UNIVERSITY OF CALGARY

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Steam Assisted Gravity Drainage (SAGD): A Unique Alberta Success Story with Implications for Future Investment in Energy Innovation

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PREFACE

The energy sector has been a dominant factor in Alberta's development and growth over the last half-century. The large capital investments and operating expenditures associated with finding and producing oil and gas have directly provided a major stimulus to the economy. But the indirect and induced impacts have been equally important. The development of many other industries supplying inputs to the energy sector, the generation of substantial export and government revenues, and the stimulus for large inflows of people have resulted in large 'multiplier' effects. In combination, these have also played a major role in shaping Alberta's 'character' which is generally distinguished by its highly educated, adjustable and entrepreneurial labour force, low unemployment and high labour force participation rates, strong work ethic and sense of self reliance, and its optimistic outlook.

In recent years the energy sector has become even more dominant and has increasingly made Alberta a key driver of the national economy. In a world with a rapidly growing demand for energy, having one of the largest concentrations of energy resources in the world might seem to translate into an assured, prosperous future. There is clearly huge potential associated with unconventional oil and gas, coal, remaining conventional resources and with alternative and renewable energy. However, translating this potential into reality will be daunting. Increasing constraints related to resource access, environmental impacts, infrastructure requirements, and availability of highly qualified people need to be addressed. Other challenges include the massive long-term investments in developing and implementing new technologies and making the right changes in the policy and regulatory framework. Indeed, the fact that relatively few nations have managed to convert resource wealth into high standards of societal welfare is a useful reminder of the magnitude of the challenges.

Alberta is in many respects at a crossroads. On the one hand complacency will almost certainly mean a dimming of the province's long-term prosperity. Declines in the conventional oil and gas sector will significantly dampen growth and prosperity. There are no other sectors of the province's economic base that could realistically expand sufficiently to offset significant declines in the dominant energy sector. On the other hand, visionary, strategic investments today can unlock non-conventional and other energy resources critical to securing a strong and prosperous long-term, sustainable future for the province.

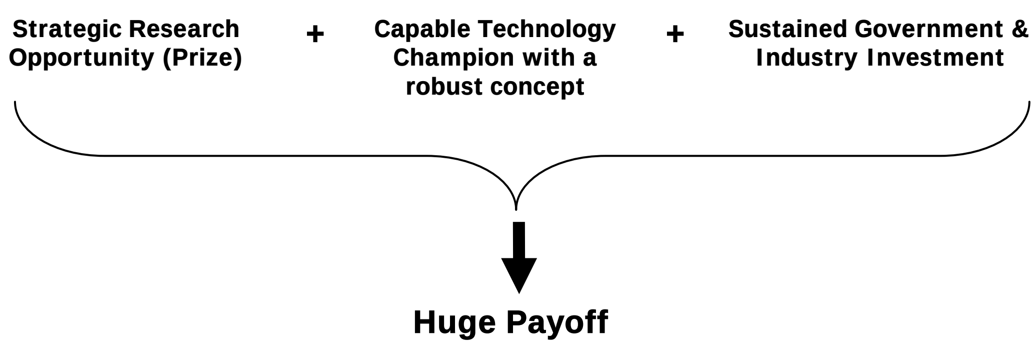
It is in this context that ISEEE has undertaken a series of papers focused on Alberta's energy futures. The intent is to take a longer term look at the challenges, opportunities and choices and what they mean for Alberta's future.

Executive Summary

Steam Assisted Gravity Drainage (SAGD) is a uniquely Canadian technology that is poised to make an enormous contribution to energy production in North America and to the Canadian economy. It is now being implemented at over 20 locations in Alberta where there is potential to increase production of bitumen by approximately one million barrels per day by 2020. That level of development would increase Provincial GDP by at least $150 billion (Canadian dollars, 2005) and create approximately one million person years of employment.

SAGD was an expensive and time-consuming undertaking. The Alberta Oil Sands Technology and Research Authority (AOSTRA) spent about $600 million between 1976 and 1994 and up to 25 percent of that was spent to develop SAGD. In addition, industry probably spent about an equal amount, bringing combined total SAGD development expenditures to roughly $300 million. However, one million barrels per day translates quite realistically, to recoverable reserves of approximately 11 billion barrels. That means that the $300 million expenditure represents only 2.7 cents per barrel of bitumen that is expected to be recovered by SAGD. By this and any other measure, the SAGD research and development expenditure has produced an enormous payoff.

Three key factors, or driving forces, were critical to the successful development of this technology and they are illustrated below:



The first key factor was the extremely large oil sands resource base (approximately 1.6 trillion barrels of bitumen that is too deep to mine). The prospect of being able to tap even a small fraction of that in-place oil provided the economic incentive for the research and development from the time SAGD was first conceived in the late 60s[1] to the start-up of a first commercial application in 2001.

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[1] Stonehouse, Darrell; Father of SAGD; Oilweek, January 6, 2005; pg. B4.

The second, and perhaps most critical factor, was a remarkable individual, Dr. Roger Butler, who believed that gravity drainage was a better way to recover oil sands bitumen. A highly respected Chemical Engineer, scientist, and academic, he conceived, patented, and for over 20 years, championed the development and application of SAGD both in the laboratory and the field. Dr. Butler first conceived (approximately 1969) and then later tested the initial SAGD concept at Cold Lake while he was an employee of Imperial Oil. In the 1980s he convinced the Alberta Oil Sands Technology and Research Authority (AOSTRA) and private sector industry partners to test the concept at an Underground Test Facility (UTF) near Fort McMurray. From 1983 to 1995, Dr. Butler was a professor and research chair at the University of Calgary. There, he developed a fuller understanding of SAGD mechanisms, enhanced computer models of SAGD processes, and used those models to predict and improve SAGD performance in a variety of reservoir situations. Even when he retired from the University, he continued to consult and advise oil companies on how best to design and implement SAGD in the field.

The third key factor was that both private sector and government invested collaboratively in research and development (R&D) of the technology and the investment was sustained over a period of over 20 years. The consortia approach not only spread the R&D risk among many sponsors, but also helped to ensure that the R&D was sustained at critical times. When one investor or group of investors lost interest, others were there to pick up the slack. For example, at the time the UTF was first being designed and constructed, the price of oil was falling and the private sector would not participate. But the Province shouldered the full cost of the research itself, and the research program continued.

The oil sand resource base in Alberta is enormous, but it is also found in a wide variety of geological settings. What works in one situation does not necessarily work in another. That is certainly true for SAGD and industry continues to learn from both its successes and disappointments. The process works very well, with recoveries in excess of 50 percent, in a variety of situations, but it is also an energy and water-intensive process. Refinements are needed to improve the process and to allow it to be adapted to a wider variety of reservoir situations.

Despite this remarkable success story, funding for research and development of this type is now only approximately one-third of what it was, in real terms, in the mid 1980s. Given the enormous potential payoffs for this type of research, and the critical need to find better ways to reduce the environmental impacts of oil sands developments, there is a sound case to restore funding to at least previous levels. The resource base is so extremely large, and the option value of such research is so compelling despite its inherent risk, that it would be very unwise not to.

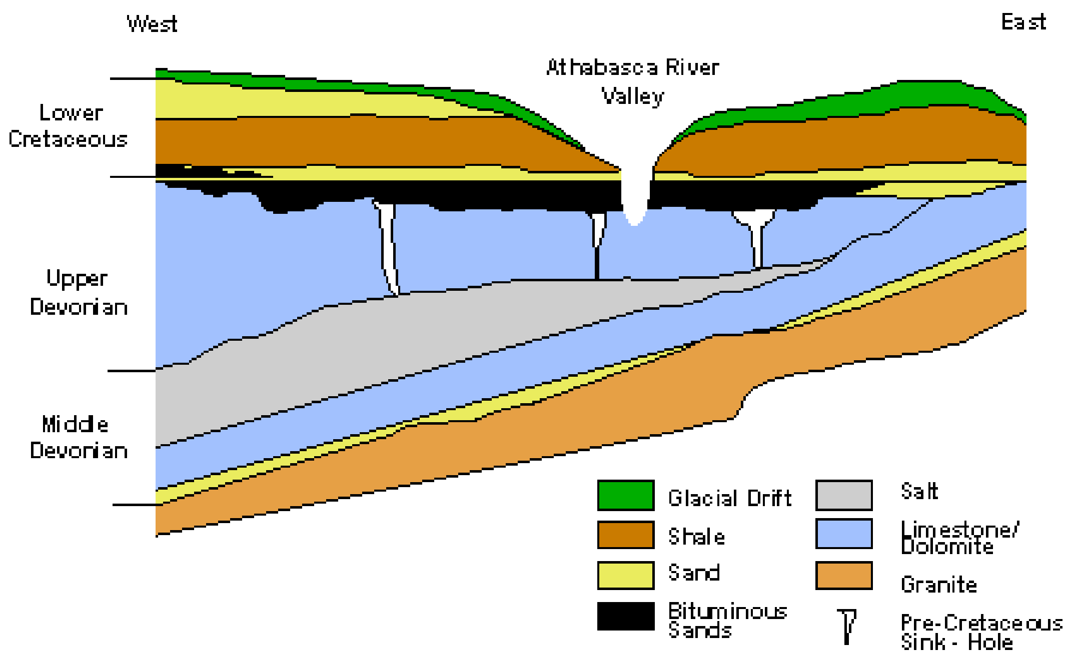
I The Strategic Research Opportunity: The Alberta Oil Sands

