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INDUSTRIAL POLICY IN ALBERTA: LESSONS FROM AOSTRA AND THE OIL SANDS

Sara Hastings-Simon, PhD

EXECUTIVE SUMMARY

Disruption, but without too much prescription, should be the Alberta government's method of choice as it shapes the province's economic future and deals with the twin challenges of diversification and decarbonization. For guidance in setting a clear course, the government need only look to the history of the province's oilsands industry and the critical role of landmark funding of the $1.4-billion (in today's dollars) Alberta Oil Sands Technology and Research Authority (AOSTRA).

The dominant conventional oil industry was hostile to both the idea of AOSTRA when it was created in the 1970s and ultimately the introduction during that period of new technology called steam-assisted gravity drainage (SAGD). However, then-premier Peter Lougheed had the foresight to prioritize development of an innovative in situ recovery method. Lougheed's tenacity and his faith in the disruption/breakthrough approach led to successful testing of the SAGD technology and the eventual creation of today's in situ oilsands industry.

The lessons learned nearly half a century ago can still stand the province in good stead even though the challenges for the oilsands and the province look nothing like they did in the 1970s. Chief among those lessons is that significant investment of public money in innovation is vital to unlocking Alberta's economic growth. This investment must play a role in future policy if the province's economy is to grow and diversify. However, it's not enough for the government to simply throw money at a project. AOSTRA's story also provides solid lessons on how the design of such an investment can contribute to its success.

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As Lougheed clearly understood, investment should avoid areas that involve only incremental advances and focus instead on aspects that are innovative and disruptive and beyond immediate commercial interests. The size of the government's investment should be reasonable in relation to the infrastructure and human capital available in the province. The work itself should be led by an organization with the expertise needed to consider advice from industry but ultimately prioritize and direct investment. Nor should efforts be directed solely to narrow commercial gain; the ability to create public benefit from the investment must also be planned for.

Sharply defined goals will quickly grow blurry if the province's political leaders are unwilling to make large investments in projects with long timelines. And while providing public money for innovative projects, government must also be prepared to forgo intervening in the work itself. That should be left to the experts.

Alberta's leaders will have to stand fast, as Lougheed did, in the face of opposition from those who have little appetite for risk and prefer the safer, slower course of incremental development. To avoid over-prescriptiveness on the government's part, all investment decisions should be managed by an independent third party with the expertise to minimize costs while allowing room for some the necessary failures in the R&D process.

Disruptive/breakthrough technology calls for flexibility by its very nature, because it involves so many unknowns. AOSTRA's success with in situ recovery research arose from shaping and directing its own activities, free of the encumbrance of a restrictive, overly prescriptive approach. As the Alberta oilsands industry and the economy as a whole faces a complex 21st century set of challenges, the lessons from the Lougheed era remain just as relevant to government and industry today.

ABSTRACT

This paper examines Alberta's record of industrial policy and proposes principles for future innovation-focused provincial policy. I find that the development of the key technology to unlock the majority of the Canadian oilsands—steam-assisted gravity drainage (SAGD)—is an example of industrial policy in Alberta responsible for disruptive innovation and economic development.

The incumbent industry preferred incremental innovation in enhanced oil recovery. However, strong political leadership raised the royalties on the conventional oil industry to fund the Alberta Oil Sands Technology and Research Authority (AOSTRA), an extensive project in what was seen as diversification in an alternative industry. The initial $854-million (2019 dollars) government investment was matched by industry funds. However, after this investment failed to demonstrate a breakthrough, the pivotal investment in SAGD was purely government-funded and led, in the face of opposition from industry that viewed the construction of the underground test facility as a boondoggle. Once SAGD was proven, the private sector—made up of personnel trained under AOSTRA, and with continued financial support from government—grew SAGD

into a significant industry. Since then, the government's pivotal role in setting direction, the $1.4 billion (2019 dollars) in government investment and the opposition it faced have been largely forgotten.

There is growing interest in the potential for mission-oriented innovation or industrial policy to address major social and environmental challenges and spur economic growth. As the Alberta government seeks to address the dual challenges of diversification and decarbonization, AOSTRA's success holds important lessons. There should be a clear, disruptive goal that is not overly prescriptive. The goal should be matched to the scale of public and private resources available and supported by strong political leadership and willingness to take on a long-term challenge. The work should be driven by a technically competent organization with freedom to partner and make sole investments. And finally, there needs to be a clear mechanism for knowledge diffusion and recovery of the value of the knowledge created.

I explore these lessons and set out an industrial policy approach for the role of government in industry creation. Alberta's economic development history shows the important role of industrial policy in creating disruptive innovations and generating economic growth. It also shows how careful policy design can minimize rent-seeking as well as the costs of the necessary mistakes in the process—the "losers" that end up picked in the process of finding the "winners".

Keywords: Innovation, economic development, diversification, industrial policy, Alberta Oil Sands Technology and Research Authority, oilsands

POLICY RECOMMENDATIONS

- Significant public investment in innovation was critical in unlocking economic growth previously in Alberta, and must be part of future policy to enable economic growth and diversification in the province.
- Public investment in industrial policy should be focused on innovation in areas that are truly disruptive/breakthrough as opposed to incremental. Work can and should be guided by industry expertise but must address challenges beyond the scope of commercial interest for current industry players.
- Goals must be clearly stated and be accompanied by political leadership that is willing and able to take on large-scale investments with long timelines. Appropriate support should continue through commercialization.
- Investments should be managed under an independent third party with the expertise and authority necessary to direct investment decisions, and with a willingness to accept some failures but the ability to minimize their costs.

INTRODUCTION

The production of oil from Alberta's oilsands was arguably one of the most important elements of the province's economic development over the past century, through both royalties and the contributions to the tax base (Mansell and Schlenker 2006). Historical documents dating back to the early 1700s discuss the oilsands resource but commercial development began in earnest only in the 20th century. Karl Clark's work at the Alberta Research Council on development of a process for separating bitumen from sand opened up the development of oilsands mining (Government of Alberta 2019a). However, of the 165 billion barrels of established reserves in the Alberta oilsands, only 20 per cent is recoverable through mining, with the remaining 80 per cent requiring in situ recovery methods (Alberta Energy Regulator 2019). The development of in situ recovery methods posed a significant technical and innovation challenge in the 20th century. The cyclic steam stimulation (CSS) technology perfected for California heavy oil reservoirs was eventually adapted for the Cold Lake reservoirs in Alberta but CSS proved unsuccessful in the Athabasca resource. Today, over 80 per cent of the in situ production uses the steam-assisted gravity drainage (SAGD) technique[1] (Oil Sands Magazine 2019).

This paper describes the Alberta government's role in the development of SAGD, including the decision to prioritize the goal of in situ oilsands development and the process of innovation, culminating in successful testing of the technology. I explore the incumbent industry's response to the initial goal setting and its involvement throughout the innovation process.

I find that the development of the key technology—SAGD—in unlocking the majority of the Canadian oilsands is an example of industrial policy in Alberta responsible for disruptive innovation and economic development. On this basis, I propose principles for future innovation-focused industrial policy in the province. As Alberta faces the dual challenges of diversification and decarbonization, this previous experience holds important lessons for future economic development and policy design.

