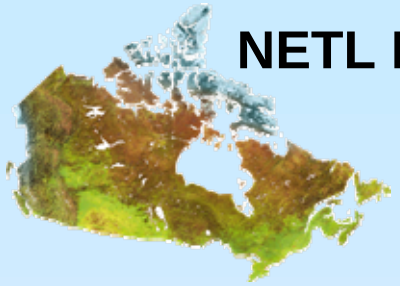


NETL Fourth Annual Conference on Carbon Capture and Storage

"Developing Potential Paths Forward Based on Knowledge, Science and Experience to Date"

Overview/Status Report on CO_2 Capture, Sequestration R&D and Deployment in Canada

"Putting The Pieces Together"

Graham R. Campbell
Office of Energy Research and Development
Natural Resources Canada
Alexandria, Virginia

4 May, 2005

Outline of Today's Presentation

- CO_2 Capture & Storage and a Sustainable Energy Economy
- Canada's Activities
- International Collaboration
- Closing Observations

"Fitting the Pieces Together"

Capture From All Sources	Transportation
Geological Assessment of Storage Capacity	Storage Deep Saline Aquifers
Enhanced Oil, Gas, CBM Recovery	Monitoring & Verification
Storage Regulations	Public Education Outreach

Achieving a Sustainable Energy Future, Transformative Energy Technologies

- **Key policy objective is sustainable development and responsible end-use of energy resources**

  - goals - sustainability, security, prosperity

- **Many of today's issues are closely linked to the supply, conversion and end-use of energy, examples are**

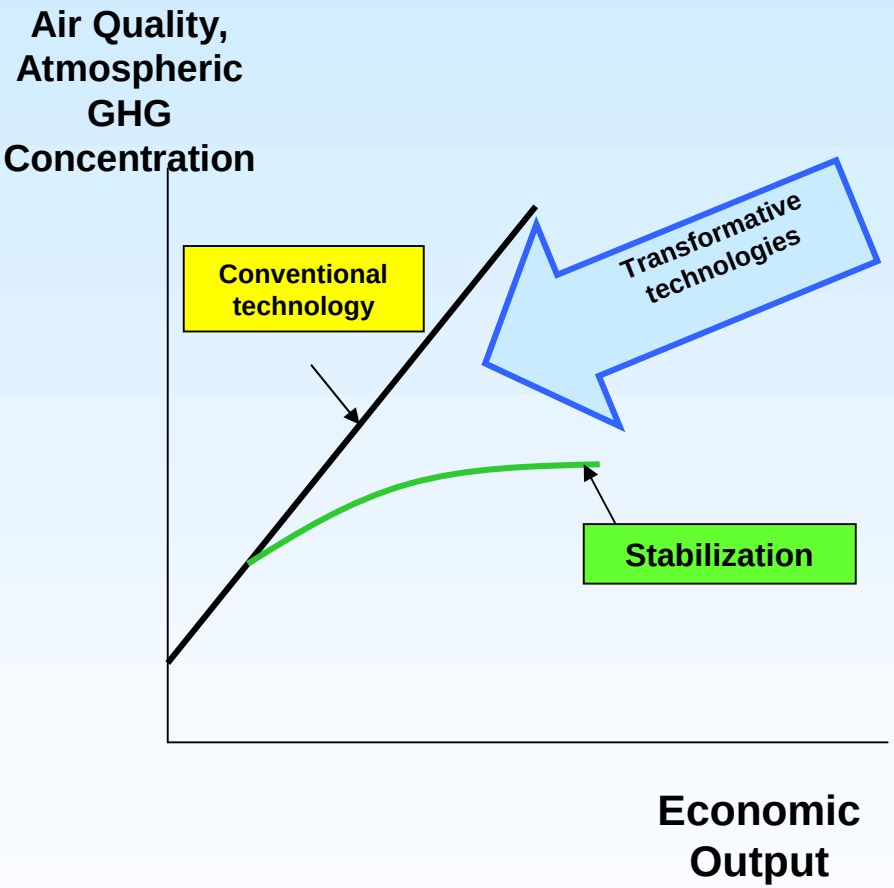
  – **long-term security of supply, environmental "footprint" of supply activities, impacts of energy end-use on urban air quality, increasing GHG emissions, foreign oil dependence**

- **Solution calls for both …**

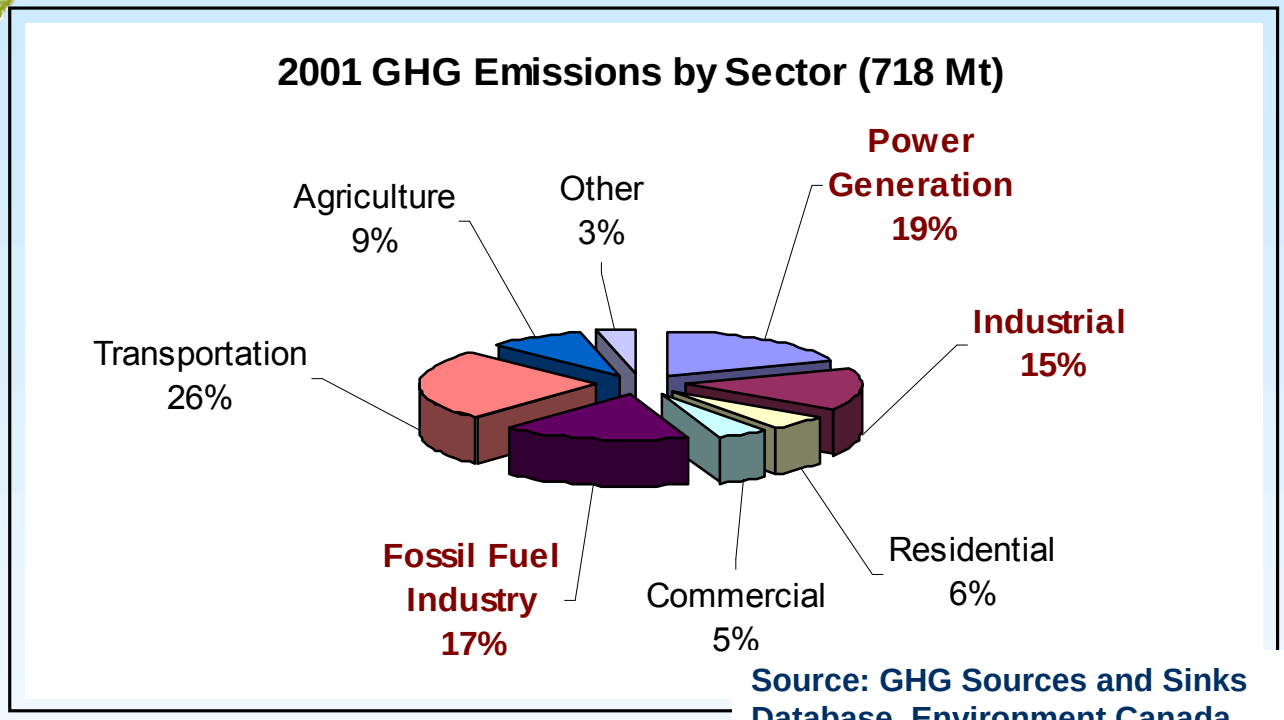
  – **transformative behaviour and practices, and**
  – **transformative energy technologies for energy supply, conversion and end-use efficiency**

Vision - Transformative Energy Technologies

- Transformative technologies can break linkage between increased use of energy and many of today's energy issues
- Offers a pathway to fundamentally-different ways of supplying, converting and using energy
- But, "transformative" technologies, by their nature, require or lead to …
  - new infrastructure
  - new skills, expertise
  - displacement of current technologies
  - new environmental impacts
- And importantly, new technologies trigger public interest - needs to be addressed up front
- Examples of transformative technologies – hydrogen, CO_2 capture and storage, advanced nuclear



