Yukon geothermal energy and cold-climate agriculture policies: a review.

Lonn Brown[1], Gideon Choi[2], Kimberly Markvoort[2], Andreas Murphy[2], Ali Yaghoubi[3]

[1] Department of Physics, University of Alberta [2] School of Public Policy, University of Calgary [3] Department of Earth and Environmental Sciences, University of Waterloo

Abstract

Challenges associated with affordable, nutritious food security for Indigenous communities have been documented for decades in Yukon. In addition to this, both the Yukon and Canadian governments have established initiatives to increase renewable electricity generation in remote communities. The water–energy–food (WEF) nexus, as defined by the United Nations, highlights the relationship between energy policy and food production. Geothermal energy extracted from internal planetary heat is a low-carbon form of energy-on-demand. Technological advancements have resulted in geothermal energy being cost competitive to other popular forms of renewable energy. Greenhouse agriculture supported by geothermal energy offers a solution to improve food security in Yukon. Modelling shows that geothermally sourced agriculture becomes cost competitive versus a more common alternative, burning diesel fuel, within 22 years. Results indicate that greenhouses attached to a 5MW geothermal power plant could provide as many as a million servings of vegetables yearly to nearby communities, while reducing carbon dioxide emissions. These developments are negatively impacted by the lack of resource specific legislation in Yukon. Geothermal energy producers are left to operate under the *Oil and Gas Operations Act*, which omits land tenure information, and a definition of geothermal resources. Geothermal specific legislation may also bring with it a royalty regime. Current food and agriculture policies in Yukon are positioned to support these developments. This paper provides a discussion on the impacts of greenhouse agriculture supported by geothermal energy for Indigenous communities in Yukon. Indigenous communities are pioneering geothermal energy development in Yukon; however, Indigenous communities are particularly vulnerable to natural resource development due to both their cultural and economic dependence on land and water resources. The paper concludes that synergies exist amongst Indigenous communities and geothermal energy. Increased public awareness on geothermal could result in resource specific legislation and future developments.

Key Words: Geothermal, Yukon Agriculture, Greenhouse Design, Yukon Energy

1.0 Introduction

It has been estimated that the warming effects of climate change in communities north of 60° latitude occur at a rate three times faster than the global average (Bush & Lemmen 2019). The global climate change crisis has altered the sphere of energy policy in Canada. Reductions in carbon emissions are central to emerging national and sub-national government policies. In 2020, the Government of Yukon established a regulatory requirement that 93% of the electricity on the main Yukon grid will come from renewable sources by 2030 (Yukon 2020). Geothermal energy is a renewable energy source that could assist in achieving this target (Fraser et al. 2019).

The Government of Canada has introduced initiatives to increase renewable electricity generation in Canada's remote communities, with the strategic benefit of reducing reliance on diesel. The "Clean Energy for Rural and Communities" is a six-year, $220-million program that aims to increase clean energy opportunities, encourage energy efficiency, and build local skills and capacity. As of October 2020, this program has provided $19.6 million of funding for low carbon energy solutions for the northern territories (Canada 2020). This initiative promotes the development of multiple renewable energy forms, including geothermal energy (Canada 2019).

Intrinsically related with energy policy is policy related to food production. The water–energy–food (WEF) nexus, as defined by the United Nations, highlights the interwoven nature of these three components. Literature on the WEF, as well as directives from the United Nations, indicate that the three components are critical to sustainable development (Loring et al. 2013; Lamalice et al. 2018, United Nations n.d.). Linkages between these components require informed policy approaches that ensure sustainable agriculture and energy production to meet local and global needs (Sharma & Kumar 2020; United Nations n.d.).

Harnessing geothermal energy in Yukon offers a unique opportunity to integrate renewable energy initiatives with sustainable agriculture. The Canadian Geothermal Energy Association (CanGEA) has conducted feasibility studies throughout Yukon highlighting opportunities to expand local agricultural development via climate-controlled greenhouses (Canadian Geothermal Energy Association 2016). This can be done with geothermal heat pumps, or from waste heat originating from geothermal power generation. Such applications of geothermal energy would align with the territory's *Local Food Strategy for Yukon* (Yukon 2016) which aims to support and increase local food production.

This paper aims to address the economic, social and regulatory barriers for geothermal assisted agricultural production in Yukon. As the WEF nexus highlights the interdependencies amongst energy and food, current directives to develop geothermal energy in Yukon may benefit from modifications to integrate sustainable development of energy and food production. The benefits and risks associated with using geothermal energy to heat greenhouses year-round in Yukon are discussed. The current regulatory systems for geothermal energy and agricultural production in Yukon are identified along with opportunities to establish targets supportive of geothermal assisted agriculture. Potential impacts on Indigenous communities in Yukon are also highlighted, with specific attention given to potential benefits to community capacity building and food security.

2.0 Background

2.1 Geothermal energy

Geothermal energy refers to the planetary heat available below the Earth's surface. The energy can be transferred via circulating fluids or air and used directly for heating or cooling. At sufficient temperatures, water can be formed into steam to rotate generators and produce electricity.

Geothermal energy is theoretically available anywhere. Temperatures in the Earth's subsurface increase with depth and the variation of temperature over depth is referred to as geothermal gradient. The average geothermal gradient is 30°C/km. Economic feasibility of geothermal projects is largely dependent on whether the geothermal gradient is hot enough at accessible depths.

Yukon has fairly average geothermal gradients over much of the territory; however, there are regions in the south with excellent geothermal resource potential (Majorowicz and Grasby 2019). There are still large regions of Yukon's geothermal potential yet to be fully explored (Grasby et al. 2012). Geothermal energy is comparatively underdeveloped in Canada. Canada is the only country on the 'Ring of Fire', as well as in North America, that does not currently produce electricity using geothermal energy (Grasby et al. 2012). However, there is a growing interest in the potential of employing geothermal systems in Canada (Majorowicz and Grasby 2019). Interest is centered around its low carbon footprint, renewable nature and potential to provide baseload power, which is power production that is not subject to large variability over the course of a day or passing of seasons (Stefansson 2000).

There are several types of geothermal energy systems with varying applications. Generally, they can be classified as either direct-use (heating/cooling applications) or in-direct use (steam generation for electricity production). Geothermal systems are also classified by the depth from which heat is extracted. Shallow geothermal systems are installed at depths of less than 500 m and are typically used for ground-source heat pump systems. A typical heat pump system uses a buried heat exchanger (a loop of pipe) that brings heat to the surface. The amount of geothermal energy used by heat pumps in Canada is increasing between 10-15% each year (Lund et al. 2005). Notably, Manitoba and Ontario have excellent financing options for investors in ground-source heat pumps, with programs that help to pay back the up-front capital costs (Lund et al. 2005).