There is growing interest in the literature on the role of state-driven innovation policy as an approach to address major social and environmental challenges and spur economic growth (Rodrik 2004; Foray et al. 2012; Mazzucato 2016)which requires long-run strategic investments and public policies that aim to create and shape markets, rather than just "fixing" markets or systems. Market creation has characterized the kind of mission-oriented investments that led to putting a man on the moon and are currently galvanizing green innovation. Mission-oriented innovation has required public agencies to not only "de-risk" the private sector, but also to lead the direct creation of new technological opportunities and market landscapes. This paper considers four key issues that arise from a market-creating framework for policy: (1. The state's approach to innovation can be categorized as "mission oriented" or "diffusion oriented" (Ergas 1987) based on how much the state focuses on radical or disruptive innovations needed to meet a clearly defined goal versus facilitating incremental adaptation. Mission-oriented innovation describes a policy approach where the state actively sets the direction of

[1] In SAGD, a pair of horizontal wells is drilled and steam is pumped into the upper well. The steam heats the bitumen which flows by gravity into the lower well where it is produced.

innovation, going beyond activities such as de-risking or addressing market barriers. The state identifies and articulates a concrete goal, the "mission", and directly supports development of the breakthrough innovations needed to meet the challenge. This is in contrast to diffusion-oriented innovation where the state facilitates ongoing and incremental innovation; for example, by providing broad support across a set of prioritized sectors, but without articulating a specific goal.

Previous case studies illustrate the role of mission-oriented innovation policy across a number of sectors including agriculture, biomedical, defence and space (Foray et al. 2012; Mowery 2012; Sampat 2012; Wright 2012; Robinson and Mazzucato 2019). These examples are characterized by the state's definition of a specific goal that is supported through targeted innovation policy. This paper adds to the body of mission-oriented innovation case studies with an example that is particularly relevant for Alberta.

Previous work on the development of the oilsands includes the industry's history in *Developing Alberta's Oil Sands (*Chastko 2004). Chastko's comprehensive history begins with the first development efforts in the early 1900s, continues through the 2000s, and examines the oilsands through the lens of economic, political and business developments. The role of the Alberta Oil Sands Technology and Research Authority (AOSTRA) is mentioned but not explored in detail within the broader story.

There has been an examination of government's role, through AOSTRA, in establishing the SAGD technology (Patton et al. 2006; Hester and Lawrence 2010; Turner 2017). These case studies explore AOSTRA's structure and finances, the projects undertaken, and the general response from industry. In addition, Hester and Lawrence propose a set of first principles for public-private alliances.

The literature has also explored the unique IP ownership structure AOSTRA uses. In contrast to the approach taken in many other government and industry partnerships, the government organization—rather than the companies participating in pilots—retained the IP resulting from innovation. Instead, a company's investment in a pilot gave it access to the IP for its own use, and AOSTRA took on the role of licensing and distributing the IP (Hester and Lawrence 2010; Tretter 2019).

This paper builds on this previous work on the development of the Alberta oilsands and the AOSTRA case studies. I explore in greater detail government's role in developing the technology, while placing it within the broader industry context and mission-oriented innovation framework. I examine the government's decision to invest in this industry development within the broader economic and industrial context at the time and the ongoing tension about the decision to pursue in situ oilsands innovation as opposed to other innovation goals.

I show how the Alberta government, through AOSTRA, was instrumental in developing the key technology for in situ oilsands production and creation of the industry, and how that role was later obscured.

In this original research contribution, I rely heavily on original archival documents from the Glenbow Archives, the Provincial Archives of Alberta, original AOSTRA reports and reviews, and the interviews conducted in the Oil Sands Oral History Project, supplemented by additional interviews.

I identify key elements that made AOSTRA successful, providing valuable lessons for future industrial policy design in Alberta:

1. The importance of defining a goal that is clear but not overly prescriptive. As disruptive innovations are by definition uncertain at the outset, it was necessary to have a target against which success could be measured, while allowing the organization freedom to shape its activities.

2. The long-term value of disruptive innovation. The government's investment was focused on the new technologies required to meet a disruptive goal rather than more incremental improvements that many preferred in the near term.

3. The need to select a goal that matches the scale of public funding, infrastructure and human capital available in the province. This approach ensured that the technology could be proven out and supported through scale-up with the resources available.

4. The importance of strong political leadership and willingness to take on and support a long-term challenge at arm's length. Political leaders articulated a clear vision in the face of pressure to support other priorities, and supported the vision with significant funding while accepting failures. However, the political leaders did not directly intervene, giving AOSTRA freedom to pursue the most promising paths.

5. The importance of a technically competent organization that can partner in joint ventures as well as make sole investments. A high degree of independent technical expertise enabled AOSTRA to function as a true partner in research and innovation. It worked with industry, but also maintained a degree of independence, which enabled unpopular decisions in the face of industry pressure.

6. The need for mechanisms to enable knowledge diffusion and recover the value of the knowledge created. In AOSTRA's case, the government enabled knowledge diffusion and some value recovery by retaining IP ownership. However, significant value was recovered through public ownership of the oil resource. Future public investments could use public IP ownership and direct investment to capture public benefits from breakthrough innovation.

The paper is organized as follows: I start with a chronological case study of the development of the oilsands and associated policy. I include the shifting attitude of both the conventional oil industry and the Alberta government toward the oilsands prior to development and the reasons for the shift. Then, I review the elements that led to identification of in situ recovery as a goal and how that goal was framed and justified at the time. I explore the steps AOSTRA took that led to the successful test of the SAGD technology, and more generally, what was required to take SAGD from idea to a fully commercialized technology. I evaluate how SAGD development was viewed as diversification. Finally, I summarize the lessons that can be learned from AOSTRA's success and discuss the implications for economic development policy in Alberta today.

CASE STUDY—EVOLUTION OF THE OILSANDS AND INDUSTRIAL POLICY IN ALBERTA

The oilsands as a threat to the dominant conventional oil industry

Prior to the oilsands' development, the "oil industry" in Alberta referred to the industry involved in the production of conventional oil. Imperial's discovery of oil at Leduc in 1947 started "the real oil boom that a generation of Albertans had dreamed of" (Breen 1992, 245-46). The sector was a major driver for the Alberta economy: "Supercharged by the influx of petroleum revenues, royalties, and associated taxes, with more oil and gas sources coming on stream, the future seemed limitless" (Chastko 2004, 79). However, the growth created a state of crisis for the industry, which by 1951 saw half of its productive capacity shut in, due to a supply glut and limited transportation options (Chastko 2004, 79).

As a result, the oil industry was subject to pro-rationing, restricting individual projects to producing only a small portion of their total capacity. The policy effectively prevented any oilsands development, as any production facility would be uneconomic if built to operate at reduced capacity.[2] More generally, in this difficult environment the oilsands was seen as an "other" and as a potential threat to the conventional oil incumbency with an inherent conflict between the interests of the two groups (Hester and Lawrence 2010). The view was that each incremental barrel of production from the oilsands would displace conventional production, with similar challenges in the competition for capital and labour. As a result, the incumbent oil industry in Alberta largely supported the government policy preventing oilsands development, with conventional producers positioning the oilsands as an expensive and risky alternative (Chastko 2004).

Government policy shifted slightly in 1962, moving from a pro-rationing system to one that limited the total amount of oilsands production in the province, to allow for construction of the first commercial-scale oilsands facility, the Great Canadian Oil Sands Project (GCOS). While a single facility was allowed to go forward, the government's policy still reflected the fact that the oilsands was seen as a threat to the conventional oil industry, and it limited overall oilsands production while deferring to conventional production. Former premier Ernest Manning's Oil Sands Development Policy (Government of Alberta 1962) stated:

> *(a) initial development be restricted to a volume in the order of five per cent of the total market for Alberta crude oil and (b) for subsequent development be restricted to ensure that 'market growth enables the conventional industry to produce at a greater proportion of its productive capacity'.*

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2 Oilsands projects are more similar to mining projects in that they require high levels of capital investment, have higher fixed costs and benefit more from economies of scale, as compared to conventional oil production.