Bitumen resources in Alberta were known very early in the history of industrial development of the Province. Records show that the Cree First Nations people brought a sample of the oil sands to the Hudson Bay's post at Fort Churchill in 1719. The sands were described as "that gum or pitch which flows out of the banks of that river."[2]

The material referred then as a gum, was bitumen, "A naturally occurring viscous mixture of hydrocarbons heavier than pentane that may contain sulphur compounds and that in its naturally occurring viscous state will not flow to a well"[3]

As the following simplified geological cross-section shows, the seeps occur at the Athabasca River because at that location the resource is exposed through erosion by the river.

Figure 1
Simplified Geological Cross-section
Through the Athabasca Oil Sands Region



(after Candgy and Kizmors, 1973)

Source : http ://collections.ic.gc.ca/oil/images/mineslid/slide8.gif

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[2] Athabasca Oil Sands; Canada's Digital Collections; http://collections.ic.gc.ca/E/view.html, accessed March 11, 2006

[3] EUB ST98-2005: Alberta's Reserves 2004 and Supply/Demand Outlook / Appendix A1

Oil sands bitumen resources in Alberta exist predominantly in three main areas: Athabasca, Cold Lake and Peace River, as shown in the following map:

Figure 2
Oil Sands in Alberta

In total, the volume of crude bitumen in place is of the order of 270 billion cubic metres or 1.7 trillion barrels.[4] A small portion of the oil sand resource, about 6 percent, is near the ground surface and recoverable by open pit mining.

[4] EUB ST98-2005: Alberta's Reserves 2004 and Supply/Demand Outlook

The first mining quarry was opened by the McMurray Asphaltum & Oil Company in 1922. In those early pioneering mining operations, the biggest challenge was to find a way to separate the bitumen from the sand and in 1921, the Province established the Scientific and Industrial Research Council of Alberta (now the Alberta Research Council) on the campus of the University of Alberta with that focus in mind. In 1929, Dr. Karl Clark, one of its first employees, was issued a Dominion of Canada patent for a hot-water extraction process for separating oil from the oil sands, and that process was first field tested by Robert Fitzsimmons at Bitumount in 1930. [5] It is a process that continues to be used today to separate the oil from oil sands that are mined.[6]

The most important current research challenge is to find an effective, economical and environmentally acceptable way to develop and produce the bitumen that is too deep to mine. As indicated in Table 1, the prize for a breakthrough that would reduce the energy required or lower the environmental impact of *in situ* recovery processes is enormous. Innovations to improve recovery processes by *in situ* means would potentially apply to 94 percent of the oil sand resource.

Table 1
In-place volumes and established reserves of crude bitumen (10^9 m^3)[7]

Recovery method	Initial volume in-place	Initial established reserves	Cumulative production	Remaining established reserves	Remaining established reserves under active development
Mineable	17.5	5.59	0.50	5.09	1.24
In situ	252.5	22.80	0.23	22.57	0.42
Total	269.9 (1 699)[a]	28.39 (178.7)[a]	0.73 (4.6)[a]	27.66 (174.1)[a]	1.66 (10.5)[a]

[a] Imperial equivalent in billions of barrels.

In conventional oil situations, the oil exists as a fluid that can be pumped to the surface, processed and shipped by pipeline to a refinery. In the case of the oil sands, the oil is typically too viscous to flow at natural reservoir conditions and must be heated to allow it to be mobilized and then recovered. As Figure 3 shows, in many cases the bitumen must be heated up to 200 degrees Celsius to allow it to flow. This is usually accomplished by injecting steam to heat the bitumen in place.

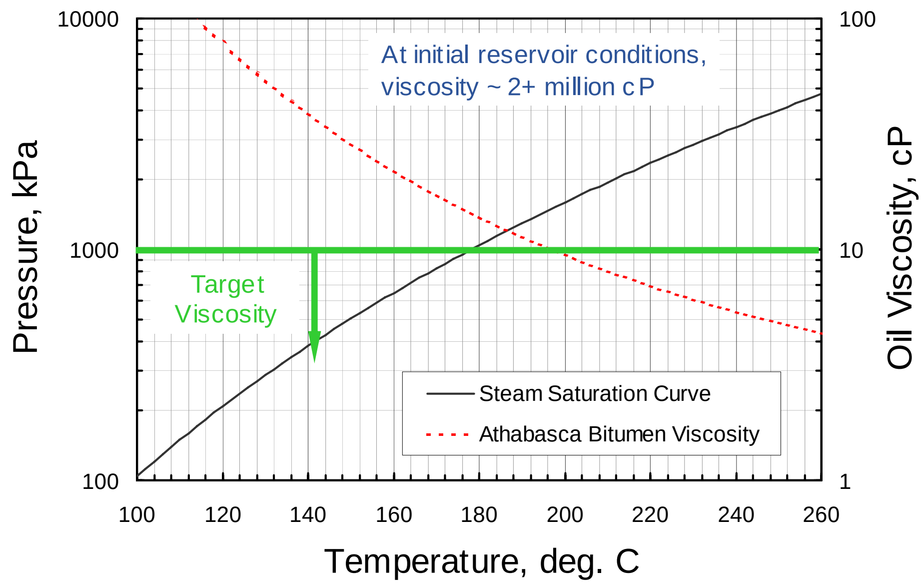
[5] http://www.oilsandsdiscovery.com/oil_sands_story/pdfs/bitumount.pdf
[6] Alberta Research Council; http://www.arc.ab.ca/Index.aspx/ARC/5816
[7] EUB ST98-2005: Alberta's Reserves 2004 and Supply/Demand Outlook

Appendix 2 provides a chronology of development and commercialization of various in-situ bitumen production processes in each of the three main oil sands regions in the Province. Shell was the leading developer of processes for the Peace River area and Imperial Oil for the Cold Lake region.

The oldest *in situ* recovery process developed for the oil sands is Cyclic Steam Stimulation (CSS). As the name implies, CSS is a cyclic process. First, high-pressure steam is injected into wells to heat the bitumen. That phase is followed by a "soak" period to allow the heat to be transmitted further into the reservoir, mobilizing oil further away from the injection well. In the final phase of the cycle, the well is "turned around" or opened as a producing well and the mixture of hot bitumen and condensed water is pumped to the surface for processing. The produced water is separated, treated and reused for boiler feed water. Cycle times for the three-step process vary from 6 months for new wells to 36 months for mature wells.[8]

Figure 3

Properties of Athabasca Bitumen[9]



Imperial Oil began small scale CCS pilots in the Cold Lake region, where the bitumen occurs at an average depth of 500 metres, in 1964. A larger pilot, producing 5,000 barrels per day was started in 1975.[10] In 1977, Imperial applied for approval for a commercial

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[8] Imperial Oil Limited Annual Report 2005, pg. 7
[9] Bitumen viscosity data: MEHROTRA, A. K. and SVRCEK, W. Y. Viscosity of compressed Athabasca bitumen. /Can.// J. Chem. Eng. /64:844, 1986. Steam data: BUTLER, R. M. GravDrain's Blackbook: Thermal Recovery of oil and bitumen. GravDrain Inc. Calgary, Alberta. ISBN 0-9682563-0-9, 1997.
[10] Imperial Oil Limited Annual Report 1977, pg. 16

project to produce 145,000 barrel per day of synthetic crude oil. Although the Alberta Energy Resources Conservation Board endorsed the plan, the project was suspended in 1981 in the wake of the National Energy Program and worsening economic conditions. Escalating project costs (from $8 billion to $12 billion), declining world prices, and a federal-provincial conflict over industry revenue sharing, contributed to the suspension. In 1983 Imperial chose to proceed instead with a phased approach to commercial development. Each 1,500 cubic metre (9,500 barrels of bitumen per day) phase was to be developed in step with the expected expansion of markets for the raw bitumen. At the end of 1985, four stages and earlier pilots were together producing 8000 cubic metres per day (50,000 barrels per day). By 1990, Cold Lake production averaged 85,000 barrels per day and by 2005, production averaged 139,000 barrels per day.[11] [12]