Climate Change and the Need to Reduce GHG Emissions is a Formidable Challenge



Source: GHG Sources and Sinks Database, Environment Canada

- **51% of Canada's emissions from three sectors - power generation (19%), fossil fuel supply (17%), industrial end-use (15%)**
- **Opportunity for GHG mitigation from large point sources**

CO_2 Capture and Storage is a Promising Transformative Pathway

- Why are we interested in CO_2 capture and storage?
  - CO_2 capture and storage is applicable to electricity generation, upstream fossil fuels and industrial sectors – 50% of Canada's total emissions – largely from point sources
  - Canada has an abundance of geological formations potentially suited to the long term storage of CO_2
  - "Buys us some time", facilitates a transition to a low carbon emissions energy economy – e.g., clean coal, hydrogen, nuclear, wind, solar, other alternatives and renewables
- Part of an integrated S&T program – technologies and initiatives for clean supply, conversion and efficient end-use, more renewables

Issues and Needs for CO_2 Capture and Storage

- **Issues and Needs**
  - **Reductions in CO_2 capture costs, increased energy efficiency, improved technologies & systems**
  - **Transportation infrastructure (pipelines)**
  - **Estimates of effectiveness and capacity of storage in geological media**
  - **Cost-effective techniques for longer-term monitoring, measurement and verification**
  - **Safety and integrity of sub-surface storage and longer-term issues affecting ‘fixation’ and ‘leakage’**
  - **Regulatory mechanisms, royalty structures, ownership, credits**

CO_2 Capture, Use and Storage
Suite of Interdependent Activities

Overall Vision and Goals

Create Conditions for Development of a "Market/Industry" for CO_2 in Canada

Capture All Sources	**Transportation**
Geological Assessment of Storage Capacity	**Storage Deep Saline Aquifers**
Enhanced Oil, Gas, CBM Recovery	**Monitoring & Verification**
Storage Regulations	**Public Education Outreach**

" … creating the conditions for a CO_2 market/industry in Canada …"

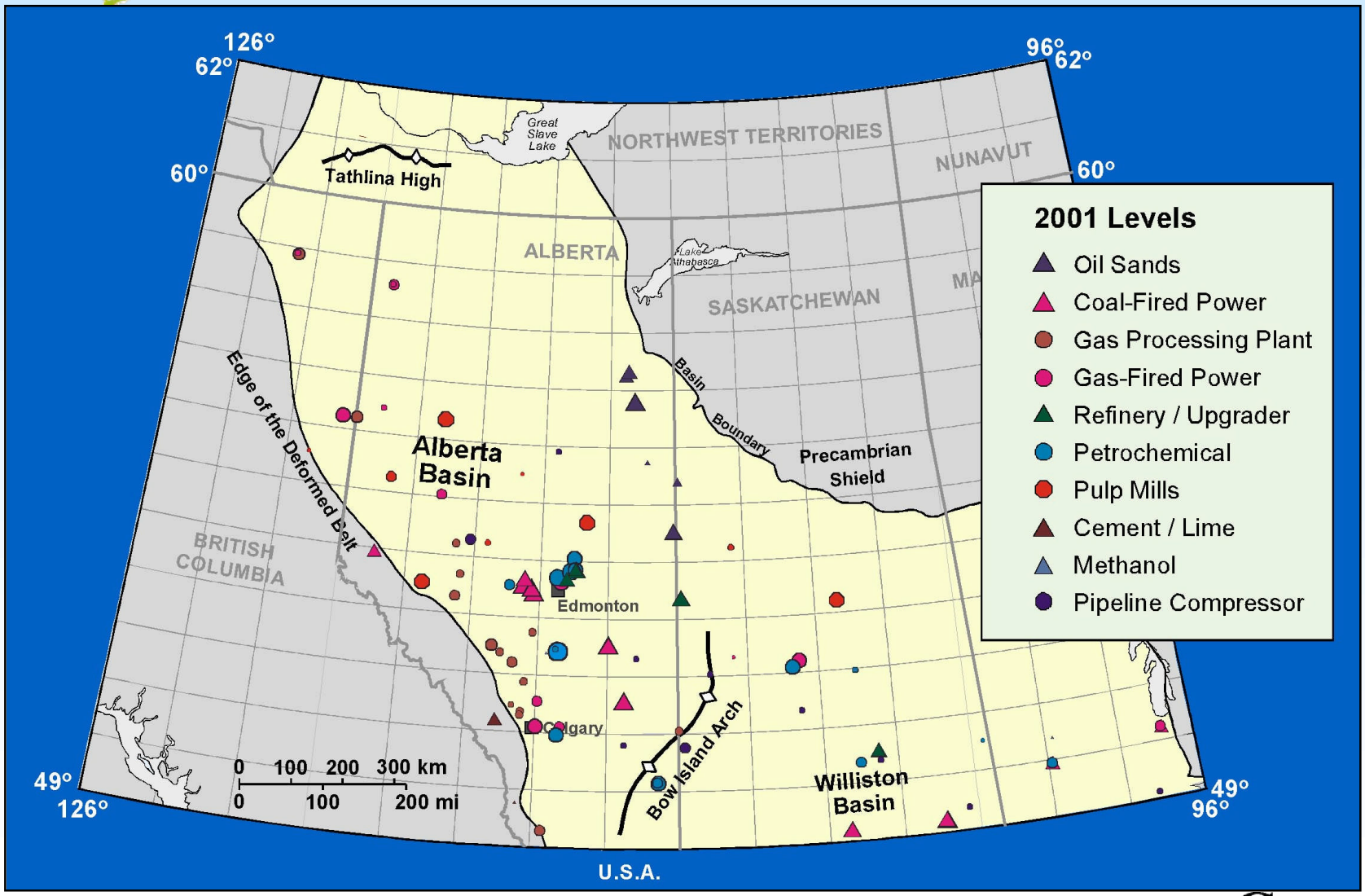
- **Several dimensions to achieve goal**
  - **Development of cost-effective technology**
  - **Development of a regulatory framework for long-term storage**
  - **Address public interests, communications**
  - **Achieve investment confidence**
- **Requires a combination of research from both physical and social sciences**
- **To date, most emphasis has been on the development of the technology**
- **Critical need to draw on social sciences to address – how to provide objective and understandable information, determine public attitudes, understand perceptions of risk, craft communication plans**

Canada's CO_2 Capture and Storage Activities
"Fitting the Pieces Together"

Capture From All Sources

Diverse Point Sources of CO_2 in Western Canada

AGS/EUB - Inventory of CO_2 Sources in WCSB



Reducing the Cost of CO_2 Capture

A Key Challenge

- **Large-scale point sources are ideal for CO_2 capture**
  - **– industrial plants, hydrogen production (oil sands), fossil-fired electricity generation**

- **Capture – Reduce the cost**
- **– Capture cost represents 70-90% of the total capture, compression, transportation and storage costs**
- **– CO_2 capture from today's coal plants very costly - dilute flue gas**
- **– Costs of CO_2 capture consist mainly of additional fuel cost and capital costs**

- **Potential for capture cost reductions:**
- **– Continuing R&D and development of a market for products is needed to stimulate cost reductions**
- **– Advancements will be made to existing technologies**
- **– Technological breakthroughs – greater efficiencies, potential for large cost reductions**

(Source:IEA GHG studies)