Electricity generation through indirect use of geothermal energy requires deep geothermal systems. Conventional deep geothermal systems involve hydraulic fracture ("fracking") to circulate fluids between injection and production wells. Hydraulic fracturing for energy extraction is typically accompanied by induced seismicity. Advanced geothermal systems (AGS) is a recently developed technology which uses a deep closed-loop heat pump-like system that does not require fluid injection, resulting in the elimination of induced seismicity (Bain & Davies 2020).

Several geothermal electricity production projects are in various stages of development within Canada. This includes the recently announced Fort Nelson First Nations' Clarke Lake 15 megawatt (MW) geothermal plant in northern British Columbia (Richter 2021), the DEEP Corp 20MW geothermal power plant in southern Saskatchewan (Morgan 2020), and the Eavor™-Yukon 6MW advanced geothermal system in partnership with Carmacks Development Corporation in Little Salmon/Carmacks First Nation (Eavor 2020).

2.2 Comparing Economics of Solar, Wind and Geothermal

The Yukon Government's *Our Clean Future* plan sets a regulatory requirement of 93% renewable electricity generation by 2030 (Yukon 2020). Currently, hydroelectric generation fills approximately 90% of electrical generation needs, and the plan outlines the increase of renewable electricity generation through exploring the potential of multiple renewables, including solar, wind and geothermal (Yukon Energy 2017). Table 1 summarizes the electrical generation and economic indicators of three different renewable energy feasibility studies completed for Yukon Energy. Solar, wind and geothermal systems of similar generation capacity were chosen for comparison. A second point of comparison is shown on Table 2, showing yearly diesel generation costs of Watson Lake, a community reliant solely on electricity generated from a 5.3MW diesel generator.

Table 1: Electricity generation feasibility study summary of economic indicators

Resource	Generation Capacity	Estimated Capacity Factor	Capital Cost of Installation	Levelized Cost of Electricity
Solar PV[1]	5MW	14%	$13 million	$0.14 - $0.18/kWh
Wind[2]	6MW	28%	$32 million	$0.15 - $0.23/kWh
Closed-loop geothermal[3]	5.5MW	95%	$ 126 million	$0.23 - $0.34/kWh

[1] Solar PV reference model: 5MW Haines Junction Fixed Tilt and Single Axis Solar PV system (Solvest 2016)
[2] Wind reference model: 6MW wind farm measures at multiple sites (CBER et al. 2016)
[3] Geothermal reference model: 5.5 MW McArthur Springs closed-loop geothermal system (KGS Group 2016)

Table 2: Electricity generation economics of diesel generation

Resource	Watson Lake Generation Capacity	Estimated Capital Cost of Installation[1]	Watson Lake Estimated 2018 Generation[2]	Watson Lake Cost of Electricity 2018[3]	Estimated Watson Lake Diesel Cost 2018[3]
Diesel thermal generation	5.3 MW	$13.6 million	15,400MWh	27.7c/kWh	$4.3 million

[1] Estimates of current day capital cost of installation extrapolated from generator reference model of $2.56 million/MW (Yukon Energy 2020)
[2] 2018 Generation statistics and cost of diesel ($1.00/L) from available from ATCO Energy (ATCO Energy 2020)
[3] Estimated efficiency of diesel generators estimated at 3.6kWh/L (Karanasios & Parker 2018)

Capital costs for geothermal systems are significantly higher compared to solar and wind, however, this is offset by a much higher capacity factor. Capacity factor is the annual electricity output as compared to the maximum possible output over a year. Figure 1 compares the assumed electrical generation amounts per year, with solar, wind and geothermal producing roughly 7,400MWh, 13,500MWh, and 45,700MWh respectively. Diesel generation is used as a comparative case, with Watson Lake requiring an estimated 15,400MWh of generation in 2018. As a point of reference, the annual electricity demand for the entire Yukon territory is roughly 675,000MWh. Though upfront costs of geothermal systems are high, it has the ability to fulfill on-demand electrical generation needs with an attractively high electrical generation output yearly.