[11] Information for Investors – May 2005; http://www.esso.ca/Canada-English/Files/Investors/Factbook_Resources.pdf

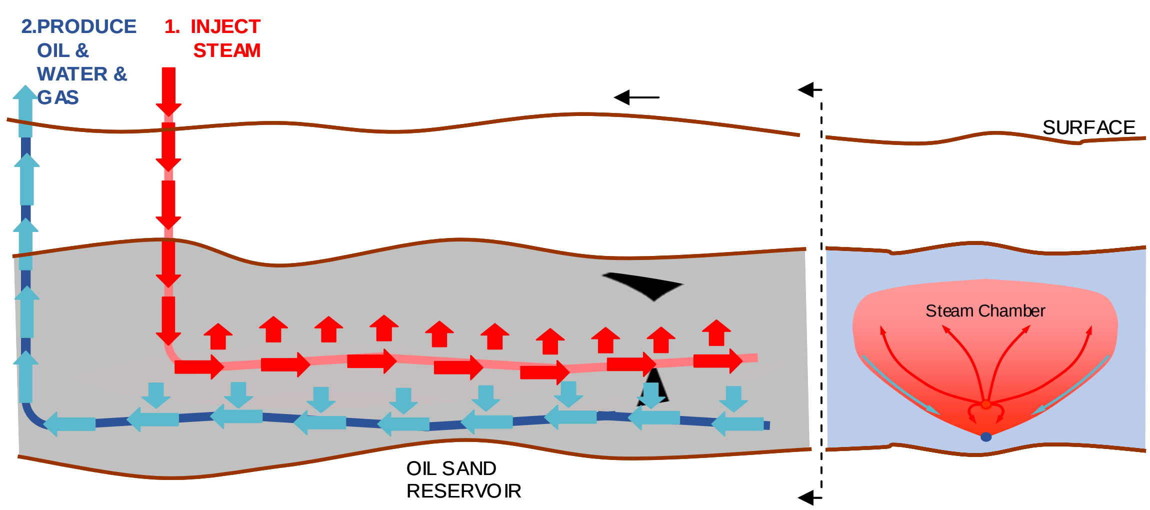
[12] Imperial Oil Annual Report 2005

II Steam Assisted Gravity Drainage (SAGD)

Steam Assisted Gravity Drainage (SAGD) is a newer technology with great potential for application to recover bitumen in Alberta.

In its most common form, SAGD utilizes horizontal well pairs, one well drilled above the other. Steam is injected into the upper well (see Figure 4 below) and releases its latent heat to the bitumen. The heated bitumen becomes mobile and drains down, under the action of gravity, to the lower production well where it is pumped, along with condensed water, to production facilities for processing. The mixture of produced fluids is processed to remove water which is then treated and recycled for steam generation.

Figure 4
Steam Assisted Gravity Drainage (SAGD)



A steam chamber forms in the reservoir and grows larger with continued production, allowing the steam to contact and heat the bitumen at the edge of the chamber. Over time, the amount of steam that is needed to produce each barrel of bitumen increases, and the process becomes less and less efficient due to greater heat losses from the steam chamber to the overlying caprock. Eventually an economic limit is reached, the operation is discontinued, and a new well pair is drilled to maintain production levels.

In both CSS and SAGD, the bitumen that is produced becomes viscous again after it cools. When it reaches surface, it must be either blended with a lighter oil product such as pentane (condensate) for transmission by pipeline to a refinery or upgraded locally to produce a lighter synthetic oil product that is easier to ship and to process at remote refineries.

Figure 5
Growth of a SAGD Steam Chamber

Steam Circulation
Establish Inter-well Thermal Communication
Initial Chamber formation

↓

SAGD Growth Mode
Inject Steam at Target Pressure
Steam Condenses at Chamber Edge
Bitumen Mobilized
Vertical and Lateral Chamber Growth

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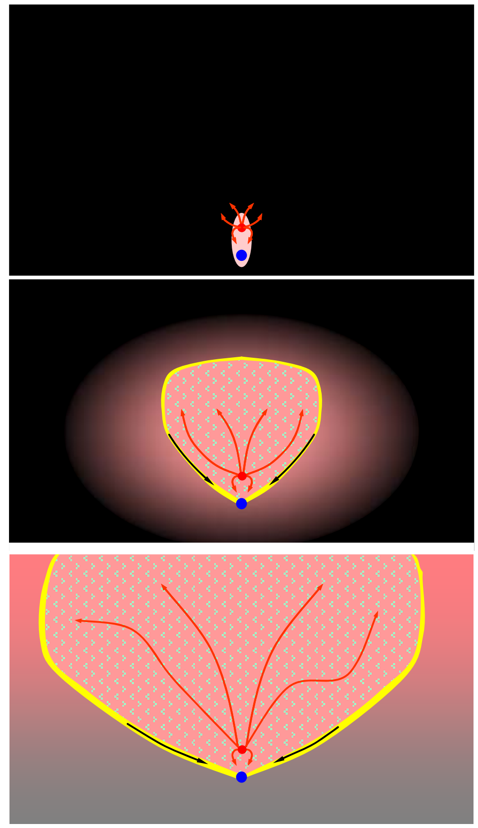
Maturing SAGD
Interference by Overburden
Heat losses become Important
Lateral Chamber Growth

Interacting Steam Chambers



III Dr. Roger Butler and Development of the SAGD Process:

SAGD was invented and championed by Dr. Roger Butler, a highly accomplished and respected engineer who died in 2005.

Dr. Roger Butler was born in Britain, but moved to Canada during the Second World War to attend high school. He graduated with honours from Sarnia Collegiate in 1944, earning scholarships in mathematics and physics. He then returned to Britain to take a BSc. in Chemical Engineering at London's Imperial College of Science and Technology, He graduated at the top of his class in 1948 and went on to complete his PhD there in 1951. After graduation, he moved back to Canada to become an Assistant Professor in the Chemical Engineering Department at Queen's University in Ontario. A few years later, in 1954, he went to work for Imperial and over a 27-year period with that company, he held a variety of positions in Sarnia, New York (with Exxon) and Calgary.

Early in his career at Imperial Oil, Dr. Butler worked in the refining side of the business with a focus on fuels and lubricants. In the late 1960s his focus shifted to methods of upgrading bitumen from Imperial Oil's Cold Lake Oil Sand leases. At that time, Dr. Butler also became interested in finding better ways to recover the bitumen from the reservoir. To that task, he brought his earlier research experience with potash mining in Saskatchewan where he had become familiar with the process of injecting fresh water in underground formations to dissolve the potash and salt, thereby creating a large underground chamber. He also observed that the heavier brine sank to the bottom of the chamber and the fresher (injected) water rose to the top. From that experience, Dr. Butler developed the concept of creating a steam chamber in the Cold Lake reservoir to heat and recover Cold Lake bitumen. He reasoned that the heated oil at the outer edge of the chamber would condense, transferring its latent heat to the cold bitumen. The condensate and warm bitumen would then drain to the bottom of the chamber where it could be collected and pumped to the surface. He extended that idea with the concept of using a pair of wells, one to inject steam to form the steam chamber and another completed below the first, to produce the warmed bitumen. His radical notion for producing heavy oil was not well received at first. "The attitude was, 'Who's this bloody fellow? He doesn't know a thing about producing oil.'"[13] He did not actively develop the concept until he was transferred to Calgary in 1975 to head-up Imperial's heavy oil research division.[14]

Dr. Butler was initially intrigued with the concept of using pairs of vertical wells for bitumen recovery, one as a steam injector and the other as a producer, but his numerical calculations showed that the resulting production rate of only two or three barrels of bitumen per day was too low to make the concept economically feasible. Subsequent

[13] Mark Lowey interview of Dr. Roger Butler, in 2004.
[14] Stonehouse, Darrell, "Father of SAGD"; Oilweek, 01.06.2005

