

The Canadian Oil Sands

Past, Present and Future



Presentation by
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Introduction



I wish to express my gratitude to the Founders of the Global Energy International Prize, the Board of Trustees, the Executive Directorate, the International Prize Award Committee, and to the people of Russia for the honour that they have extended to those of us who have worked for many years to bring the Oil Sands of Canada into commercial reality. The story of the Canadian Oil Sands in the Province of Alberta can be told in three chapters.

Chapter 1 is a tale of adventure and exploration and early research investigations that provided the foundations for a thriving industry.

Chapter 2 is a description of initial commercialization and a summary of new projects currently under development.

Chapter 3 is in the process of being written and concerns the work to overcome three huge challenges facing the oil sands industry related to water, hydrogen, and carbon dioxide – water needed for the recovery of the hydrocarbon, hydrogen to upgrade it to usable products, and technology to separate and store carbon dioxide. Unless these challenges are met, the future of a resource of equivalent size to that of Saudi Arabia could be limited.

I have been involved as an active participant in all three chapters, as an energetic young researcher in Chapter 1, as a middle-aged manager in Chapter 2 and as a hopefully thoughtful elder in Chapter 3.

In this presentation, I will briefly describe the highlights of each chapter of this story and outline the potential of Canada to become a sustainable, environmentally-sound energy superpower. This was a vision that the Prime Minister of Canada presented at the 2006 G8 Summit in St. Petersburg, Russia.

CWBowman

Clement W. Bowman

Images on cover and on pages 2, 15 and 16
courtesy of Suncor Energy Inc.

Nuclear reactor photo on page 15
courtesy of AECL

CHAPTER 1

Adventure, Exploration and Research

Along the Athabasca River in the province of Alberta, there is a clear record of the many adventures and struggles of countless explorers, engineers and scientists. These were the pioneers who played their

part in a century-long pursuit of what has been called the 'black gold' of Alberta.

The Canadian Oil Sands occur over a 140,000 square kilometer area of the

province of Alberta Canada (Figure 1), covered by overburden ranging in depth from a few metres to 500 metres. About 10% of the resource can be surface mined; the balance is too deeply buried and must be

FIGURE 1



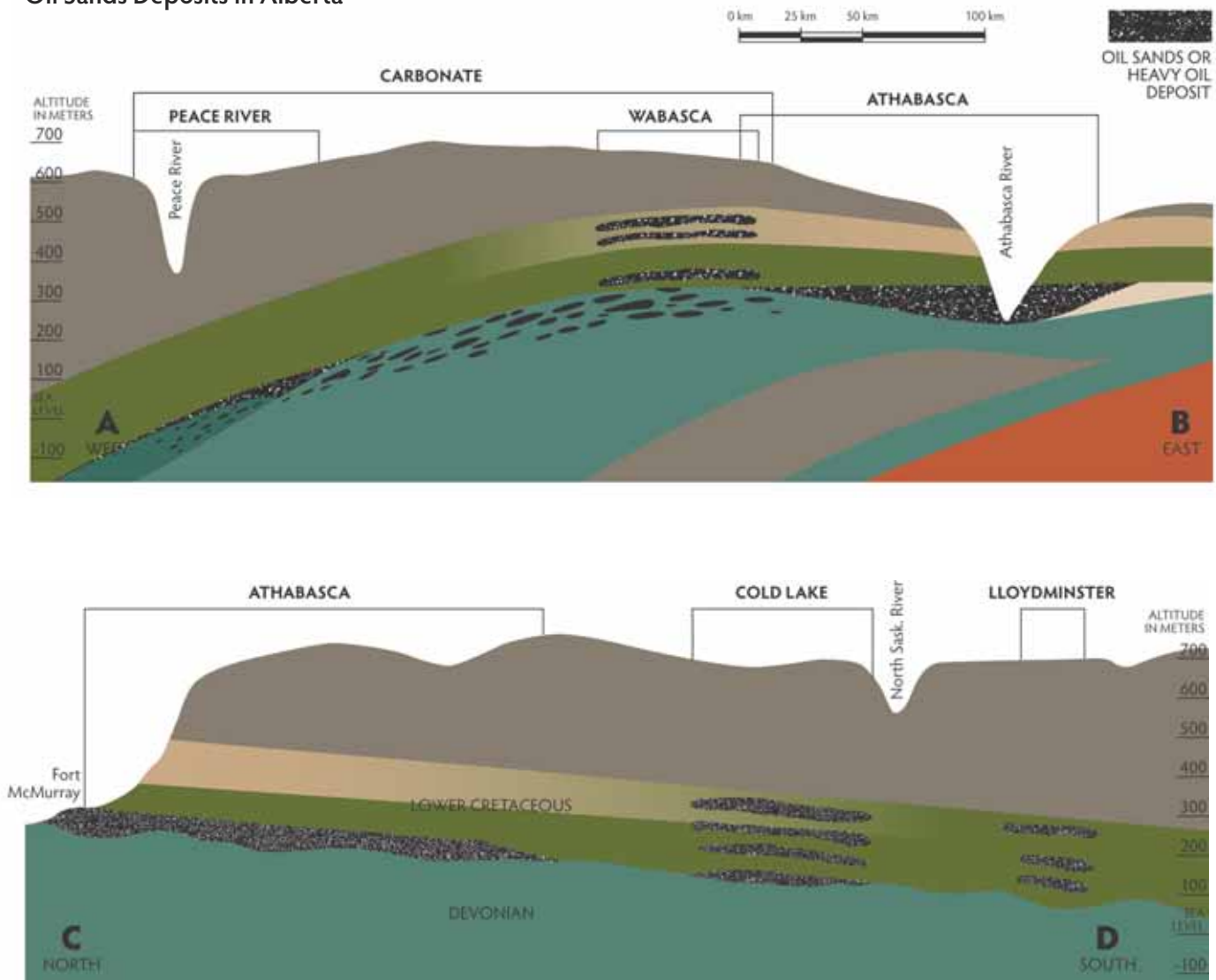
recovered by insitu recovery techniques. Two geological cross sections are shown in Figure 2, illustrating the location of