Tensions continued to flare between the conventional producers and those in the oilsands with members at the Calgary Petroleum Club trying to get an "oil miner", as the oilsands developers were then referred to, thrown out of the club in the 1960s (Maciej 2011).

The Conservation Board, the government entity responsible for approving new oilsands facilities, followed the advice of the conventional industry in its review of additional oilsands projects. For example, the board rejected the Cities Service and Shell application for a new facility—acknowledging the conventional industry's various objections to the projects—because it threatened the conventional industry's market share (Chastko 2004, 114). Even GCOS, which was ultimately found to be in the public interest, faced a delay before the board approved it because of concern around the impact on the conventional industry (Desorcy 2012).

Setting the goal of in situ technology development

Two key events in 1971/1972 began to shift the positioning of both government and industry toward the oilsands: the decline in conventional oil reserves in Alberta and the election of Peter Lougheed to premier with a majority government in 1971, the first government change in 36 years.

Conventional oil reserves began to decline with production outpacing reserve additions in the province for the first time in 1972 (Canadian Petroleum Association 1973). With conventional production expected to decrease on its own, and thus no longer directly threatened by potential oilsands growth, the industry responded by relaxing its opposition to development of the oilsands. The Canadian Petroleum Association's (CPA) oilsands development policy committee met to review the forecast for supply and demand of Canadian crude from 1971 through 1980 and concluded: "The Committee agreed that the C.P.A. submission to the province should incorporate a request for release of all restrictions on further oil sands development" (Canadian Petroleum Association 1972).

While the threat that development posed to the conventional industry was mitigated through decline in conventional production and direct opposition also mitigated as a result, the conventional oil industry did not see direct government investment in in situ innovation as a top priority. The CPA's position on government support for oilsands development was that the government should focus on the royalty rate as the most important lever for it to unlock development of the resource. As the association stated in its submission to the government: "In the matter of the oil sands development policy … the most effective method of encouraging further development now available to the province, in the opinion of the association, is the establishment of a realistic royalty rate on bitumen" (Canadian Petroleum Association 1971).

The industry's view on government's appropriate role in innovation was one of only a third-party co-ordinator and arm's-length funder. In a letter to Lougheed, then-chairman of the Energy Resources Conservation Board, George Govier (1972) cautioned that "industry is extremely wary of joining programs involving the Government." The CPA echoed this view: "The government should encourage the elimination of costly duplication of research efforts through financial support by the Government of joint industry research or by royalty reduction to research program participants" (Canadian Petroleum Association 1971).

Instead, the industry preferred that government innovation focus on increasing recovery from conventional wells through enhanced oil recovery (EOR) technology. EOR, or tertiary recovery, describes a set of methods that can be used to increase the recovery of oil from a reservoir beyond what can be recovered through natural or artificial pressure (primary recovery), or injection of water and gas (secondary recovery) to displace the oil. Through thermal recovery, gas or chemical injection, EOR produces more of the original oil from the reservoir.

EOR is an innovation that was closer to the incumbents' business concerns, offering an incremental improvement to current production. It was more limited in scope in its ultimate potential impact, but had more ability to increase profits in the short term. Some work on EOR, though modest in scale, was underway. The Petroleum Recovery Institute (PRI) was originally formed in 1966 as a joint effort between the industry and the Alberta government with the goal of increasing oil recovery from conventional reserves.

Estimates showed that an increase in recovery of one percentage point from conventional oil wells in Canada would "represent 350 million barrels and would be equivalent to finding an oil field containing three times this amount, i.e. over 1 billion barrels, which is equivalent to a major discovery" (Petroleum Recovery Institute 1980).

Comments by Opposition MLA James Henderson in the legislature on May 9, 1974 later reflected this preference for government research investment in EOR: "So if the minister wants breakthroughs he had better concentrate on conventional oil recovery because there is a tremendous base to build on and he can squander the whole provincial budget on it" (Alberta Legislative Assembly 1974). This is also in line with the recollection of the industry preference for EOR funding among those in the innovation space at the time.[3]

Though significant in scale for the conventional industry, this potential was much smaller than the province's total in situ resource potential. Improvement in conventional oil recovery could provide significant benefit in the near term but was fundamentally limited by the number of discovered reserves—making it a technology capable of providing only incremental improvement.

This desire for a focus on more incremental improvements that deliver results in the near term with clear benefits is the typical preference of an incumbent industry in technology development (Narula 2002; Christopherson and Clark 2007, chap. 6)using a systems of innovation (SI. In expressing a desire for innovation in EOR over in situ recovery, the oil industry was following this typical preference.

Instead, Lougheed put forward a clear vision for economic development in the province—to increase government revenues from conventional production and use the funds to develop the technology necessary to unlock the in situ oilsands resource. Government

3 Eddy Isaacs (former CEO of Alberta Innovates—Energy & Environment Solutions), interview with author, Nov. 22, 2018.

would set the direction of disruptive innovation but with the necessary funds coming from the incumbent industry.

Lougheed explained that the expected decline in revenue from conventional crude necessitated such action. David Redford (2013), an oilsands researcher with AOSTRA, recalled that Lougheed's explanation drew the connection between the revenue that came from conventional production and the potential in unlocking the in situ resource:

> *Look, we've got all of this money coming in from conventional crude. We have all royalties coming in and land sales coming in from conventional crude. But, it's limited. It's going to start going down. We have this huge resource out there. Everyone knows how much is there because of the work of the Alberta Research Council. We know that we have one of the largest hydro-carbon resources in the world, if not the largest. But, it's all in-place reserves. It's not proven reserves. We don't know how to produce the in-situ material and that's the largest part of it … So, he said, 'Why don't we take some of this revenue that we've got coming in from the royalties and invest it in the development of the technology which will make the in-situ recovery possible and make the mine material economic'."*

Government's first step in implementing this plan was to dramatically increase the royalties on conventional production with very limited consultation with industry (Chastko 2004, 155). Lougheed clearly understood the resistance to his plan, telling the CPA in a 1972 speech in Calgary that he "recognize[s] that my job is not a popularity contest … that some of the remarks that I make I know in talking to many of you may not be fully met with favour and complete and positive response."Lougheed was positioning himself as "no buddy of Big Oil"—at the time, meaning the conventional industry (Hester and Lawrence 2010). However, it is notable that Lougheed may have had some connection with the oilsands industry through his close ties with the Mannix construction company. Lougheed was first hired as an assistant secretary and legal assistant at the Mannix company, quickly becoming vice-president of administration (Wood 1985, 35). Mannix construction interests had ties to the oilsands dating back to the beginning of commercial operations; for example, receiving contracts for overburden stripping in the Great Canadian Oil Sands mine (Wood 1985, 112).

On the conventional oil industry's future in the province, Lougheed didn't shy away from a difficult truth, telling the Calgary Chamber of Commerce and conventional oil industry leaders in a speech (1974a) that: "Basic facts simply cannot be ignored. The conventional crude oil resources and reserves in Alberta are estimated to last only another twelve years." Lougheed put his vision into action and announced the "Energy Breakthrough" project on Jan. 14, 1974, along with the creation of the Alberta Oil Sands Technology and Research Authority (AOSTRA). Focusing his description of the project on the in situ recovery challenge, the news release stated: "I have charged the Project with the important and major responsibility to achieve as rapidly as possible the breakthrough in research and technology that is essential to guarantee production of that part of Alberta's Oil Sands that cannot be recovered through a surface mining process" (Lougheed 1974b).

