RENEWAL AND REINVENTION OF ALBERTA'S HYDROCARBON CLUSTER LEARNING FROM THE PAST

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Smart Prosperity Institute

energyfutureslab

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About Energy Futures Lab

The Energy Futures Lab is an award-winning, multi-stakeholder initiative to accelerate the transition to the energy system that the future requires of us. Initiated in the Fall of 2013, the Energy Futures Lab is powered by The Natural Step Canada, in collaboration with a number of Convening Partners and Funding Partners. The EFL also involves dozens more organizations in an unprecedented series of innovative partnerships and collaborations.

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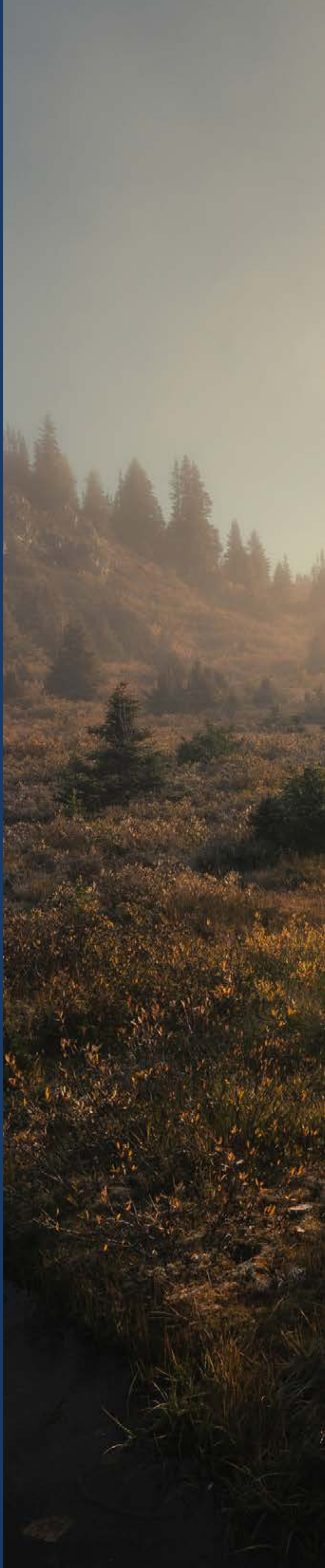
About Smart Prosperity Institute

Smart Prosperity Institute is a national research network and policy think tank based at the University of Ottawa. We deliver world-class research and work with public and private partners – all to advance practical policies and market solutions for a stronger, cleaner economy.



LIST OF ABBREVIATIONS

BAU	Business as usual
BNEF	Bloomberg New Energy Finance
BP	British Petroleum Company
CCUS	Carbon capture, use and storage
CIPO	Canadian Intellectual Property Office
CO2	Carbon dioxide
EOR	Enhanced oil recovery
EU TEG	European Union Expert Group on Sustainable Finance
GDP	Gross Domestic Product
GHG	Greenhouse gas
ICP	Institute for Competitiveness and Prosperity
IEA	International Energy Agency
ISED	Innovation, Science and Economic Development Canada
IISD	International Institute for Sustainable Development
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
REA	Renewable Energy Act
R&D	Research and development

RENEWAL AND REINVENTION OF ALBERTA'S HYDROCARBON CLUSTER

Introduction

As an increasing number of countries commit to net-zero greenhouse gas emissions targets, resource-producing regions and sectors are considering the threats and opportunities associated with ambitious climate action. In alignment with this emerging and important debate, the Energy Future Policy Collaborative is seeking to answer a single guiding question:

> *How might we use public policy to help attract greater investment into the innovation and infrastructure for "future-fit hydrocarbons", in light of global investors' increasing concern with climate change and growing appetite for low-emissions/transition-oriented opportunities?*

The EFPC defines "future-fit hydrocarbons" as economic activities that use existing assets (including infrastructure, workforce skills, and intellectual property) from Alberta's hydrocarbon industry but are competitive in a decarbonizing world.

In answering EFPC's question, it is helpful to look at similar situations from the past to see what lessons can be learned. This involves comparing and contrasting past transitions to determine best practices and important drivers for a successful transition. Currently, the hydrocarbons sector in Alberta can be characterized by the following four stylized facts and trends:

1. There is a regional concentration and a dense network of firms in the Alberta hydrocarbon sector, along with substantial existing infrastructure and soft capital assets (i.e., know-how, relationships, brand value, intellectual property). This regional concentration and dense network meets the Porter (1998) conditions to be considered a cluster.

2. The market for 'traditional' hydrocarbons, along with other goods and services that can be spun off from the current hydrocarbons sector, is expected to be flat, or decline, over the next three decades. This is due to a number of factors, including efforts to reduce greenhouse gas emissions. In terms of the life cycle of clusters, this would meet the definition of a cluster in the *sustainment* phase, entering into a *decline* phase.

3. The market for clean energy is growing rapidly, and the "future-fit hydrocarbons" component of that market can realistically surpass the size of the existing "traditional" hydrocarbons market in the coming decades.

4. The clean energy sector is expected to be highly competitive. Fortunately, the existing infrastructure and soft capital in Alberta give the province a potential competitive advantage if the transition is well managed. According to the cluster life-cycle model, there is a potential for a *renewal* of the cluster.

These four stylized facts and trends provide valuable insights on where we are unlikely to find appropriate policy guidance and answers when analyzing the potential for a regional transition in Alberta. This potential transition would not be driven by a single company facing pressure from a new competitor, nor by resource depletion; Alberta is still abundant with hydrocarbon resources. This provides Alberta with options, unlike a scenario where a dominant industry in a region goes into decline due to heightened international competition, with no obvious industry to replace the lost jobs and prosperity, and no way to utilize the existing infrastructure and soft capital, as has occurred in many 'rust-belt' communities in North America. In Alberta, there is an heir apparent industry in -- future-fit hydrocarbons -- where existing infrastructure and soft capital could be extraordinarily helpful. The policy issue of the day is therefore how to successfully navigate transition from traditional hydrocarbons to future-fit hydrocarbons.

Since the Alberta hydrocarbons industry can be considered a cluster, the literature on the life of clusters allows for a deeper understanding of the economic dynamics and factors that could enable and encourage a successful transition to a future-fit hydrocarbon sector. The life cycle of a cluster involves four main stages: emergence, growth, sustainment, and decline (Menzel & Fornahl, 2009). However, the evolution of a cluster is not a simple linear path, as clusters can develop very differently and go through processes of adaptation, renewal or transformation (Martin & Sunley, 2011; Menzel & Fornahl, 2010).

This paper builds on this literature to examine factors that could allow for the *renewal* of the Alberta hydrocarbons cluster into a future-fit hydrocarbons cluster. The goal of this paper is not to describe the entirety of the life cycle of Alberta's hydrocarbon cluster, but to identify catalytic conditions and factors for the renewal of an the already-mature hydrocarbon sector, which faces threats and opportunities brought by efforts to decrease greenhouse gas emissions.