the oil sands relative to the underlying Devonian carbonate formation. Although the geographic extent of the resource is

small, the resource is huge (Figure 3), with approximately 1.6 trillion barrels of bitumen in place. Over 300 billion barrels is

FIGURE 2

Geological Cross Sections of Non-Conventional Oil Sands Deposits in Alberta



From: Fifth Annual Report and Five-Year Review, Alberta Oil Sands Technology and Research Authority

Two geological cross sections through Alberta's oil sands and heavy oil deposits are shown in Figure 2. Cross sections A-B runs approximately east and west through the Peace River, Wabasca, and Athabasca oil deposits. The vertical scale is exaggerated to illustrate the comparative locations of the oil sands deposits and the Devonian carbonate formation. Cross section C-D runs approximately north and south through the Athabasca and Cold Lake oil sands deposits, the Lloydminster heavy oil pools, and the underlying Devonian carbonate rocks.

expected to be recoverable. The latter figure is larger than the estimated reserves in Saudi Arabia.

Bitumen was long known to seep along the valley floor

FIGURE 3

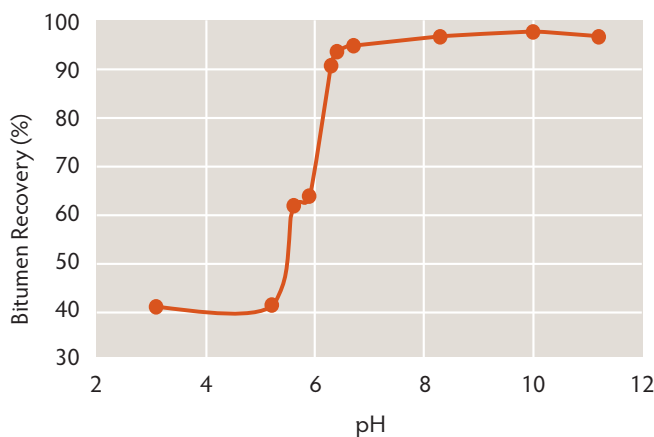
Alberta Oil Sands Resource

(Data of Alberta Energy and Utilities Board)

	Billion Barrels
Total In-Place Resource	1629
Established Reserves	175
Ultimate Reserves	310
Expected Annual Production within 10 Years	1
Saudi Arabia Reserves (Oil and Gas Journal – January 2006)	266

FIGURE 4

Effect of pH on Bitumen Recovery



Data extracted from Reference 2

of the Athabasca River and was used by the indigenous peoples to waterproof the bottom of their canoes. It was initially believed that the bitumen was a residue from a lighter petroleum which had been subjected to high temperatures and pressures over geological time. Geologists drilled into the Alberta oil sands many times in an attempt to find the lighter source oil. A source oil was never found. The oil sands were what they appeared to be, a young heavy bitumen, biologically degraded, embedded in a mineral matrix. There were early attempts to use the oil sands in their original state as a road paving material. However, the bitumen softens with even modest increases in temperature and this application was not successful.

Once it was recognized that the future of the oil sands lay in the recovery and processing of the bitumen itself, research work began in earnest. The investigations of Dr. K.A. Clark in the 1920s proved that the oil sands were very different from an oil shale. In the latter, the hydrocarbon appears as a solid kerogen, insoluble in organic solvents. When the oil sands are mixed with hot water, the bitumen appears as a

separate phase with the bulk of the mineral matter settling to the bottom. Dr. Clark developed what is now known as the Hot Water Separation Process, by which 90% of the bitumen can be recovered.¹ Dr. Clark found that the chemistry of the process is crucial, slightly alkaline pHs were needed (Figure 4) and divalent ions such as calcium interfered with good bitumen/mineral separation.²

Research continued sporadically over the next twenty years in spite of the lack of any sustained commercial interest. During the 1960s, a major research effort was undertaken by the author in collaboration with Imperial Oil researcher J. A. Bichard, focused on the molecular and interfacial properties of the oils sands.³ This work led to a more precise understanding of the fundamental properties of the oil sands system. The quartz sand grains are essentially entirely water wet. But depending on the horizontal and vertical location of the oils sands in the deposit, there are varying amounts of fine clays. These are partially oil wet, and are difficult to separate from the bitumen.

