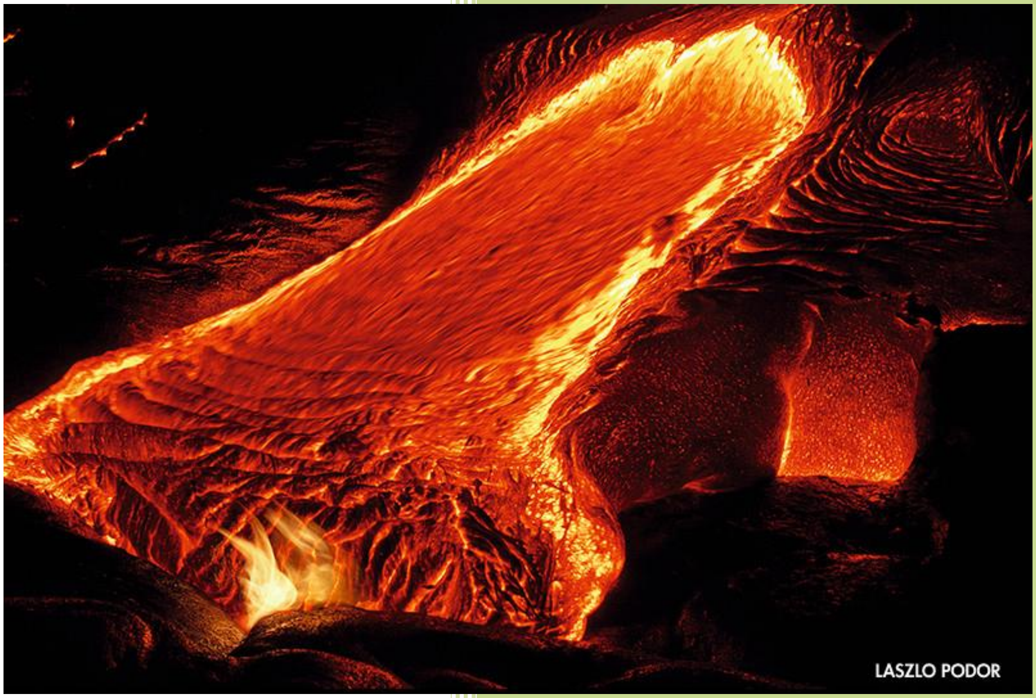
Geothermal for Alberta? A Case for Caution



Friends of Science Society

6/20/2016

Executive Summary

CANGEA - the Canadian Geothermal Energy Association – has been making a concerted case for the development of Enhanced Geothermal Systems (EGS) in Alberta. They propose to use existing abandoned oil wells and repurpose them for geothermal electricity power production (at low temperatures) and as sites for geothermal heat exchange for local heating – such as building a greenhouse above or adjacent to the well.

In this report, Friends of Science Society reviews the potential of geothermal in Alberta and explores the differences between geothermal in well-known spots like Iceland and the differences in Canada that make geothermal a less likely power producer for Alberta.

Additional literature is reviewed regarding various Enhanced Geothermal Systems around the world.

This is intended to be a plain language document for the average reader though the information has been compiled with the assistance and direction of expert Professional Geophysicists, Professional Geologists, Professional Engineers and energy economists.

In general, there may be some potential in repurposing old wells, however due to serious concerns that are unique to the Alberta geology – specifically the risk of deadly hydrogen sulfide (H_2S) leaks along with deep well high pressure risks– we strongly recommend that reasonably long-term pilot work on a demo project that properly evaluates all costs and risks, be undertaken before proceeding down this path.

Though somewhat different in nature, Australia's Geodynamics "Cooper Basin" Enhanced Geothermal System (EGS) [1] project offers numerous lessons. MIT reviews a number of EGS projects.[2] We would hope a similarly thorough assessment of any Alberta pilot project be documented, reviewed and approved or rejected, before any further initiatives on the CANGEA proposals for EGS for Alberta or Canada.

This is an independent report. Friends of Science Society is a registered non-profit society, funded by individual members, with no corporate members, and it does not represent any industry. This is an educational, non-commercial work.