The structure of the paper is as follows. The first section provides evidence to support the four stylized facts and trends stated above, as well as our argument that these facts pose risks and opportunities to Alberta's hydrocarbon sector. The following section presents the theoretical framework from which the paper draws inspiration to examine the two distinct paths that Alberta's hydrocarbons industry is facing: sustainment followed by decline *or* sustainment followed by renewal and growth into a future-fit hydrocarbons sector. Acknowledging the life cycle of clusters and the vast variety of factors that can drive cluster development and evolution, the paper then explores the literature to identify past *sustainment->renewal->growth* transitions. There are many examples of this occurring successfully, but the few case studies identified in our research provide valuable insights on drivers of cluster renewal that make sense for Alberta's hydrocarbon sector. The paper ends with a discussion on policy implications.

Understanding the cluster model for Albertan hydrocarbons

Alberta's firms in the hydrocarbon sector are clustered

Hydrocarbon development in Alberta has created a group of firms, institutions and infrastructure which meets Porter's (1998) most basic definition of a cluster:

"a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities. The geographic scope of a cluster can range from a single city or state to a country or even a network of neighboring countries" (p. 199).

Oil and gas activity in Canada is highly concentrated in Alberta (ICP, 2021), with 1,026 firms in oil and gas extraction, and 3,514 in support activities operating in the province (Government of Canada, 2020a). However, a cluster is more than a geographically-concentrated collection of competing and cooperating firms. It also involves significant soft capital assets and infrastructure, which have been developed around Alberta's hydrocarbon industry.

Alberta's hydrocarbon cluster includes a specialized workforce and educational institutions. In 2017, 72,472 people worked in oil and gas production and transportation in Alberta, following a significant drop from 127,790 in the prior year (ICP, 2021). Several educational institutions in Alberta offer programs which are tailored to hydrocarbon extraction and processing, notably the University of Alberta, the University of Calgary, the Northern Alberta Institute of Technology, and the Southern Alberta Institute of Technology. Alberta's specialized workforce included the highest per-capita number of engineers in Canada in 2018 (Engineers Canada, 2019), as well as skilled blue collar workers and engineering procurement and construction firms with the know-how to manage large, complex projects.

Intellectual property and innovation infrastructure are also important components of the cluster. Canada was second only to the United States in hydrocarbon-related patents per energy output in 2010 (Bladek et al., 2010), and Alberta had the most patents granted in Canada per capita among Canadian provinces in 2019-2020 (CIPO, 2020). Canada has one of the largest oil reserves in the world (Government of Canada, 2020b), and substantial public and private resources have been invested in Alberta in research and development (R&D) of extraction and processing techniques (IISD, 2018). In the 1990s, provincial government institutions were instrumental to organizing and financing the development and demonstration of technology and processes needed to extract Alberta's unconventional oil reserves and to training personnel who would go on to implement these techniques in the private sector (Hastings-Simon, 2019). Private institutions such as the Petroleum Technology Alliance Canada and the Oil Sands Innovation Alliance have also supported innovation. Recently, public and private institutions in the cluster have advanced the R&D of carbon capture, use and storage (CCUS) technologies (Natural Resources Canada, 2016).

Alberta's hydrocarbon cluster also includes supporting industries, such as those providing infrastructure, capital markets, and environmental services. Alberta's hydrocarbon resources are remote, and developing these resources requires significant transportation and housing infrastructure. Specialized public and private capital providers have emerged to meet the needs of the hydrocarbon cluster, particularly oil sands projects, which are often only economically viable at large scales. Hydrocarbon projects in Alberta, particularly oil sands projects, cause serious environmental harm, and regulation and pressure from investors have created demand for environmental services. Between 2006 and 2016, oil and gas spent more than any other Canadian industry on environmental services, and firms in Alberta spent more than in any other province (Venkatachalam et al, 2010). In 2018, roughly 10% of Canadian clean technology ventures were located in Alberta, and the majority of these serviced primarily the oil and gas industry (Switzer et al., 2019).

A counterargument to applying a clusters model to the Alberta hydrocarbon sector would be that "the firms are there because that's where the oil is". While this may be true, it does not mean that the sector is not a cluster that drives innovation and economic growth. The dense network of firms, supporting industries, knowledge and labour skills meets any reasonable test for what constitutes a cluster. While there is no universally-accepted methodology to determine what is and is not a cluster, Gordon and McCann (2000) developed a taxonomy that classifies clusters in one of three categories:

1. Model of Pure Agglomeration: There are positive externalities from proximity, which include transmission of ideas, the development of a pool of specialized labour, and the emergence of support firms.

2. Industrial-Complex Model: Firms in the same industry locate close to each other to reduce transaction costs.

3. Social-Network Model: Proximity provides personal connections between agents in the cluster, which fosters trust. This trust can allow agents to engage in higher-risk endeavours and partnerships, particularly in environments where contracts are incomplete or not costlessly enforceable.

At the very least, there are clear agglomeration effects taking place in Alberta's hydrocarbon sector, with a substantial pool of skilled labour and thousands of support firms. For this reason, it makes sense to classify this sector in the Model of Pure Agglomeration category. It is important to note that clusters can develop disadvantages, such as overspecialization, lock-in, and vulnerability to external shocks (Grabher, 1993; Uyarra and Ramlogan, 2012). Policymakers must acknowledge these characteristics to better address the threats and opportunities that Alberta's hydrocarbons sector face.

The declining market for 'traditional' hydrocarbons

Despite its historic success, Alberta's hydrocarbons cluster risks stagnation or decline if it fails to pivot to future-fit hydrocarbons. For decades, commentators have unsuccessfully predicted peak extraction followed by terminal declines in oil supply. Now, declining demand for oil, and eventually gas, may be in sight. This is due to changes in consumer preferences, policies, and technologies, primarily driven by the climate change crisis.

Unlike demand for renewables, which have proven resilient to the pandemic, fossil fuels faced decline in demand and volatile markets throughout the pandemic (IEA, 2021a). Even prior to the pandemic, Alberta's oil sector had been struggling to recover from the 2014 oil price shock. A combination of technological changes, enhanced climate action, changes in investment practices, consumer practice changes, and geopolitics is expected to drive a long-term decline in Alberta's oil sector, with electric vehicles being the most significant driver in the short-term (IISD, 2021). The gross domestic product (GDP) from the oil and gas sectors is expected to decrease between CAD 4.4 billion to CAD 24.3 billion per year out to 2050, depending on a scenario of low oil prices or significant price volatility (IISD, 2021). Employment decline is expected to range from 6,300 to 24,300 full-time jobs every year until 2050. Studies and modelling by several expert agencies and research institutes indicate that the traditional hydrocarbon sector risks significant turbulence, and even irreversible decline.