Examples – CO_2 Capture Technologies

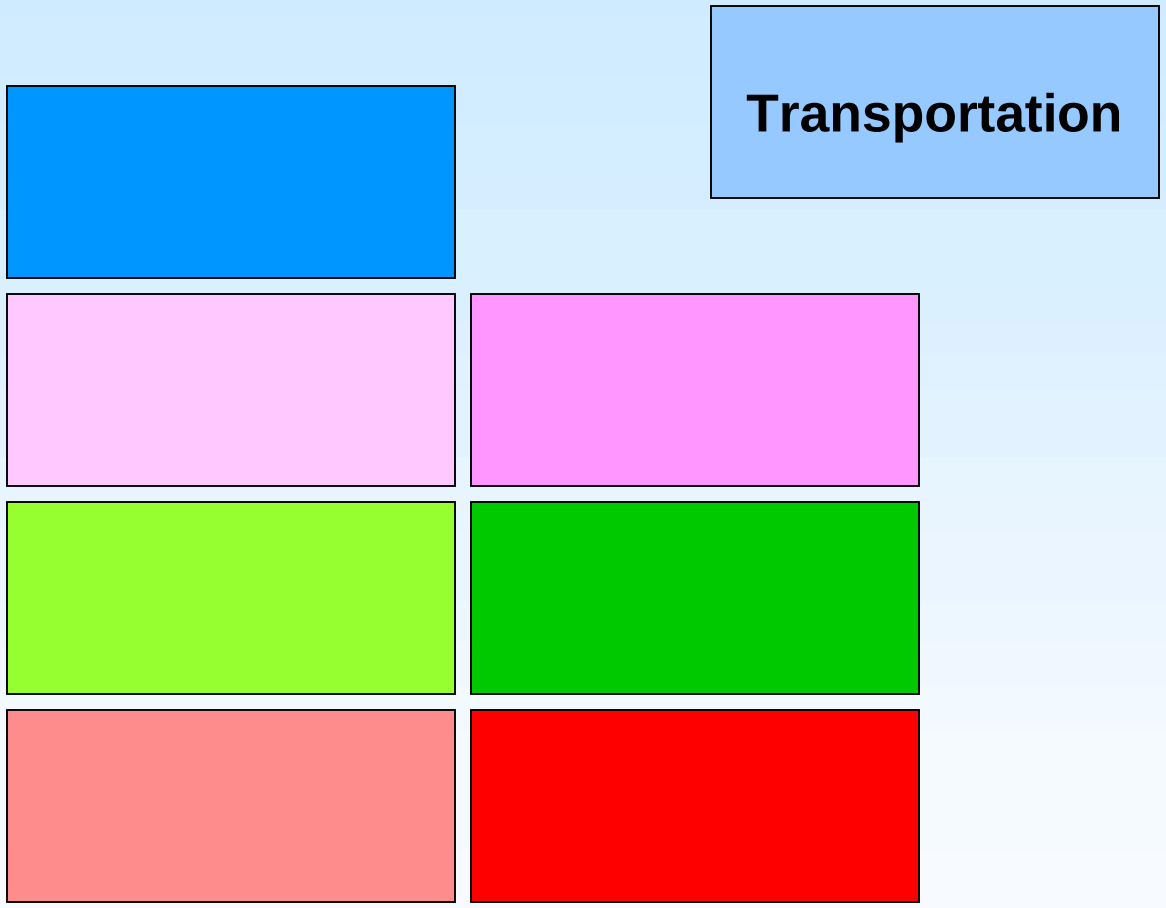
- **Three major lines of investigation**
  - **Amine capture**
  - **CO_2/O_2 recycle**
  - **Gasification with CO_2 capture**

- **Amine capture**
  - **International Test Centre, University of Regina**

- **CO_2/O_2 Recycle**
  - **NRCan Energy Technology Centre, Ottawa**

- **Gasification with CO_2 capture**
  - **Canadian Clean Power Coalition**
  - **NRCan Energy Technology Centre, Ottawa**

Canada's CO_2 Capture and Storage Activities
"Fitting the Pieces Together"

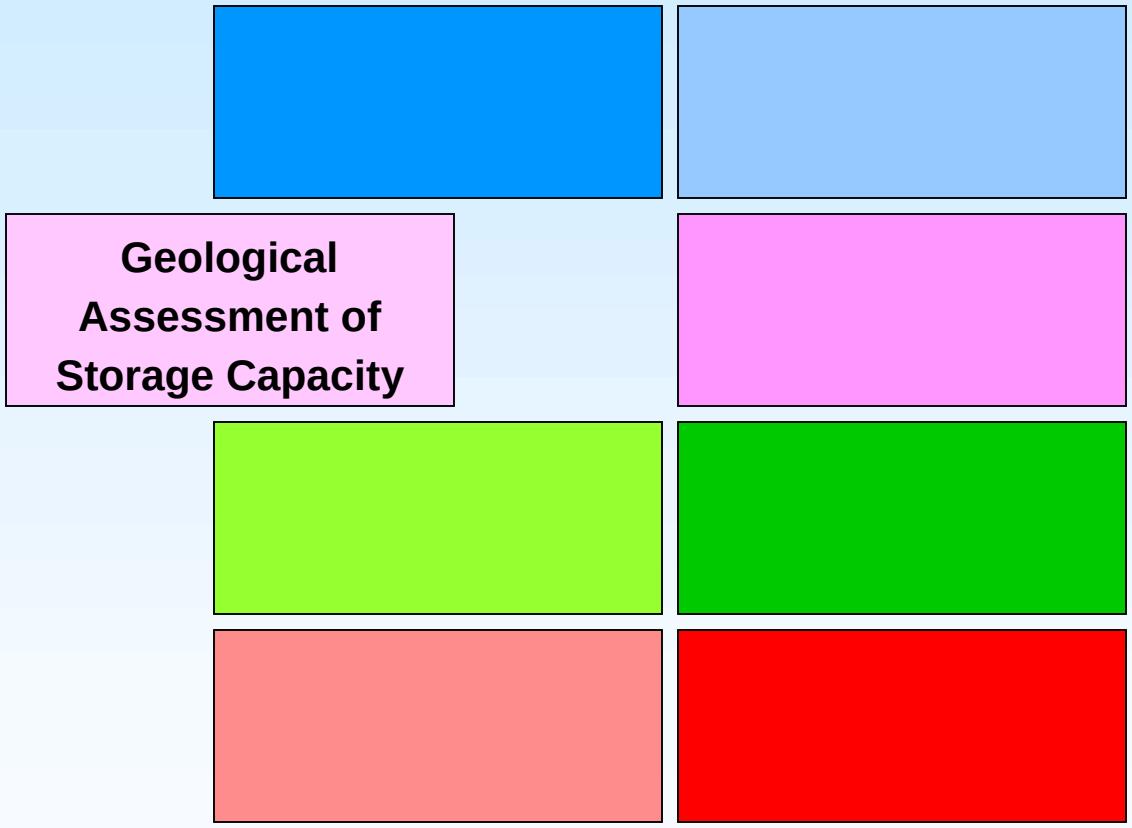


Large-Scale CO_2 Uses Require New Pipeline Infrastructure

- **Pipelines**
  - **High pressures and easy handling but corrosion and safety issues – the only viable transportation means**
  - **Two existing commercial EOR projects in Canada are fed by pipelines**

- **For EOR, main sources of CO_2 are often distant from fields with EOR potential**
- **Calls for a "trunk pipeline", carefully sized and staged**
- **For storage in deep saline formations, many CO_2 sources are favorably located**

Canada's CO_2 Capture and Storage Activities
"Fitting the Pieces Together"



Initial Assessments of Storage Capacity are Impressive

- **Geological studies completed for**
  - **Western Canada Sedimentary Basin (basin-wide, Alberta Geological Survey/ Energy and Utilities Board)**
  - **Nova Scotia (coal basins, Geological Survey of Canada)**

- **Assessed – regional geological characteristics, EOR candidates, depleted oil gas fields, deep saline formations, deep coal measures**

