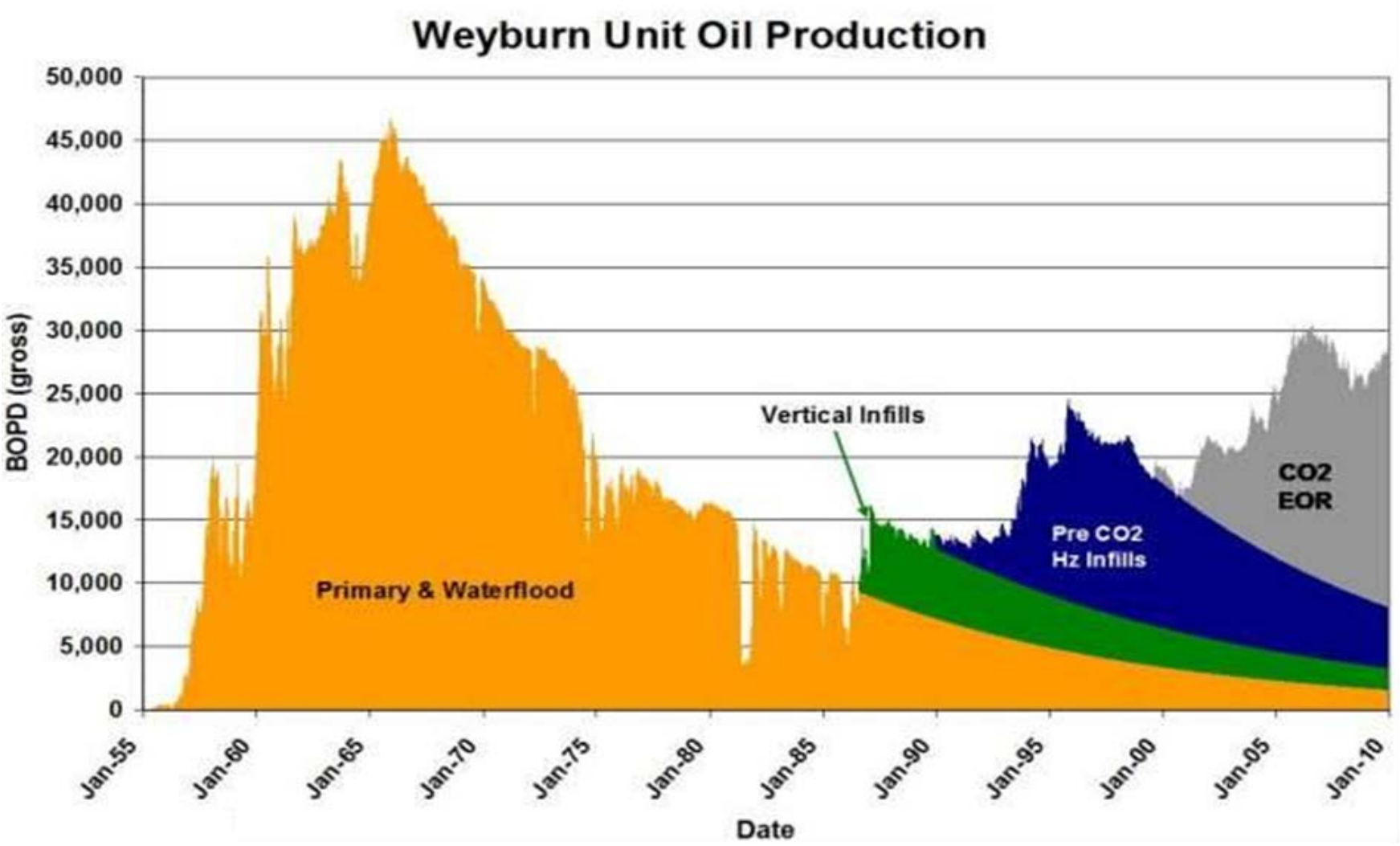
Project Overview

- The world's largest, full-scale, in-field CO2 geologic storage measurement, monitoring, & validation study with CO_2 EOR.
- Launched in 2000
- 11-year, $85 million (CAD) international project.
- CO_2 captured from Dakota Gasification Plant (320 km pipeline).
- Alternated CO_2-water injection.
- Injected CO_2 is separated from produced oil & water and re-injected.
- At the end of EOR, all injected and recycled CO_2 is permanently stored in deep underground.