After a historical peak in oil demand in 2019 (IEA, 2020), the socioeconomic impacts of the coronavirus pandemic led to global projections of oil and gas demand to be revised downwards. The pandemic reduced overall demand for energy as well as oil's share of energy demand (BP, 2020; IEA, 2021a). It also significantly reduced gas demand (IEA, 2021a). However, if no new policies are set in place, modelling indicates that demand for oil would rebound, returning to 2019 levels by 2023 (IEA, 2021b: 37). Meanwhile, an increasing number of governments, corporations, and investors have pledged net-zero targets, which is likely to advance climate action and sustainable energy technologies.

There is no overall agreement on when the demand for oil and gas will peak. While past projections by the IEA, the Organisation for Economic Co-operation and Development (OECD), and a number of oil majors have differed on projections of demand growth, a recent groundbreaking IEA report on reaching net-zero emissions by 2050 identified that "there is no need for investment in new fossil fuel supply" (IEA, 2021b: 21). This makes clear that Alberta's hydrocarbon sector will need to consider alternative economic opportunities to succeed in the coming decades if Alberta is to align with global climate ambitions.

The rising market for 'future-fit' hydrocarbons

There are potential renewal pathways for Alberta's hydrocarbons cluster. With appropriate policies and support, some "future fit" uses for hydrocarbons could see rising, rather than falling, demand.

Demand for blue hydrogen is projected to rise in a climate-ambitious world (BP, 2020; IEA, 2021a, 2021b). Growth in demand for gas is likely to be almost entirely driven by hydrogen, and low- and zero-carbon hydrogen could represent between 7 and 16% of energy consumption by 2050 in BP's climate-ambitious scenarios (BP, 2020). To compete with green hydrogen, blue hydrogen technologies will need to effectively reduce methane emissions and increase carbon capture ratios. While blue hydrogen is currently cheaper than green hydrogen, this is likely to change as green hydrogen production technology is deployed in greater quantities, which lowers unit costs.

Improvements in carbon capture technologies are likely to support demand for direct use of natural gas. In 2050, natural gas combustion for electricity usage, combined with carbon capture, could account for 6.5% of total primary energy use in BP's climate-ambitious scenario and 1% in business as usual (BAU) scenario. As with blue hydrogen, future demand depends on advances in carbon capture technologies and methane emissions reductions for gas. Demand may be depressed by the European Union's recent decision that gas with carbon capture does not qualify as a "transition" fuel in its internationally influential investment taxonomy (EU TEG, 2020). Canada is developing an alternative taxonomy, and it remains to be seen how it will classify natural gas combustion facilities paired with carbon capture technologies.

Demand for non-combustion uses of hydrocarbons, particularly for plastics, fibers, and fertilizers, may also grow. This is seen in all of BP's projection scenarios, but this demand for non-combustion uses is expected to be slower than in the past due to increased recycling and decreased use of single-use plastics and fertilizers. In particular, petrochemicals account for over 50% of oil demand growth in the next decade if only current policies remain in place (IEA, 2021a). While neither organization specifically projected demand for carbon fibers, this is likely to grow in the future (Grandview Research, 2017).

Existing infrastructure and soft capital can be repurposed to future-fit industries

A future-fit hydrocarbon sector would not need to start from scratch when it comes to labour markets, capital investments, or even physical and organizational structures and facilities. Assets from the Alberta hydrocarbon cluster, including its hydrocarbon supply, but particularly its infrastructure and soft assets, can be repurposed towards a variety of future-fit industries. Multiple assets from Alberta's hydrocarbon cluster can be repurposed towards the production, transportation, and use of blue and green hydrogen. Alberta has abundant natural gas, whose primary consumer is currently heavy oil and oil sands production (Government of Canada, 2020b). The hydrocarbon cluster offers repurposable infrastructure such as pipelines for natural gas and carbon. In addition, Alberta's has supported the formation of a nascent carbon capture cluster (IEA, 2015; ISED, 2017). Removing CO_2 from hydrocarbons so they can be safely transported by pipeline has long been part of the refining process (Haszeldine et al., 2018). Furthermore, federal and provincial governments, as well as firms in the hydrocarbon cluster, have invested significantly in carbon capture, use, storage, and transportation, through projects such as the Alberta Carbon Trunk Line, in the hope of facilitating continued hydrocarbon extraction amid tightening climate change measures (Heal & Kemp, 2013; IEA, 2015).

While Alberta currently has a comparative advantage in blue hydrogen, it has the potential to develop an advantage in hydrogen regardless of its type. Albertan blue hydrogen is on track to be one of the cheapest hydrogen sources globally by 2030 (Layzell et al., 2020a). However, the future fitness of blue hydrogen depends on improvements to methane leak control and carbon capture technologies and the viability of carbon storage. Further, the cost of green hydrogen is projected to fall dramatically in the medium term (BNEF, 2021). The hydrocarbon cluster's engineering and construction know-how can also be paired with Alberta's wind or agricultural resources to produce hydrogen through electrolysis or biomass gasification. Know-how, intellectual property, and infrastructure for pipeline transportation and long-term storage of gases in salt caverns can be repurposed towards the transportation and storage of hydrogen regardless of its source.

Alberta is home to world-class expertise on subsurface mapping and operations, which can be redeployed in several ways. For example, the geothermal energy industry can directly reallocate expertise in drilling, subsurface thermodynamics and fluid dynamics, and 3D subsurface mapping, as well as industrial electrical co-generation and resale (Leitch et al, 2019). Geothermal projects can even repurpose existing active or inactive oil wells - indeed, most operational projects in Alberta have done so (Leitch et al, 2019). These complementarities are already being explored in Alberta: of 46 private sector firms with activities or interest in geothermal energy in 2018, 44 had a prior connection to the oil and gas sector (Leitch et al, 2019). Academic researchers are also using oil and gas industry data to identify Albertan geothermal resources (Banks, 2017). And there are potential complementarities in environmental assessment and regulatory approvals, although Leitch et al. (2019) find that these are underexploited. Geothermal resources in Alberta could be used to provide heat and power to nearby communities and industrial facilities.

Hydrocarbon cluster expertise and infrastructure can also be reused to extract and process lithium from subsurface brine. Lithium ion batteries are currently a frontrunner in electric vehicle technology, and lithium demand is likely to grow significantly if current technological trajectories continue (Hund et al., 2020). Alberta has a large, low-concentration lithium resource in subsurface brine (Alberta Energy Regulator, 2020). Several firms in Alberta have developed techniques to extract it either from oil and gas operations' wastewater or dedicated extraction of lithium-enriched brine (Smith, 2020). Lithium extraction with these techniques requires similar skills to oil and gas extraction and processing, including in geology, drilling, project management, and moving large quantities of brine. It is also possible to repurpose infrastructure such as roads, pipelines and well pads, seismic data, and environmental assessments and regulatory approvals. Existing wells can also be used in future-fit hydrocarbon industries. While lithium brine extraction has significant downstream environmental benefits compared to oil and gas extraction, it would likely have similar upstream environmental costs, including damage to land, air and water and carbon-intensive extraction processes (Tscherning & Chapman, 2020). As such, lithium brine extraction can also repurpose environmental expertise, intellectual property, and infrastructure from the hydrocarbon cluster, including those related to co-generation, geothermal energy, and carbon capture.