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[1] http://www.geodynamics.com.au/Geodynamics/media/GDY-PDF/Announcements%202014/COM-FN-OT-PLN-01166-1-0-HGP-Field-Development-Plan-for-General-Distribution.pdf

[2] https://mitei.mit.edu/system/files/geothermal-energy-full.pdf

CONTENTS

1 Introduction – A Plain Language Document for the Public 3
2 What is Geothermal Energy? 4
3 It Works for Iceland – Why not in Alberta or Canada? 6
4 Iceland is Tiny, Sits on New Magma, And is Limited in Scale of Production of Geothermal Power 7
5 Geology of Alberta 13
6 Cangea Claims are Big – But Not One Operational Pilot …Yet 21
7 Global Geothermal 26
8 IPCC – To Decarbonize or Not To Decarbonize 28
9 Social Costs of Carbon are Net Beneficial 28
10 Conclusion 30

Photo/Illustration credit; Many geological images in this report are from downloadable files of "Four Billion Years and Counting" – http://www.fbycbook.com/#!home/mainPage *"Four Billion Years and Counting"* Canadian Federation of Earth Sciences/Fédération Canadienne des Sciences de la Terre http://www.cfes-fcst.ca/ .The lower banner has been removed in subsequent images in this report to reduce distraction. The name of the copyright holder remains. Nexen sponsored the book "Four Billion Years…" but is not affiliated with this report or Friends of Science Society.

Geothermal for Alberta?
A Case for Caution

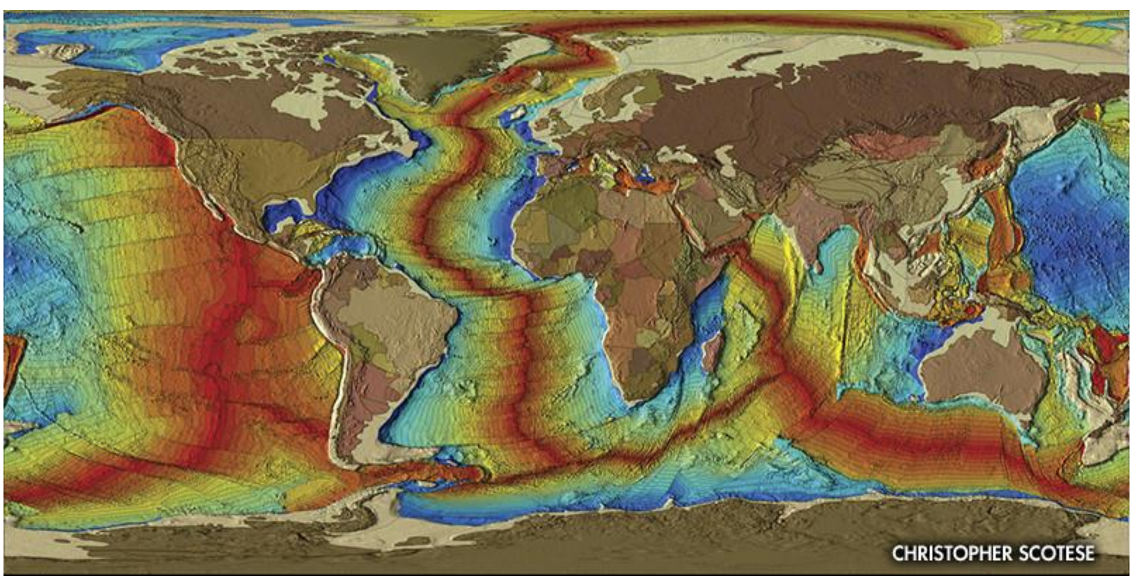
1 INTRODUCTION – A PLAIN LANGUAGE DOCUMENT FOR THE PUBLIC

"Canada has not yet produced a single watt of geothermal energy."

- Thana Boonlert, CANGEA Ambassador, Speaker's Corner Debate May 8, 2016, Calgary[3]

CANGEA – the Canadian Geothermal Energy Association – has been making a concerted case for the development of Enhanced Geothermal Systems (EGS) in Alberta. Pembina Institute claimed in their Alberta Climate Panel brief and in *"Power to Change"* that Alberta had *"120 GW of potential demonstrated geothermal power (Canadian Geothermal Energy Association, 2013)."* [4] [5] CANGEA claims they can "*install 5,000 MW of geothermal baseload power by 2025"* and *"replace, in its entirety, the installed coal-fired power plant fleet in Alberta and replace all of the coal and natural gas fired power plants in Saskatchewan*."[6] If the potential is so great, and eight times existing Alberta capacity, why has it not been exploited before by investors?