Again, he framed the government investment as a response to the decline in conventional crude: "Especially since it now appears that supplies of conventional crude are becoming increasingly more expensive and more difficult to find and develop." Though Lougheed didn't put them forward as part of his vision, a number of other factors, beyond the decline in conventional production, strengthened the case for the Alberta government to move forward on oilsands development. These included (but were not limited to) the additional pressure on conventional production decline from the oil crisis, the perceived threat of foreign influence and ownership in the Canadian resource, and positioning by the federal government to invest significantly more in the oilsands, which threatened continued provincial ownership of the resource (Chastko 2004).

Also of note is the relative modesty in the claims of what AOSTRA would deliver. In responding to Henderson's criticism in the legislature that "if their policy planning is based on technical breakthroughs to get heavy oil out of the ground in situ, (they) have got some sad experience coming," then-minister of Mines and Minerals William Dickie said: "Nobody's going to guarantee that what you're spending dollars on you're going to get results on ...We're prepared to take those steps to see what we can do to encourage these breakthroughs that are going to develop the oil sands" (Alberta Legislative Assembly 1974).

While government moved ahead with support for in situ innovation, there was also a more modest expansion of PRI in 1975—the year after AOSTRA's creation—by the addition of the Applications Division, a group that will "examine the possibilities of applying the latest research findings on improved recovery methods to Canada's oil fields." This funding for EOR could be viewed as a compromise or consolation given to industry. The total funding to PRI in 1979/1980 was $4.3 million with $3.5 million from government ($2.2 million to the applications program and $1.3 million to the research program), $580,000 from industry and $290,000 in contract research (all numbers in 2019 dollars) (Petroleum Recovery Institute 1980). While significant, it was small in comparison to the funding allocated to AOSTRA targeted at in situ recovery.

From the very start of operations, AOSTRA continued to face pushback to its independence; for example, when it moved forward independently to establish regulations and guidelines. The CPA registered disappointment at this move with the task force on AOSTRA funding, reporting to the oilsands and heavy oil committee in the annual report of activities (Canadian Petroleum Association AB Division 1975):

> *Following enactment of The Oil Sands Technology and Research Authority Act in June 1974, the then Minister of Mines and Minerals, Mr. Dickie, stated that industry would have an opportunity to advise and consult with the Authority prior to the establishment of any regulations or funding guidelines. In May of 1975 it became apparent that AOSTRA did not intend to do this, since by that time Regulations had been issued, an information booklet prepared and a funding application form drafted. In addition, guidelines for funding had been prepared and reviewed with Cabinet.*

This independence ultimately would prove to be critical in allowing AOSTRA to eventually move forward on key projects without industry participation.

Proving the SAGD technology

AOSTRA started work on testing in situ extraction methods. Projects were funded in a 50/50 split—up to half of the funding for a given project coming from government, matched by funding from a company or group of companies from the industry. The first 10 years of AOSTRA's operations saw over $311 million ($854 million in 2019 dollars) in government funding spent with only limited successes to show for the investment (AOSTRA 1985). The 10th annual report describes AOSTRA as "continuing to make good progress" but no major breakthroughs in in situ recovery are yet identified (AOSTRA 1985). In fact, the authority was still four years and an additional $369 million (2019 dollars) in government funding away from its first major success (AOSTRA 1989).

By the 1986-1987 fiscal year, the assignment of original capital from the Heritage Savings Trust Fund for AOSTRA had been largely depleted. In spite of the relatively unremarkable results to date, additional capital funding was nonetheless appropriated from the General Revenue Fund, allowing AOSTRA's efforts to continue (AOSTRA 1987). This represented a key funding commitment just prior to the commencement of work on the first test of SAGD (AOSTRA 1988).

Ultimately, AOSTRA's most significant technology innovation was SAGD for the production of in situ resources. The work to prove out SAGD included a number of elements such as construction of an underground test facility (UTF), the drilling of "pseudo" horizontal well pairs[4] for SAGD, a large number of monitoring wells drilled from the surface and geotechnical instrumentation to collect data from the tests (Meyer and Wiggins 1989, 17). The work was planned in a phased approach with a first phase to test the fundamentals of SAGD in horizontal wells and a second to demonstrate the approach over longer wells before moving to a commercial scale test (Petroleos de Venezuela SA 1991, 487-95).

AOSTRA developed detailed project designs and presented them to the industry in 1984 to identify industry partners (Gilbertson 1989). The authority proposed an agreement under which government would cover all initial construction costs, investing the estimated $50 million ($112 million in 2019 dollars) required to construct the UTF on its own. Once built, industry partners could then conduct pilots in collaboration with AOSTRA, with half of the industry partners' pilot funding going retroactively to cover half of the UTF construction costs (AOSTRA 1984). With this proposed funding structure, if the UTF ended up being of little use as a test facility, the cost to industry would be minimal, reducing the risk for industry to participate.

In spite of favourable terms for the cost sharing, however, doubts about the technology, expected recovery rates and the general approach of construction of an UTF, along with economic constraints faced by industry, meant there were no industry partners willing to join the project aside from in unfunded advisory roles. As Gerry Stephenson (2011), one of the UTF developers, recounted in an interview years later:

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4 Horizontal wells drilled directly from the UTF, as opposed to from the surface, which wasn't feasible with the technology at the time.

Very early on in the process, in the early mid-80s, AOSTRA asked most if not all of the major oil companies, and some mid-level companies, to join in the project. And they gave a presentation in Gulf Canada Square … quite a few people came, but the major oil companies didn't send anybody to really influence them as to whether this is a good idea or a bad idea. In fact, from the point of view of having vice presidents there and people in a decision-making situation, the response was very disappointing. And in fact, people in the industry were very negative about what AOSTRA was doing … the initial reaction from industry was, this is ridiculous you don't need to go into underground tunnels to do this.

I remember meeting a very senior guy from Shell on the airbus when I was going up. We were constructing the UTF at that time, and I sat beside him, we introduced each other, and he said: "Oh you're one of the buggers that are wasting the taxpayers' money on this silly underground idea?" And he said, well you know, the gist of the conversation was why on earth would the oil industry go into a dirty, old, dangerous, underground mine to do this?

With the failure to recruit any industry funding partners, AOSTRA's leadership broke with the rules—that all projects must have at least a 50-per-cent industry contribution—and made the critical decision to proceed with constructing the UTF and testing of SAGD as a government-led project without any industry matching funds. Commenting on the decision years later, Harbir Chhina (2011) noted:

When I look back, I think there was one moment that changed our business significantly, and that was back in about 1985 … and then AOSTRA decided … testing out SAGD at UTF was the thing to do, that this would be a game changer. So they invited, I believe, any oil company that would come and listen to them from North America. And I remember that meeting well with all these oil companies and we were trying to explain the SAGD, how it was going to work. And at the end of the meeting there wasn't one company that believed SAGD would work. Nobody was willing to fund it.

So that's where, because nobody was interested, I believe Maurice Carrigy made the gutsiest call in our industry … and he made the decision to fund it a hundred percent.

With this decision, construction went ahead as planned on phase A with field work beginning in November 1984 (AOSTRA 1987). The industry's skepticism didn't go away as UTF work moved forward. Richard Luhning (2012) recalled: "There was a lot of negative feedback from industry about the Underground Test Facility, and why you're down there and what are you actually doing down there." In situ process testing started in 1987 and early results dramatically exceeded the expectations for oil recovery. In 1985, AOSTRA had funded 10 groups, a mix of oil companies and consulting companies, to estimate how much oil recovery would happen in the UTF from SAGD, with estimates falling mostly in the range of 15- to 20 per cent. Once constructed, phase A of SAGD testing saw recovery levels over 90 per cent in the two central wells with the results generally far surpassing the estimates (Dusseault 2011).