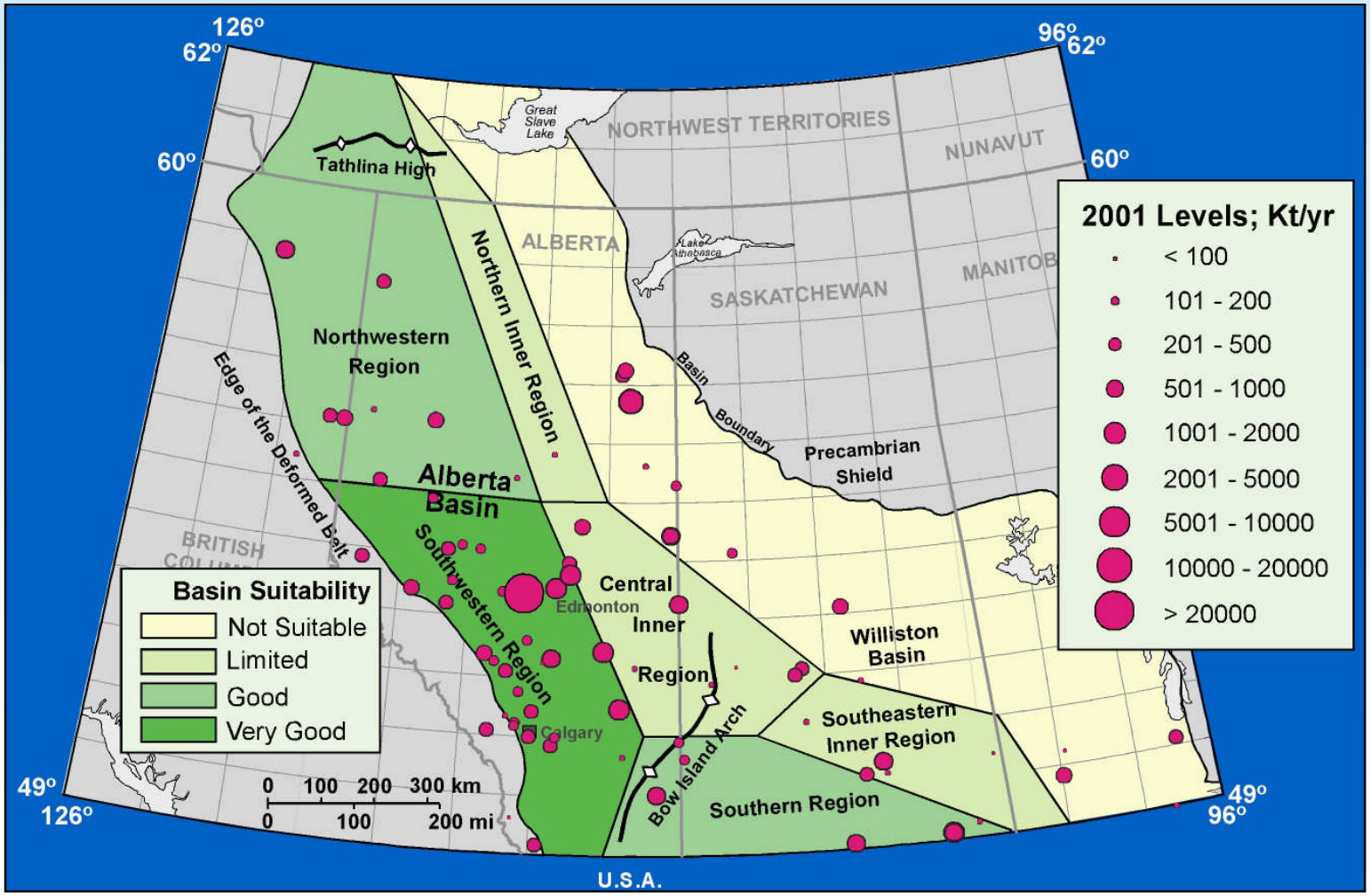
- **Estimates of storage volume indicate huge technical storage potential in Western Canada**

CO_2 EOR	450 megatonnes
ECBM	10,000 – 100,000 megatonnes
Depleted Reservoirs	111 megatonnes (non-EOR oil)
	13,200 megatonnes (gas)
Deep Saline Aquifers	100,000 - 1,000,000 megatonnes

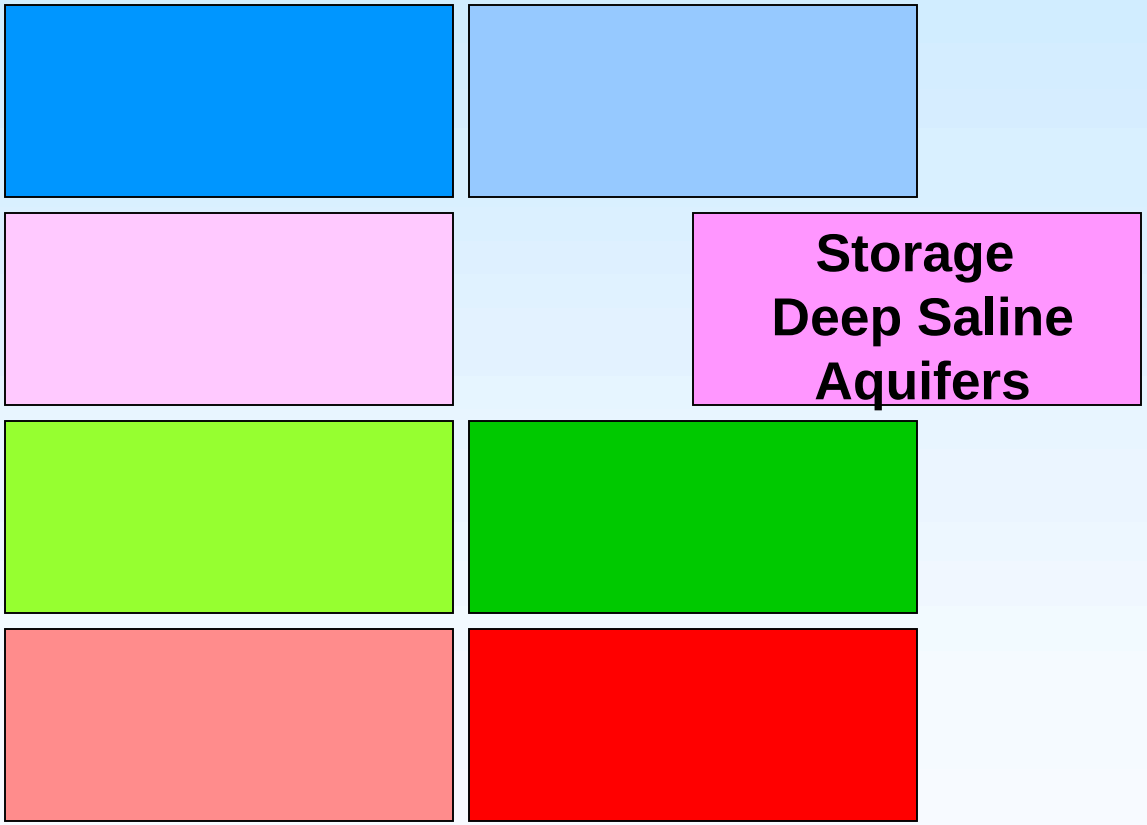
Sources: Alberta Energy and Utilities Board (S. Bachu); NRCan/EnergyINet

Good Geographic Match Between Best Storage Areas and Major Sources

AGS/EUB - Inventory of CO_2 Sources in WCSB



Canada's CO_2 Capture and Storage Activities
"Fitting the Pieces Together"



Canada's Sedimentary Basins Offer Ideal Storage Capacity

- Results from geological studies are positive – suitable geology, well-isolated from fresh water aquifers, good understanding of subsurface water movement
- Prime storage areas in Canada – most of the Western Canada Sedimentary Basin, coal basins in eastern Canada, northern and offshore basins
- Storage configurations, no resource recovery – deep saline aquifers, depleted oil and gas fields
- Storage capacity is immense, relative to Canada's annual emissions
- International examples – Norway's Sleipner project (offshore platform), Frio Brine project