The key word is 'potential.' The challenge is self-evident in the map below.[7] The red lines show tectonic plate lines where earth's magma (below surface lava) rises closest to the surface. It is obvious that Iceland is a good candidate for geothermal energy – and that Western Canada is not. This does not mean geothermal is impossible in Canada or Alberta; it does mean the *potential* is very far from being tapped or even demonstrated.



[3] https://youtu.be/PIuXMLtmzgk

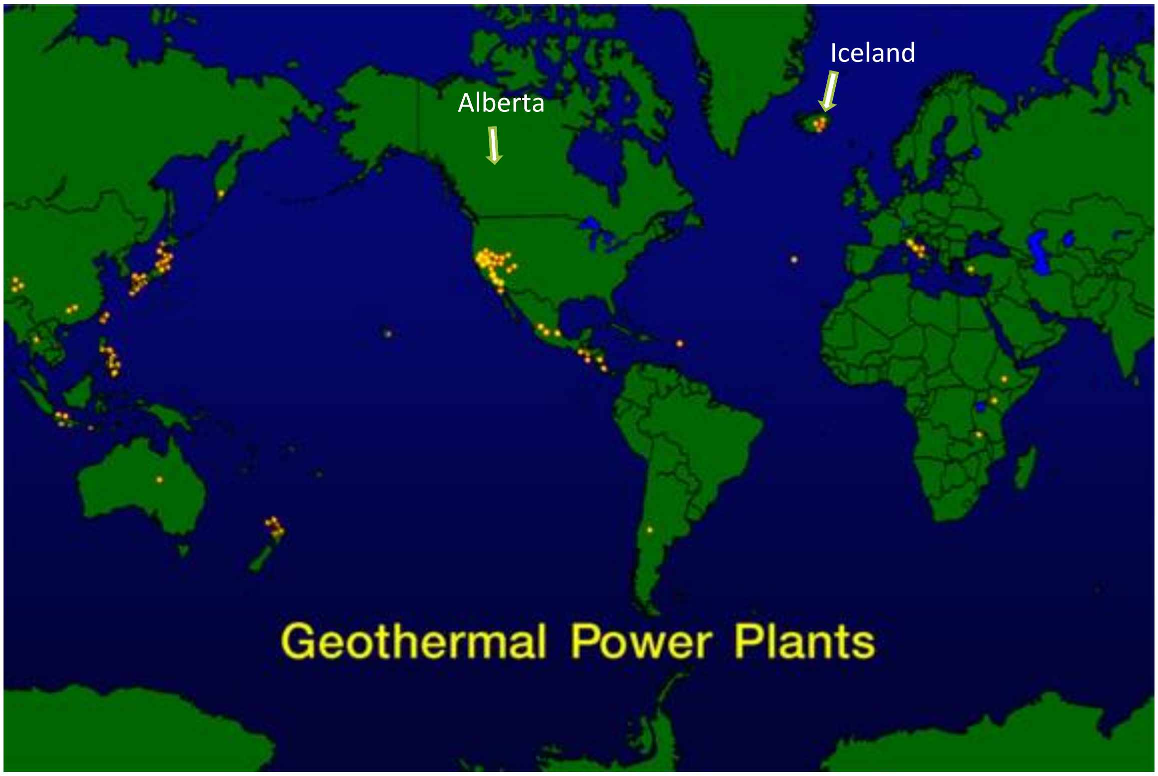
[4] http://cape.ca/wp-content/uploads/2015/02/Pembina-AB-coal-report-May-2014.pdf

[5] https://www.pembina.org/reports/albertaclimatepanel-2015-pembinabrief.pdf

[6] http://www.cangea.ca/geothermal-fact-sheet.html

[7] http://www.fbycbook.com/#!home/mainPage *"Four Billion Years and Counting"* Canadian Federation of Earth Sciences/Fédération Canadienne des Sciences de la Terre http://www.cfes-fcst.ca/

The yellow and red dots on the map below, follow closely along the red marked tectonic plate lines shown in red in the map above, because for the most part, geothermal is about 'location' – near a natural fissure or fault where hot magma, convection heat or superheated steam (natural or from pumped cold water on hot stone) from the earth's interior, is easily and naturally accessible at or near the surface. Note the complete absence of such facilities in Canada and much of the world for that matter.