Despite the early success in phase A, there was still pressure on AOSTRA to demonstrate industry participation in the project to satisfy the mandate of a 50/50 split in government and industry spending. By this time, the government had made a solo investment of over $115 million (2019 dollars) in the UTF construction and SAGD testing (AOSTRA 1988). AOSTRA addressed this concern by allowing six companies to retroactively buy into phase A, the UTF lease and the SAGD technology, at a reduced price—allowing the organization to have the record reflect that it had met its mandate for collaboration though the effort was in fact government-funded (AOSTRA 1992). The reduction in price for the retroactive buy-in was substantial—the original project proposal that reflected actual costs offered industry participants only a one-per-cent interest for each $2 million contributed, in line with project costs (AOSTRA 1984). As Chhina (2011) recounted:

> *And so we were building it and … all this money had been spent and so there was still pressure that we didn't live up to our mandate of the fifty percent, so at that time AOSTRA offered the companies, at a very low price, I think it was like a million, million and a half bucks for like a sixteen percent interest so they get six to eight companies to join at that time for a nominal price.*

Once SAGD was proven in phase A, an additional seven industry participants joined for phase B with construction starting in 1990 (AOSTRA 1991). Phase B testing proved similarly successful, showing significant oil recovery rates on commercial-scale wells as well as generating additional data about the operation of SAGD that would prove invaluable for future SAGD design and operation.

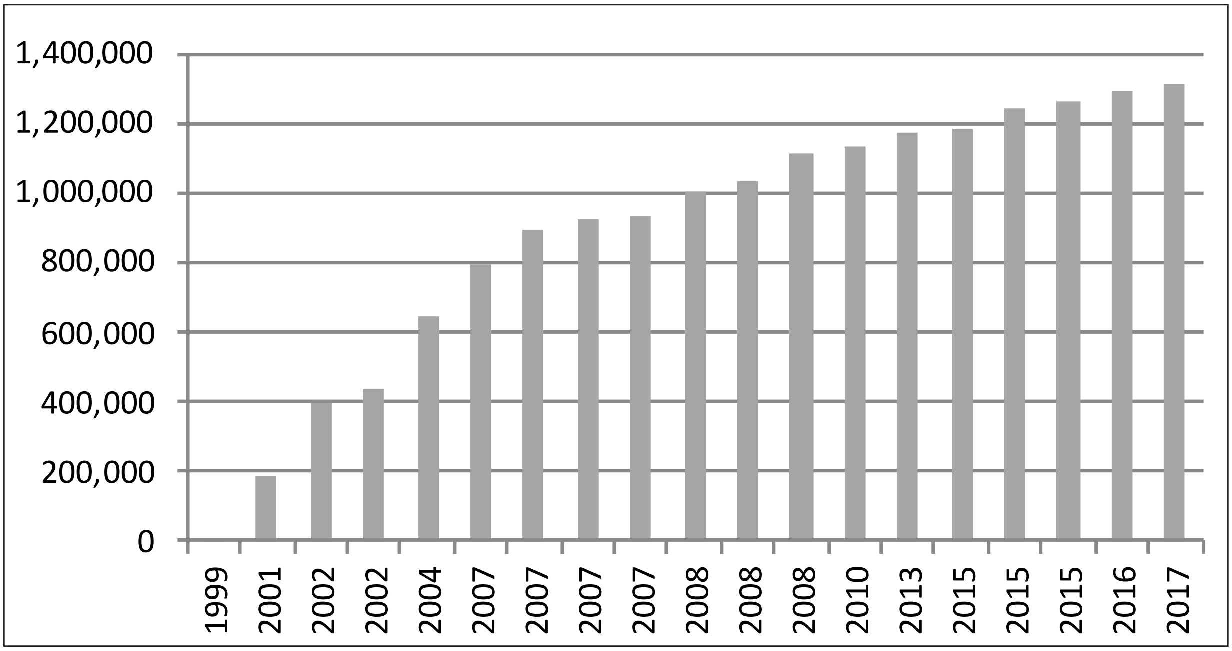
Recounting the experimentation that went on in UTF, the value of the data that were generated and how they were used in later periods of SAGD development, Simon Gittins (n.d.) noted:

> *There was a lot of experimentation. There were three wells pairs, but there were dozens of vertical observation wells put in to measure movement of the ground. The full geomechanical effects that are a unique data set. To date, no one has ever gone back and done anything like that. So, we still refer back to a lot of that—a lot of the papers that came out of the U of A. One of the main reasons they did it was because of the mine. There was a lot of concern that by heating up the ground with this mine only 15 metres below while you were doing it, you would have thermal expansion. You would have lots of geomechanical effects. So, there were concerns about the integrity of the mine.*
>
> *They put in a lot of wells, a lot of measurements to actually measure the movement of the earth and the stresses and strains that were being caused. So, it is a fantastic set of data that will never be repeated. I learned a lot as well. A lot of things that did not go exactly as expected. It turned out the mine was fine. But, there was a lot of movement in the ground. We're sort of seeing it today, we see sort of surface heave and lots of things. Well failures are fairly common due to these geomechanical effects that we still refer back to our original data set to find what has happened.*

Scale-up of SAGD/development of the industry

While planning for the UTF began in 1982 (AOSTRA 1989), it wasn't until almost 2000 that the first commercial-scale plant came online, with true scale-up in production following later (Figure 1).

FIGURE 1. CUMULATIVE IN SITU SAGD CAPACITY



Source: Oil Sands Magazine 2019Once SAGD had been fully proven, the industry embraced the technology. At this point, the bulk of government support moved from direct technology investments to financial support. This took the form of significant royalty discounts for oilsands projects during the pre-payout period, i.e., before its revenues exceeded the cumulative costs (Government of Alberta n.d.) and favourable regulatory regimes (Steward 2017). As the oilsands industry grew under these favourable terms, it eclipsed the conventional industry which saw a reversal that made it harder to attract investment to EOR.

Many of the industry leaders responsible for the scale-up of SAGD came from AOSTRA or associated training programs (Dusseault 2011). This training of the industry leaders represented another key output of AOSTRA.

SAGD as entrepreneurial innovation

In order to evaluate AOSTRA's role in the development of SAGD, we have to consider how value is created through innovation. Rather than simply an idea, it is the transition of ideas into knowledge that represents real value and innovation. Entrepreneurial innovation includes the initial idea, as the first step in an iterative process, but also the research and development along with prototype/pre-market implementation (Shearmur 2015).

While the concept itself of SAGD existed prior to AOSTRA, with, for example, Roger Butler patenting a gravity drainage approach in 1969 (Government of Alberta 2019b), it would be incorrect to consider the innovation of SAGD for in situ resource recovery completed before the demonstration in the UTF. Rather, SAGD was just one of many ideas that had been proposed for in situ production. Until significant funds were invested in testing, it did not represent a solution. The existence of a patent is a notoriously weak measure of its ultimate usefulness, with the vast majority of patents issued never used (Shepherd 1979, 400). The patent itself only becomes useful once investment is made to prove out the idea. Other ideas being considered and patented at the time ran the gamut from those still in consideration and testing today to wild plans that were ultimately abandoned, including detonation of a nuclear bomb to liquefy the oilsands (Government of Alberta 2019c).