There are appreciable amounts of carboxylic acids in the bitumen which serve as bridging agents between flecks of bitumen and the fine clay minerals. The complex association among the flecks of bitumen, solid mineral particles and air bubbles is illustrated in Figure 5. At a slightly alkaline pH, the association between bitumen and the mineral matter is minimized and the attachment of air bubbles to the bitumen is maximized. There was a debate at the time whether air bubble/ bitumen attachment actually occurs.

This was confirmed by the high speed photograph shown in the image below, taken by a device inserted into the separation cell.⁴

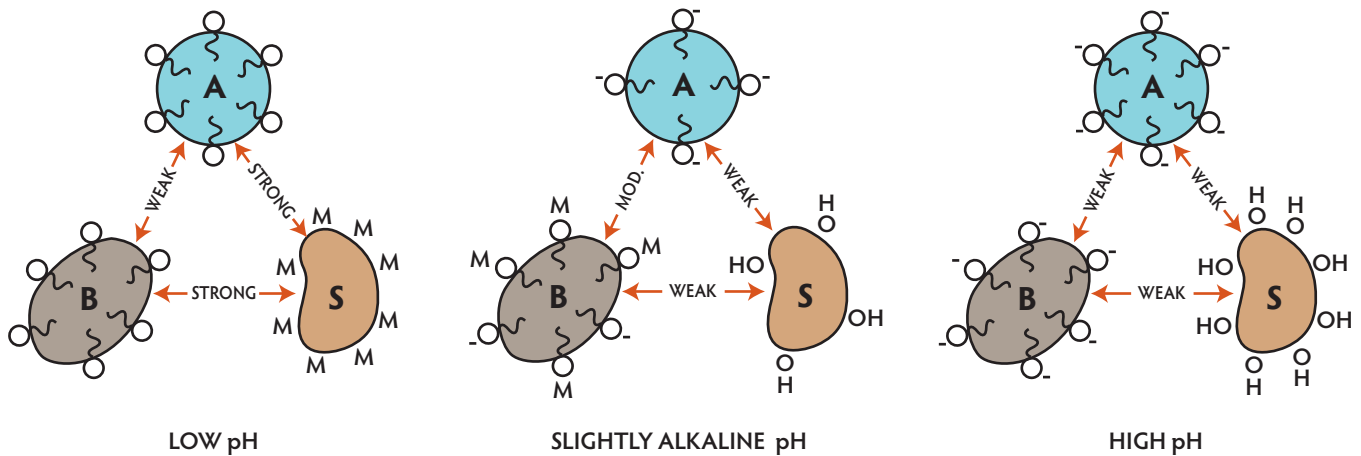
Quantitative data were obtained on the effect of pH and various polyvalent metal ions on both the recovery of bitumen in

Attachment of Bitumen to Air Bubbles



FIGURE 5

Association between Interfaces at Various pH



Legend:

- ~O Carboxylic Acid
- ~O⁻ Carboxylate Ion
- ~OM Polyvalent Metal Carboxylate

- A Air
- B Bitumen
- S Solid

hot water processing and on the extent of mineral contamination of the separated bitumen.

Considerable research work was also done on the properties of the bitumen. The hydrogen to carbon atomic ratio is about 1.5, well below the value for typical light crude oils which exceed 2.0. The bitumen is a complex mixture of saturates, aromatics, resins and asphaltenes, as shown in Figure 6. Strausz⁵ carried out extensive research over many years on the composition of the bitumen

and documented the structure of various naphthenic/aromatic compounds, with sulphur in both the ring structure and as sulphides. There are various nickel and vanadium porphyrins in the asphaltene fraction. When the bitumen is heated to moderately high temperatures, the molecular weight decreases to less than half, indicating the complex ring structures will readily crack. When processed at coking or fluid cracking temperatures, the bitumen is a full range of

lighter petroleum fractions, with about 20% converted to coke or a heavy tar residue.

A key finding was the viscosity dependence on temperature as shown in Figure 7. At reservoir temperatures, the bitumen viscosity is in the hundreds of thousands of centipoises. At steam temperatures, the viscosity decreases to below 100 centipoises. It is this feature that is the basis of essentially all the thermal insitu recovery processes.