Expertise in financing and managing large, risky, capital-intensive projects has also potential use in future-fit hydrocarbon industries. Upstream oil projects are capital intensive and oil sands projects, in particular, need significant scale to produce economically. This means

huge capital costs: for example, the Teck Frontier Mine was projected to have a capital cost of $20.6 billion and operating costs of $67 billion. Upstream hydrocarbon projects are also risky due to fluctuating commodity prices and the uncertainty of exploration, among other factors. Expertise in financing and managing hydrocarbon projects can be repurposed towards other large, risky, capital-intensive projects, such as CCUS. While power projects tend to have different capital structures, these assets might also be reallocated toward the development of large-scale renewables such as offshore wind, as suggested by BP and Equinor's offshore wind collaboration in the Northeastern US (Parnell, 2020).

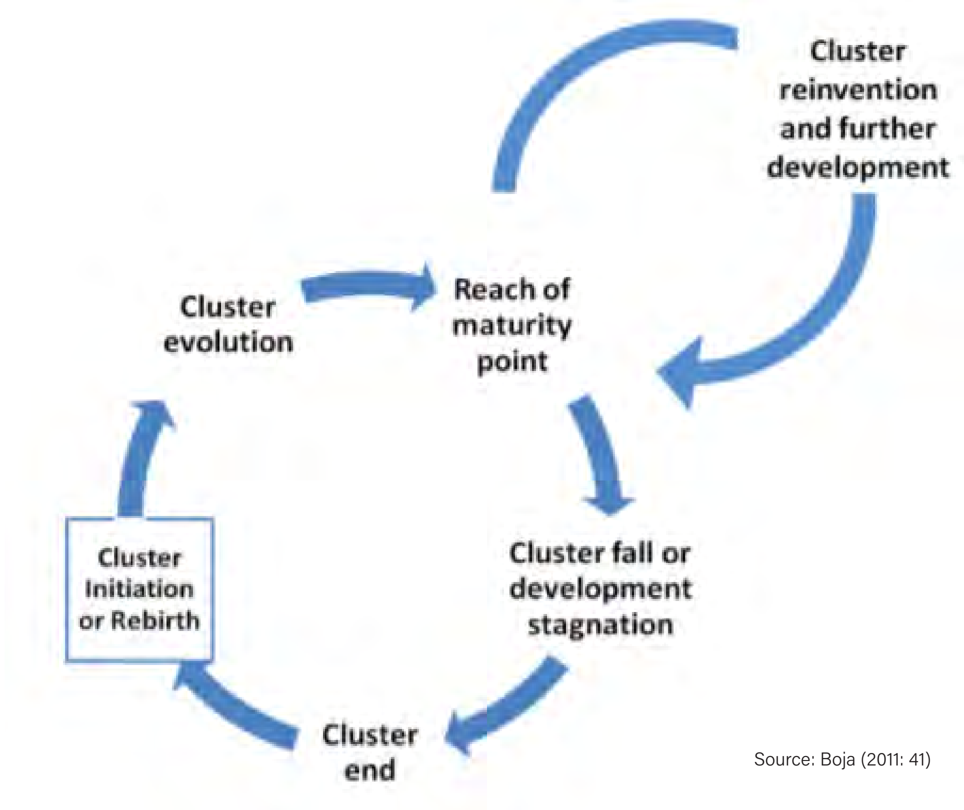
There are many other ways in which the hydrocarbon cluster's assets might be repurposed in a clean economy. Alberta has developed excellence in transportation and logistics, and has a world-class education system. Furthermore, the provincial government has developed expertise and institutional infrastructure for supporting energy research, development, and demonstration (Hastings-Simon, 2019). These assets could give an edge to future-fit industries if the right policies are put in place.

Clusters are dynamic and tailored policies can encourage renewal: Insights from the cluster life cycle approach

In the first section of this paper, we have established that Alberta's hydrocarbon cluster is faced with threats and opportunities brought by increasing climate action. Particularly promising is the possibility to repurpose existing infrastructure and soft capital to foster future-fit hydrocarbons industries that are primed for growth in the near future. In this second section, the paper discusses the life cycle of clusters to address the following pressing questions: How do clusters change over time? Can they be reinvented? And if so, what factors determine the success or failure of that reinvention?

Within the field of evolutionary economic geography, cluster researchers propose to exame clusters as emerging or evolving processes, rather than as static entities. This recent research agenda was formed to consider How clusters grow and decline (Santner, 2018). Concepts such as *cluster evolution* and *cluster life cycles* were developed to emphasize this dynamic feature of clusters (Martin & Sunley, 2011; Østergaard & Park, 2015). Using this research to understand Alberta's hydrocarbon sector naturally leads to the question: *is it possible to revitalize or even reshape a cluster after it reaches maturity*?

There are several representations of what a cluster life cycle looks like, many of them sharing some commonalities. An abstract, yet insightful, representation was advanced by Boja (2011), who views clusters as undergoing a process of birth, evolution, maturity and then an inflection point, where they either stagnate or die, or are reinvented or further developed, as shown in Figure 1.



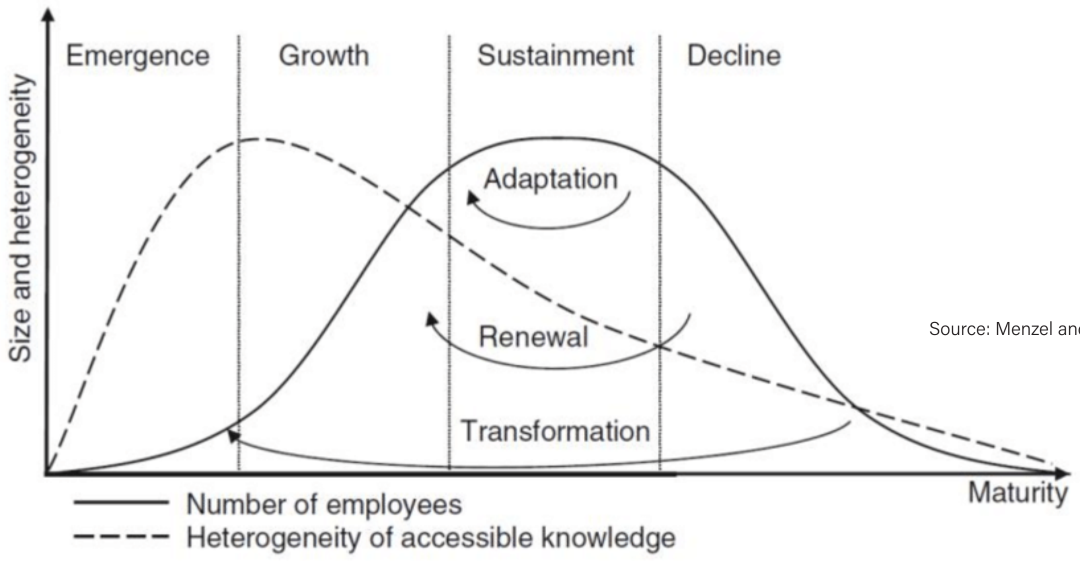
Source: Boja (2011: 41)