The general idea of gravity drainage along with the underground access of in situ resources interested the industry for over a century with tests and trials conducted as early as the 1860s in Ohio and California. There was active production in France and Germany in the 1920s (Meyer and Wiggins 1989, 5) and in Russia in 1937. One of the inspirations cited for the UTF was a 1976 visit by a delegation of Canadians to a mine in Yarega, Russia (Duncan 2013; Turner 2017).

Prior to the successful testing of SAGD, the idea had little support across the industry in Alberta. A description of the general view of SAGD at the time shows the widespread doubt about its viability; these doubts were also reflected in AOSTRA's inability to find industry partners for any tests. Speaking about Butler, Maurice Dusseault (2011) recalled:

> *I guess I had met Roger back in the early 1980's, back in '81, '82 when he was just trying to get his SAGD concept off the ground and of course, as you know, he couldn't get it off the ground at Imperial Oil and he went to the Alberta Oil Sands Technology and Oil Sands Authority and they decided to go with it, but they couldn't get industry interested in this idea because industry generally had the concept that it was a pretty silly idea.*

Neil Edmunds (2013) recounted the reaction to Butler's talk at a conference in Fort McMurray as "not invented here" recalling that "most people thought he was a crackpot." SAGD itself saw false starts that may have further contributed to the doubts about its viability. An early approach in testing SAGD by AOSTRA and Gulf on the Surmount Project failed due to the use of high-pressure steam in an attempt to fracture the oilsands (Stephenson 2011). In addition, previous tests of a variation with a vertical steam-injection well by Imperial at a Cold Lake pilot showed disappointing results compared to other technologies Imperial was using in the region (Government of Alberta 2019b). Early AOSTRA and industry collaborative work on the mine-assisted in situ process, which looked at adapting the Russian experience with thermal mining to the resource in Alberta, did not lead to any active industry interest in an underground test (Meyer and Wiggins 1989, 5).

Hardly unusual or specific to the oilsands or oil industry, such skepticism about unproven new technology and the challenge in securing the funding needed to demonstrate success are common barriers to new technology development. This proves most challenging in capital-intensive industries because of the large investment needed for full-scale pilots to prove technologies, making them ill-suited for solutions such as venture capital. In many cases, even the challenges or problems with the technology are not really known until you start testing, making the process of innovation even more challenging and costly, as two AOSTRA participants reflected:

> *These oil sands projects, in-situ and mining alike had initial technical challenges but they were based on limited knowledge as to what the real technical problems were. You had to be into them to find out what they were. I mean there were tremendous challenges … And, think of the changes that occurred after the initial projects were in place. And, tens of millions of dollars spent on them, they had to be re-worked because they just weren't understood (Desorcy 2012).*
>
> *One of the biggest misconceptions is that this is easy; SAGD is an easy process. In theory it is very easy. We can describe it with a single equation, which works and we still use that equation all the time. But, the complexities of doing SAGD in reality, the actual application of the technology is not easy. It is very, very hard.*
>
> *Obviously, we look at the reservoir like it's a simple box of sand, but generally it is not. Generally, it's much more complicated than that (Gittins n.d.).*

One of the additional challenges in gathering support for SAGD was the need for a number of other innovative technologies to be developed alongside in order for it to be commercially viable, including horizontal drilling and measurement while drilling. AOSTRA worked to address these technology gaps (Fair 2013) and created a significant amount of new technology and techniques in both mining and drilling (Meyer and Wiggins 1989, 7-14). The commercialization of SAGD benefited, for example, from U.S. government work on horizontal drilling innovation (Trembath et al. 2012).

In situ oilsands as economic development and diversification

While the promise of in situ oilsands production was clearly a case of disruptive innovation and an economic development opportunity, there is good evidence that it was seen credibly as diversification. Viewed through a present-day lens, the idea of diversification through in situ resource development is questionable; however, in the early 1970s there was some logic to such a view. Accessing the in situ resource required a completely new technology and approach—ultimately growing different sectors of the economy. Success would provide access to a significant new resource base that could be produced to meet an unquestionably growing demand for oil, in the face of an expectation for a peak in global oil production. The resource was relatively unique to Alberta and the province could not rely on innovation in other jurisdictions. Unlike in the case of EOR, the technology for in situ recovery would have to be developed in Alberta.

At the same time, the oilsands were not seen as part of the oil industry of the day. The oilsands were often referred to as "alternative energy" or an "alternative fuel" to the conventional oil industry (Isaacs 2011). This characterization can be found, for example, in a conference report (Geological Association of Canada 1974), supporting the idea that the oilsands were seen as a separate industry.

Allan Warrack, minister of Lands and Forests in the Lougheed government, confirms that oilsands development was viewed as diversification. He stated in an interview (2013) that, “our perspective at that time was that a fuller development of the oilsands would be economic diversification, because at that time, of course, there was crude oil and natural gas that was very prevalent … But particularly seeing the development of the oilsands as economic diversification, looking back from today it seems like the dominant activity, but it wasn’t at that time.”

As late as 1979, governments in most countries did not ask for data on oilsands occurrence and reserves and did not collect data on the production of heavy crude. Even the American Petroleum Institute in the United States did not compile statistics on heavy crude and oil from oilsands (Meyer and Steele 1981, chap. 1), all reflecting the fact that these resources were not viewed in the same way as the conventional oil industry of the day.

The fact that this view is questionable now is an example of the resource-making process by which the practical technological advances that enable the unconventional resource to be extracted are accompanied by a set of political and economic practices through which the resource becomes seen as mainstream (Ferry and Limbert 2008; Richardson and Weszkalnys 2014; Kama 2019). But this change in the way the resource is now seen today, and the fact that increased oilsands production would no longer be seen as diversification, does not invalidate the assessment of the original investment in innovation through AOSTRA as one targeting diversification.

Implications for future policy design in Alberta

With renewed pressure for diversification and economic growth in Alberta, there is a need to examine the role for government in industrial policy and what form potential support should take. A wide range of views are represented in the debate with some advocating for only indirect measures such as tax reductions, while others push for direct public investment in economic restructuring. Many sit along the spectrum in between; for example, supporting public investment but targeting only specific market failures or following industry-defined priorities.

A detailed review of the case for or against such industrial policy is beyond the scope of this paper. Rather, AOSTRA’s success which I present here can contribute to the debate in two ways, First, it demonstrates that it is possible for direct public investment to unlock economic growth through disruptive innovation and diversification, and that this is in fact how Alberta successfully responded to the last period of serious threat to the province’s long-term economic prosperity. Second, it provides lessons on how the design of such an investment can contribute to its success.