FIGURE 6

Typical Bitumen Composition*

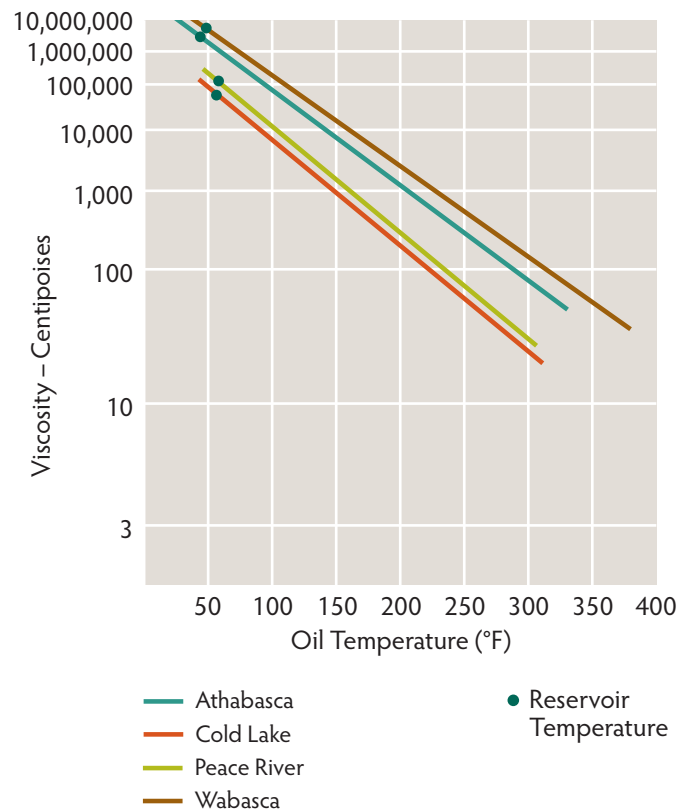
Fraction	Wt %
Saturates	17
Aromatics	18
Resins	45
Asphaltenes	17

*From The Chemistry of Alberta Oil Sands, Bitumens and Heavy Oil, Otto P. Strausz, Elizabeth M. Lown, ISBN 0778530965

**From "Heavy Oil Sand In-Situ Pilot Plants in Alberta (Past and Present)" by J.H. Nicholls and R.W. Luhnig, AOSTRA. Presented at the Canada/Venezuela Oil Sand Symposium 77, sponsored by the Petroleum Society of the CIM in Edmonton, May 30 to June 3, 1977.

FIGURE 7

Viscosity-Temperature Relationship of Bitumen**



CHAPTER 2

Commercialization

The oil sands literature documents numerous attempts to recover bitumen from the Alberta oil sands. It is a tale of persistence and enormous

demonstrated at a realistic scale. A demonstration plant was constructed in 1949 at Bitumount, a site north of the town of Fort McMurray. A successful run was completed over a period of months and then shut down once sufficient operating data was obtained. The Government commissioned an independent report, called the Blair Report⁶, which concluded 'the bituminous sands can be mined and the bitumen processed by established methods'.

However, commercial interest in the oil sands lagged over the next 20 years. This was due to the reluctance of the conventional oil industry to share markets, and also to the low oil price at that time (below \$3 per barrel). This was insufficient to provide an acceptable rate of return. In the 1960s, Sun Oil Company displayed considerable courage by building a small surface mining oil sands plant (designed at 31,500 barrels per day). It had all the risk inherent in a first-of-kind commercial plant, and with uncertain oil prices. This company is one of the heroes in this story.

Syncrude Canada Limited followed with the second surface mining commercial plant, nominally designed at 110,000 barrels per day. A number of subsequent expansions has brought Syncrude's production to about 350,000 barrels per day.

However, this is only the story of the 10% of the deposit amenable to surface mining. The deeply buried oil sands have a very different history. The major international oil companies all owned leases in the oil sands region, which provided the right to commercial production provided certain obligations were met. The Alberta government of Peter Lougheed was not satisfied with the pace of development. He decided that the Province should become an active partner in oil sand technology development. The Alberta Oil Sands Technology and Research Authority (AOSTRA) was established, with an initial fund of \$100 million (Figure 8). The purpose was to undertake joint field demonstration projects with industry. Rules were established which vested ownership of new technology with the Alberta

FIGURE 8

Unlocking the Deeply-Buried Oil Sands

1974

Establishment of the Alberta Oil Sands Technology and Research Authority (AOSTRA)

The purpose – to get the private sector back working on the 90% of the oil sands too deeply buried to be mined.

The initiative was launched by a \$100 million seed fund that grew to \$1 billion (1970s dollars). Projects funded 50/50 by the private/public sector.

AOSTRA board made investment decisions. New technology owned and licensed by the Alberta government.

effort by countless entrepreneurs. Until the 1960s, these efforts were without commercial success. A typical venture was the Abasand project in the early 1940s, designed to produce petroleum products in support of the war effort. This project suffered a disastrous fire and was eventually shut down. The Alberta Government decided that commercialization would not likely proceed until the Clark Hot Water process was