Figure 1: The life cycle of a cluster

According to Boja (2011), there are two potential pathways for a cluster, and these can be thought of as a series of stages and triggers. The *initial stage* of a cluster occurs when there are a minimum number of firms operating in a region in the same or similar fields. This could be due to government policies designed to attract those businesses, a local university or community college creating a specialization that creates enough local labour to obtain a critical mass of skilled labour, discovery of a natural resource in an area, or a local entrepreneur whose business idea created enough activity to facilitate the emergence of support companies and competitors.

This stage is followed by a period of exponential *growth*. The triggers of that growth are typically unique to a cluster, and scholarship has acknowledged that there is no one-size-fits-all solution. Demand for the products and services of that cluster emerges from beyond the local market, which allows for rapid growth. Typically, but not always, spin-off companies are created, often founded by employees leaving existing firms in the cluster. Employees switching firms is common, leading to information and best practices being transmitted between firms. This growth stage is then followed by *cluster maturity*, which is reached when the cluster enters a period of stability or more modest growth. In this stage, the market demand for the products and services offered by the service plateaus.

Particularly relevant to the discussion of Alberta's hydrocarbon cluster is what happens after the maturity point of a cluster. There are two paths: either a cluster goes through renewal and further development or *cluster decline* occurs, wherein a shock significantly reduces the demand for the products and services offered by the cluster. The shock can be fast-acting, such as the eruption of violent conflicts or social unrest, but is often the result of a slower process. One example is the emergence of new competitors, often in lower-cost jurisdictions. Another is the emergence of new technologies which render the products and services of the cluster obsolete. Cultural



Source: Menzel and Fornahl (2010: 218).

Figure 2: Quantitative and qualitative dimensions of cluster life cycles

or technological 'lock-in' can also lead to cluster decline, where incumbent firms resist change within the cluster, threatening profitability. Despite having fewer resources, emerging clusters are more often able to embrace new ways of doing things due to a lack of incumbents.

Cluster renewal is fundamentally different. It happens when the cluster undergoes a substantial reform. This can happen when cluster agents develop or deploy new technologies, or when firms within the cluster enter a new market. This new market could be a new geographic market or the market for a different product or service, such as the renewal of Silicon Valley's cluster in the 1980s**.**

Boja's abstract model treats any stage posterior to the point of maturity as a cohesive single path, either as decline or renewal. Other models provide a more nuanced and complex picture of possible pathways to reinvention. The Menzel and Fornahl (2010) framework is one such model. It shares many commonalities to Boja's framework, but they argue that cluster development is a function of both quantitative factors (number of employees, firms, revenue) and qualitative ones (the heterogeneity of available knowledge to cluster agents).

According to Menzel and Fornahl (2010), clusters evolve through four stages, very similar to Boja's representation (2011): emergence, growth, sustainment, and decline (Figure 2). However, the stages are differentiated in more detail, specified by the number of firms in the cluster and the degree to which knowledge is shared across participants of the cluster. In the early stages of a cluster lifecycle, a great deal of knowledge is generated, but is not shared between firms, and the number of employees is small. As the cluster grows, in terms of the number of firms and employees, knowledge is shared through knowledge transfer activities and individuals switching firms. Decline happens when firms exit and workers leave the cluster, either voluntarily or involuntarily, outnumbering those entering. This is mostly the consequence of reduced creation of new knowledge, which decreases innovation and growth, pushing both firms and workers to exit the cluster.

However, instead of a single pathway to stave off a decline phase, the Menzel and Fornahl framework identifies three possible transition forms for mature clusters, other than decline: incremental adaptation, renewal through systemic implementation of innovative technologies or transformation into an entirely different market (Table 1). This is particularly relevant to the Alberta hydrocarbons cluster, as it shows that there is not one transition pathway for a cluster, but several.

Table 1: Transition forms for mature clusters

Transition Form	Description	Example
Adaptation	Firms in the cluster incrementally adapt to a changing environment, by slowly adapting methods and technologies from outside the cluster. This helps prevent the cluster slipping into a decline phase.	Detroit auto manufacturers adopting kanban frameworks from their overseas rivals.
Renewal	Wholesale adoption of new technologies, either from outside the cluster, or a technological breakthrough within the cluster that opens up different, but related, markets (in either a product or geographic sense) to ones the cluster are currently in.	Silicon Valley's transformation away from hardware (particularly semiconductors) and towards software during the 1980s would meet this definition.
Transformation	A cluster utilizes its existing hard and soft capital (networks, relationships, skills) and enters into entirely different markets as their pre-existing markets go into decline.	The example used by Menzel and Fornahl is of the Ruhr Area's declining coal cluster transforming into one that provides environmental services, as detailed by Grabher (1993). Arguably, Pittsburgh's development of a robotics cluster from their pre-existing steel cluster would meet this definition as well.

Adapted from: Menzel and Fornahl (2010: 218)].

It is important to note that both the Menzel and Fornhal (2010) and the Boja (2011) models describe cluster development and renewal as mainly driven by factors that are internal to the cluster. This is a typical characteristic of cluster life cycle approaches (Santner, 2018). For instance, Menzel and Fornhal (2010) argue that cluster development is dependent on firms' capacity to absorb and adapt external knowledge. What is equally important is that the use of new knowledge must be systematic and diffused. As such, professional and trade organizations as well as educational systems within the cluster play an important role in the diffusion of knowledge, and consequently on cluster renewal. Similarly, for Ter Wal and Boschma (2011), the development of clusters is dependent on a firm's capabilities to reposition itself within the cluster network and to reproduce routines in different contextual settings. However, it is a cluster's network dynamics that allow these dynamic capabilities to be a characteristic of the entire cluster, which increases the potential of cluster renewal. Maskell and Malmberg (2007) also acknowledge the importance of an individual firm's routines, but they argue the most important drive to cluster development is a cluster's institutional settings. Institutions, the argument goes, are fundamental to encourage mutual learning and collaboration between firms that are unlikely to establish ties and share knowledge. That is because firms tend to collaborate mostly with partners that have similar characteristics or are in spatial proximity. Cluster rejuvenation thus depends on an institutional setting that supports establishment and utilization of ties between dissimilar firms.