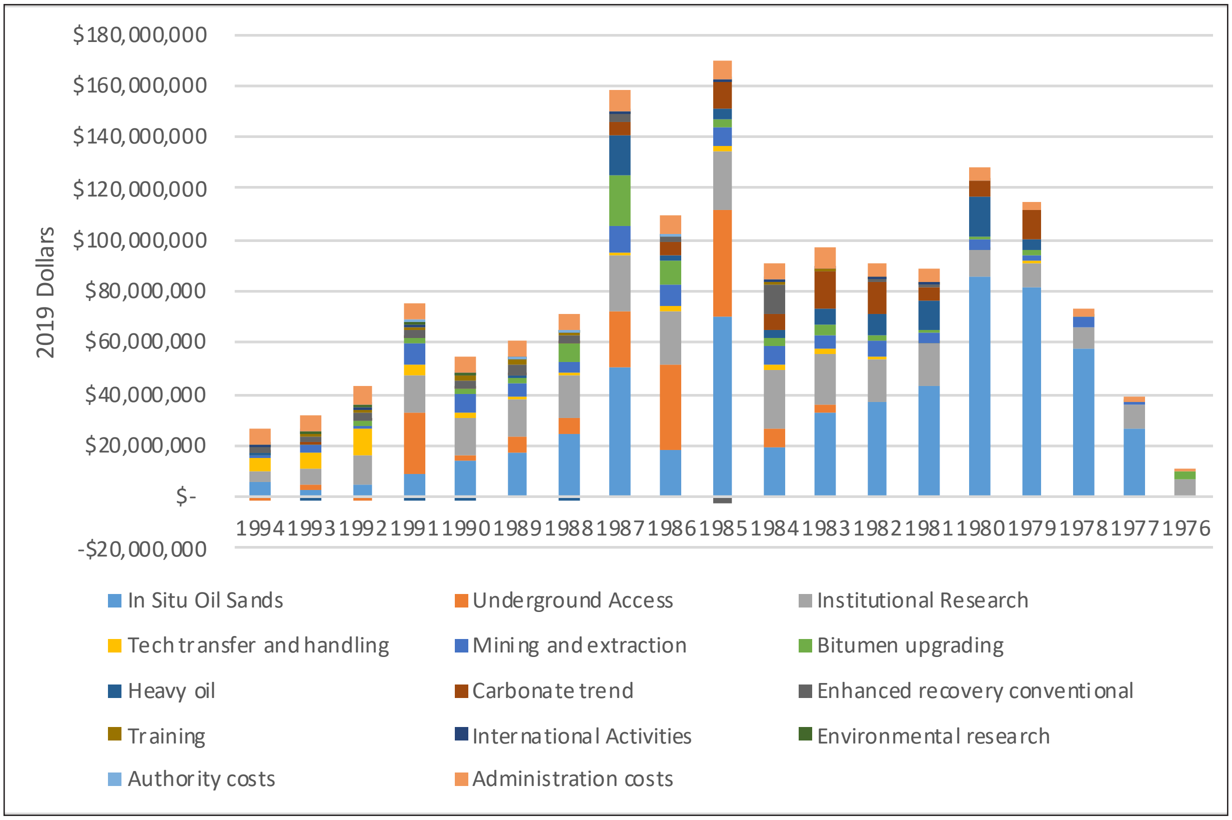
The example of public investment unlocking economic growth

Government’s role is clear in the detailed history of the development of SAGD through AOSTRA, including in both the decision to pursue in situ recovery and the critical government-led investment in construction of the UTF and testing of SAGD. While the model of joint industry and government investment was followed for a significant fraction of investments, the averages hide the true story as the most impactful AOSTRA project was in fact purely a government investment (AOSTRA 1988).

Moreover, from today's perspective, it is tempting to view the investment through AOSTRA as simply growing an existing industry i.e., an incremental innovation or improvement. In fact, the oilsands started not only as a disruptive innovation with diversification potential, but as a direct threat to the conventional oil industry. While the threat was diminished with the increased demand for oil and decrease in conventional production, there was no existing in situ industry and in situ technology remained a truly disruptive innovation. One of the most promising incremental innovation opportunities available at the time—enhanced oil recovery from conventional oil reservoirs did receive some funding increase, but on a much more limited scale. AOSTRA was created not as a direct response to the industry's wishes but rather in the face of its opposition.

The total government investment in AOSTRA was significant with the bulk of the funding going to the in situ and the associated underground access work (Figure 2). Administration costs were funded in addition directly by the General Revenue Fund and amounted to seven per cent of total costs over the operation of AOSTRA.

FIGURE 2. AOSTRA EXPENDITURES 1976 TO 1994[5]



Source: AOSTRA 1977, 1982, 1987, 1992,1994.

5 Negative expenditures represent sales from project production from heavy oil projects, sale of bitumen from the underground test facility and participants' contributions to that facility.

Ultimately, government's ability to have a specific goal for the research and development agenda, as well as the direct investment in the UTF, both proved critical to achieving the resulting industry development and economic growth.

Future work could include a NPV cost-benefit test, comparing the public investment in AOSTRA and associated academic/training and infrastructure to the public benefits in the form of resource rents and public value of the domestic capital returns and employment. Such an analysis could evaluate the decision to pursue in situ development in terms of the social and private discount rates at the time of the decision.

Lessons from AOSTRA's design for future policy

Rodrik (2004) in "Industrial Policy for the Twenty-First Century" focuses on the need for industrial policy to balance two competing goals; namely, ensuring that (a) the public sector is not acting in a vacuum, and (b) the research funding does not end up captured by industry. Rather than measure industrial policy against the impossible and suboptimal goal of no failures or mistakes—which would result in no self-discovery—he proposes that the objective should be to minimize the cost of mistakes when they do occur.

The decision to pursue in situ technology development, along with the design and implementation of AOSTRA helped it to deliver on these objectives, and provides a valuable case study for future industrial policy design in Alberta. Key elements include:

1. A clear, but not overly prescriptive, goal.

   The foreword to AOSTRA's annual reports describes the clear mission that was set for AOSTRA:

   In creating the Oil Sands Technology and Research Authority, Premier Lougheed stated that a major responsibility of the authority is to develop the technology needed to establish a commercial in-situ method of oil sands recovery in Alberta at the earliest possible date (AOSTRA 1985).As a champion for the project, Lougheed took an active role in hiring AOSTRA's leadership, interviewing the first AOSTRA lead, Clem Bowman, (Isaacs 2011) but leaving the approach up to the leader he hand-picked.

   This formulation of the responsibility provides a clear target for the organization while respecting the fact that by definition, disruptive innovations start out largely unknown. AOSTRA was free to shape its activities over time. Not restricting the approach allowed for the organization to borrow from other industries; for example, from the mining industry where needed in the UTF approach. The goal also gave a clear target against which to measure success, making it easier to stop pilot projects when they did not show successes and contributing to the aim of minimizing costs.

In considering current policy design, the need to define a clear goal and provide this flexibility is apparent. It is necessary to overcome a tendency to prescribe a specific technology path, thereby closing off potential solutions, or the alternative whereby the goal is too broad and doesn't allow for unsuccessful paths to be stopped. The selection of the goal itself is a challenging question for industrial policy design in Alberta today and is discussed further in lesson 2 below.

2. A disruptive vs. incremental innovation goal, maintained in the face of pressure.

   While AOSTRA did drift, perhaps unavoidably, into funding work on more direct commercial interests (e.g., enhanced oil recovery), the bulk of the funding remained focused on disruptive innovation and new technologies required to access the in situ resource. These disruptive technologies were riskier and further from the commercial interests, and industry was therefore less likely to pursue them.

   Technology to access the in situ resource may be viewed today as an obvious choice because of the existence of the significant resource and the uniqueness that meant a solution was unlikely to come from another jurisdiction. That didn't mean it was embraced at the time, as seen in the pushback to AOSTRA. One might expect similar pushback to a goal that is selected today.

   Similarly, in understanding what the goal for AOSTRA was, it is important to consider it in the context of the view of the in situ resource at the time, which had yet to go through the resource-making process. Part of the pushback could be traced to the fact that the resource was not viewed as a resource as it is today.

   Defining the goal today will require a more sophisticated consideration of the province's potential competitive advantages. But the properties of the right goal are clear—it must be sufficiently far from direct commercial interests (i.e., disruptive as opposed to incremental), and enable economic development into a significant (and growing) market. The experience from AOSTRA shows that a goal with the potential to be successful may not be widely embraced.