Key Findings

- 18,000 incremental barrel of oil per day (BOPD) has been achieved.
- Geological characteristic of Weyburn oil pool is considered to be highly suitable for the secure long-term storage of CO_2.
- Soil gas sampling above the injection site found no evidence of escaped CO_2.
- Estimated storage capacity of 45.15 million tons of CO_2.
- Long-term risk assessment/performance studies confirm the geological study that CO_2 can be store securely in the reservoir.
- The CO_2 storage can be economically satisfied when combined with EOR.

Weyburn Project Results



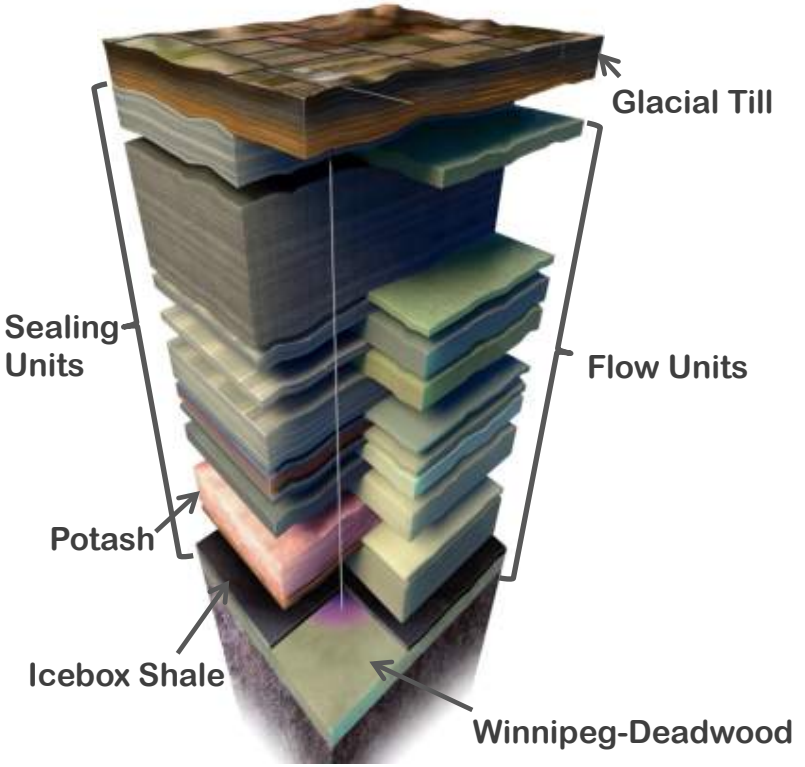
Life Cycle Analysis (LCA)

Results

Weyburn Oil Field	Capacity (million tonnes)	Capacity/barrel of incremental oil (tonnes/barrel)
CO_2 purchased	20	0.1538
CO_2 recycled	23	0.1769
CO_2 injected	43	0.3307
CO_2 emitted	1.4	0.0107
CO_2 net storage	18.6	0.1430

Aquistore – Project Objectives (CO_2 Storage Demonstration)

- **Demonstrate Capture, Transportation and Storage of CO_2 in saline formation**
- **Identify and develop best methods & technologies**
- **Involve research institutions, policy makers, industry, and public.**



Commercial Demonstration of CCS in Saskatchewan

Boundary Dam 3 Carbon Capture and Storage Project (BD3)