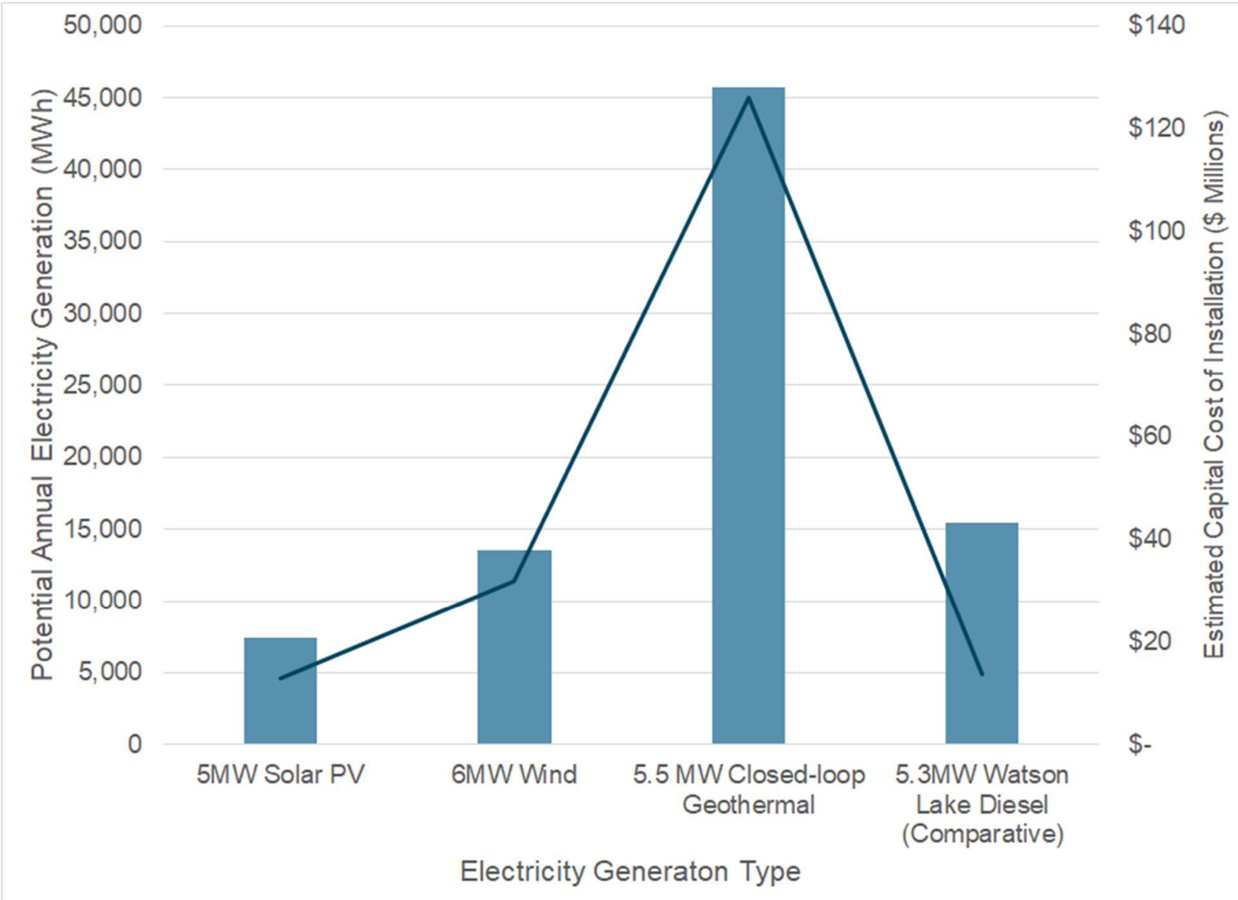

Figure 1: Potential annual electricity generation amounts and estimated capital costs of installation of four generation types.

2.3 Agriculture in Yukon

The Government of Yukon has established a *Local Food Strategy for Yukon* (2016). The goal of the strategy is, "to increase the production and use of locally-grown vegetables, meat and food products" (Yukon 2016, p.6). *The Local Food Strategy for Yukon* highlights the unique challenges that Yukon faces with respect to food security. These challenges are grouped in six categories: production, processing, distribution, access, consumption, and resource and waste recovery.

Yukon has faced challenges with accessing produce outside of growing seasons (Yukon 2016). When local food is not available, food must be transported in, resulting in inflated food costs due to high costs of transportation. Inflated food prices in the Yukon are often sensationalized in the media (Garfield 2017). Yukon often relies on food delivered from the Alaskan Highway. The severity of this dependency came to light in 2012, when the highway was closed for a brief period of time due to severe weather. The closure resulted in a food shortage across the territory (Canadian Geothermal Energy Association 2016). Conditions including inflation in food prices and delivery dependence on the Alaskan Highway contribute to food insecurity. The results of the Canadian Health Survey, conducted by Statistics Canada, determined that 16.9% of the Yukon population experienced food insecurity in 2017-18 (Tarasuk & Mitchell 2020).

There is growing interest in sub-arctic agriculture (Genest 2016). Indigenous communities in Canada have long identified the need for food security and food sovereignty (Croft 2020; Lamalice et. al 2018; Skinner et al. 2013). Although not a replacement for traditional foods and hunting, Indigenous communities have identified that gardens and farms can bring communities back to the Land (Genest 2016; Lamalice et al. 2018; Thompson et al. 2018). In addition to land-based learning, northern indigenous communities have identified improvements to food security, economic opportunities, social programming and health with community-based agriculture initiatives (Genest 2016; Lamalice et al. 2018; Thompson et al. 2018; Delormier et al. 2017; Skinner et al. 2013). Select Yukon First Nations have established agricultural farms including: Tr'ondëk Hwëch'in Farm just outside Dawson City, established in 2014 as a teaching farm (Genest 2016), Carcross/Tagish First Nation's farm's first harvest was in 2018, and recently the Na-Cho Nyak Dun First Nation in central Yukon refurbished a farm built in the 1980s (Croft 2020). Additionally, there are 14 First Nations in Yukon, and all have some kind of greenhouse (Hein 2016).

Given the unique food security challenges faced in Yukon through outside dependence on food, the *Local Food Strategy for Yukon* aims to increase the number of agricultural producers in Yukon. Increasing the number of farms (both indigenous and non-indigenous) that are able to produce local food year-round would assist the Yukon Government in accomplishing goals set out in *Local Food Strategy for Yukon*.

3.0 Scientific Analysis

Geothermal energy projects in Yukon have a unique opportunity to integrate renewable energy initiatives with sustainable agriculture. Limiting factors for plant growth in northern climates are heat, light, and humidity. A greenhouse is often a passive (non-energy requiring) solution which can extend the growing season in climates which do not naturally provide suitable conditions. A greenhouse works by retaining heat that would otherwise dissipate and is often able to sustain temperatures well above ambient temperatures.

The growing season in Yukon is very short and intense due to its prolonged hours of daylight (over 20 hours around the summer equinox) and over-night temperature lows below freezing as early as mid-July (Yukon Agricultural Association n.d.). Produce farmers have established techniques for season extension and frost protection, including the use of greenhouses designed for northern conditions (Yukon Agricultural Association n.d.).

To investigate if geothermal energy could improve established northern greenhouse design, a comparative theoretical case study was completed. Two geothermal energy sources were considered:

- ground-source heat-pump installed via purpose-drilled boreholes, and
- waste heat energy optimization from a geothermal power plant.

Energy inputs and outputs were calculated for two different greenhouse shape structures: rectangular and conical. Assumptions were made on crop selection and quantities. Water and soil sourcing were beyond the scope of this project and were not considered for economic feasibility modeling. The greenhouse designs were modeled across four different applications to determine economic feasibility:

1. **Passive**: a passive greenhouse which extends the growing season to 4 months out of the year (no utilization of geothermal energy).

2. **Heated**: A greenhouse heated by a geothermal ground-source heat pump 10 months of the year.
3. **Container**: A greenhouse outfitted with extra insulation and with heat and light provided 12 months of the year.
4. **Waste Heat:** A greenhouse heated through waste heat from a geothermal power plant.

Additionally, to confirm geothermal energy as a feasible heat source, applications (2) and (3) were further compared to utilizing diesel for modeled heating needs. Results were applied to three proof-of-concept communities: Carmacks, Watson Lake, and Old Crow, YT.

Construction costs of the greenhouse designs were estimated at approximately $36,000 for the rectangular design and $51,000 for the conical design. For application (2) and (3), estimates for drilling and installation of a heat pump are estimated to be $200,000[1]. For application (4) the vast majority of the capital investment is in the geothermal power plant. The cost of the powerplant was not accounted for in this case study, as a greenhouse is being presented as a potential optimization and local buy-in strategy for large-scale geothermal production.

Crop yields were determined for each design and harvest cycles were calculated based on months of operations per year. The assumed model price for cost of vegetables per serving is $1.85/serving[2]. While this price is higher than the average price in Whitehorse, this is considered cost competitive in remote communities. It should be noted that all crops were considered equivalent in value. Costs were calculated based on grams of yield, with one serving of vegetables considered to be 100-200 grams based on size and water content of the vegetable (United States Food and Drug Administration 2017). Figure 2 shows projected return on investments for applications (1), (2) and (4), along with the comparative diesel heated scenario. Application (3) is not shown as the return on investment time exceeded the 35 year mark. Additionally, application (4) returns do not include power plant capital investment costs.