3. A goal that matched the scale of resources available in Alberta.

   While significant, the scale of the government investment and matching industry funds required to prove the technology on a commercial basis was still reasonable on the scale of public funding, infrastructure and human capital available in the province. Once proven, additional funding could be attracted for industry development. If, however, the technology had required significantly more funding to prove and scale, there is a real risk it would have not been successful, with funding being fully expended before important breakthroughs were made. In such a case, even significant funding committed could have resulted in limited success.

   The oilsands example also illustrates the importance of continued support for new technologies through commercialization, as there was significant additional support for the ultimate scale-up of the industry following the technical breakthrough. This support, for example, in the form of favourable royalty structures, other subsidies and tax reductions, is beyond the scope of this paper. However, it is important to note that while the role of government support shifted form, it did not stop after the initial innovation work via AOSTRA; this continued support was critical in the growth. A very co-ordinated model of continued support for breakthrough technologies—connected R&D—is practised for example by the U.S. Defence Advanced Research Projects Agency (DARPA) (Bonvillian 2009).

In considering goals, policy-makers should realistically estimate the costs required from R&D through commercialization and compare these to the scale of resources available within a region. Goals that require significantly larger scales of funding than available could be pursued jointly with other jurisdictions. However, strong partnerships would be required to ensure that programs would be sufficiently robust to deliver results.

Strong political leadership and willingness to take on a long-term challenge.

AOSTRA's success required a clear vision for the effort in the face of pressure for other priorities, long-term sustained investment at a significant level and acceptance of a certain level of failure.

The commitment from the highest political level to a long-term project was made clear in the initial investment, the framing of the challenge and the premier's involvement in hiring decisions. The commitment was further reinforced when AOSTRA requested and received more funding multiple times. AOSTRA was initially well capitalized with a budget of $100 million ($540 million in 2019 dollars), an amount equivalent to over three per cent of the whole government of Alberta's budget at the time (Lougheed 1974b; Government of Canada n.d.). Only a year after starting, when the authority had identified a number of projects it considered promising, it was able to have an additional $132 million ($636 million in 2019 dollars) in funding approved without delay (Hester and Lawrence 2010).

There was a willingness to allow for the necessary mistakes to happen with a commitment of funding, even when the 10-year report had only limited progress to show for the more than $854 million (2019 dollars) in government investment to date. Ultimately, AOSTRA would invest over $1.4 billion (2019 dollars) in public money from 1975-1994 (AOSTRA 1977, 1982, 1987, 1992, 1994).

Importantly, this strong political leadership was not in the form of significant direct involvement in AOSTRA beyond the initial hiring decisions and goal setting. This freedom allowed the organization's decisions to be driven by technical expertise, free from political considerations. It also enabled AOSTRA to take more risks, including the decision to move forward with the UTF. This requires a significant amount of trust in the organization's leadership.

The government's longevity likely made this sustained commitment more easily achievable. A similar effort today may require building broader coalitions of support that can withstand more frequent changes in government. Experience from organizations like the National Institutes of Health show it is possible to maintain a high level of bipartisan political support (Sampat 2012).

4. A technically competent organization with freedom to partner and make sole investments.

   Unlike most funding agencies today, AOSTRA functioned as a true partner in research and innovation with industry. The authority could enter into projects as a joint venture, rather than simply being a fund provider, and could partner either with projects brought to it by industry partners or those it brought to industry. The government had retained leases in Athabasca where AOSTRA could do its own experiments.

   This was made possible by the high level of technical expertise of junior and senior staff along with an experienced and highly competent technical board.

   As a result, AOSTRA could both work with industry—i.e., not in a vacuum—but also maintain an independence from industry to evaluate ideas, which allowed it to make the call to do UTF. Similar examples can be seen in other cases. For example, the talent of the managers and scientific team figured importantly in the success of the grand missions in agricultural innovation (Wright 2012). And the successful track record of innovation at DARPA relies on program managers with technical expertise to manage award selections (Bonvillian and Van Atta 2011).

   Organizational design should reflect the need for this technical competence at all levels, as well as grant the required freedom to use this expertise in making decisions.

5. A clear mechanism for knowledge diffusion and recovery of the value of the knowledge created.

   Much has been written about AOSTRA's approach to IP and the fact the organization retained IP ownership for innovations (Hester and Lawrence 2010; Tretter 2019). By retaining the IP, AOSTRA was able to directly control and encourage the diffusion of knowledge. Unlike a funding organization with no IP control, which at most can require knowledge sharing and diffusion plans as a condition of grants, this direct diffusion doesn't rely on a company to put significant efforts into licensing a technology that might be of direct commercial value. The organization invested significantly in technology management and transfer with almost $40 million (2019 dollars) spent during AOSTRA's operations on activities that ensured that the technology developed could be broadly used (AOSTRA 1977, 1982, 1987, 1992, 1994).

While the original plan of recovering a significant portion of investments in research and development through IP sales fell short of raising the targeted amount, it did generate some funds. Just as importantly, it contributed to AOSTRA's ability to act independently in the case of the UTF and SAGD testing as there was already a clear procedure for the organization to own the resulting IP.

This direct method of IP ownership also has some similarities with the proposals to ensure government retains a venture capital-like investment in innovation (Mazzucato 2016) and serves as an example where industry concerns were addressed and such a structure was set up.

The unique feature of ownership of the resource in the case of the oilsands meant that public investment value could also be recovered through royalty payments in addition to more indirect methods such as taxes on the increased economic activity. This made the direct ownership of the technology ultimately less important. However, future public investments should consider how public benefits from breakthrough innovation can result in public benefits through more direct investment and partial ownership structures.

CONCLUDING THOUGHTS

The experience with AOSTRA and the recognition of government's critical role in economic development through disruptive innovation can inform the current debate over government's role in economic development and diversification. The AOSTRA experience demonstrates how a significant Alberta industry came from a clear case of the government "picking winners", with a number of losers picked and then efficiently discarded along the way. Smart policy design can be used to minimize the cost of "losers" in investment, but it requires a long-term commitment and significant funding. In addition, it is important to design innovation support such that the public investment can be recovered. Government IP ownership or direct investment is a model that should be explored further.

This approach of industrial policy targeting disruptive innovation can be clearly differentiated from public policy and support for incremental innovation, or from non-innovation-based support. The challenges that played out with incremental and non-innovation-focused government support during the same time period in Alberta are well documented (Morton and Meredith 2015)and deservedly so. Prime Minister Pierre Trudeau was a formidable opponent. He was able and willing to use the full arsenal of federal powers to redirect soaring western energy revenues away from Alberta to Ottawa. For those of us in Western Canada, it is unpleasant to imagine what the outcome of this struggle would have been if a lesser man than Peter Lougheed had been at Alberta's helm. But there is another aspect of the Lougheed legacy that is less remembered because it is less celebrated—also deservedly so. These were Lougheed's ambitious economic diversification projects. Between 1973 and 1993 (when Ralph Klein became premier.

One of the biggest challenges to applying this approach is determining the appropriate goal or target for investment, while resisting the pressure to focus on incremental innovations that target more near-term needs and that will fail to deliver significant economic growth. Governments must balance the need to leverage current capabilities in the economy without being pulled away from the diversification mandate.

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About the Author

Sara Hastings-Simon (PhD, University of Geneva) is a research fellow with the Global Research Initiative at the University of Calgary. Her research focuses on low carbon energy transitions and climate and energy policy at the intersection of technology, business and policy.

Dr. Hastings-Simon serves on the Board of directions of Emissions Reduction Alberta

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