Disposal of Acid Gas in Alberta
A Working Example

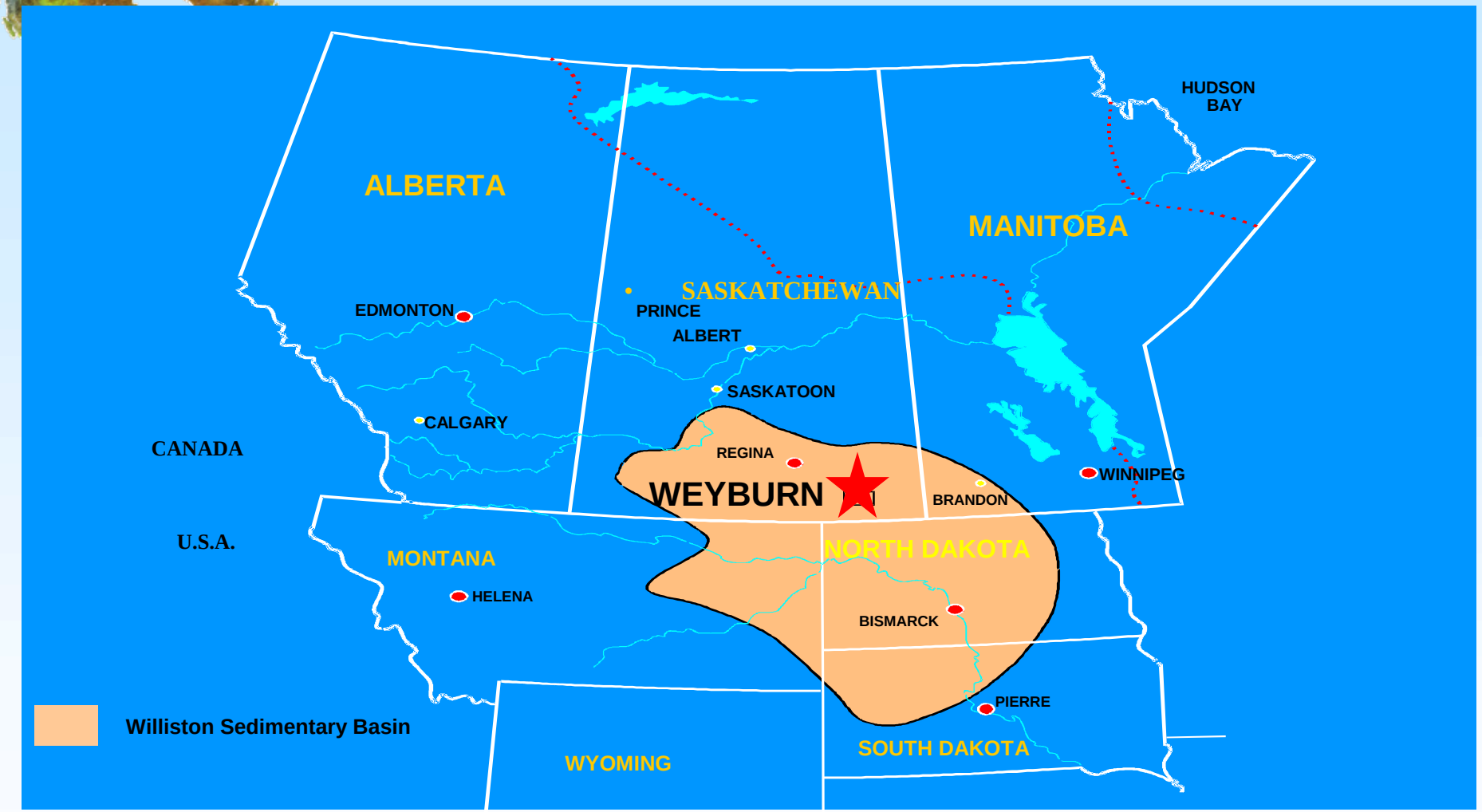
- Production and processing of sour natural gas yields by-products – e.g., H_2S, CO_2
- Disposal of acid gas in deep saline aquifers is a routine practice – over 40 projects in Alberta
- Regulatory requirements and practices are well-established
- Volumes are small relative to anticipated CO_2 to be stored
  - Roughly 1 Mt annually of acid gas, versus 70 Mt annually from power production in western Canada

Canada's CO_2 Capture and Storage Activities
"Fitting the Pieces Together"

CO_2 Floods Open up Pathway to Increasing Recovery of Oil, Gas from Existing and New Fields

- Recovery rates of oil and gas using conventional techniques are low
  - 15% for heavy oil, 35% for light oil
- Recovery rates can be increased by flooding reservoir with CO_2
  - Enhanced oil recovery (EOR), enhanced coal bed methane (ECBM), enhanced gas recovery
- Over 70 CO_2 EOR fields in US, two to date in Canada, additional field announced recently – commercial successes
- Examples (light and medium oil)
  - EOR - EnCana's Weyburn EOR Project
    - Apache Canada's Midale Project (recently announced)
    - Several new EOR pilot projects
  - ECBM - R&D underway, multi-well pilots, Suncor project

EnCana's Weyburn Oil Field – CO_2 Enhanced Oil Recovery Project

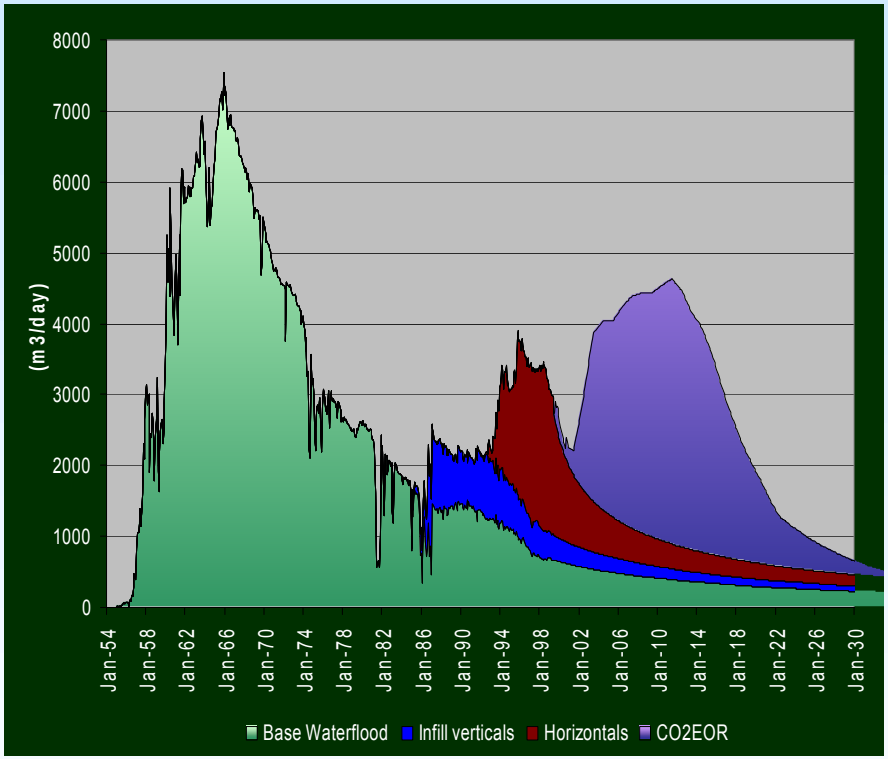


Weyburn Unit: Field Size: 179 km^2 OOIP: 220 million m^3
Oil Recovered: 56 million m^3 CO_2 IR: 20 million m^3