Application (1), (passive), showed the fastest return on investment. Results indicate that a simple passive rectangular greenhouse with a plantable area of 188 m^2 can produce roughly 7300 servings of vegetables per year. The base case grows enough vegetables to completely satisfy the required intake for 2.5 adults for an entire year. Application (2), (heated), results in two times the yield as the base case and return on investment in roughly 14 years. Application (2) provides about 1% of annual community vegetable needs for the selected test communities.

One area of potential further study is a cost benefit analysis between heat pumps and diesel generation. We estimate a significant reduction in start-up cost for the diesel generator versus geothermal ground-source heat-pumps. However, the lifetime of the geothermal system is longer than the diesel system, and the geothermal system has significantly reduced carbon dioxide emissions.

In application (4), (waste heat), the amount of thermal energy available in power generation waste heat is very high compared to shallow ground-source heat pumps. Approximately 15MW of

[1] Based average price of drilling as per conversations with drilling operations local to Whitehorse, Yukon

[2] Average online prices for the month of April 2021 in Whitehorse is $0.81/serving, as advertised online by major food retailers. Reference vegetables used are bell pepper, cabbage, tomato and onion. Additional cost per serving based on estimated shipping costs as proposed by the community spatial price index for shipping of vegetables to various Yukon communities. ://yukon.ca/sites/yukon.ca/files/ybs/2019cpiannual.pdf

thermal energy is available from a 6MW geothermal power plant[3]. This could potentially heat between 600-1200 greenhouses. To be conservative and to accommodate the use of approximately 85% of the waste heat for other community purposes (such as food processing, district heating, etc.) heating 100 greenhouses of the demonstration designs were considered. The potential outcome of application (4) are yields that support 65-100% of annual community vegetable serving needs and potentially add commercial agriculture options to the community.

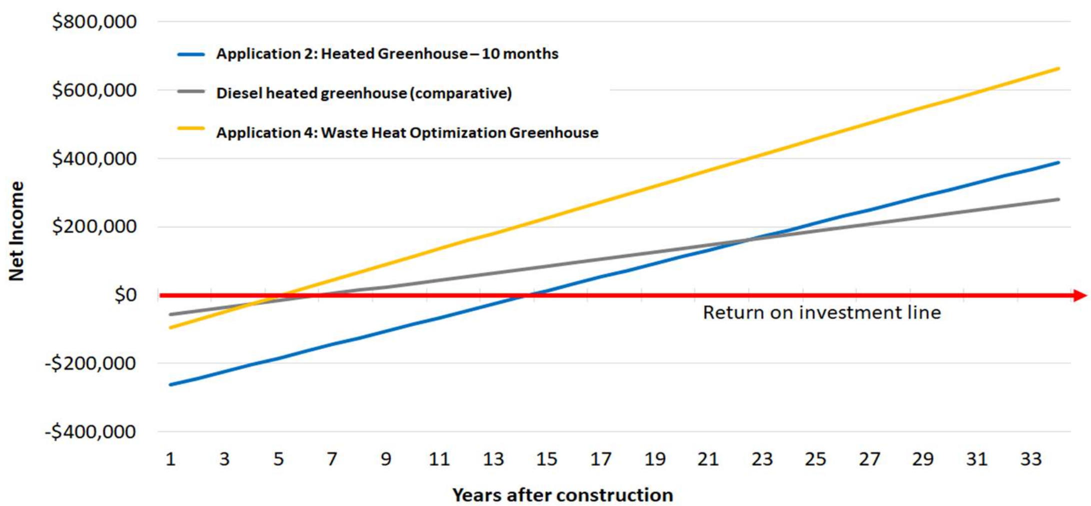

Figure 2: Return on investment (ROI) modeling for three greenhouse models: Passive, Heated, and Waste Heat.

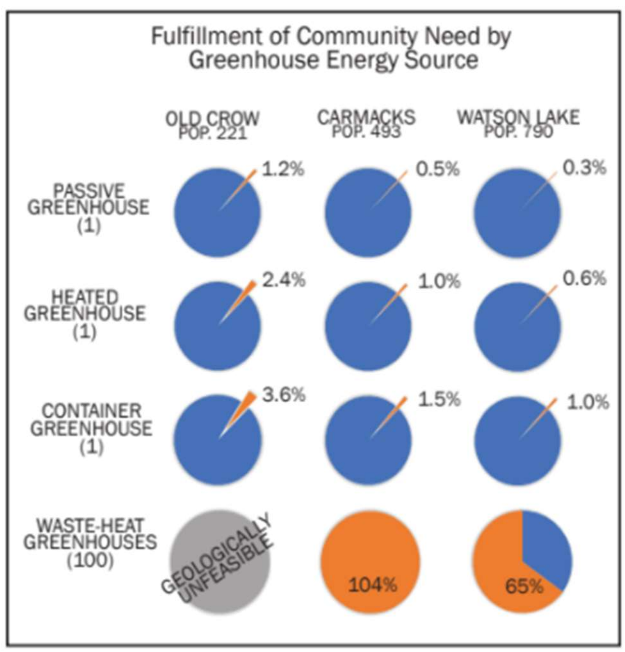

Figure 3: A summary of the proportion of population served annually by four applications of greenhouses for various test communities.

[3] Based on waste heat production estimates from conversations with Eavor™ Technologies regarding the planned 6MW Little Salmon/Carmacks power plant.

The waste heat optimization case benefits both the producer and consumer of geothermal energy. The geothermal power plant can sell thermal energy reliably and the greenhouse can buy heat at a cheaper rate with much lower start-up costs than drilling boreholes for ground-source heat pumps. Additionally, yearly usage of the total waste heat capacity is low, varying between 3-14% throughout the year.

4.0 Review of Current Directives

4.1 Geothermal Energy

There is presently no legislation governing geothermal development, engineering, and practices in Yukon. There are examples of geothermal specific legislation in other Canadian jurisdictions (British Columbia n.d.; Legislative Assembly of Alberta 2020). Despite this lack of legislation, the Government of Yukon has acknowledged the benefits of geothermal specific legislation in the *Yukon Energy Strategy* (Yukon 2009). This strategy set the development of a geothermal policy framework as a priority. Over a decade later though, no such legislation or regulations have been developed. With the absence of geothermal specific legislation, the applicable legislation in Yukon for geothermal practices is the *Oil and Gas Act* (Yukon 2002), and relevant regulations under the Act.