2 WHAT IS GEOTHERMAL ENERGY?

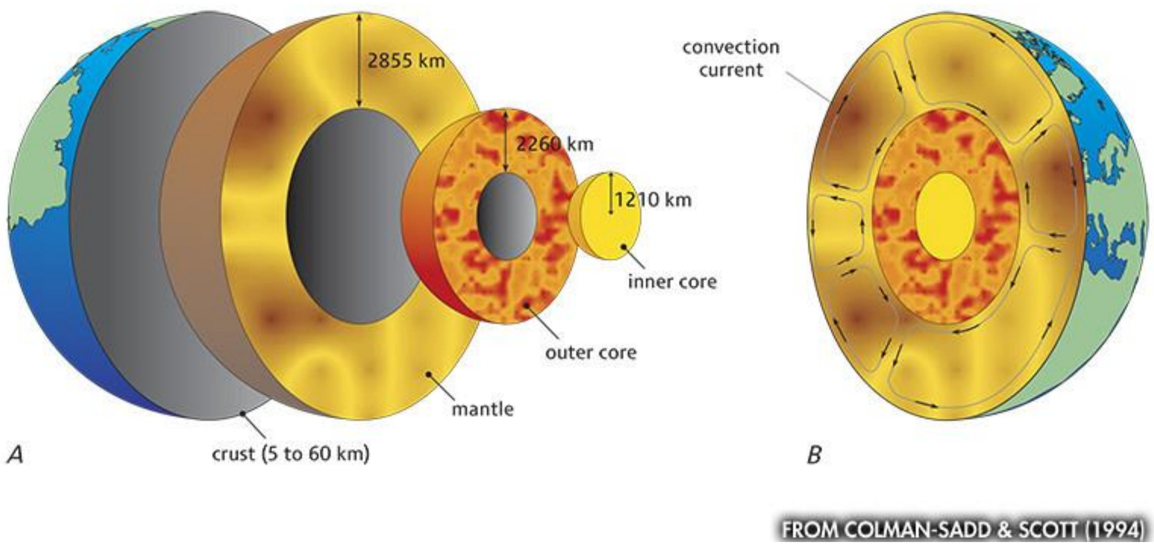
The earth's interior is filled with molten lava which most people are familiar with due to seeing volcanic eruptions. The earth's interior temperatures are about 5,500°Celsius (C). The 'mantle'[8] of the earth is the solid rock layer surrounding the molten core. As most people know, 'heat rises' – therefore, simply put, the idea of geothermal energy is to tap into the earth's own naturally heated deep rock layers, usually by either finding near surface or underground pockets of steam, streams or springs of superheated waters, and then using that steam heat to drive power turbines ("wet" geothermal), or by pumping cold water down to hot rocks in order to create steam that is pumped up to a turbine for the same purpose ("dry" geothermal). In general, most of the power plants on the map above are at natural "wet" locations.

The steam drives turbines which in turn produce electrical power, similar to the principles of power generation used by modern coal or natural gas plants, but without the burning of fossil fuels (thus reducing most emissions).

[8] Plain language explanation from National Geographic http://nationalgeographic.org/encyclopedia/mantle/

A good plain language discussion of geothermal (and energy in general) by geophysicist, Prof. Michael Wysession, professor of Earth and Planetary Sciences of Washington University in St. Louis[9] is summarized below.