EnCana Operations

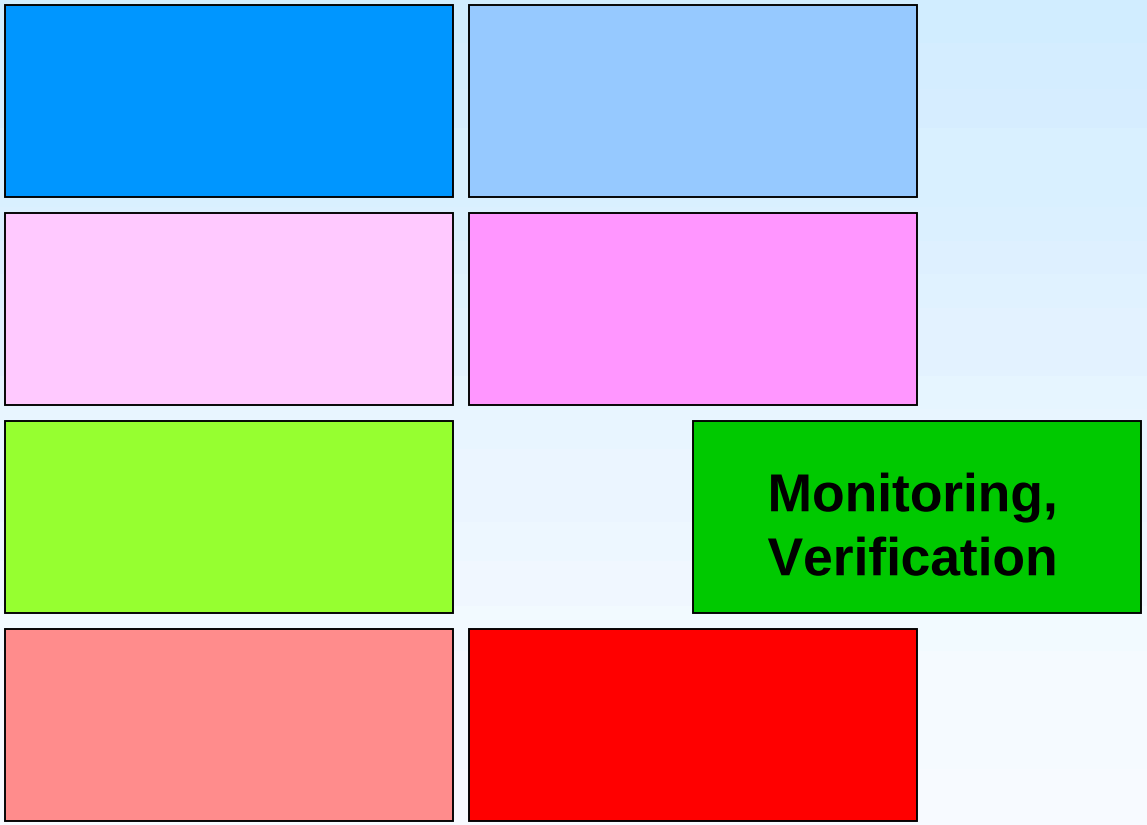
Update (Sept. 2000 – Dec. 2002)

- **CO_2 injection into Phase 1A started Sept. 2000**
- **CO_2- EOR flood to 2025**
- **14 M tons (net) of CO_2 stored over 25 yrs**
- **Commercial project is rolling out beyond the Phase 1A monitoring project area**
- **Current CO_2 purchase: 5000 t/day**
- **29% injected gas recycle**
- **2.71 M tons injected to the end of Dec. 2002 (1.7 M tons stored)**
- **4.14 M tons injected to the end of Dec. 2003 (2.7M tons stored)**



Courtesy: EnCana Corporation

Canada's CO_2 Capture and Storage Activities
"Fitting the Pieces Together"



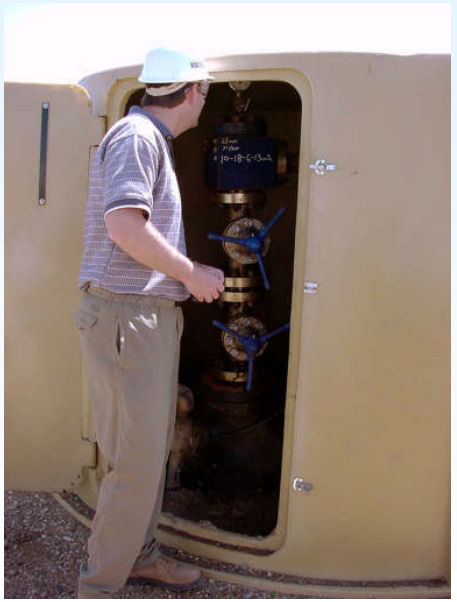
Any Proposal for CO_2 Storage Requires Sound Methods for Monitoring and Verification

- Critical questions – How much is stored? Where does the CO_2 go? How long does it stay there? Does it move away? will it leak to the surface? – in essence, determining "storage capacity and integrity"
- EOR sites are an excellent platform for study, analysis of CO_2 storage
  - Excellent geological drilling records and production data, ideal test site for storage capacity analysis and monitoring techniques
- Need monitoring and verification techniques suitable for
  - EOR, ECBM
  - Deep saline aquifers
- Essential ingredient to assure public confidence, achieve international recognition of stored volumes
- Example:
  - IEA GHG Weyburn CO_2 Monitoring and Storage Project

Why Was The Weyburn Unit Selected for Canada's Initial Monitoring Project?

- World-class CO_2 Enhanced oil recovery (EOR) project
  (CDN $1.5 billion, US $1.1billion)
- Easily accessible site
- Substantial historical data base
- Extensively drilled with accurate records
- Pre-injection baseline data could be gathered
- Extremely supportive industry host and partner (EnCana Corporation)

A CO_2 injector site



Long-Term Risk Assessment of the Storage Site Yielded Positive Results

- " A Long-term assessment of the fate of CO_2 injected into the Weyburn reservoir" – identify all risks, assess the ability of the Weyburn reservoir to securely store CO_2 for 5000 years

- Results:
  - Cumulatively over 5000 years – 75% stays in the EOR area, 18% moves below the reservoir, 9% moves laterally, 0.02% moves into overlying caprock, nil into potable aquifers
  - From abandoned wells, cumulative leakage of 0.14%
  - 95% probability that 98.7% to 99.5% of the initial CO_2 in place will remain stored in the geosphere for 5000 years

- Conclusion

  "The geological setting at Weyburn is highly-suitable for the long-term storage of CO_2"

How Did The Initial Weyburn Project Advance CO_2 Storage Technology?

- **Yielded several critically important results:**

1. **Reliable estimates of net CO_2 stored in this reservoir, via production monitoring**
2. **Means to follow movement of CO_2 in the reservoirs, using seismic monitoring, fluid sampling**
3. **Evidence of possible chemical reactions between the CO_2 and reservoir fluids, using geochemistry modeling**
4. **Advancements in monitoring techniques – seismic, computer simulation, geochemistry**
5. **Increase database of information – for regulation, for studies which will inform public, build interest and confidence in CO_2 geological storage**

Collaboration at Weyburn Was Excellent Some Highlights

- **Partners – EnCana, governments - Canada, Alberta, Saskatchewan, US DOE, EU, IEA, 9 companies, 24 research providers – 5 European, 5 US, 14 Canadian – managed by the Petroleum Technology Research Centre**
- **Built on a solid foundation provided by the IEA Greenhouse Gas R&D Programme - expertise, ongoing engagement and collaboration**
- **High quality, sound scientific experiment – excellent baseline information, complementary disciplines brought to bear**
- **Widespread dissemination of information**
- **Field operator is strongly supportive, cooperative with the international monitoring project**

Leading Sponsors' Overall Plan CO_2 Storage and Monitoring

- **Leading Sponsors have developed an overall plan for the advancement of CO_2 Capture and Storage - EnCana, NRCan, Saskatchewan Industry and Resources, US DOE, ChevronTexaco**