The presence of geothermal legislation in Yukon would assist in the development of geothermal practices in the territory. Firstly, geothermal legislation would provide the territorial government with the ability to respond to land tenure requests, assuming that geothermal resources are classified as minerals. Land tenure is defined as the rules and regulations in place for land ownership used in natural resource development (Soule et al. 2000). For geothermal producers, land tenure is crucial when seeking funding (Canadian Geothermal Energy Association 2016). Researchers such as CanGEA have developed criteria that geothermal producers need to provide before obtaining land tenure. This includes the need to show suitability, meaning interest, and the capacity for development (Canadian Geothermal Energy Association 2016).

In Yukon, the territorial government owns the majority of all land, with the exception of Category A First Nations Settlement Land, and federally administered land. There are also protected lands of Indigenous peoples where ownership has not yet been accredited, such as the White Water and Kaska land territories (Canadian Geothermal Energy Association 2016). The territorial government has jurisdiction to grant land tenure in any of their owned lands. Without a framework in place to identify how land tenure would operate, clarification of ownership and control may only be resolved in courts (Powell 2020b).

An appropriate definition of geothermal resources has been touted as a key issue with legal implications for resource ownership, tenure, and licensing, as well as a crucial component to an effective regulatory regime (Powell 2020a). An appropriate definition of geothermal resources would assist geothermal producers as it would simplify operations (Canadian Geothermal Energy Association 2016). There are technical differences found in the drilling and completion of geothermal wells compared to oil and gas wells, which create discrepancies for geothermal practices. Specifically, current technical standards differentiate between fluid extraction containing hydrocarbons versus those not containing hydrocarbons. CanGEA recommends a removal of such distinctions for geothermal resources as both cases do not affect the geothermal operations nor do they present any additional environmental risk.

Despite these technical differences, there are some similarities in both geothermal, and oil and gas operations that *The Oil and Gas Act* can provide a directive on. At a low level, geothermal and oil and gas projects make use of wells to extract fluids from the sub-surface, collect and use sub-surface data, and are subject to high financial risk (Leitch et al. 2017).

One regulation under *The Oil and Gas Act* that may provide direction for geothermal practices is the *Oil and Gas Geoscience Exploration Regulation* (Yukon 2004). The regulation sets out operating and reporting requirements for geoscience operations. While the term geothermal is not stated once in the regulation, there are definitions provided for geoscience operations, and procedures are outlined to obtain licenses or permits. Additionally, standards set out for choosing locations of project test holes can inform geothermal practices.

One other major consideration and risk factor to developing geothermal resources is royalty regimes. Presently, Yukon has an oil and gas royalty regime under *The Oil and Gas Act* titled the *Oil and Gas Royalty Regulations* (Yukon 2008). In this regulation, royalty calculations for crude oil, gasoline, and field condensates are determined. Further to this, reporting and penalty information are provided. Under this regulation, geothermal practices would not be subject to a royalty regime in Yukon. CanGEA (2016) states that a royalty regime is an important consideration in the development of geothermal practices, presumably for the benefit of reducing regulatory ambiguity. The association recommends that if a royalty regime specifically for geothermal practices is implemented, there should be a ‘royalty holiday’ for a fixed period to allow for initial industry development.

4.2 Food and Agricultural Policies

In 2016, the agricultural branch of the Government of Yukon published a five-year *Local Food Strategy* encompassing the years 2016-2021. The goal of the strategy is to “support the development of a sustainable localized food system” through four main objectives: (1) enhancing the resilience of the local agri-food sector, (2) developing a framework for better market access, (3) making local food conspicuous and widely available, and (4) informing consumers of the value of supporting local food (Yukon 2016, p.6). Key initiatives of the report aim to improve access and availability of local produce to help reduce their cost, recognizing that lower income families are at higher risk of poor health outcomes due to having less access to affordable healthy foods. Other initiatives aim to address the limitations of the short growing season in the Yukon which result in needing excess processing and preserving capabilities for a limited-time window each year. The report recognizes the vital role of greenhouses to increase the non-commercial growing capabilities of Yukon through community greenhouse initiatives. The strategy works in support of the Government of Yukon’s acknowledgement of the value of country foods, which serve a vital part of First Nations traditional community, culture and wellness. The strategy does not explore the potential for heated greenhouses to increase the types and quantities of local produce available over a longer period of time in the year. Such an addition could include frameworks for commercial and non-commercial greenhouses which would likely have the ripple effect of better use of agricultural processing capabilities, decreased need for costly imports, and ultimately, decreased cost of fresh produce. Heated greenhouses also provide an opportunity to increase availability of fruits, vegetables, herbs and plants which are native to Yukon and hold cultural significance to local First Nations.

The 2006 *Yukon Agriculture Policy* laid the initial foundation for the production of high quality products for local consumption in a way that promotes community well-being. The policy prioritized improved utilization of agricultural lands, expanding of agriculture land in a planned manner, and developing infrastructure supports in an economically viable and environmentally sustainable manner (Yukon 2006). Building on these initiatives, the Yukon *Agriculture State of the Industry Report 2013-2017* (Yukon Agriculture Branch 2018) reported that from 2011 to 2016, Yukon saw a doubling of the land purposed for fruit production (from 12 to 24 ha), and a 46% increase of the land purposed for vegetable production (from 13 to 19ha). Initiatives such as Growing Forward 2 (GF2) agriculture funding program and the Innovation in Cold Climate Greenhouses conference reveal an agriculture sector that is innovating and creating strategies to best use the agriculture resources available in Yukon. In 2013, the federal government provided nearly $1.3 million worth of GF2 grants for 58 Agriculture Development Program projects, supporting the purchase of agriculture infrastructure and equipment, along with expansion of greenhouse vegetable production. The Yukon Government Agricultural Branch has also developed the *Yukon Agricultural Research Plan*, identifying greenhouses as a key area of study in both of the most recent published reports (Yukon Agriculture Branch 2018; Yukon 2018).

The State of the Industry report notes the steadily increasing agricultural activities in First Nation communities, as First Nation governments recognize the important role agriculture plays in addressing concerns around food security, protecting traditional foods, ensuring healthy food choices, and building community self sufficiency (Yukon Agriculture Branch, 2018, p.21). Projects such as the Little Salmon Carmacks First Nation community greenhouse, and the Tr'ondëk Hwëch'in teaching and working farm are among the multiple recent examples of First Nation communities desiring to build agricultural capacity in Yukon (Yukon Agriculture Branch, 2018). Also indicative of growing interest in community-based agriculture, five First Nation communities and two non-First Nation community gardens received Canadian Agricultural Partnership grant funding in 2019-2020 alone (Canadian Agricultural Partnership, 2020).

5.0 Indigenous Communities Impact

Yukon is home to 14 Yukon First Nations, 11 of which have signed modern treaties (Yukon n.d.). First Nations with modern treaties are responsible for making laws and decisions on their land, which emcompasses geothermal projects and agricultural infrastructure.