Though the earth's interior is about the same heat as the photosphere (outside layer) of the sun, the earth's heat travels very slowly through the layers of rock, cooling as it goes. While the sun's light reaches us in about 8 1/3 minutes, it takes hundreds of millions of years for the heat from the earth's core to rise. That heat from the earth gives off about 46 Terawatts (TW) in energy – but this is nothing compared to the power of the incoming sun (at light speed) of 123,000 TW. Part of earth's heat comes from radioactive decay of various isotopes (Potassium 40 [K-40], Thorium 232 [Th-232], Uranium 235 [U-235], Uranium 238 [U-238]) and part of it from rising heat of the molten core. The radioactive decay of the long-lived isotopes which are prevalent in earth's 40 km crust supply much of earth's stable temperature. The mantle, about 3,000 km thick, also contains these isotopes. The core – liquid and solid exude heat and magma which slowly make their way up through the rock, finding fissures and breaks between tectonic plates where the heat or magma can rise and escape.



[10]Humans presently consume about 18 TW of energy, so the exuding energy from the earth is only 46 TW or about 2 and ½ times that of what people consume. Consequently**, it is unlikely geothermal can ever be a replacement for the energy dense, portable fossil fuels or nuclear power we use today**. However, geothermal is a valuable supplement in places that are naturally suited to its exploitation.

Another kind of geothermal energy can be that of simply tapping into the deep heat of the earth and using it for distributed heating of a region or a facility (i.e. greenhouse, food drying operation) where a stable heat source is required over the long-term with little or no demand for changes in temperature once set.

This document will address the *potential* electricity generation of geothermal in relation to Alberta.

[9] "The Science of Energy: Resources and Power Explained" The Great Courses

[10] http://www.fbycbook.com/#!home/mainPage *"Four Billion Years and Counting"* Canadian Federation of Earth Sciences/Fédération Canadienne des Sciences de la Terre http://www.cfes-fcst.ca/

3 IT WORKS FOR ICELAND – WHY NOT IN ALBERTA OR CANADA?

DeSmogBlog Canada recently produced a video clip in Iceland,[11] demonstrating the effectiveness of geothermal power generation and heating there. Let us not assume that what works in Iceland would work the same way in Canada or Alberta.

> *"DeSmog provides an exciting look into what the future holds for geothermal energy production in Canada by showcasing the outstanding capacity of the Hellisheidi power plant, which has an installed capacity of approx. 300 MWe (electricity) and 150MWth (thermal)."[12]*

Hellisheidi in Iceland is the world's largest geothermal plant.[13] But, it is not that big in the scope of things.

By ThinkGeoEnergy - http://www.flickr.com/photos/thinkgeoenergy/4473298115/, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=10907139

[11] https://youtu.be/OxoILW-ChjM

[12] http://www.cangea.ca/news--featured-information

[13] http://eandt.theiet.org/magazine/2015/05/iceland-geothermal.cfm

The pristine images of Heilisheidi and the happy people enjoying Iceland's hot springs in the DeSmog video are deceptive - tremendous power and danger lies beneath the surface of the earth, particularly in Iceland. The book *"Island on Fire"* documents "The Extraordinary Story of a Forgotten Volcano that Changed the World" which recounts the fire and brimstone horror of the 1783 eruption of Iceland's volcano - Laki. The story is recounted in a Dec. 19, 2007 article in The Economist.[14]