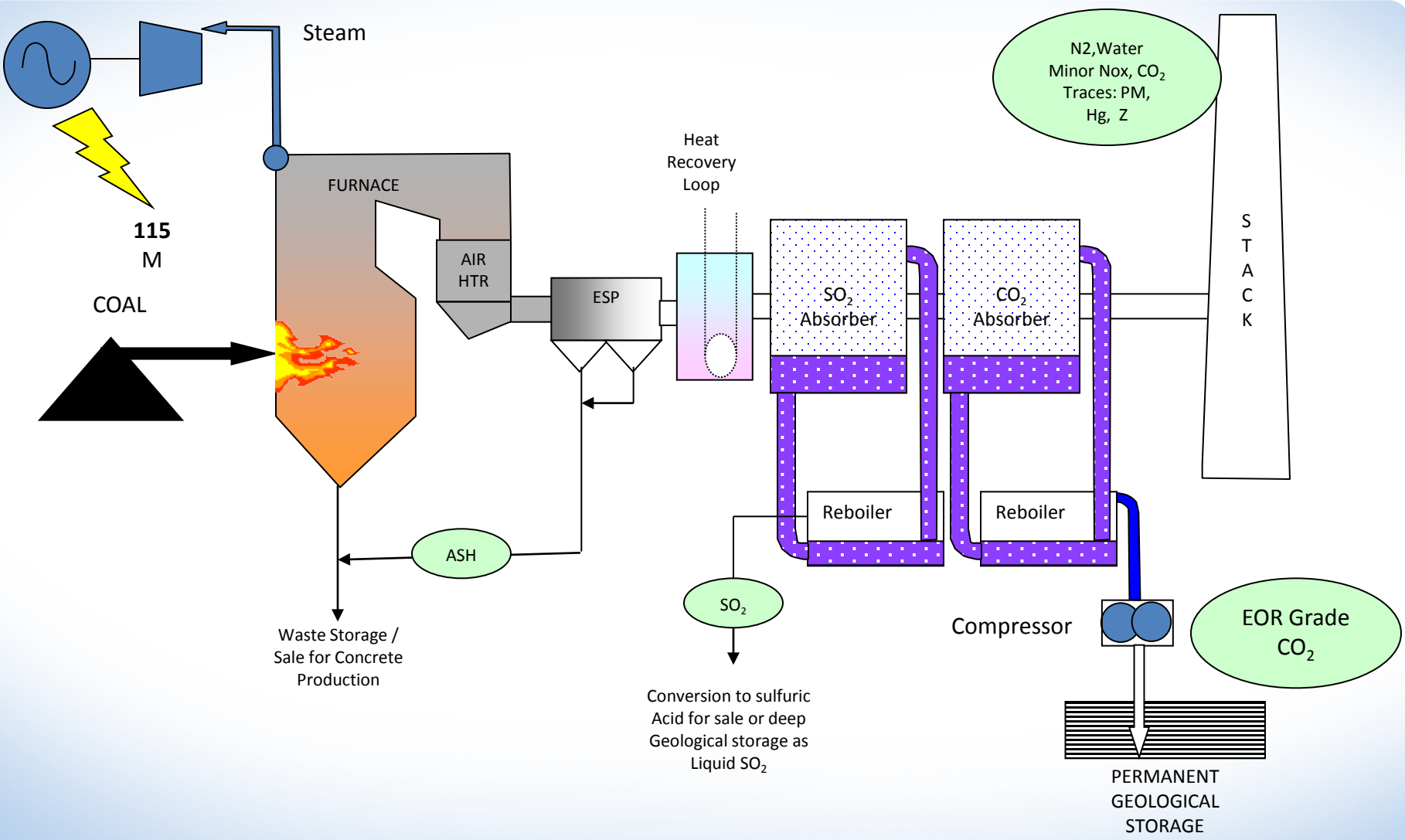
www.saskpower.com

BD3 ICCS

Boundary Dam ICCS Demonstration

BD3 ICCS

BD 3 Repowered



Boundary Dam 3 – SaskPower – Saskatchewan, Canada

- Boundary Dam Integrated Carbon Capture and Storage Demonstration Project
- $1.24-billion partnership involving the Government of Canada, the Government of Saskatchewan, SaskPower, and private industry
- In construction and scheduled to begin operation in 2014.
- 1 million tonnes CO2/year captured at 90% emission reduction
- Upgrading the unit’s output to help meet the additional power demands of the CCS operation.