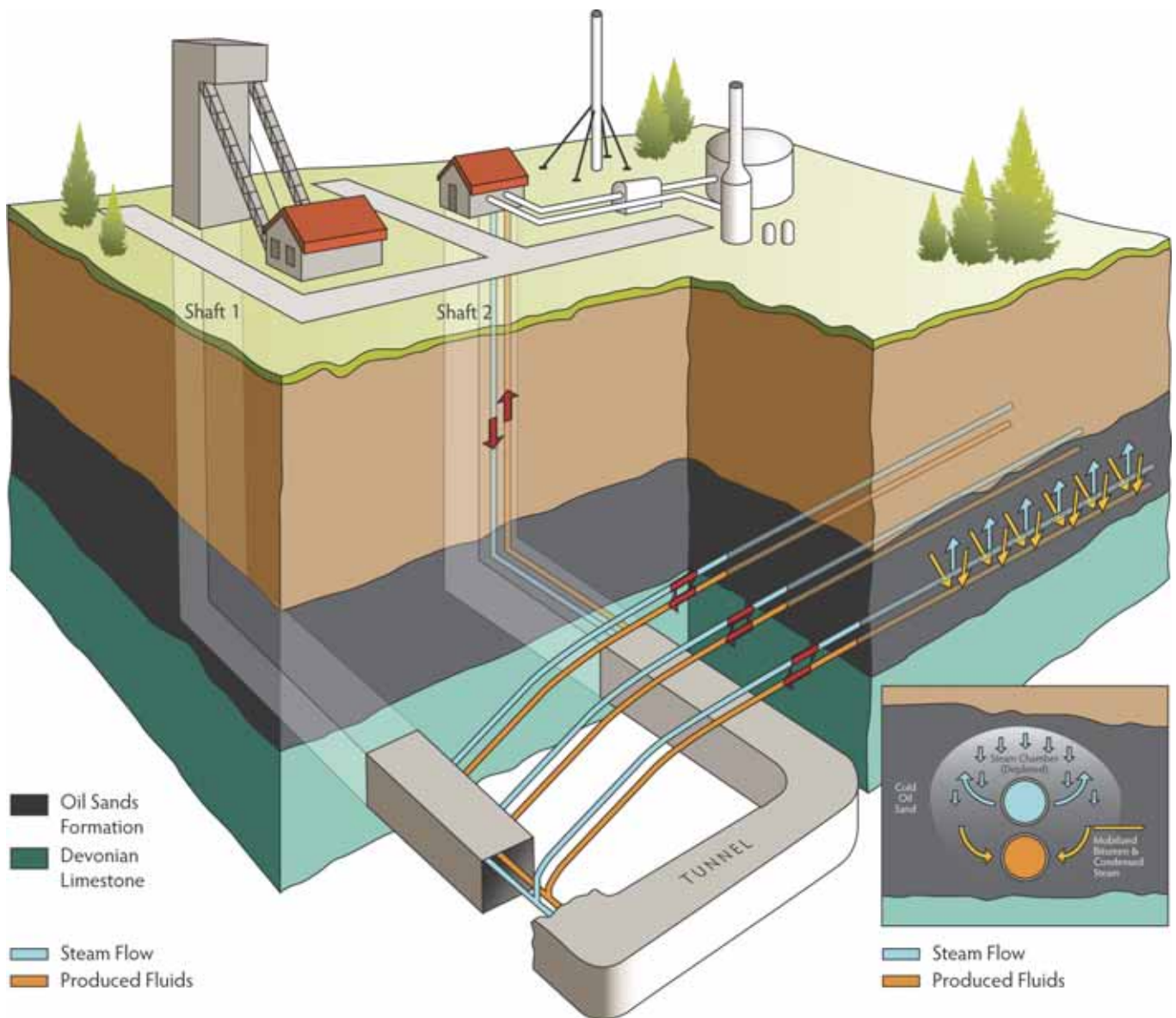
Government, with the company partners having the right of use for their leases. Through the issuance of a Request for Proposals, a number of promising new technologies were proposed. Five were selected for immediate field testing.

The Alberta Government provided additional funds to ensure the projects were fully completed. The total amount investment by government and industry over the life of these projects was in the order of

\$1 billion. This is roughly equal to \$3 billion in today's dollars. The goal was to establish a viable commercial project in each of the three major oil sand deposits. A number of promising processes were

FIGURE 9

Underground Test Facility (UTF) Cross Section



The Steam-Assisted Gravity Drainage (SAGD) process demonstrates the effectiveness of gravity forces in contacting and draining an oil sands reservoir.

field tested, including steam stimulation, steam flood and insitu combustion.

Imperial Oil developed one of the first steam stimulation projects in the Cold Lake deposit, which was classified as an oil sand but with the bitumen having a slightly higher API gravity, and therefore less viscous.

There was one technology approach that deserves special mention, the drilling of a mine shaft and tunnels to enable the positioning of horizontal wells. With this

approach, each foot of well drilled was located in the pay zone. This was an approach in which the oil companies had limited experience. In this case, it was necessary for AOSTRA to fund the entire project, with the guidance of an experienced mining company. The project was called the Underground Test Facility (UTF), as shown in Figure 9. This led to the development of a process called SAGD, (Steam Assisted Gravity Drainage). Much of the theoretical