Literature on the role of Indigenous communities in emerging renewable energy projects shows that Indigenous communities are motivated to take on an active role in the development of these projects in pursuit of self-governance and economic development (Karanasios & Parker 2018). Further to this, Indigenous peoples are championing efforts in renewable energy efficiency, conservation, and development in Canada for a multitude of reasons - one being to address food insecurity (Stefanelli et al. 2018). There has been recent interest from Yukon First Nations into exploratory research of geothermal potential, including Kluane First Nation, Liard First Nation, and Teslin Tlingit First Nation (Natural Resources Canada 2021). Another example is that of a First Nation community forming a partnership to develop a geothermal resource, as seen with the Carmacks Development Corporation and Eavor™ Yukon partnership (Eavor 2020).

As a counterpoint, Indigenous communities are particularly vulnerable to natural resource development due to both their cultural and economic dependence on both land and water resources (Atlin & Gibson 2017). Geothermal energy projects have a high capital investment need; which may limit opportunity or have adverse impacts on Indigenous communities. Historically, Indigenous communities have faced challenges relating to economic security.

Economic security has impacts on quality of life, and public services available within a community (Hossain & Lamb 2019).

Indigenous knowledge of what constitutes sustainability is “produced contextually, locally, and is based on the experience of multiple generations” (Virtanen et al. 2020, p.78). ‘Story’ across indigenous cultures teaches how to care and relate to the land, stewardship, caretaking and guardianship (Whyte et al. 2015; Virtanen et al. 2020). The nature of reciprocity and interconnectedness between all beings (human and non-human (animals, plants), sacred places, the elements) among other indigenous ways of knowing are incorporated into the relationships needed for communal well-being (Whyte et al. 2015; Virtanen et al. 2020; Vásquez-Fernández & Ahenakew pii tai poo taa 2020).

Collaboration and cooperation are the keys to incorporate Indigenous methodologies/protocols into sustainable development projects and the only way to find synthesis across knowledge systems. Recognizing each place has its own set of beings and relationships, development of respectful “inter-being-relationality” (Vásquez-Fernández & Ahenakew pii tai poo taa 2020) need to be based where the relationships are cultivated. Success of many Indigenous health and food initiatives have been correlated with the presence of and connection to “program champions” (Skinner et al. 2014, Thompson et al. 2018). This is highlighted in Oji-Cree First Nation Hoop House garden in the Wapekeka community in northern Ontario (Thompson et al. 2018), as well as in the Red Earth Garden which is part of Meskwaki Food Sovereignty Initiative in Iowa, USA (Whyte et al. 2015). In order for the proposed geothermal energy and food production system to succeed, relationship-building must be a foundational principle of the project.

Food and energy systems are closely linked, especially in energy-intensive food production and distribution systems (Loring et al. 2013). These interdependencies and interrelations are highlighted with the United Nations WEF nexus. Ideally, security of these systems can be mutually supportive; however, trade-offs are often needed (Loring et al. 2013). There are multiple frameworks that benefit the analysis of the food, water and energy systems (Barrett 2010; Cook and Baker 2012) of which many have some variation of availability, access, utilization and stability (Loring et al. 2013).

From a systems perspective, geothermally-heated greenhouse offers mutually supportive initiatives for energy and food production. Availability, access, stability and utilization of food and energy are improved. Further, the carbon-emissions associated with the energy-foods systems currently active in proof-of-concept test locations can be reduced. In studying community greenhouse gardening in Kuujjuaq in Nunavut, Lamalice et al. (2018) focused on food and energy security and concluded that a “deeper understanding of the linked social and ecological dynamics of food and energy systems…across the Canadian Arctic are needed” (p.338). Addressing food and energy challenges as linked systems will aid in making more efficient policies and successful project development.

6.0 Conclusion

Geothermal power is an often overlooked power source that has the advantage of 24-hour power generation, favourable acceptance among First Nation and non-First Nation groups (Natural Resources Canada 2021; Canadian Geothermal Energy Association 2016), and opportunities for waste-heat optimization. Geothermal resources in Canada have been largely under-utilized due to high costs and exploratory risk. Recent developments in advanced geothermal systems have decreased seismic and exploratory risks of developing geothermal resources. Modeling conducted by the authors shows significant agricultural benefit if geothermal can be utilized to heat greenhouses. This would strengthen the Yukon Agriculture Branch's local food production strategy and decrease reliance on costly, high emission-based and often unreliable long-haul produce delivery.

The WEF nexus and the interwoven nature of energy and food policy presents a compelling argument to renew interests in developing geothermal resources in Yukon. As Canada sets policies to address climate change, success in achieving a low carbon transition will likely depend on rapid adoption of renewable energy generation solutions. Equally important in policy development is consideration of a just transition for under-represented northern communities. This paper highlights the potential synergies that exist between geothermal resource development and agricultural capacity of northern and First Nation communities, providing improved protection of traditional foods and increased First Nation self-reliance for energy generation. Recognizing the clear benefits of strengthening geothermal specific policies will undoubtedly result in a strengthened ability for Canada to achieve a transition to sustainable development.

Acknowledgements

Authors are scholarship recipients of CREATE REDEVELOP Grant #386133824, a collaborative research and training experience in responsible energy development funded by NSERC. We would like to extend a special thank you to Dr. Celia Kennedy, Dr. Jennifer Winter, Jeanine Vany, Dr. Robert Shcherbakov, Chief Sharleen Gale, and all REDEVELOP members for their guidance throughout this project.

Bibliography

ATCO Electric Yukon. 2020. “Independent Power Production.” ATCO Electric Yukon. https://www.atcoelectricyukon.com/en-ca/our-services/independent-power-production.html

Atlin, Cole , Robert Gibson. 2017. “Lasting regional gains from non-renewable resource extraction: The role of sustainability-based cumulative effects assessment and regional planning for mining development in Canada.” *The Extractive Industries and Society* 4, no. 1 (January), 36-52. https://doi.org/10.1016/j.exis.2017.01.005

Bain, Graham, Bryn Davies. 2020. “Geothermal Primer: Is Geothermal Gaining Steam?”. T*he Houston Geological Society Bulletin* 63, no. 3 (November): 19. http://archives.datapages.com/data/HGS/vol63/063003/19_hgs630019.htm

Barrett, Christopher B. 2010. “Measuring food insecurity.” *Science* 327, no.5967 (February), 825-828. DOI: 10.1126/science.1182768

British Columbia. n.d. “Geothermal Regulations”. Government of British Columbia. Accessed April 4, 2021. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/renewable-energy/geothermal-energy/regulatory-information