International Test Centre for CO_2 Capture
University of Regina

Carbon Capture R&D at ITC:

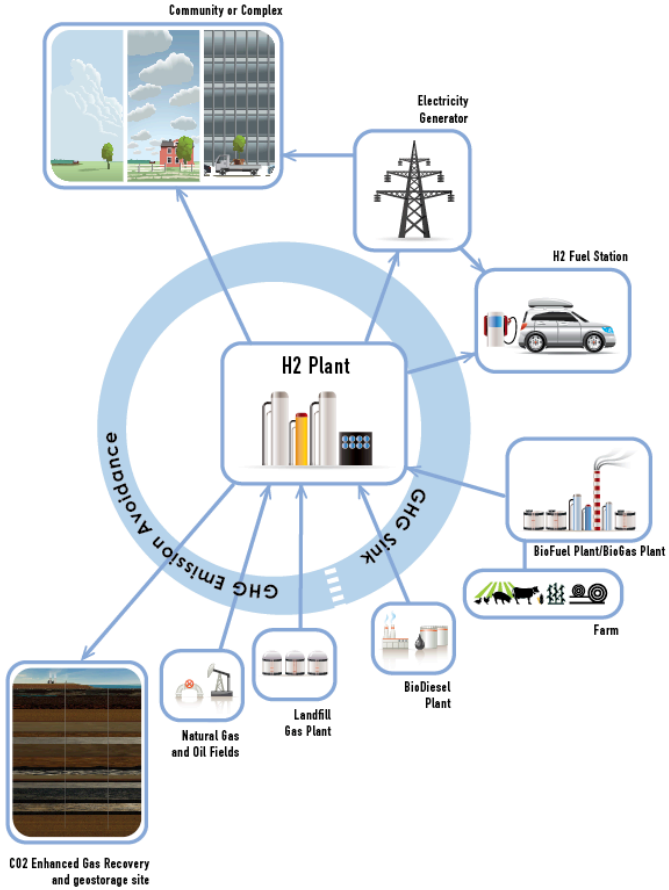
- Solvent Development and Testing
- Packing, solution, and membrane development and testing
- Process configurations
- Corrosion studies
- Simulation and modeling
- Artificial Intelligence/knowledge-based process control and monitoring systems

In-house pilot plant (1 t/d)