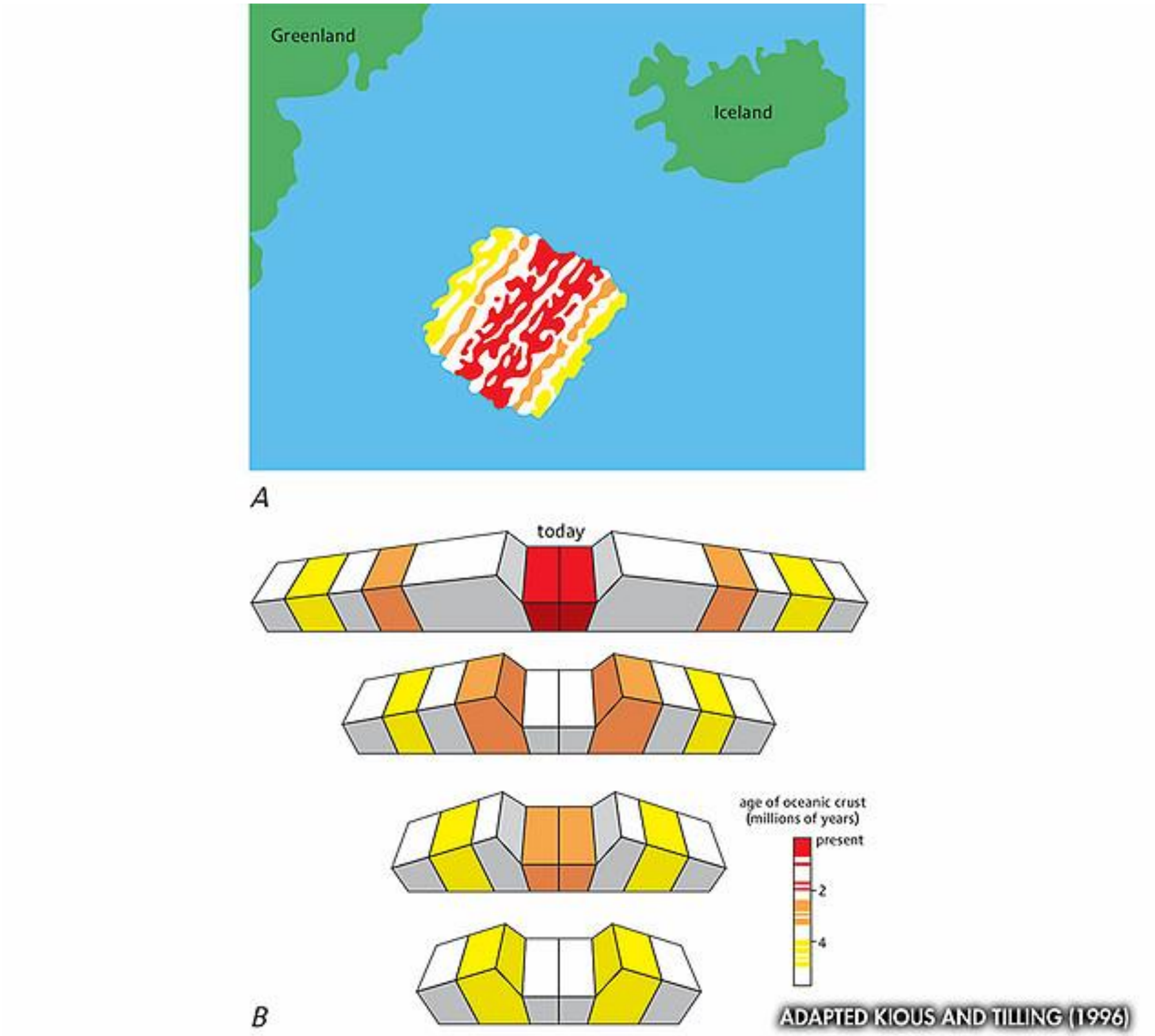
15

Obviously Iceland sits on a very 'hot-spot' near the surface, relatively easy to exploit for heat and power generation. Despite the success of Iceland's geothermal industry, Canadians and Albertans must evaluate the potential based on geology, climate, scale, cost-benefit and risks. This is not an apples-to-apples comparison.

4 ICELAND IS TINY, SITS ON NEW MAGMA, AND IS LIMITED IN SCALE OF PRODUCTION OF GEOTHERMAL POWER

Iceland is a tiny country with no fossil fuels. In terms of size, Iceland is "*490 kilometers (304 miles) from east to west; 312 kilometers (194 miles) from north to south*."[16] Just to put things in perspective, the distance between Calgary and Edmonton in Alberta is 289.9 kilometers. Iceland sits on new, surface level magma formations. It is a geothermal paradise. By contrast, Alberta is part of the 'old continent' (see page 14 below) which means it is tectonically stable (a good thing). Any source of geothermal would be at great depths.

[14] http://www.economist.com/node/10311405
[15] https://stevengoddard.wordpress.com/2010/11/04/eruption-of-laki-1783/
[16] http://www.nationsencyclopedia.com/geography/Congo-Democratic-Republic-of-the-to-India/Iceland.html#ixzz4BOYWvoko



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Also by contrast, Canada, and even Alberta, are vast areas; see how Iceland 'fits into' Canada and Alberta.