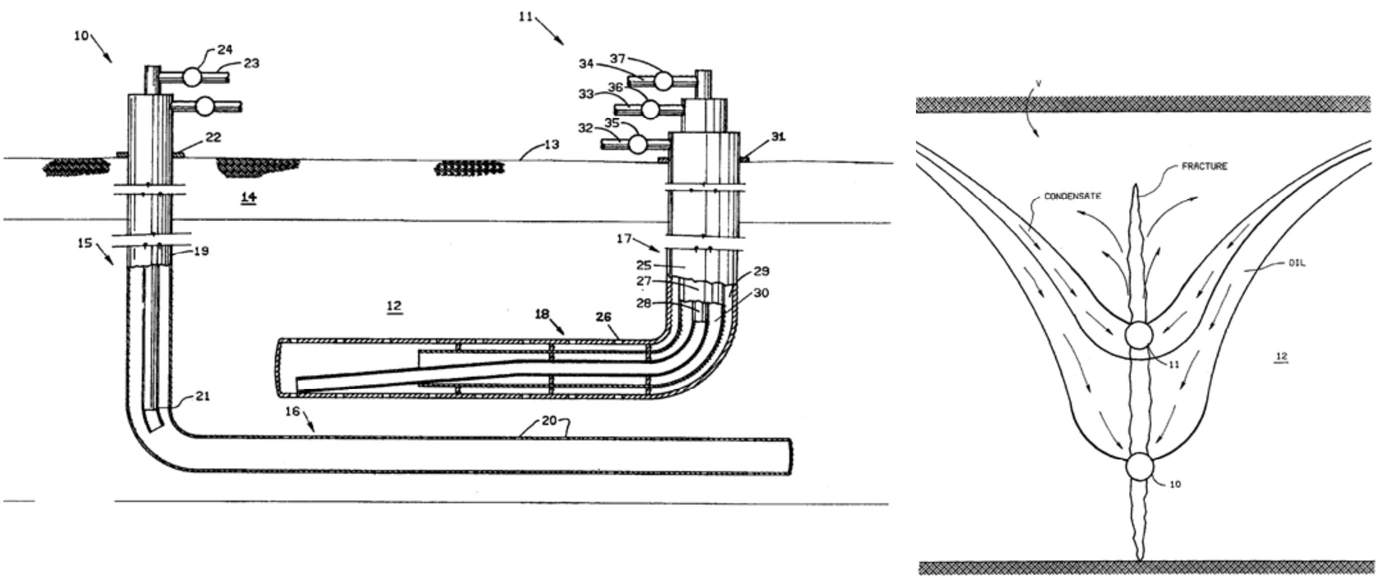
numerical models indicated that a horizontal well, low in the reservoir, would be much more effective because it would create numerous drainage points along the entire length of the horizontal well to capture the oil. "I could get a thousand barrels a day out of one of these wells on my paper calculations."

In 1978, Dr. Butler persuaded Imperial to drill the HWP1 pilot at Cold Lake – the Western world's first modern horizontal oil well and the first paired with a vertical steam-injection well. The horizontal well was about 150 metres long, in contrast to today's paired horizontal SAGD wells that are typically about 800 metres, but he was pleased with the results of the world's first working SAGD project and it confirmed the expected improvement in the production rate at close to 140 barrels of bitumen per day. In 1982, Imperial Oil and Exxon Production Research received patents in both Canada and the United States, respectively, for Dr. Butler's invention. He was credited with a method for continuously producing hydrocarbons by gravity drainage while injecting heated fluids.

As shown in Figure 6, key elements of the invention included the following:

- Two wells, in a variety of combinations, including one above the other: a hot fluid injection well (Top) and a fluid production well (Bottom);
- Establishing thermal communication between wells before first oil production;
- Forming a Steam Chamber at the boundary of the chamber as the steam condenses and releases heat to the formation and the bitumen;
- Oil / Condensate flowing down (by gravity) to the production well;
- Operating the wells in a way that minimized the mixing of the heated mobile oil and hot fluid (steam), to maximize flow rates;

Figure 6
SAGD Patent 4244 485



Source: Patent 4244 485

Despite the improvement in productivity of the horizontal well/vertical well combination, Imperial did not pursue SAGD at Cold Lake primarily because the reservoir conditions were not optimal for utilization of the SAGD concept. SAGD permits higher production rates and lower steam/oil ratios, but does not work well when there are poor heat transfer zones (vertical permeability barriers) within the reservoir.

After his retirement from Imperial Oil in 1982, Dr. Butler pursued the SAGD concept for application at other oil sand locations. His first 'post-retirement' position was Director of Technical Programs at AOSTRA.

AOSTRA, an Alberta Crown Corporation, was established in 1974 to promote the development and use of new technology for oil sands and heavy oil production, with emphasis on reduced costs, increased recovery and environmental acceptability. The corporation reported to Alberta's Ministry of Energy and base funding was transferred from the Alberta Heritage Savings Trust Fund ($419 million). Additional funds came from Alberta's General Revenue Fund and from technology sales. AOSTRA was expected to spend more than $600 million over its life and those expenditures were expected to be matched with comparable industry expenditures on a project-by-project basis.[15] Projects were selected by a government-appointed board consisting of up to nine members with experience in petroleum development and technology management.

[15] E. J. Wiggins, The Canadian Encyclopedia, Hurtig Publishers Ltd., 1988, Pg. 57.

The resultant technology was available to any user at fair market value. AOSTRA also supported research at Canadian universities and research institutions, provided grants to inventors, funded the operation of a technical information system and promoted international co-operation in oil sands development. Over the years leading up to a test of the SAGD concept in 1987, 30 pilots were tested at a cost of over $700 million.[16]

In 1983, AOSTRA developed detailed designs for the Underground Test Facility (UTF) near Fort McMurray to test *in situ* techniques and strategies for accessing oil sands resources that were too deep for surface mining[17] AOSTRA could not initially attract any industry co-funding and proceeded with the design and construction of the UTF on its own.[18] Dr. Butler, then a professor at the University of Calgary, convinced AOSTRA to test the SAGD concept at the UTF. Horizontal well pairs were drilled from the underground facility and utilized to confirm the effectiveness of gravity forces in contacting and draining an oil sands reservoir. Nine commercial partners contributed to finance the demonstration project including Amoco Canada Petroleum Ltd., Chevron Canada Resources Ltd., Conoco Canada Ltd., CNPC Canada Ltd., Imperial Oil Resources Ltd., Japex Oilsands Ltd., Petro-Canada, Shell Canada Ltd., and Suncor Inc. The federal government participated in a geotechnical program.[19] Two phases were involved. In the Phase A, three well pairs were completed with 60-metre completions. Production rates, steam-oil ratios and ultimate recoveries exceeded expectations. Phase B, consisting of an additional three well pairs 500 metres into the oil sand, was designed to verify scale-up in performance for commercial length (600 m) wells and to confirm that drilling accuracy could be obtained. Results also exceeded expectations.[20]

AOSTRA studies showed that a 30,000 bpd *in situ* operation using SAGD could produce bitumen at a supply cost of $7.50 (Canadian)/bbl, well below the lowest cost for *in situ* production of bitumen at that time. The supply cost included capital payback and operating cost ($3.65/barrel) but excluded royalties and taxes. The studies showed that a 30,000 b/d operation was the most economically attractive minimum size. A $225 million initial capital investment would be needed and an additional $250 million would be required over the following 25 years.[21]

Dr. Butler continued to perfect and better understand the SAGD process as holder of the first PanCanadian[22]/Petroleum Society Endowed Chair in Petroleum Engineering (1983

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[16] Elsie Ross, Research And Development Study Underway To Boost Conventional Activity; Daily Oil Bulletin, 2003 06 23.
[17] http://collections.ic.gc.ca/oil/index1.htm
[18] AOSTRA A 15 Year Portfolio of Achievement, pg. 48.
[19] AOSTRA: Field tests prove oilsands SAGD production method, Oil and Gas Journal, Tulsa, July 11, 1994. Vol. 92, Iss.28; pg. 22.
[20] AOSTRA: 1993 Annual Report, pg. 7.
[21] AOSTRA: Field tests prove oilsands SAGD production method, Oil and Gas Journal, Tulsa, July 11, 1994. Vol. 92, Iss.28; pg. 22.
[22] PanCanadian is now EnCana

to 1995) at the University of Calgary. When he was interviewed in 2004 at the age of 77, the semi-retired professor emeritus in the Chemical and Petroleum Engineering Department said that his work at the U of C was very important. "Most of the thinking I've done on SAGD I did there." Author or co-author of more than 100 scientific papers and patents and sole author of two seminal books on horizontal wells and SAGD, Butler allowed that his SAGD invention "is a significant contribution." But, he modestly added: "It's good fortune. If I hadn't thought of it, somebody else would have." While at U of C, he also invented another gravity-drainage process he called VAPEX, which uses vaporized solvents instead of steam to mobilize the heavy oil. VAPEX has the potential to significantly reduce energy use and emissions.