Typically, cluster life cycle studies identify factors that are internal to the cluster as drivers for cluster development and renewal (Santner, 2018). Martin and Sunley (2011) offered a critical argument against this emphasis on factors that are endogenous to the cluster. They argue that cluster development is dependent on both cluster's characteristics *and* the environment in which they are embedded. Cluster development depends not only on cluster-internal drivers, such as firm's absorptive capacity, access to external knowledge, and institutional characteristics, but is also affected by exogenous factors, such as national and global economies, societal trends, and political agendas. These exogenous factors strongly influence knowledge flows and spillover within the cluster (Coenen, Moodysson, & Martin, 2015; Cooke, 2012; Martin & Sunley, 2011). However, in each case of cluster renewal, a different set of driving factors might be at play (Santner, 2018). Table 2 summarizes factors that drive cluster evolution and renewal, as identified by cluster researchers.

Table 2: Factors that drive cluster evolution and renewal

Factors internal to the cluster	Factors external to the cluster
▪ Absorptive capabilities to adopt, adapt, and use external knowledge ▪ Cluster network dynamics ▪ Firm's ability to reposition itself within the cluster network ▪ Firms' ability to reproduce routines into new geographical areas ▪ Firms' capacity to establish and utilize external ties to agents with dissimilar routines, which ultimately leads to the development of new adjusted institutions ▪ Institutional characteristics of the cluster: shared routines, mutual learning, and collaboration patterns ▪ The creation of network of firms, municipal services and governments, research centres, and technology transfer agencies are another important driver ▪ Technology similarity between old and new specialization of firms in the cluster	▪ Interrelationship between the cluster's internal and external environment: this interactive relationship impacts capability building and the use of external knowledge. ▪ Political discourses are crucial to redirect government policy, which, in its turn, trigger social change ▪ Subsidy programs encourage experimentation, knowledge spillovers, niche market evolution, demand-driven innovative practices and technologies ▪ Subsidy and cluster renewal programs that take into account the particularities of mature locked-in clusters, and the barriers they face to establish a pathway for renewal, are important drivers of cluster evolution ▪ Consumer demand is a crucial driver for incremental innovation and cluster renewal

Note: This table presents research findings from Coenen, Moodysson, and Martin (2015), Cooke (2012), Martin and Sunley (2011), Maskell and Malmberg (2007), Menzel and Fornhal (2010); Ter Wal and Boschma (2011), and Santner (2018).

Real-World Examples of Cluster Renewal

The previous sections of this report outlined how clusters work in theory. However, there are a number of real-world examples that can help ground these concepts, and illustrate how they shaped investment and economic growth in the past. This section presents a few of these examples.

The Silicon Valley case

California's Silicon Valley and Massachusetts' Route 128 are particularly instructive cases on how clusters can be reinvented. In a comparative study, Saxenian (1994) described how in the 1960s and 1970s, each area was a thriving hub in the burgeoning computer industry, with Silicon Valley being particularly strong in semiconductor design and manufacturing, and Route 128 arguably having the largest minicomputer cluster in the world. Each cluster faced an existential threat, with Japanese and later Taiwnese competitors undercutting American semiconductor manufacturing, and the introduction of microcomputers eroding the market for minicomputers. While Silicon Valley was able to transform itself into the globe's largest start-up hub, with a particular focus on software and design, Route 128 largely stagnated.

While both Route 128 and Silicon Valley are technology clusters, they had many significant differences during the 1970s, which may explain their divergent paths. As Saxenian argued, workers in Silicon Valley were more likely to change employers during this period, and firms tended to be smaller and more specialized, which led to increased formation of collaborative ties in the supply chain. This led to more knowledge transfer between companies and a need to continually innovate in order not to be left behind. This happened less frequently in Route 128, as companies were larger and leaving a firm to join a new one (or found a start-up) was seen as an act of disloyalty rather than a natural career progression. A culture of risk taking was prevalent among both financiers and workers in Silicon Valley, with one interviewee reporting "In Boston, if I said I was starting a company, people would look at me and say: 'Are you sure you want to take the risk? You're so well established. Why would you give up a good job as vice president at a big company?' In California, I became a folk hero when I decided to start a company." (Saxenian, 1994: 63) This risk-taking also extended to firms, with one observer noting, "[t]actical decisions that take six weeks in Boston can take anywhere from six days to six nanoseconds in Cupertino… If you bomb in Palo Alto, you blame the advertising agency and start another company." (Saxenian, 1994: 66)

Saxenian concluded that policymakers should address outdated cultural perceptions that innovation is an isolated, individualistic endeavour. Instead, innovation should be seen as a collective and collaborative process, and policymakers should focus on creating a robust network of firms and institutions that encourages knowledge sharing and risk taking. She notes that "[i]nstitutions that provide capital, research, managerial and technical education, training, assistance to entrepreneurs, and market information are vital to the firms in a decentralized industrial system. Yet the firms have little incentive to provide such services individually." To develop these institutions, governments need to make substantial investments in these areas and "cuts in public funding… or transportation congestion and soaring housing prices may undermine the institutions and infrastructure that support the region's network-based system." (Saxenian, 1994: 163)

Key takeaway: Governments have a role to play in creating the conditions for the emergence of decentralized industrial systems and promoting the risk taking culture needed for clusters to reinvent themselves in response to changing economic factors.

The Norwegian Centre of Expertise (NCE) programme

The NCE is a governmental initiative to enhance innovation and internationalization of mature clusters in Norway, created with the hope of contributing to regional development. The programme was based on the premise that internationalization, or the development of international market linkages and global value chains, is fundamental to cluster evolution. A culture of risk taking emphasis of the programme was to establish *global pipelines*, usually defined as channels of communication between firms located in different regions but that still share an institutional context that enables joint problem-solving, learning, and knowledge creation (Bathelt, Malmberg, & Maskell, 2004). As such, the emphasis of the NCE was to expand the geographical scale of Norwegian clusters in the belief that doing so would encourage cluster evolution and innovation.

However, evaluations of the NCE programme indicate that the programme activities mostly reinforced the internationalization of firms that already had international ties prior to the programme, and that innovative output left much to be desired. Njøs and Jakobsen (2016) argue that these results are partially explained by the preponderance of *hubbing*, a particular strategy to rejuvenate clusters that seeks to geographically expand value chains, mostly through the establishment of extra-regional ties and satellite nodes. It is true that the NCE programme deployed other strategies, such as *monocropping* (which entails efforts to strengthen a particular region by incentivizing regional specialization) and *blending* (which refers to bridging related knowledge bases and encouraging cross-industry innovation, mainly by stimulating cooperation and learning between firms and cross-industry ties). However, the hubbing strategy was clearly predominant, prioritizing internationalization as a main source for cluster renewal. This, at best, allowed for a *regional path extension* involving incremental products and processes, leading to more short-term economic growth, rather than innovative breakthroughs and significant innovation. Njøs and Jakobsen (2016) argue that blending would have been a better strategy to renew clusters because the focus would have been not on optimizing value chains, but on encouraging regional innovation platforms in which *related variety* can flourish, allowing markets and R&D to drive innovation and embark on a truly regional path renewal. The notion of related variety implies that interaction between actors both within and across similar industries lead to knowledge creation, sharing, and positive spillovers, which are necessary for increasing innovation and productivity (Andersen, 2011; Cooke, 2012). The actors that interact, or blend, should not belong to the same well-defined industry or perform the same specialized activity, but be somewhat technologically related. Blending strategies, as the argument goes, are more likely to facilitate regional path renewal because cooperation and learning between firms have the potential to introduce new activities and markets in a region with an already established industrial structure. The NCE programme case is a cautionary tale that internationalization may lead to modest short-term economic growth, but is unlikely to renew a regional cluster and lead to long-term, sustainable economic growth (Njøs & Jakobsen, 2016).