[17] http://www.fbycbook.com/#!home/mainPage *"Four Billion Years and Counting"* Canadian Federation of Earth Sciences/Fédération Canadienne des Sciences de la Terre http://www.cfes-fcst.ca/

Iceland's climatic conditions are moderate and stable, with winters going to -1°C, modified by the continuation of the Gulf Stream in the form of the North Atlantic Drift.[18] By contrast, Canada's winter temperatures can be severe, dipping to -40°C or more, with extreme wind chills, sometimes for weeks on end.

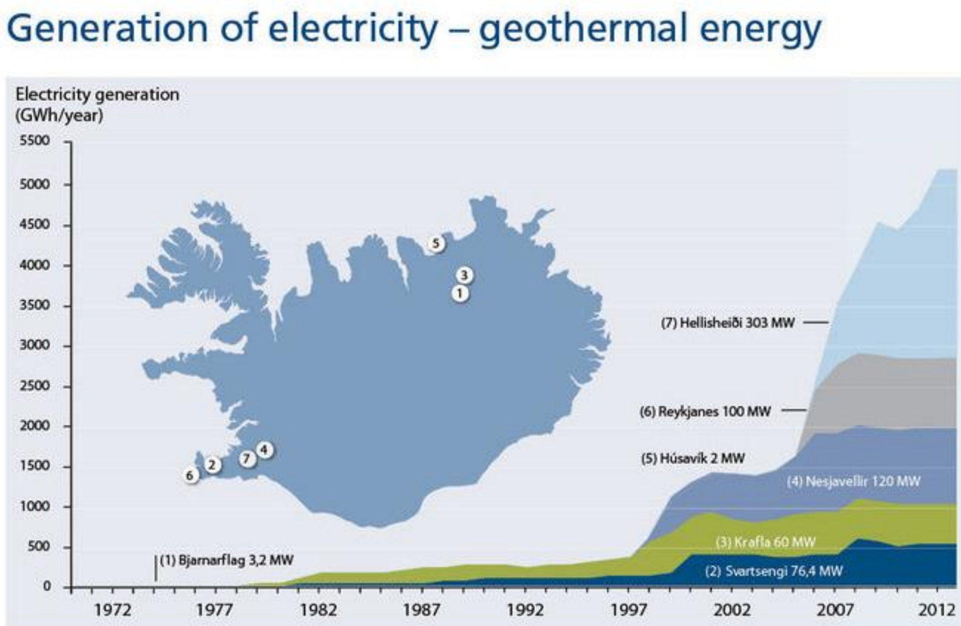
Furthermore, Alberta is a far more diversified industrialized region than the country of Iceland. In Alberta, diversified industries use 75% of the power generated. Alberta exported $121.4 Billion(CDN) in 2014.[19] In Iceland, the aluminum industry consumed 71% of the power in 2011 and total exports were an estimated $5.1 Billion USD in 2012.[20]

These figures suggest that Alberta's priority must be the maintenance of a reliable power grid with full capacity availability for times of winter weather extremes, in order to support industry and jobs, as well as providing safe and comfortable lifestyles for consumers during life-and-death weather extremes. Any proposed changes to the power generation system (and it is a system, designed to run together as a whole) must be reliable, affordable, scalable, and have significant cost-benefit factors.

According to the Alberta Utilities Commission (AUC) total electricity generation in 2014 in Alberta was 80,343 GWh meaning Alberta's power generation is about 4 times that of Iceland.

[18] http://www.nationsencyclopedia.com/geography/Congo-Democratic-Republic-of-the-to-India/Iceland.html
[19] http://www.albertacanada.com/Albertas-Export-Performance-2014.pdf
[20] https://en.wikipedia.org/wiki/Economy_of_Iceland

In Iceland, “The installed generation capacity of geothermal power plants totaled 665 MW_e in 2013 and the production was 5.245 GWh, or 29% of the country's total electricity production.”[21]



As shown below from an Alberta Electric System Operator (AESO) market report, Alberta’s Maximum Capacity (MC) in coal is 6,299 MW and in natural gas 7,227 MW. Albertans require vast power generation capacity, presently some ~90% is provided by affordable, reliable coal and natural gas. There is no easy, cheap or fast replacement for this power.[i]