Production Facilities for Catalysts and H_2

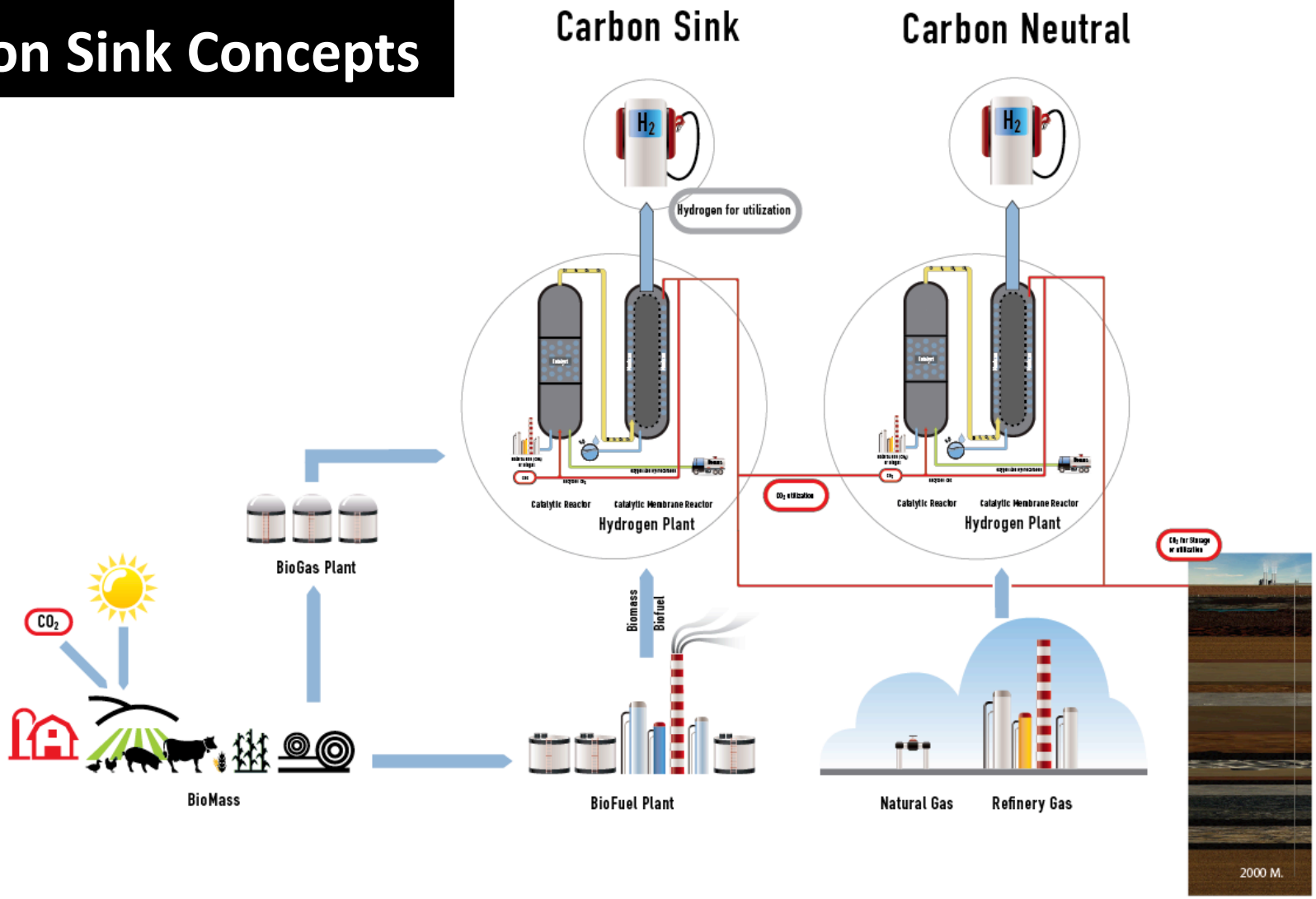
Our Catalytic Research

- H_2 from fossil fuels or bio-based feedstock
- Reduced energy consumption
- Feed- and Process-Flexible
- Zero emissions with fossil fuel + CO_2 capture
- CO_2 sink with bio-feedstock + CO_2 capture
- Scalable
- Not geographically limited



H2 and Catalysis Pilot Plant

Carbon Neutral & Carbon Sink Concepts



Carbon Capture Technologies: Past, Present and Future

- Conventional solvents
  - ❖Steam requirement: 1.8 ton steam / ton CO_2
- Currently avialable solvents
  - ❖Steam requirement: 1.4 – 1.2 ton steam / ton CO_2
- Up and coming solvents
  - ❖Steam requirement: 1.0 to 0.8 ton steam / ton CO_2
- Game-changer
  - ❖Steam requirement: ~ 0.5 ton steam / ton CO_2 (or less)

Key parameters for PCC

- Steam efficiency – lower needs, the better
  - Conventional processes ~ 2.0 kg steam / kg of CO_2
  - Current advanced processes ~ 1.4 to 1.2
  - Future technologies ~ 1.0 or below ???

Very Important

- Solvent losses
  - Emission losses
    - From Regeneration column
    - From Absorption column
  - Degradation losses
    - Thermal
    - Chemical
    - Re-claimer ???
- Corrosion issues
  - Additives

Future ?

- Technical Issues
  - Cost optimizations
    - $50 per ton?
    - $30 per ton?
    - $20 per ton?
  - Energy minimization
    - Steam ratio:
      - 1.0?
      - 0.8?
      - 0.5?
  - Emission control
    - Near “Zero” water used?
    - Near “Zero” emission?
  - Etc..

- Policy issues
  - Collaborations
  - Joint detail cost studies
  - Joint demonstration projects
  - Political determinations to move on CCS!