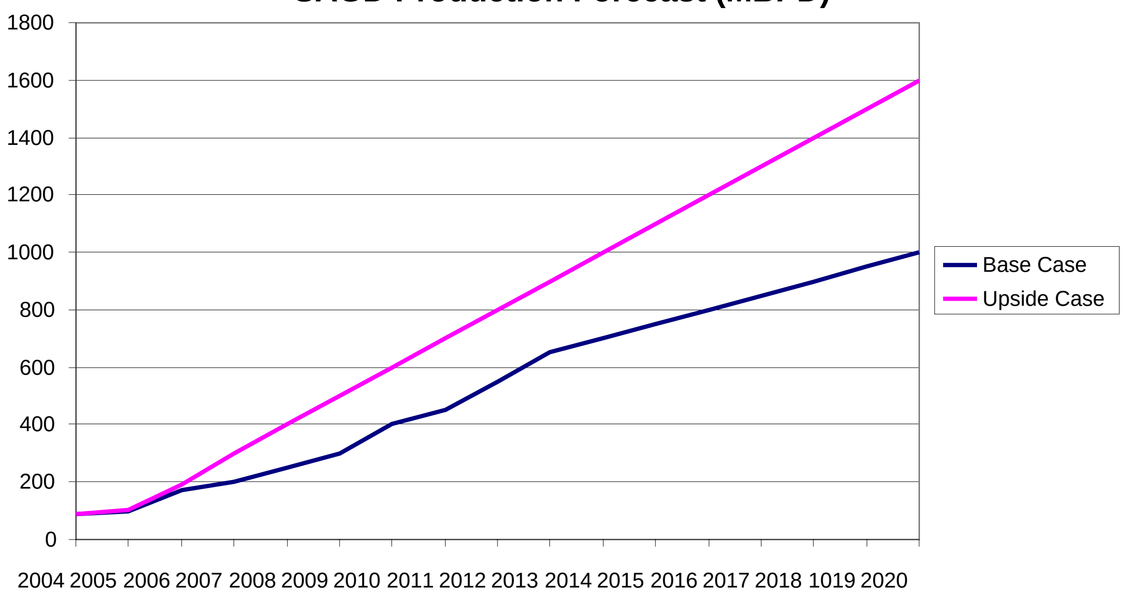
After his retirement from U of C, Dr. Butler continued to work through a consulting company he formed, GravDrain Inc. Early SAGD projects included EnCana Corporation's advanced SAGD projects at Foster Creek and Christina Lake, Petro-Canada's MacKay River project, ConocoPhillip's Surmount project, Suncor's Firebag, and OPTI Canada/Nexen's Long Lake project. More than a dozen other smaller operations were also proposed.

Dr. Butler received the first Syncrude/ASTech Innovation in Oil Sands Research award in 1992 and was a co-recipient of an ASTech Foundation Special Award in 2005.

IV The Impact of SAGD on Alberta and Canadian Economies

To date, at least 23 SAGD projects have been announced. If all of these projects were developed, as announced, over the next 15 years, SAGD production would grow to close to 2 million barrels of bitumen per day by 2020 (Appendix 1). More conservative upside and base case forecasts which assume pipeline capacity restrictions and limited diluent supply constraints are shown in Figure 7. The base case projection of one million barrels per day by 2020 was used for an assessment of economic impacts of SAGD developments.

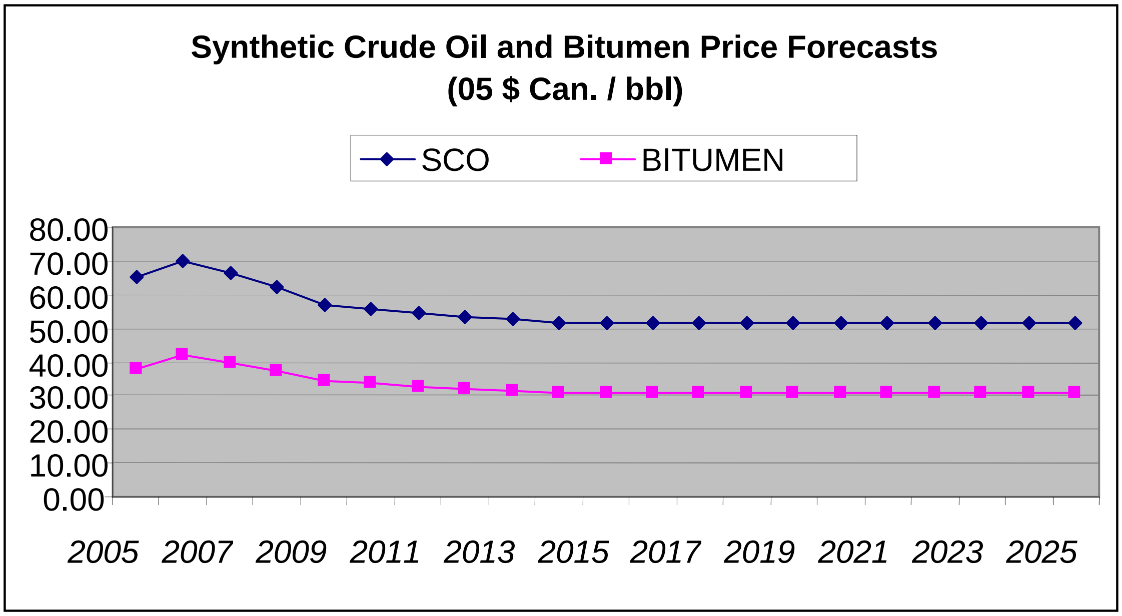
Figure 7
SAGD Production Forecast (MBPD)

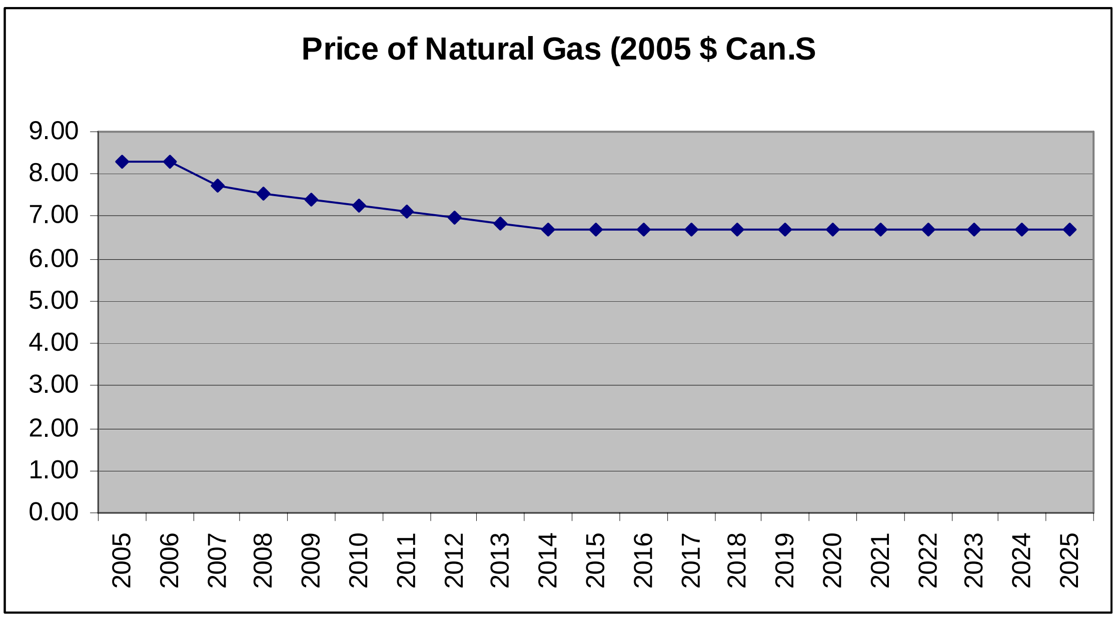


To assess the impact of this production on the Alberta and national economies, the following key additional assumptions were made:

- Market prices for synthetic crude oil, bitumen and natural gas were assumed to be the same as those utilized by the Alberta Energy and Utilities Board in its AEUB 2005 Supply/Demand Outlook (see Figure 8)
- The percentage of bitumen that is upgraded in Alberta was assumed to be 20 percent in 2006, rising to 50 percent by 2010 and remaining at 50 percent thereafter.
- Capital and operating costs were based on National Energy Board report "Canada's Oil Sands Opportunities and Challenges to 2015," May 2004.

Figure 8
Price Forecasts





Using the base case production forecast (one million barrels per day by 2020) and the preceding price assumptions, the direct economic impacts to 2025 on the Alberta and Canadian economies were calculated to be as follows:

Table 2
Summary of Economic Impacts of SAGD

	Provincial Impact*	Federal Impact*
Increase in GDP (billions $2005 Can.)	155	173
Labour Income (billions $2005 Can.)	60	72
Employment (000 person years)	944	1191

* With induced impacts, GDP was estimated to be 25-30 percent higher. Labour Income and Employment Impacts would be 40-50 percent higher.