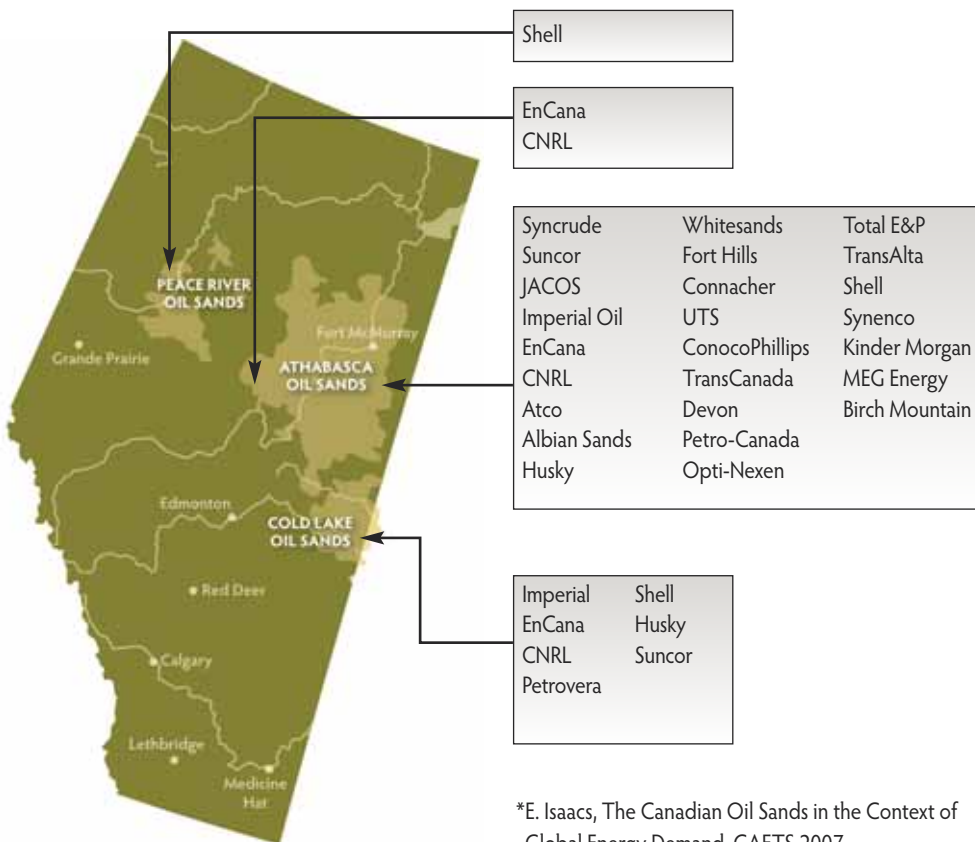
reservoir engineering work related to this was carried out by Dr. Roger Butler of the University of Calgary.

The net result has been a flurry of commercial activity which has led to the oil sands industry of today, as shown in Figure 10. It is expected that production will reach 3 million barrels a day before 2020.

At current oil prices, the wealth generated for the companies involved, and for the citizens of Canada through the involvement of their governments, is enormous. But this surge is causing both social and environmental problems which Canada must now address. The social problems include the shortage of housing, insufficient skilled personnel, and the affect of high salaries in the oil sands industry on other industrial sectors. The environmental problems include the requirement to clean up and reuse large quantities of water, and the release of massive quantities of greenhouse gases. A further issue is the need for a sustainable supply of hydrogen to upgrade the hydrogen-deficient bitumen into usable petroleum products. Due to these issues, a new strategic look at the oil sand industry is currently underway.

FIGURE 10

Many Active Oil Sands Projects*



*E. Isaacs, The Canadian Oil Sands in the Context of Global Energy Demand, CAETS 2007.

CHAPTER 3

The Pathway to a Sustainable Energy Superpower

The Canadian Academy of Engineering (CAE) has recently undertaken a major evaluation of the Canadian energy system, involving more than 100 energy experts*. The objective was to define the technological barriers that are preventing the development of economic and environmentally acceptable energy

products in Canada. A focus of the study was on energy pathways that would permit Canada to achieve its greenhouse gas emission (GHG) targets. The Prime Minister of Canada, Stephen Harper, stated at the G8 Summit in St Petersburg in 2006 that because of the oil sands, his government was committed to make Canada

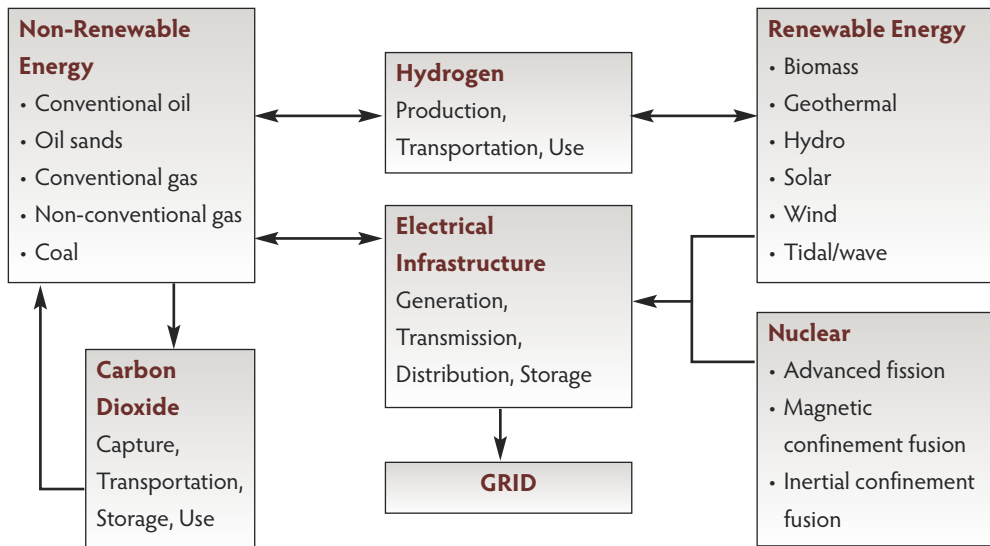
an energy superpower. This became an important vision as the CAE evaluation proceeded.