Key Sources of Information

- *GHGT-9: 9th International Conference on Greenhouse Gas Control Technologies, 16 - 20 November 2008, Washington DC;*
- *Symposium on Amines for Post Combustion Capture, Co-hosted by The Commonwealth Scientific & Industrial Research Organization (CSIRO) and Research Institute of Innovative Technology for the Earth (RITE), 26th May 2009, Kyoto, Japan;*
- *12th MEETING of the INTERNATIONAL POST-COMBUSTION CO2 CAPTURE NETWORK, 29th September - 1st October 2009, Regina, Canada;*
- *1st France-Canada Carbon Capture and Storage Conference, held in Regina, Saskatchewan, Canada, on November 16-17, 2009*
- ***GHGT 10 (Amsterdam),***
- ***GHGT 11 (Kyoto) in November 2012***
- ***PCCC1 (UEA) and PCCC2 (Norway)***
- *IEA GHG Programs*
- *Etc…*

SERIES FOREWORD

Recent progress and new development of post-combustion carbon-capture technology using reactive solvents

Carbon Management (2011) 2(3), 261–263

FUTURESCIENCE

Summary

Carbon Management
June 2011, Vol. 2, No. 3, Pages 265-288 , DOI 10.4155/cmt.11.19
(doi:10.4155/cmt.11.19)

Series Review

Part 1: Design, modeling and simulation of post-combustion CO_2 capture systems using reactive solvents

CCS or CCUS

- We have come a long way BUT we have a very long way to go!
- A lot of small projects and small pilot plants
- Also … a number of CO2 for EOR projects planned
- However, we need many more large CCS projects to make major impacts.

CO_2 Life-cycle Analysis:
"Green oil" from CO_2 for EOR application

	CO_2 Emission: Life-cycle analysis
"Green" Oil from CO_2 – EOR applications	*~ 0.5 to 0.75*
Primary oil production	*1.0 (up to 50% more CO_2)*
Oil from Oil Sand Projects (or secondary oil productions using steam)	*~ 1.5 to 2.0 (up to 100% more CO_2)*

Costs

Two ways of expressing costs:

- Additional electricity costs
  - Energy policymaking community
- CO_2 avoidance costs
  - Climate policymaking community

Different outcomes:

0.01 - 0.05 US$/kWh

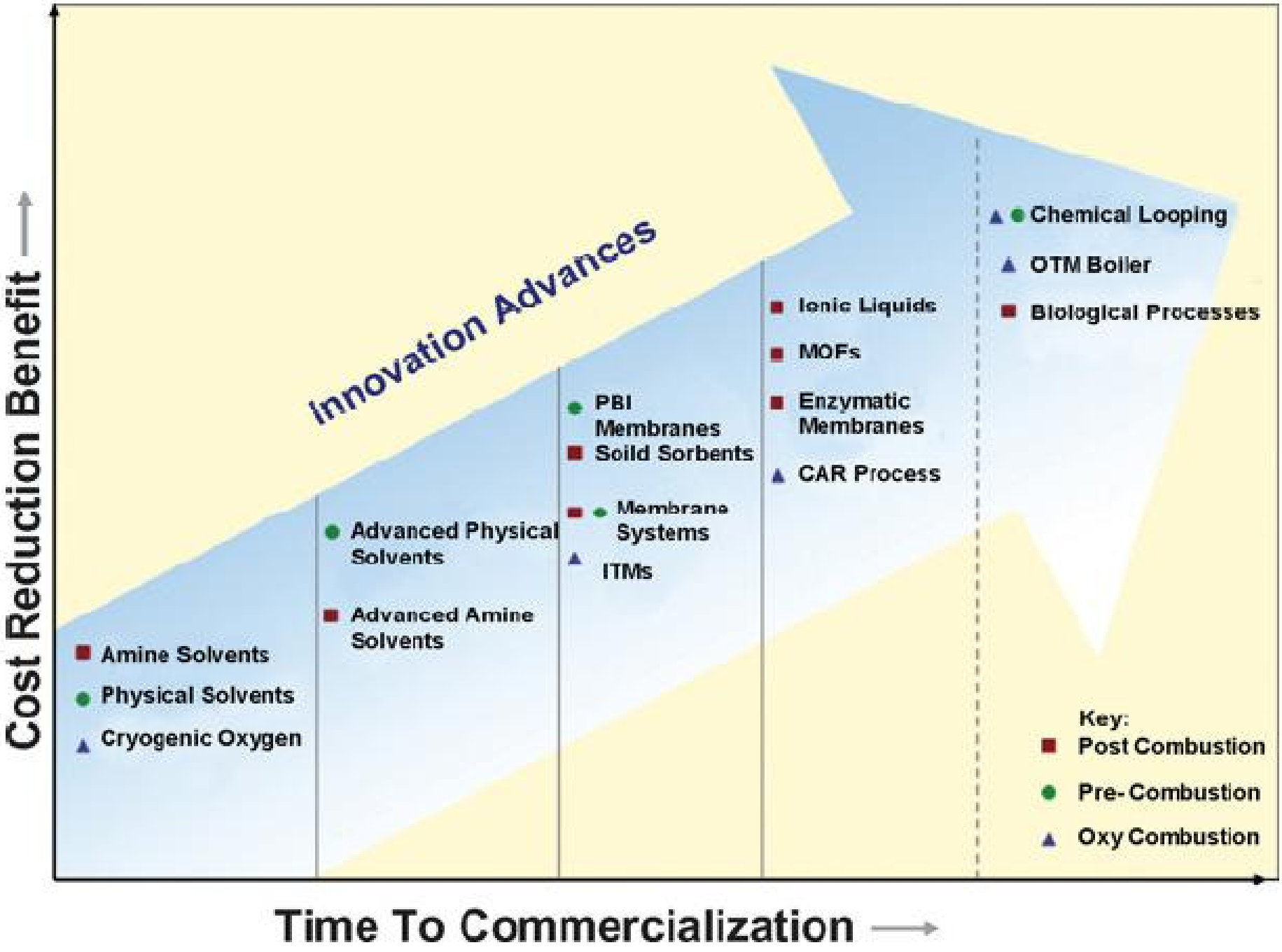
20* - 270 US$/t$CO_2$ avoided

(with EOR: 0*– 240 US$/t$CO_2$ avoided)

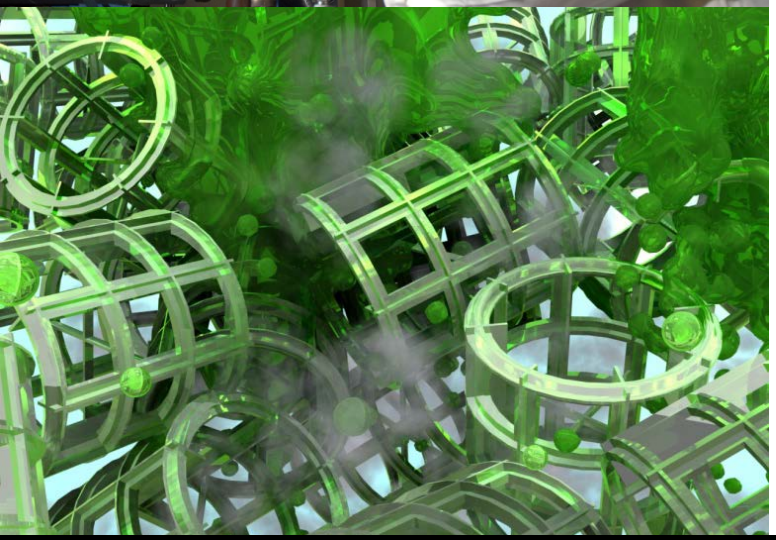
* low-end: capture-ready, low transport cost, revenues from storage: 360 MtCO_2/yr

CCS component costs

CCS component	Cost range
Capture from a power plant	15 - 75 US$/$tCO_2$ net captured
Capture from gas processing or ammonia production	5 - 55 US$/$tCO_2$ net captured
Capture from other industrial sources	25 - 115 US$/$tCO_2$ net captured
Transportation	1 - 8 US$/$tCO_2$ transported per 250km
Geological storage	0.5 - 8 US$/$tCO_2$ injected
Ocean storage	5 - 30 US$/$tCO_2$ injected
Mineral carbonation	50 - 100 US$/$tCO_2$ net mineralized


Cost Reduction Benefit
Time To Commercialization
Innovation Advances
Amine Solvents
Physical Solvents
Cryogenic Oxygen
Advanced Physical Solvents
Advanced Amine Solvents
PBI Membranes
Solid Sorbents
Membrane Systems
ITMs
Ionic Liquids
MOFs
Enzymatic Membranes
CAR Process
Chemical Looping
OTM Boiler
Biological Processes
Key:
Post Combustion
Pre-Combustion
Oxy Combustion

Thank you



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