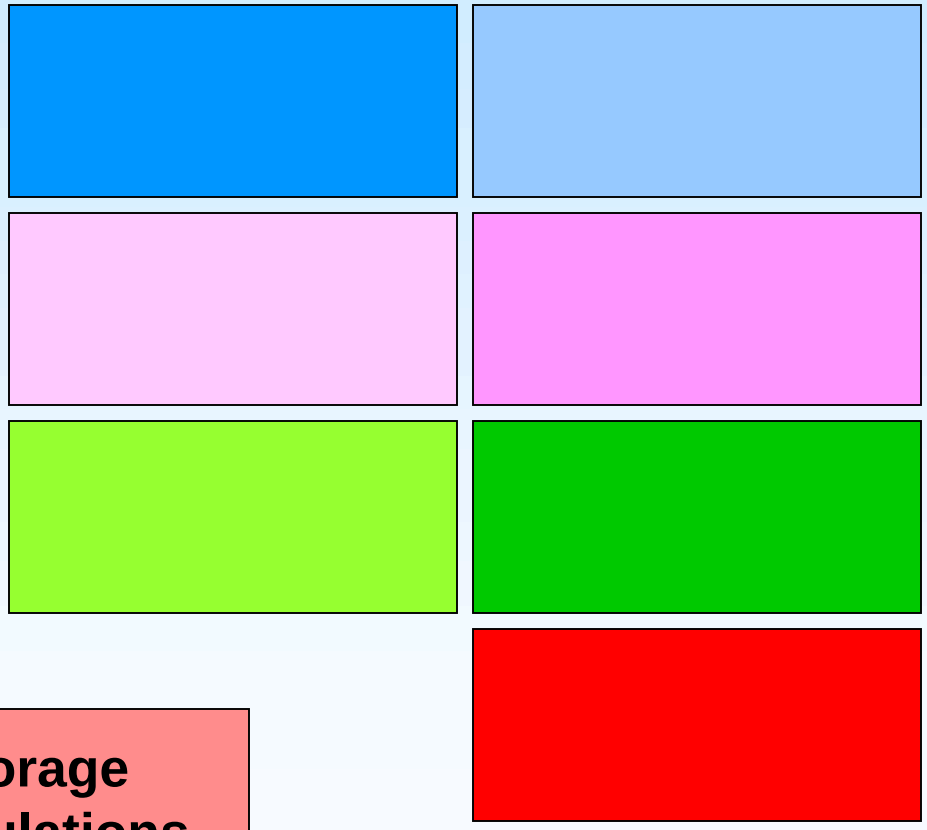
- **Mission:**

  "Use the IEA GHG Weyburn CO_2 Monitoring and Storage Project (Final Phase) as the "flagship" for developing the necessary technical and operating information to guide regulatory policy on EOR-based CO_2 geological storage projects"

- **Scope covers – science & technical, regulatory, pubic awareness**

- **Weyburn Final Phase will play a central role in all science and technical components – managed by the PTRC**
  - **Will support regulatory, public awareness, frameworks for national and international credits/trading of emissions**

Canada's CO_2 Capture and Storage Activities
"Fitting the Pieces Together"



Storage Regulations

Need a Harmonized Regulatory Framework Operations, Disposal, Long-Term Monitoring

- **Ongoing EOR activities regulated today**
  - **"good oilfield practice" under provincial regulation in Saskatchewan and Alberta**
- **Disposal of acid gas underway at 40+/- sites**
  - **"acid gas injection" of H_2S, CO_2**
- **Requirement for regulation of long-term storage of CO_2**
  – monitoring, leakage, safety, ownership
- **Activities underway**
  - **Provincial-federal working group**
  - **Assessment of regulatory regimes (Clifton Associates Report)**

Study: Develop Principles and Regulatory Criteria for Effective Storage of CO_2

- Examined existing legal and regulatory frameworks to identify strengths and gaps
- Study found that improvements are needed to existing laws, regulations and standards to provide a basis for an effective regulatory framework
- Examples of areas to consider – CO_2 capture, CO_2 transportation, injection wells, storage, monitoring and measurement, well abandonment, long-term management, risk analysis

Study: Develop Principles and Regulatory Criteria for Effective Storage of CO_2 .. *cont'd*

- **Three main areas for follow-up work were recommended**
  - **Regulatory review, consolidation and integration**
  - **Research and development**
  - **Public consultation**
- **Advocates for a sustained effort in research and public consultation**

Canada's CO_2 Capture and Storage Activities
"Fitting the Pieces Together"

Public Education Outreach

Addressing Public Concerns re CO_2 Capture and Storage Research from the Social Sciences

- **Even if all technology needs and economic hurdles are overcome, widespread deployment could be delayed by public concerns**
- **Wide range of issues – defines questions to be addressed through social science research**
  - **Describing complex technology in objective, understandable information on how the technology works.**

    How to describe a complex technology to a non-technical audience?
  - **Perceptions of risk**

    What are the risks, what are the consequences, frequencies?
  - **Tolerance for risk**

    What level of risk of leakage is acceptable 1%, 0.1%?
  - **Long-term aspects**

    Do we need to worry about leakage for the next 100 years, the next 1000, the next 10,000?
  - **Climate Change overall**

    How does it fit in the overall approach?
- **Social science research underway now – assess public opinions**

Assessing Issues re Public Education and Outreach – Developing Strategies

- Created an Ad Hoc Committee in 2003 – representatives from Alberta, Federal Government, Pembina Institute
- Work so far via three studies, and on strategy development
- Study: *"Towards a Strategy for Stakeholder Engagement in Geological Carbon Storage"*
  - Needs, purpose, potential participants, delivery, challenges
- Study: *"Steps Towards a Strategic Plan for Citizen Involvement in Carbon Capture Storage Decisions in Canada"*
  - Guidance and input towards a strategic plan to structure and conduct citizen involvement

Assessing Issues re Public Education and Outreach, Developing Strategies .. *cont'd*

- **Survey: *"Public Attitudes Towards Geological Carbon Dioxide Disposal in Canada"* – School of Resource and Environmental Management, SFU**
- **Objectives – to identify and prioritize issues which policy makers, regulators, and industry need to be concerned about**
- **Two-phase approach**
  - **First Phase – two focus groups, in Toronto, Edmonton, to identify attitudinal differences between the two regions**
  - **Second Phase – Internet survey of 2000 Canadians**

Assessing Issues re Public Education and Outreach, Developing Strategies .. *cont'd*

- **Key research questions**
  - **Identify state of knowledge, identify and prioritize concerns**
  - **Identify and prioritize reasons for public support**
  - **Separate and identify opposition stemming from concern about the *risks* from *fundamental* opposition to the concept**
  - **Identify and understand features that might determine the degree of public support for this technology as a GHG mitigation measure in Canada**
  - **Determine how positive (benefit-focused) information versus negative (risk-focused) information impacts support for the technology**
  - **Determine attitudinal difference between geographic areas**
- **Results being compiled and analyzed, report due in mid-2005**

IEA Study of Public Perceptions Towards CO_2 Capture and Storage

- IEA Publication *" Prospects for CO_2 Capture and Storage"* – December 2004
- Widespread deployment of CCS technologies will require broad understanding and long-term commitment by numerous constituencies – local governments, public, ENGOs and NGOs, industry, academia, media
- Few people are aware of CCS, or its potential re climate change mitigation
- First step – increase awareness via openness, high-quality data, national consultations, local negotiations
- Anticipate two types of opposition
  - From those who prefer other mitigation measures, object to continued use of fossil fuels
  - Local opposition – safety, long-term integrity of storage, risks
- Absence of organized, effective communication strategies could result in obstacles to scientific research, demonstration projects and widespread CCS deployment
- Underlines importance of developing a better understanding of public perception, risk tolerance, how to articulate a technical activity, frank-open-early information

"Fitting the Pieces Together"
Creating Conditions for a CO_2 Market/Industry in Canada

Capture All Sources	Transportation
Geological Assessment of Storage Capacity	Storage Deep Saline Aquifers
Enhanced Oil, Gas, CBM Recovery	Monitoring & Verification
Storage Regulations	Public Education Outreach