Bush, Elizabeth, & Donald S. Lemmen (Eds.). 2019. “Canada's Changing Climate Report”. Government of Canada. https://changingclimate.ca/CCCR2019/

Canada. 2019. “Reducing reliance on diesel”. Government of Canada. https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/reduce-emissions/reducing-reliance-diesel.html

---. 2020. “Clean Energy for Rural and Remote Communities: BioHeat, Demonstration & Deployment Program Streams”. Government of Canada. https://www.nrcan.gc.ca/reducingdiesel

Canadian Geothermal Energy Association. 2016. “The Yukon Geothermal Opportunities and Applications Report”. Canadian Geothermal Energy Association. https://www.cangea.ca/store/p122/Yukon_Geothermal_Opportunities_and_Applications_Report_2016.html

CBER, Envint, and V3 Energy. 2016. “Yukon Energy 2016 Resource Plan Appendix 5.9 Wind Site Inventory.” Yukon Energy. https://yukonenergy.ca/energy-in-yukon/electricity-in-2030/2016-resource-plan

Cook, C. and K. Bakker. 2011. “Fresh water-related indicators in Canada: An inventory analysis.” *Canadian Water Resources Journal*, no.22, 94-102.

Croft, Dave. 2020. “Yukon First nation turns to farming to help ensure food security.” CBC News North: https://www.cbc.ca/news/canada/north/yukon-na-cho-nyak-dun-farm-food-1.5621706

Delormier, Treena, Kahente Horn-Miller, Alex M. Mcomber, Kaylia Marquis. 2017. “Reclaiming food security in the Mohawk Community of Kahnawà:ke through Haudenosaunee responsibilities”. M*aternal and Child Nutrition* 13, no. 3, (January), 1-14. https://doi.org/10.1111/mcn.12556

Eavor. 2020. “Eavor Yukon and Carmacks Development Corporation Reach Agreement on bringing Eavor’s Green Baseload Energy Solution to the Yukon”. Eavor. https://eavor.com/press-release/eavor-yukon-and-carmacks-development-corporation-reach-agreement-bringing-eavors

Fraser, T., M. Colpron, C. Relf. 2019. “Evaluating geothermal potential in Yukon through temperature gradient drilling”. Yukon Exploration and Geology 2018, K.E. MacFarlane (ed.): 75–90.

Garfield, Leanna. 2017. “Food prices are insanely high in rural Canada, where Ketchup costs $14 and Sunny D costs $29”. Business Insider. https://www.businessinsider.com/food-prices-high-northern-canada-2017-9

Genest, Miche. 2016. “Farming helps First Nations reconnect with the land.” Yukon News: https://www.yukon-news.com/life/farming-helps-first-nations-reconnect-with-the-land/

Grasby, S. E., D. M. Allen, S. Bell, Z. Chen, G. Ferguson, A. Jessop, M. Kelman, M. Ko, K. Majorwicz, M. Moore, J. Raymond, R. Therrien. 2012. “Geothermal Energy Resource Potential of Canada, Geological Survey of Canada, Open File 6914 (revised)”. Government of Canada. https://doi.org/10.4095/291488

Hein, Treena. 2016. “Growing in the north: Local producers and communities are making the cultivation of fresh fruit and vegetables feasible in Northern Canada.” Food in Canada. https://www.foodincanada.com/features/growing-in-the-north/

Hossain, Belayet, Laura Lamb. 2019. “Economic Insecurity and Psychological Distress among Indigenous Canadians”. *Journal of Developing Areas* 53, no. 1 (2019): 109-125. DOI: 10.1353/jda.2019.0007

Karanasios, Konstantinos, Paul Parker. 2018. “Tracking the transition to renewable electricity in remote indigenous communities in Canada”. *Energy Policy* 118 (July), 169-181. https://doi.org/10.1016/j.enpol.2018.03.032

KGS Group. 2016. “Yukon Energy 2016 Resource Plan Appendix 5.10 Geothermal Review and

Site Inventory.” Yukon Energy. https://yukonenergy.ca/energy-in-yukon/electricity-in-2030/2016-resource-plan

Lamalice, Annie, Didier Haillot, Marc-André Lamontagne, Thora Martina Herrmann, Stéphane Gibout, Sylvie Blangy, Jean-Louis Martin, Véronique Coxam, Julien Arsenault, Lara Munro, François Courchesne. 2018. “Building food security in the Canadian Arctic through the development of sustainable community greenhouses and gardening.” *Éoscience* 23, no. 4 (July): 325-341. doi:10.1080/11956860.2018.1493260

Legislative Assembly of Alberta. 2020. “Bill 36: Geothermal Resource Development Act”. https://www.assembly.ab.ca/assembly-business/bills/bill?billinfoid=11871&from=bills

Leitch, Aleitta, Sara Hastings-Simon, Brendan Haley. 2017, “Heat Seeking: Alberta’s geothermal industry potential and barriers”. Pembina Institute. https://www.pembina.org/reports/heat-seeking.pdf

Loring, Philip A., S. Craig Gerlach, Henry P. Huntington. 2013. “The new environmental security: Linking food, water and energy for integrative and diagnostic social-ecological research”. *Journal of Agriculture, Food Systems and Community Development* 3, no. 3 (July), 55-61. https://doi.org/10.5304/jafscd.2013.034.005

Lund, John W., DereK H. Freeston, Tonya L. Boyd. 2005. “Direct application of geothermal energy: 2005 Worldwide review”. *Geothermics* 34, no. 6 (December), 691-727. https://doi.org/10.1016/j.geothermics.2005.09.003

Majorowicz, Jacek , Stephen E. Grasby. 2019. “Deep geothermal energy in Canadian sedimentary basins VS. Fossils based energy we try to replace - Exergy [KJ/KG] compared”. *Renewable Energy* 141 (October), 256-277. https://doi.org/10.1016/j.renene.2019.03.098

Morgan, Geoffrey. 2020. “Saskatchewan driller hits 'gusher' with ground-breaking geothermal well that offers hope for oil workers”. Financial Post. https://financialpost.com/commodities/energy/saskatchewan-driller-hits-gusher-with-ground-breaking-geothermal-well-that-offers-hope-for-oil-workers

Natural Resources Canada. 2021. Natural Resources Canada Announces $2 Million in Funding For Geothermal Exploration in Yukon. Geothermal Canada. https://www.geothermalcanada.org/news/2021/3/11/natural-resources-canada-announces-2-million-in-funding-for-geothermal-exploration-in-yukon

Powell, Brenda Heelan. 2020a. “Gaining Steam: A Regulatory and Policy Framework for Geothermal Energy Development in Alberta: Module 1: Geothermal Energy and Alberta’s Current Regulatory Landscape”. Environmental Law Centre (Alberta) Society.