The first step was to examine the various energy sources in which Canada is endowed, including non-renewable energy, renewable energy, and nuclear power as shown in Figure 11. The energy system is more than energy sources. Hydrogen and electricity are important intermediate energy products, and carbon dioxide is a by-product which must be recovered and stored.

There are many energy pathways from energy source to the final end user embedded in this chart. Twenty-seven pathways were selected for detailed evaluation. The goal was to identify a small number of major projects that Canada should undertake immediately to help meet its own energy demands, and to provide for international trade. An evaluation methodology called ProGrid was used to assist in the evaluation.⁷ Key to the evaluation was the establishment of the

FIGURE 11

Canada's Energy Potential



*Sponsored by industry and two levels of government (Alberta Research Council, Natural Resources Canada, Suncor Energy, Encana, Atomic Energy Canada Limited, Hatch, Alberta Energy Research Institute, Petro-Canada).

Evaluation Matrix shown in Figure 12. The criteria in this matrix range from strengths (i.e. assets) that an energy pathway has, which are included in Column A, to the expected Impacts of that pathway (both economic and environmental) in Column C, with various enabling factors included in Column B.

Statements indicative of the strength of a particular

pathway were defined, called Language Ladders. These provided the metrics by which experts could measure and compare the 27 pathways, producing the results shown in Figure 13. The axes on this grid are the headings of Columns A and C of the Evaluation Matrix. It is not just the position of a pathway on this grid that is important; the diagnostic approach that was used determined what needs to

be done to move a pathway to a higher position on the grid. Through this process, three pathways were selected as the framework for major Canadian national projects (Figure 14):⁸

- Gasification of Fossil Fuels and Biomass
- Greenhouse Gas Emission Reduction
- Upgrades to Electrical Infrastructure

FIGURE 12

FIGURE 13

ProGrid Evaluation Matrix

A Pathway Assets (Inputs)	B Canadian Capacity (Enablers)	C Expected Impact (Outputs)
Scientific Principles	Corporate Capacity	Economic
Technology Validation	Canadian Competitive Advantage	Environmental (ex GHG)
Commercial Readiness	Sustainability	GHG Emission Impact
Societal Acceptability	Enabler for Another Pathway	Energy Efficiency
Fit to Canadian National Initiative	Delivery/ Infrastructure Issues	Value-Added

Energy Pathways Database

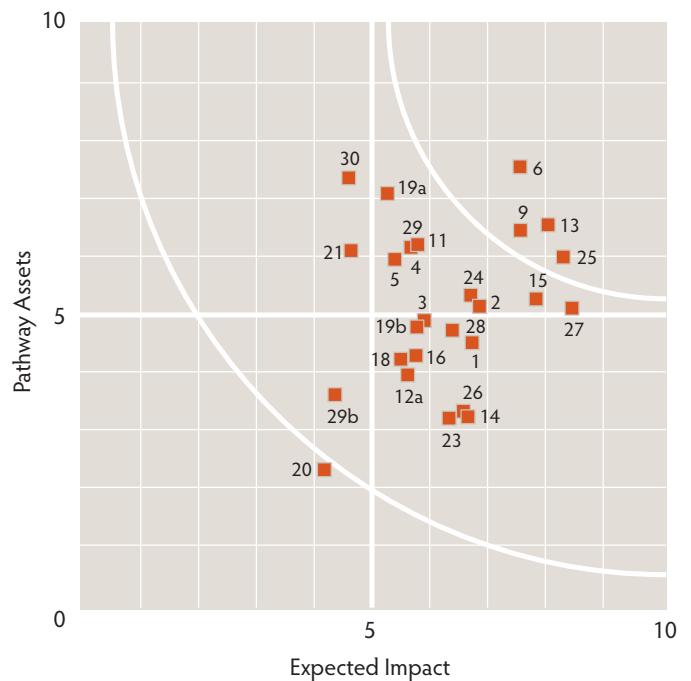


FIGURE 14

Three National Technology Projects

<p>Gasification of Fossil Fuels and Biomass</p> <ul style="list-style-type: none"> • Produces electricity, hydrogen, and CO₂ rich streams
<p>GHG Control</p> <ul style="list-style-type: none"> • CO₂ capture, transportation, long-term storage and/or use
<p>Upgrades to Electrical Infrastructure</p> <ul style="list-style-type: none"> • National grid, grid access/storage for renewables, enhanced distribution infrastructure

These three national projects will provide a sustainable supply of hydrogen through the gasification of feedstocks such as coal, the ability to meet Canada’s carbon dioxide emission targets, and will create a more robust ‘electrical highway’ across Canada.