Table 3 and Figure 9 summarize AOSTRA expenditures over the 1976 to 1994 time period. Cumulative AOSTRA expenditures to 1994, at the time AOSTRA was merged into the Provincial Ministry of Energy's new Oil Sands and Research Division, were $617 million in dollars of the day or a little over $1 billion in constant $2004.

Table 3
AOSTRA Expenditures 1976 – 1994
(in millions of Canadian dollars)

	1976	77	78	79	80	81	82	83	84	85
As spent	2.2	8.9	18.5	31.9	38.7	29.2	32.9	37.8	37.7	73.9
$ 2004	6.4	24.3	47.4	74.3	82.0	55.7	57.9	63.1	61.0	115.7

	86	87	88	89	91	91	92	93	1994	Total
As spent	49.3	75.2	32.8	29.6	27.5	41.5	21.3	15.9	12.4	617.2
$ 2004	75.1	109.4	45.7	39.4	35.5	52.0	26.4	19.4	14.9	1005.6

Figure 9
Summary of AOSTRA Expenditures   1976 – 1994

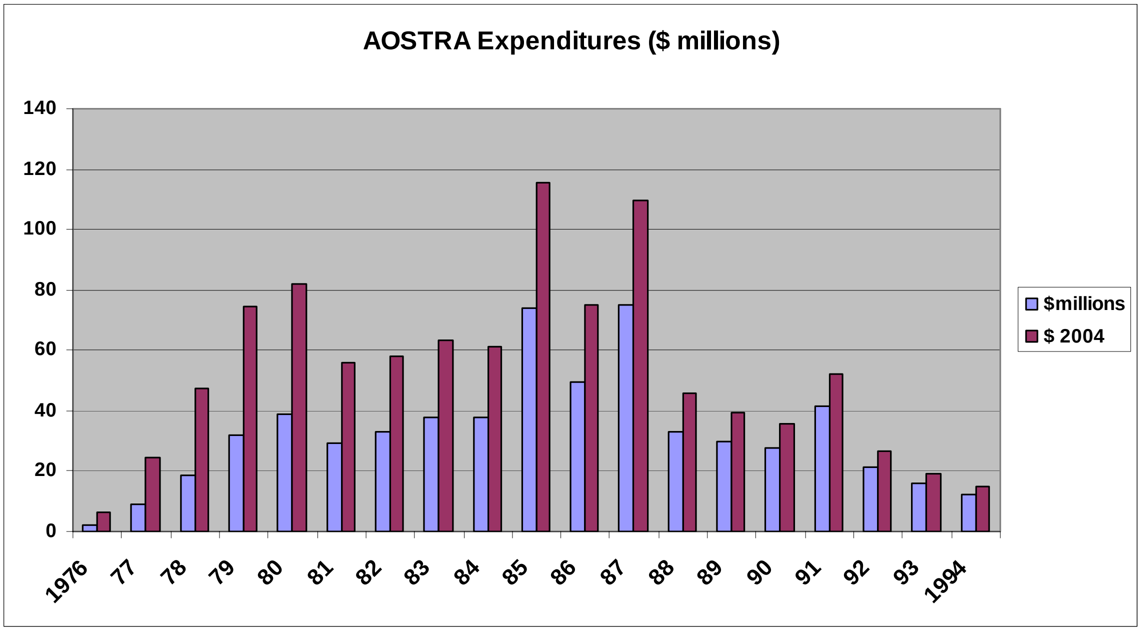
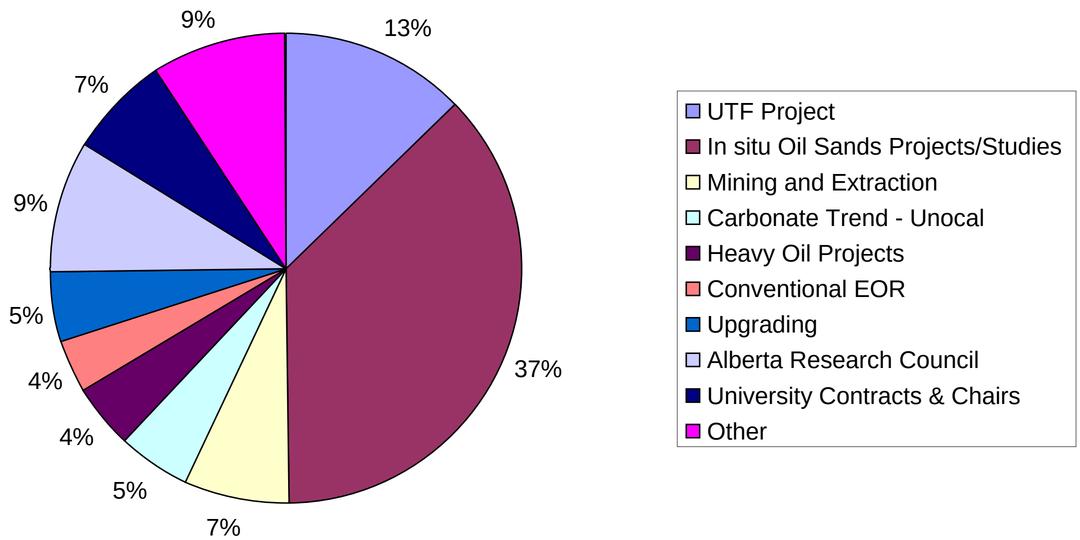


Figure 10 shows the distribution of cumulative AOSTRA expenditures (in as spent dollars). As much as 25 percent of the expenditures could be attributed to SAGD-related research, including most of the UTF expenditures and perhaps an equivalent amount for *in situ* projects and studies. Cumulative AOSTRA expenditures for SAGD would therefore be approximately $150 million. AOSTRA expenditures were generally matched by industry, bringing total SAGD R&D for the period to approximately $300 million.

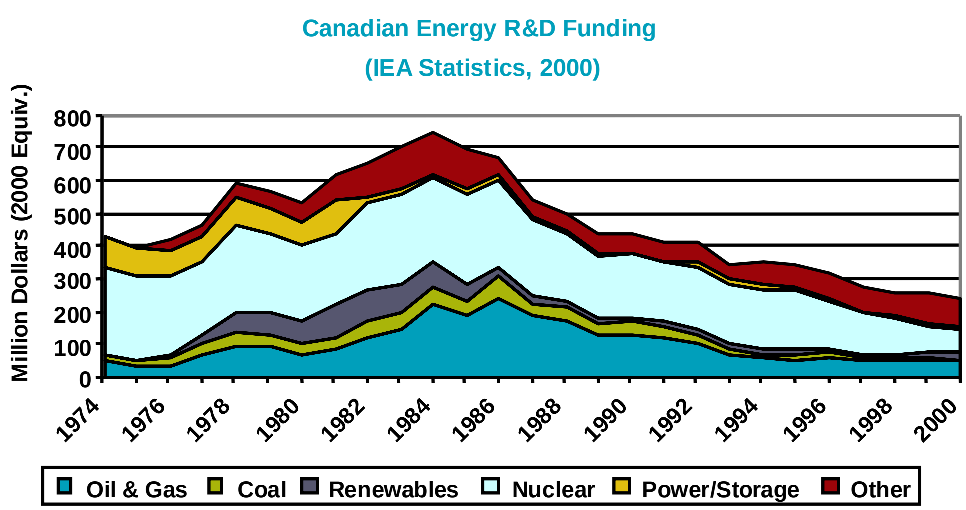
Figure 10
Distribution of AOSTRA Expenditures (1976 – 1994)



Source: ASRA 1993 – 1994 Annual Report

The decline in AOSTRA research expenditures after the mid-1980s parallels the decline in energy research expenditures that occurred nationally, as shown in Figure 10.
By 2000, energy R&D was approximately one-third the level it was in 1984 (in constant $2000).

Figure 11



Source: IEA Statistics 2000

V Observations and Conclusions

We have known for almost a century that large volumes of bitumen exist in oil sand deposits in the Peace River, Athabasca and Cold Lake regions of the Province but only recently have we learned just how extremely large that volume is. The vast majority of that resource, about 1,600 billion barrels, is too deep to mine, and only recently have we had technology to make it feasible to develop the deeper resources. It has taken close to 40 years to develop, but recovery processes are now to the point that it is economically feasible to undertake development of significant portions of the resource in all three oil sand regions.

SAGD is one of the most innovative and dominant new *in situ* recovery processes to be developed. It was made possible by taking advantage of horizontal drilling technologies that were developed at about the same time. Canada was a world leader in development of horizontal drilling technology and much of it was spurred by the need to develop technologies to recovery heavy oil and bitumen.