Examples of Canadian S&T Activities

CO_2 Sources	CO_2 Capture		CO_2 EOR, Storage	
Inventories of CO_2 Sources (NRCan, AGS)	Solvent-based Capture (ITC-U of Regina)	Oxy-fuel Combustion* (NRCan)	Enhanced Oil Recovery-phase I* (IEAWeyburn-EnCana)	Storage Capacity in Canadian Basins (NRCan, GSC)
	Clean Coal – phase I Feasibility and Demo (CCPC)	Hollow Fibre Membrane Capture (ARC, Edmonton)	Enhanced Coal-Bed Methane Recovery* (ARC, NRCan, EC)	Acid-Gas Re-injection (ARC, AGS, IEA, EC, WED, CCP)
	Zero Emission Coal Alliance (Coal producers, utilities, LANL, NRCan)	Modelling Cycles Clean Energy Centre (U of W)	CO_2 Storage in Gas Hydrates* (NRCan)	CO2 Storage Capacity of Alberta's Oil & Gas Pools (AGS-EUB)
	Carbon Capture Project (BP, ChevronTexaco, StatOil, EnCana, Shell, Suncor, Hydro)	Clean Coal Retrofit & New Plant (CCPC)	CO_2 Sequestration in Oil Sands Tailings* (NRCan)	Suitability of Sedimentary Basins for CO2 Storage (AGS-EUB)
			Gas Over Bitumen CO_2-SAGD (NRCan)	Thermal Solvent Bitumen Recovery (ARC, Suncor, NRCan)
			Risk Assessment For ECBM (NRCan, EcoAssociates	

*** World-leading position for Canada**

Heavily networked: nationally (Canadian CO_2 Capture & Storage Technology Network), internationally (IEA, CSLF, IPCC)

Canadian Technology Roadmaps: CO_2 Capture and Storage, Clean Coal Technology, Oil Sands Technology

Canada's CO_2 Capture and Storage Technology Roadmap

- **Purpose**

  "To identify technology strategies, processes and integration system pathways which are needed to enable CO_2 to be captured and stored in Canada"

- **Identifies three main challenges**
  - **Capture and transport**
  - **Geological storage**
  - **Cross-cutting (risk assessment, MMV, capacity building, awareness)**

- **Further develops the "Hub Concept" – "hubs" for gathering CO_2, for using CO_2, pipeline to connect them**

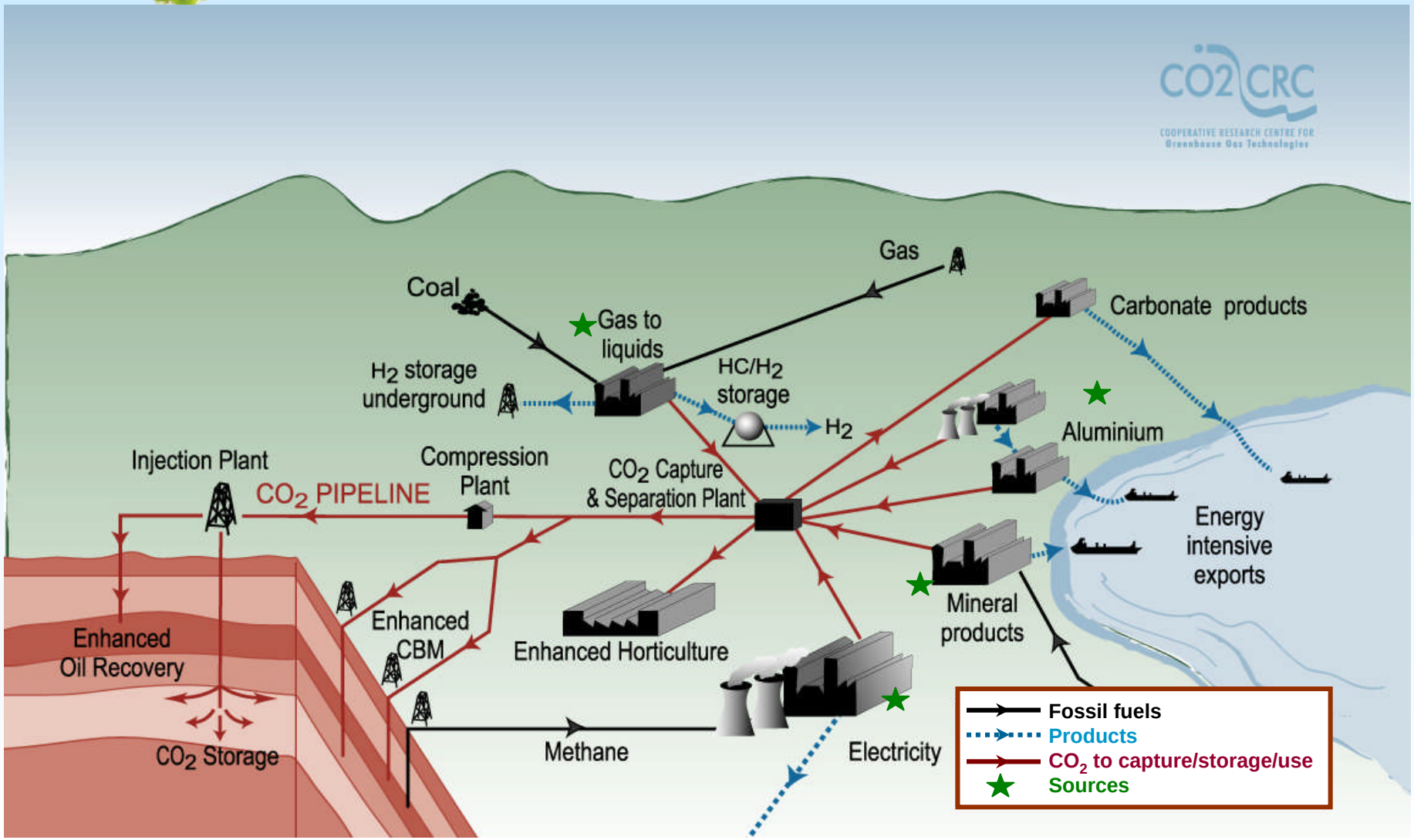
- **Sets out an Action Plan for follow-up, to be issued in mid-2005**

www.nrcan.gc.ca/es/etb/cetc/combustion/co2trm

Current Situation

- **Presently marginal economics for majority of pure sources of revenue generating opportunities due to:**
  - **Distance of sources to sinks – lack of infrastructure**
  - **Uncertainties – storage regulatory frameworks, price for CO_2, crediting/trading framework**
- **Good progress is being made – activities underway:**
  - **Excellent progress at Weyburn Phase 1, launching Final Phase**
  - **New EOR pilot projects – recently announced**
  - **Discussions underway on infrastructure needs, possible "backbone" pipeline**
  - **MMV techniques being developed, documented**
  - **Addressing regulatory issues**
  - **Climate Change "Project Green" – reference to CO_2 pipeline, technology development initiatives**
  - **Scoping work, analysis on public perception, communication and outreach**
- **Western Canada CO_2 capture and storage market/industry is getting closer**

A Vision - CO_2 Market/Industry



Some Closing Observations

- CO_2 capture and storage technologies - an integral component of Canada's climate change response options and part of a sustainable energy future
- A truly "transformative technology" - breaks link between emissions of CO_2 from fossil fuel use and permits the continued use of the existing energy infrastructure
- Canadian industry has taken the lead in many technology projects with strong support from provincial and federal governments, academia – approximately $40M for R&D projects, plus $42M at Weyburn, over 5 years
- Many R D and D challenges remain to be addressed before CO_2 Capture and Storage technologies become adopted on a wider scale – e.g., improved CO_2 capture technologies, advanced energy cycles, lower penalties and costs, transportation infrastructure, enhanced geological mineralization, reduced risks of leakage, establish MMV and improved ECBM productivity
- There is a compelling need for an integrated approach to carbon management
- Close cooperation both nationally and globally is vital for success