Key takeaway: Encouraging cooperation and learning between firms, as well as facilitating ties between industries with similar technologies, are much more likely to drive innovation and, ultimately, cluster renewal, than implementing programs that promote the internationalization of clusters.

Agricultural engineering clusters in Germany

Although hubbing and internationalization are not the most appropriate strategies to encourage cluster renewal, it is important to avoid the pitfall of assuming that clusters are isolated from the rest of the world. In a comparative case study of two German agricultural engineering clusters, Santner (2018) identified that renewal processes may be strikingly different even in clusters that share similar and overlapping regional, social, and industrial context. The author examined two case studies: the farm trailer cluster and the biogas stable technology, both in the Ruhr region, an agricultural part of Germany.

The farm trailer cluster is a constellation of firms and services catering to the regional agribusiness sector, specialized in farm trailers and self-propelled farm vehicles At the turn of the millenium, the firms of this region refocused on high-tech information and communication technology, repositioning themselves in the market. This process of cluster renewal involved the development of standardized technologies that can be used by most producers of farm vehicles and trailer-related machinery. The main factor that allowed the development of this innovative technology, and the cluster renewal as a consequence, is the establishment of cluster-internal infrastructure that encouraged collective learning and the use of technological knowledge. The local university established a research centre (the Competence of Applied Agricultural Engineering) that conducted applied research to provide high-tech solutions and highly-skilled workers for the cluster's firms. This enhanced the cluster's absorptive capacity and learning. Another factor that allowed cluster renewal was the formation of a network of trailer producers, supporting firms, and local researchers. This institutionalized network facilitated the access to technology and knowledge from other network members, encouraging knowledge diffusion and spillovers.

Fundamentally different was the process of biogas diversification in the stable technology cluster. In the second half of the twentieth century, this stable technology cluster specialized in animal farming-related machinery (feeding, water supply, egg collection, waste disposal, caging, and similar tools). However, since the turn of the millenium, firms in this cluster diversified into the field of biogas technology. Unlike the farm trailer cluster, this case of cluster renewal was driven by external factors, particularly the introduction of the Renewable Energy Act (REA) in 2000, as well as other regulatory amendments (Santer, 2018). What is important to note is that the biogas cluster renewal did not involve the presence of a research centre nor the establishment of a network that encouraged the widespread use of new technology and knowledge. Instead, the development and application of new technology was merely incremental, to satisfy changing regulation requirements, such as animal protection or new environmental regulations. The primary driver of this cluster renewal was fiscal policy incentives and subsidies, such as the bonuses implemented in 2005 for manure utilization in biogas plants (Danie-Gromke et al., 2018). Although firms in the stable technology cluster only became involved in biogas or electricity technology after the REA, it is inaccurate to explainthe renewal of this cluster merely by referencing exogenous regulations. Another element that drove renewal was the striking similarity between biogas and stable technologies (Santner. 2018). This facilitated incremental learning, an important factor when there is no systemic knowledge sharing and learning due to the absence of networks and research centres. Technological similarities also allowed diversification without significant change in cognitive and procedural abilities, building a path for diversification and renewal. Nonetheless, diversification, in this case, did not preclude the continuation of the pre-existing stable technology cluster context and business ecosystem.

These two case studies illustrate a variety of contextual factors that determine potential for cluster renewal. Factors endogenous to the cluster are likely to be more relevant when the use of technologies by firms in the cluster has the potential to lead to innovative activities. On the other hand, when a cluster diversifies into a more mature technological industry, relying on existing technological structures and procedures seems like a viable option, especially when there are cognitive similarities (Santner, 2018).

Key takeaway: Cluster renewal depends on collective learning and collaboration, which can be encouraged through established networks and research centres. Firms with similar technologies that collaborate and learn from one another are also more prone to diversification and renewal.

The renewal of the forest industry in Northern Sweden

The Örnsköldsvik-Umeå area in the North of Sweden is home to a mature cluster of firms in the forest industry that traditionally employed a large number of individuals. However, since the drop in global demand for paper products, volatile prices of raw material, and the implementation of sustainable forestry management regulations, the cluster started to enter a phase of decline characterized by depopulation, a subpar change in gross value added, and drop in employment decline. A new programme called Biorefinery of the Future was designed to develop a research and innovation environment around emergent biorefining technology in order to promote regional growth through exploration of a new market niche: biorefinery. This entails the development of technology capable of integrating biomass conversion and equipment to produce biofuels and chemicals from biomass. As such, firms are encouraged to use forest biomass not for the production of paper and pulp, but for producing low-carbon fuels, chemicals, substances used in the construction sector, materials for the textile industry, and ingredients for the food or pharmaceutical industries (Coenen, Moodysson, & Martin, 2015).

Through strategic R&D and innovation investments, the Biorefinery of the Future initiative motivates firms to engage in collaborations across industries, which facilitates mutual learning and knowledge sharing. For instance, some firms in the forest industry are collaborating with the chemical industry to abandon fossil-based chemicals. However, as promising as the programme is, a number of barriers hold back cluster renewal. There has been resistance from the forest industry to engaging in new market niches that are seen as overly disruptive. First, forest industries are capital-intensive, and investments that have already been allocated to facilities, machinery, and productive processes reinforce negative lock-in. A significant barrier is thus the difficulty of attracting and retaining long-term investments that can scale operations in the new industry. Second, insufficiently developed markets do not compensate for initial loss of profitability. There is a lag for profit returns, which discourages firms from exploring new market niches and activities. Third, public perception of new technologies impacts demand for products and services that deploy a specific technology or activity, but there is little effort to clarify the importance and consequences of different technologies and industrial activities (Coenen, Moodysson, & Martin, 2015).

Key takeaway: Cluster renewal policies and programs must encourage the adoption of new technologies or activities, but it is equally important to address regional and context-specific barriers to cluster transition.

The renewable energy cluster in North Jutland in Denmark

The North Jutland region in Denmark is an illustrative case of a cluster transition involving a change in technological regimes to respond to climate action demands, as described by Cooke (2012). Until the 1980s, the energy grid in North Jutland was mainly powered by coal, but this region has since developed into a world-class renewable energy district.