Although SAGD is being employed in all three oil sands regions and is now a proven technology, it is far from being a mature technology. It continues to be developed as industry learns from both its successes and disappointments. In appropriate situations, the process has worked well, with recoveries in excess of 50 percent. It works best where reservoirs are thick, clean and of high quality, with 15 metres or more pay, high bitumen saturations and high permeability. Problems are encountered where there are heterogeneities that can interfere with steam as it rises in the steam chamber and when the bitumen reservoirs are underlain by bottom water or are capped by natural gas zones.[23] In its current form, it is also an energy and water-intensive process. Refinements are needed to allow the process to be employed in a wider variety of reservoir situations and to reduce environmental impacts. That said, there is perhaps no other uniquely Canadian technology that has as much potential to contribute to the development of this province and the country as a whole. The impact on Provincial GDP, for example, is estimated to be over Cdn$200 billion (with induced impacts) over the next 20 years (in constant 2005 dollars).

SAGD is a technology with roots in the Cold Lake Oil Sands Region that was transplanted, developed and now utilized more extensively in other regions, especially in the Athabasca Oil Sand Region.

Successful development of the technology was largely due to the talent and leadership of one key individual: Dr. Roger Butler. He was the inventor of the SAGD concept and the principal technology development champion. What was most remarkable was that

[23] Peggy Williams, Canada's In-situ Oil Sands, Oil and Gas Investor, September 2005, pg. 46.

he continued to successfully develop and champion the technology throughout his career with three different organizations, and then also as a private consultant after he retired for the second time.

SAGD benefited not only from Dr. Butler's exceptional scientific and engineering talent, but also from his experience in being involved with other industries (i.e. potash mining) and from his openness to try new concepts (e.g. horizontal drilling). At least partially through his efforts, Imperial Oil drilled the first horizontal well of its kind in 1978. This openness to other technologies and industries may have been partially due to his career path. Universities provide an ideal home for this kind of cross-fertilization. Dr. Butler started his career in academia (at Queen's) and after a long career with Imperial Oil, returned to academia (University of Calgary). His success as an inventor and technology champion was probably attributable too to this back and forth career path between industry and academia. Dr. Butler developed the initial concept of SAGD during his career with Imperial Oil, but did "most of his thinking on Steam Assisted Gravity Drainage" while a professor at the University of Calgary.

The impact that this remarkable man had on the industry and the Province leads to a series of important questions:

- Are there other Roger Butlers working in industry, government or academia?
- Would we recognize them and encourage them if there was?
- Are we doing enough to develop people like Roger Butler?
- Are we listening and respecting bright people with ideas that appear to be a little too "off the wall"?
- Would industry and academia benefit from more interaction, perhaps through encouraging hybrid career paths and/or more frequent use of sabbatical exchanges?

Sponsors of research over the years were, of course, also critical to the successful development of SAGD. Most notable organizations are Imperial Oil, Dr. Butler's long-time employer, and AOSTRA. Imperial drilled the first horizontal well of its kind and used that well in combination with a vertical injector to conduct the first test of the SAGD concept. AOSTRA was also critical to the successful development of SAGD. AOSTRA stepped up at a critical time to fund the development of the Underground Test Facility (UTF), when the private sector would not. The SAGD experiments that were subsequently undertaken at the UTF facility proved that SAGD worked, countering the mixed results that were being experienced elsewhere in the Province. The UTF tests also allowed Dr. Butler and others to refine the analytical models that were used for the design and management of SAGD operations. AOSTRA also made the technology and know-how available to other companies, and built the confidence necessary to encourage other companies to invest in SAGD pilots.

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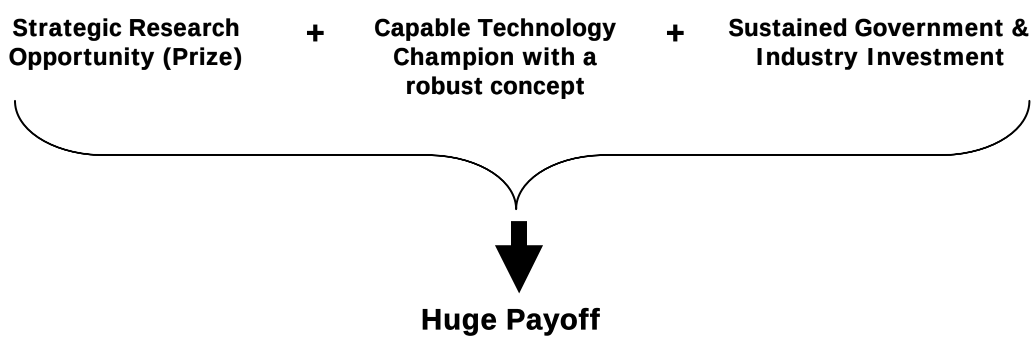
The money that AOSTRA spent on development of the UTF and SAGD was in the range of $150 million and that sum was probably matched by similar industry expenditures. But what seems like a very large sum of money, $300 million, pales in relation to the economic benefits produced. The technology is already being utilized in developments that are likely to produce in the range of one million barrels of bitumen per day, resulting in the development, over time, of 11 billion barrels. The $300 million expenditure, then, represents an expenditure of less than three cents per barrel.

The investments over the years were undertaken collaboratively. Industry, government and academia worked closely together. Not only did the collaboration expand the range of options considered, but it also diversified the investment risk for each organization and helped to ensure that the sufficient investment was sustained over the lengthy period of time that it took to develop and prove the technology.

The research expenditure has also paid through developing highly qualified people employed in the industry and academia. If we are short of highly qualified and experienced people now, where would we have been without AOSTRA?

The SAGD experience can therefore be summarized schematically as follows:



Although SAGD is now a proven commercial technology, there are significant opportunities and a compelling need to further develop it to enhance its economic and environmental impacts. As SAGD technology is refined and improved, the sustainable economic impact of the technology will become even greater.

Despite this remarkable success story, funding for research and development of this type is now only approximately one third of what it was, in real terms, in the mid 1980s. Given the enormous potential payoffs for this type of research, the successful track record of previous AOSTRA and industry expenditures, and the emerging critical need to find better ways to produce oil and gas with reduced environmental impacts, there is a very compelling case to increase research funding to previous levels, and probably beyond. The resource base is so extremely large that the option value of such research is truly remarkable. There are few places in Canada and in the world where the option value of targeted research is as high.

Appendix 1

Potential SAGD Production Capacity Forecast
(thousands barrels of bitumen per day)

	Operator	Project	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	1019	2020
1	Suncor	Firebag	11	18	45	55	80	90	115	125	140	140	140	140	140	140	140	140	140
2	CNRL	Horizon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3		Kirby	0	0	0	0	0	0	0	30	30	30	30	30	30	30	30	30	30
4		Birch Mountain	0	0	0	0	0	0	0	0	0	30	30	60	60	60	60	60	60
5		Gregoire Lake	0	0	0	0	0	0	0	0	0	0	0	0	30	30	60	60	90
6		Primrose / Wolf Lake	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
7	Total	Josleyn	0	0.5	10	20	30	40	50	50	50	50	50	50	50	50	50	50	50
8	Connoco	Surmont	0	0	0	20	40	60	80	100	110	110	110	110	110	110	110	110	110
9	EnCana	Foster Creek	29	29	41	50	60	80	100	110	120	140	150	150	150	150	150	150	150
10		Christina Lake	5	5	8	12	18	25	40	60	100	150	200	250	250	250	250	250	250
11		Borealis (SAGD?)	0	0	0	0	0	0	0	0	5	20	50	75	100	100	100	100	100
12	Petrocan	MacKay River	17	21	28	29	30	50	60	60	60	60	60	60	60	60	60	60	60
13		Meadow Cr	0	0	0	0	0	0	0	0	30	30	40	40	40	40	40	40	40
14		Lewis	0	0	0	0	0	0	0	0	0	0	10	20	30	40	40	40	40
15		Chard	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	20	20
16	Devon	Jackfish Lk	0	0	0	25	35	35	70	70	70	70	70	70	70	70	70	70	70
17	JACOS	Hangingstone	9	9	10	10	45	50	50	50	60	60	60	60	60	60	60	60	60
18	Nexen	Long Lake	11	18	45	55	80	90	115	125	140	140	140	140	140	140	140	140	140
19	Blackrock	Hilda Lk. / Orion	1	1	1	6	10	15	20	20	20	20	20	20	20	20	20	20	20
20	Husky	Tucker Lake	0	0	0	30	30	30	30	30	30	30	30	30	30	30	30	30	30
21		Sunrise	0	0	0	0	0	25	50	75	100	125	150	175	200	200	200	200	200
22	MEG	Christina Lk.	0	0	0	0	0	0	0	25	50	75	95	95	95	95	95	95	95
23	Connacher	Great Divide	0	0	0	5	10	15	20	20	20	20	20	20	20	20	20	20	20
		Total	87.1	106	192.5	321.5	473	610	805	955	1140	1305	1460	1600	1690	1700	1740	1750	1780