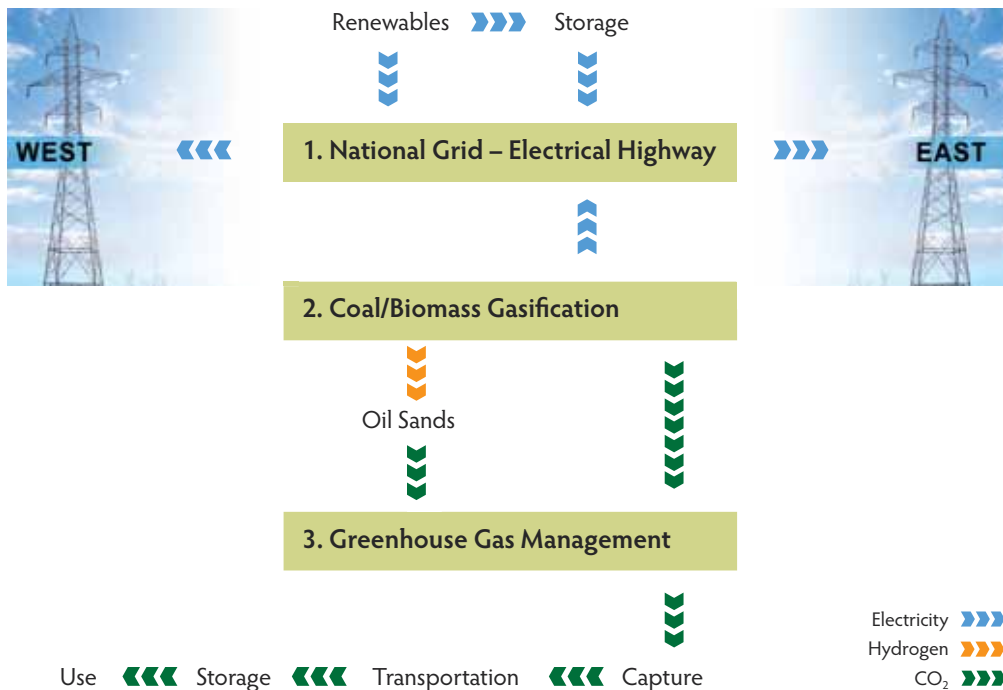
Thus, the integration of oil sands, coal and biomass will resolve many of the issues that each energy source faces on its own, and create a sustainable and environmentally-sound national energy strategy.

This is illustrated in Figure 15, with coal gasification providing both electrical power for the grid and hydrogen for the oil sands, with carbon dioxide emissions from all fossil fuel production recovered and stored underground. Renewable energy sources across Canada will be able to feed into the cross-Canada electrical highway.

At present, about 25% of the energy consumed in Canada is derived from renewable sources, mainly

FIGURE 15

Three Canadian Nation-Building Projects



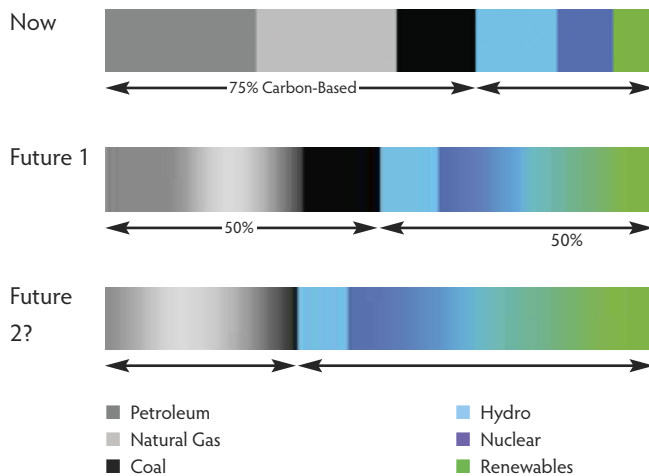
nuclear power and hydroelectric power, with the balance coming from fossil fuels (Figure 16). Through the strategy proposed in the Canadian Academy of Engineering Energy Pathways Phase 1 report, the contribution of renewable energy can be increased to 50% by mid-

century, with oil sands, coal and natural gas providing the remainder. If fusion power becomes available in the longer term, reliance on fossil fuels can be further decreased, to perhaps one-third of Canada's energy needs. In this scenario, oil sands and coal will remain as critical sources of petroleum

and petrochemical products for an essentially unlimited future. For oil sands and coal to provide this capability, their current environmental issues must be resolved by national projects such as those described in this presentation.

FIGURE 16

The Expected Shift to Renewables



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- 8 Energy Pathways Task Force Phase 1 Final Report, Canadian Academy of Engineering, May 2007

Steam Assisted Gravity Drainage (SAGD) well pad



Oil sands heavy hauler



CANDU nuclear reactor



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