https://elc.ab.ca/wp-content/uploads/2020/10/Geothermal-Energy-Module-1-Geothermal-Energy-and-Albertas-Current-Regulatory-Landscape.pdf

---. 2020b. “Gaining Steam: A Regulatory and Policy Framework for Geothermal Energy Development in Alberta: Module 2: The Missing Pieces in Alberta’s Regulatory Landscape and a Path Forward for Geothermal Energy Development”. Environmental Law Centre (Alberta) Society. https://elc.ab.ca/wp-content/uploads/2020/10/Geothermal-Energy-Module-2-The-Missing-Pieces-in-Albertas-Regulatory-Landscape-and-a-Path-Forward-for-Geothermal-Energy-Development.pdf

Richter, Alexander. 2021. “Clarke Lake geothermal project in BC, Canada going ahead”. Think Geothermal. https://www.thinkgeoenergy.com/clarke-lake-geothermal-project-in-bc-canada-going-ahead/

Sharma, Pritee, Salla Nithyanth Kumar. 2020. “The global governance of water, energy, and food nexus: allocation and access for competing demands.” *International Environmental Agreements: Politics, Law & Economics* 20, no. 2 (June), 371-399. Doi: 10.1007/s10784-020-09488-2

Skinner, Kelly, Rhona M. Hanning, Ellen Desjardins, Leonard JS Tsuji. 2013. “Giving voice to food insecurity in a remote indigenous community in subarctic Ontario, Canada: traditional easy, ways to cope, ways forward”. *BMC Public Health* 13, no. 427 (May). doi:10.1186/1471-2458-13-427

Solvest. 2016. “Yukon Energy 2016 Resource Plan Appendix 5.11 Solar Site Inventory.” Yukon Energy. https://yukonenergy.ca/energy-in-yukon/electricity-in-2030/2016-resource-plan

Soule, Meredith J., Abebayehu Tegene, Keith D. Wiebe. 2000. “Land Tenure and the Adoption of Conservation Practices”. *American Journal of Agricultural Economics* 82, no.4 (November), 993-1005. https://doi.org/10.1111/0002-9092.00097

Stefanelli, Robert. D., Chad Walker, Derek Kornelsen, Diana Lewis, Debbie H. Martin, Jeff Masuda, Chantelle A.M. Richmond, Emily Root, Hannah Tait Neufeld, Heather Castleden. 2018. “Renewable energy and energy autonomy: how Indigenous peoples in Canada are shaping an energy future”. *Environmental Reviews* 27, no. 2 (September), 95-105. https://doi.org/10.1139/er-2018-0024

Steffansson, Valgurdur. 2000. “The Renewability of Geothermal Energy”. Proceedings World Geothermal Congress 2000. https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2000/R0776.PDF

Tarasuk V, Mitchell A. 2020. “Household Food Insecurity in Canada, 2017-2018”. PROOF. 7

https://proof.utoronto.ca/resources/proof-annual-reports/household-food-insecurity-in-canada-2017-2018/

United Nations. n.d. “Water, Food and Energy”. Accessed February 22, 2021. https://www.unwater.org/water-facts/water-food-and-energy/

United States Food and Drug Administration. 2017. “Nutrition Information for Raw Vegetables”. United States Government. https://www.fda.gov/food/food-labeling-nutrition/nutrition-information-raw-vegetables

Vásquez-Fernández, Andrea, Cash Ahenakew pii tai poo taa. 2020. “Resurgence of relationality: reflections on decolonizing and indigenizing ‘sustainable development’”. Indigenous conceptualizations of ‘sustainability’. *Current Opinion in Environmental Sustainability* 43, no. 43 (April), 65-70. https://doi.org/10.1016/j.cosust.2020.03.005

Virtanen, Pirjo Kristiina, Laura Siragusa, Hanna Guttrom. 2020. “Introduction: toward more inclusive definitions of sustainability”. *Current Opinion in Environmental Sustainability* 43, (April), 77-82. https://doi.org/10.1016/j.cosust.2020.04.003

Whyte, Kyle Powys, Joseph P. Brewer II, Jay. T. Johnson. 2015. “Weaving Indigenous science, protocols and sustainability science”. *Sustainability Science* 43*,* no.11 (April), 25-32. https://doi.org/10.1016/j.cosust.2020.04.003

Yukon. n.d. “Find out about Yukon First Nations”. Government of Yukon. Accessed February 6, 2021. https://yukon.ca/en/find-out-about-yukon-first-nations

---. 2002. Oil and Gas Act. RSY 2002, c.162. https://legislation.yukon.ca/acts/oiga_c.pdf

---. 2004. Oil and Gas Geoscience Regulation. O.I.C. 2004/156. https://legislation.yukon.ca/regs/oic2004_156.pdf

---. 2006. Vision for Yukon Agriculture: 2006 Yukon Agriculture Policy. Yukon Agriculture Branch. https://yukon.ca/sites/yukon.ca/files/emr/emr-2006-yukon-agriculture-policy.pdf

---. 2008. Oil and Gas Royalty Regulation. O.I.C. 2008/25. https://legislation.yukon.ca/regs/oic2008_025.pdf

---. 2009. “Energy strategy for Yukon”. Government of Yukon. https://yukon.ca/en/energy-strategy-yukon

---. 2016. “Local Food Strategy for Yukon”. Government of Yukon. https://yukon.ca/en/local-food-strategy-yukon

---. 2018. “Yukon Agriculture Research Plan”. Government of Yukon.

https://yukon.ca/sites/yukon.ca/files/emr/emr-yukon-agriculture-research-plan-2018-2023.pdf

---. 2020. “Our Clean Future: A Yukon strategy for climate change, energy and a green economy”. Government of Yukon. https://yukon.ca/en/our-clean-future-yukon-strategy-climate-change-energy-and-green-economy

Yukon Agricultural Association. n.d. “About Yukon Agriculture’. Accessed March 3, 2021. https://yukonag.ca/resources/about-yukon-agriculture/

Yukon Agriculture Branch. 2018. “Yukon AgricultureState of the Industry Report 2013 to 2017. Government of Yukon Department of Energy Mines and Resources Agriculture Branch.” https://yukon.ca/sites/yukon.ca/files/emr/emr-agriculture-state-of-the-industry-2013-2017.pdf

Yukon Energy. 2017. “Yukon Energy 2016 Resource Plan.” https://yukonenergy.ca/energy-in-yukon/electricity-in-2030/2016-resource-plan

---. 2020. “10-Year Renewable Electricity Plan Technical Report.” Yukon Energy. https://yukonenergy.ca/energy-in-yukon/electricity-in-2030/our-draft-10-year-plan