Appendix 2
Chronology of Development and Commercialization of In-Situ Bitumen Production Processes[24]

Athabasca

	Year	Event / Milestone
1	1719	Cree guide (Wa-Pa-Su) shows sample of oil saturated, bituminous sand to representative of the Hudson's Bay Company
2	1778	Peter Pond (Northwest Trading Company) - First writing about the occurrence of oil sands along outcrops of Clearwater-Athabasca rivers
3	1848	Sir John Richardson – first geological assessment of the oil sands – on his journey to the Arctic in search of the missing Franklin expedition
4	1870	Canada purchases "Rupert's Land" from the Hudson's Bay Company
5	1906	Count Alfred von Hammerstein drills for oil into Devonian limestone beneath the oil sands and finds salt
6	1920	D. Diver first attempt at in-situ production (bottom hole distillation by lowering a heating unit to the bottom of a well)
7	1926	First steam test by the Bituminous Sand Extraction Co. Limited
8	1957 1962	Shell Canada Resources – Muskeg River Pilot (hot caustic stimulation plus steam injection). Poor economics due to need for repeated well stimulations.
9	1957 1976	Amoco Canada Production Company Ltd. Gregoire Lake combustion tests (COFCAW – combination of forward combustion and water)
10	1963 1965	Atlantic Richfield Pilot at Pony Creek – attempt to establish horizontal fractures between injectors and producers and to operate a steam drive.
11	1963 1965	Mobil Oil Canada inverted nine-spot combustion test in a propped horizontal fracture
12	1966 1969	Fina Oil Company Steepbank Pilot – hydraulic fracturing to establish communication between wells (steam drive)
13	1969	Suncor inverted five-spot combustion pilot near their surface mining operation
14	1973 1985	Texaco Exploration Co. Ltd. – series of three pilots using steam injection. The third involved use of parallel horizontal wells.
15	1974	Alberta Oil Sands Technology Research Authority (AOSTRA) created
16	1976	Williams Brothers Canada Ltd. proposes study of a shaft and tunnel access scheme for in situ recovery (Mine Assisted In Situ Process (MAISP) for zones too deep for mining and too shallow for in situ methods – an adaptation of Russian thermal mining experience. An industry group conducted a small-scale escarpment test.
17	1983	AOSTRA (without industry support) undertakes detailed design of an Underground Test Facility (UTF) with mine access and a tunnel system in the limestone underlying the oil sands.

[24] Primary Sources:
- Historical Overview of the Fort McMurray Area and Oil Sands Industry in Northeast Alberta; Alberta Energy and Utilities Board Earth Sciences Report 2000-05
- AOSTRA 2003 and 2003-04 Annual Reports
- AOSTRA A 15 Year Portfolio of Achievement
- Peggy Williams; Canada's In-situ Oil Sands; Oil & Gas Investor; Sept. 2005; pg. 44-56.

18	1986	UTF Mine is completed, providing access for drilling.
19	1987 1990	UTF Phase A – 3 horizontal well pairs; 160 m length, 60 m completion. Producer 5 m below the injector. Results exceed expectations.
20	1991 1997	UTF Phase B – 3 horizontal well pairs, 600 m in length, 500 m completion. Results exceed expectations and demonstrate that SAGD can be applied economically.
21	1996	EnCana startup of Senlac, Saskatchewan SAGD pilot.
23	1997	EnCana initiates Foster Creek SAGD Pilot project.
24	1998	Surmont pilot project started (two pairs of horizontal SAGD wells). A third pair added in 2000.
25	1999	Japan Canada Oilsands begins SAGD demonstration project at Hangingstone, with commercial operations projected to reach 60,000 bpd by 2012.
26	2001	EnCana full commercial operation at Foster Creek and Cristina Lake SAGD pilot started up.
27	2002	Startup of Petro-Canada's MacKay River SAGD Pilot – 25 well pairs and production increased to 24,000 bpd by 2005.
28	2003	Suncor starts steam injection at Firebag SAGD Project. First production, January 2004 and production of 20,000 bpd by 2005.
29	2003	Production from Nexen Inc. and OPTI Canada Inc. SAGE pilot project at Long Lake starts.
30	2004	ConocoPhillips starts construction of Surmont Oilsands Project, expected to lead to 100,000 BPD by 2012 and ultimate potential of 200,000 BPD.
31	2004	Deer Creek Energy SAGD pilot launched at Joslyn. Expected to lead to production of 40,000 BPD by 2010.
32	2005	Nexen Inc. and OPTI Canada start drilling of 65 horizontal well pairs for Long Lake Commercial Project. Full production to be 72,000 bpd of bitumen for onsite upgrading.
33	2005	Construction of Devon Energy's Jackfish SAGD Project begins. Full production of 35,000 bpd expected by 2008.

Cold Lake

1	1920s	Bitumen deposits at Cold Lake discovered
2	1962	Imperial Oil drills 10 evaluation wells
3	1964	First Imperial Oil Steam Stimulation Pilot start up
4	1966	Imperial Oil Cyclical Steam Stimulation Patent
5	1975	Larger pilot completed and started up (5,000 bbls per day in 1976) using CCS.
6	1977	Imperial applies to the Alberta Energy Resources Conservation Board for approval of a project to produce 145,000 bbls per day of synthetic oil. Project is estimated to cost at least $4 billion. By 1981, estimated cost had escalated to $12 billion.
7	1978	First horizontal well (Imp 78 Horizontal Leming Ex 9-6-65-3) with extensive pay contact drilled in the Western World. Cost of the well was eight times the cost of a conventional vertical well. A pilot operation is constructed using this horizontal well in combination with a vertical steam injector located above the horizontal well. Pilot is operated for over ten years.
8	1978	BP Exploration Canada Limited, with AOSTRA, Dome Petroleum and PanCanadian Petroleum startup Marguerite Lake Pilot Project to test steam stimulation and simultaneous combustion. Project demonstrated that oxygen could

		be utilized following cyclic steam injection to increase ultimate recovery.
9	1982	BP "B-Unit" Wolf Lake pilot started (with AOSTRA and Petro-Canada) using CSS.
10	1982	U.S. patent 4,344,485 (Aug. 17, 1982) and Canadian Patent 1130201 (Aug. 24, 1982) granted to Exxon Production Research Company and to ESSO Resources, respectively, for Dr. Butler's steam assisted gravity draining production system design (SAGD).
11	1983	Imperial announces plan for phased development of Cold Lake and starts construction of the first two phases. Each phase expected to cost $125 million and to produce 9500 barrels of bitumen per day.
12	1984	A second horizontal well is drilled by Esso at Cold Lake and produced in combination with vertical wells for steam injection. SAGD tested and proven, but Esso concluded that it did not work as well as CSS for their oil sands geology.
13	1985	Cumulative Imperial research and technology development expenditures total $250 million
14	1985	Start up of first commercial CCS bitumen production (four phases) with total production of 50,000 bbls per day.
15	1985	BP Wolf Lake Project started based on steam technology developed at Marguerite Lake pilot.
16	2004	Husky begins construction of 30,000 BPD Tucker Lake SAGD project. Commissioning took place in 2006.
17	2006	Imperial Oil bitumen production exceeds 150,000 BPD per day.

Shell - Peace River

1	1875	Geological Survey of Canada (John Macoun) finds oil seeps on the Peace River
2	1950s	Shell discovers Oil Sand deposit
3	1960s	Shell conducts three small pilots with inconclusive results.
4	1973	Single-cycle injectivity test without fracturing and excellent production response.
5	1979-1992	31 well Peace River In Situ Pilot (PRISP) using a pressure cycle steam drive process. AOSTRA participates.
6	1983	Multi-soak pilot tests cyclic steam injection in four wells with excellent results
7	1986	Startup of Peace River Expansion Project (PREP). First project in which AOSTRA was a partner that led to commercial exploitation of the oil sands. Problems with steam leaking into producing wells.
8	1993	Shell and AOSTRA initiate test of feasibility of Enhanced Steam Assisted Gravity Drainage (ESAGD) using horizontal wells (two pairs of wells). A second pilot was also undertaken. Problems with bottom water in the first test and problems with permeability variations in the second, caused mixed results.