There are two main mechanisms that encouraged the firms in North Jutland involved in marine and agricultural engineering to branch into the energy industry. First is a process of *preadaptation*, in which firms apply a pre-existing technology out of its initial context, which in itself produces innovation. An example is the energy company Vestas, a firm that started in the agricultural engineering business, working on milk-cooler technology for the dairy industry, but that eventually transitioned to produce turbo-coolers for marine engines. Vestas applied its rotary blade technologies to explore new evolving market niches, mainly taking advantage of the Danish government's subsidies and incentives to transition national energy systems towards renewables. Second, *adjacent possible*, a cluster feature that allows cumulative capability, which is enhanced by related variety, allowed firms to go beyond the initial development of wind and solar energy solutions, to explore branching into the development of biogas energy which used animal waste from the local dairy industry.

It is important to note that factors external to the cluster drove both preadaptation and firms to take advantage of the adjacent possible. A strong subsidy program by the Danish government induced demand for renewable energy, which incentivized firms that had proximity to this technology to explore new market niches. However, these governmental programs did not happen naturally. Political discourse was critical to stimulate change. Anti-nuclear energy and pro-renewable energy discourses highly influenced government policy and the redirection of nuclear research towards renewable energy.

Efforts to decarbonize and to transition firms in the North Jutland region towards renewable energy industry entailed a great degree of transversality. *Transversality* is the condition whereby firm relatedness incite the diffusion of innovative technologies and practices across the cluster. As such, the North Jutland cluster renewal teaches us the importance of both cluster internal characteristics (such as transversality and firm proximity) and demand-driven knowledge transfer and application. Instead of merely focusing on productive capacities, policymakers can encourage demand-driven creation of new paths for mature clusters.

Key takeaway: Transversality (a condition where similar firms support the diffusion of technologies and practices) facilitates cluster renewal, but the role of external drivers, such as government incentives and political discourses, must not be overlooked.

Policy Implications

Cluster policies are framework policies rather than as 'hands-on' interventionist policies that pretend to know the future better than the market. Supporting clusters is therefore different from the orientation of traditional industrial policies that try (and usually fail) to choose winners. Instead, modern cluster policies aim to cultivate an ecosystem, wherein winners can emerge (without knowing who they might be and where they come from). With this caveat, this section concludes the research paper with identifying important policy implications that can be derived from the cluster life cycle approaches and the case studies described above.

Stimulating variety in Alberta's hydrocarbon cluster is a better strategy to encourage regional development and cluster renewal than seeking to specialize in a new economic activity that is unrelated to the cluster's existing activities.

Path dependence and lock-in are typical issues associated with overspecialization in old industrial regions and mature clusters. Evolutionary economic geographers increasingly argue that regional diversification is more likely to lead to innovation, new technological pathways, and cluster renewal than a policy that simply focuses on specialization. That is because renewal is dependent on the combination of related knowledge, technologies, competencies, and procedures, which fosters innovation.

Encouraging the adoption of new necessary for cluster renewal, but may be insufficient in the presence of path-dependence and lock-in in mature clusters

Cluster renewal programs that merely focus on advancing a specific technology will likely yield unsatisfactory results. Indeed, as Coenen, Moodysson, and Martin (2015) argue, policies seeking to introduce new products and technologies tend to overlook context-specific bottlenecks that constrain cluster renewal. It is important to create an environment that facilitates renewal, including by establishing networks and collaborative innovation activities. Public policy is needed to support firms in their exploration of new technologies, and mitigate uncertainties and risks, especially when a cluster is traditionally reliant on capital-intensive industries, which may lead to disincentives to explore new paths. Policymakers should, thus, focus on supporting collaborative learning at the same time as supporting the necessary experimentation processes and long-term transitional activities. This is particularly important when new technologies and industries are still immature, as it is the case for Alberta's future-fit hydrogen industry.

Firm relatedness or proximity is one of the most important drivers of cluster evolution and renewal.

Cluster renewal policies and programs are more likely to be successful if they develop and exploit regional variety. However, there is no one-size-fits-all approach to encourage related variety. It is important to design and implement blending strategies to renew Alberta's hydrocarbon sector into future-fit hydrocarbons. Policies for the utilization or repurposing of existing assets and infrastructure must not belong to or intervene in one particular industry, but create an environment in which related variety can develop. This will stimulate innovation and long-term adaptability. Potential blending strategies include trust-building and developing a cluster identity, developing innovation infrastructure, and assisting in knowledge development. The most promising strategy, as Njøs and Jakobsen (2016) claim, is to stimulate linkages between traditional sectors and to prioritize cross-industry innovations.

In short, clusters an ecosystem of related industries and competencies with dense inter-industry interdependencies.

Preference for one-size-fits-all policies will likely backfire. A better approach is to design a set of policies that can address context-specific conditions, macroeconomic and structural conditions, as well as non-cluster-specific factors. Köcker and Lämmer-Gamp (2017) provide some guidance with an insightful integrated four level cluster development (and redevelopment) approach that summarizes many of the policy implications outlined above. This four-level framework has the great potential to be successfully applied to the (potential) Alberta future-fit hydrocarbons. It allows policymakers to identify the types of policy and tools that are most likely to create the conditions that usually drive cluster renewal (Table 3).

Table 3: An integrated firm level cluster development approach

Level of intervention	Description	Policy tools/types
Macroeconomic Framework Conditions	Policies that are not specific to a cluster or even a sector, but rather foster a positive environment for business activity.	Broad tax, infrastructure, skills policy. Infrastructure. Trade agreements. Monetary policy.
Development of Structural Framework Conditions	Policies, programs and regulations that are specific to the cluster, to help facilitate growth and create a market for the products/services developed by that cluster.	Cluster specific infrastructure, regulations, sector-specific tax policies, economic roadmaps.
Non-cluster-Specific Thematic Programmes for Project Funding	Targeted policies that help companies within the cluster.	R&D/innovation programs, university tech-transfer offices, tailored training programs, cluster-focused export promotion programs.
Integrated Cluster Programme	Programs that aid the development of an integrated cluster (rather than the individual members of the cluster).	"Superclusters" program, COSIA.

Adapted from: Köcker and Lämmer-Gamp (2017)

In conclusion, Alberta's hydrocarbon cluster seems to be approaching a stage of decline. However, there is evidence to suggest that future-fit hydrocarbons could renew Alberta's hydrocarbon cluster. Cluster renewal does not always happen organically, especially in mature clusters where incumbent industries have advantages that make it difficult for new ones to compete. Luckily, governments have an opportunity to influence the fate of Alberta's hydrocarbon cluster. By creating context-sensitive and targeted policies that encourage the repurposing of hydrocarbon assets towards future-fit industries, governments can help steer Alberta towards renewal and avoid decline.

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