TNG - Total Net Generation
* Indicates that the value reported in MC column actually represents the asset's MCR

GENERATION			
GROUP	MC	TNG	DCR
COAL	6299	4467	40
GAS	7227	4309	250
HYDRO	894	210	115
OTHER	437	150	0
WIND	1445	41	0
TOTAL	16302	9177	405

For instance, the table above (AESO Market Servlet screenshot of April 19, 2016 17:08) shows that wind has an installed Maximum Capacity of 1,445MW, but on that day and at that time only generated 41 MW. By contrast, coal was putting out over half its installed capacity. Coal provides about 55% of Alberta's electrical energy, because it is reliable, steady and economic.

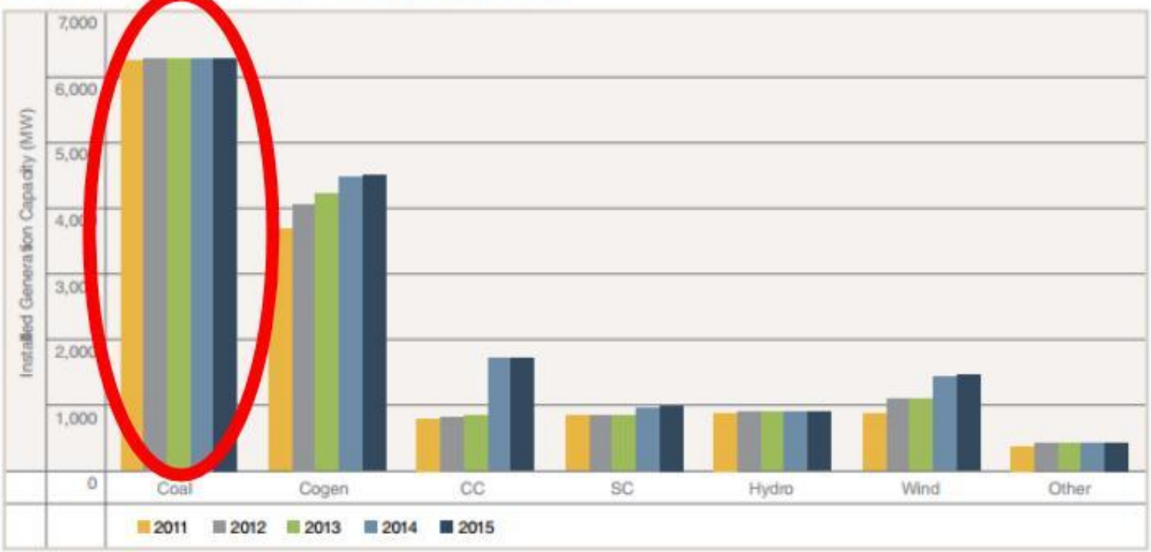
[21] http://www.nea.is/geothermal/electricity-generation/

Installed Generation

Total Generation Capacity Increased One Per Cent

The total installed generation capacity in Alberta increased one per cent to 16,288 MW in 2015. Figure 7 shows the annual installed capacity at the end of each calendar year. Most of the increase in installed capacity over the past year occurred due to the addition of 41 MW of new simple-cycle gas generation and 29 MW of new wind generation.

FIGURE 7: Annual Generation Capacity by Technology



Source: http://www.aeso.ca/downloads/2015_Annual_Market_Stats_WEB.pdf

The geothermal facilities of Iceland shown on the preceding map are also conveniently located adjacent to major centers of population and industrial activity. However, Iceland's population is 1/12th the size of Alberta.

Population Comparison

	Major city Name	**Major City Population**	**National/Regional Population**
Iceland	Reykjavik	120,000	330 680
Alberta	Edmonton Calgary	**877,926** **1,096,833**	Provincial 4,196,457
Canada	Ottawa	870,250	**36,266,775**

Clearly the demand for affordable, reliable power generation in Alberta and Canada are many times that of Iceland, and in Alberta, the access to geothermal heat, except in a few places, is far more complicated than Iceland's open, bubbling hot springs.

Getting Power to the People

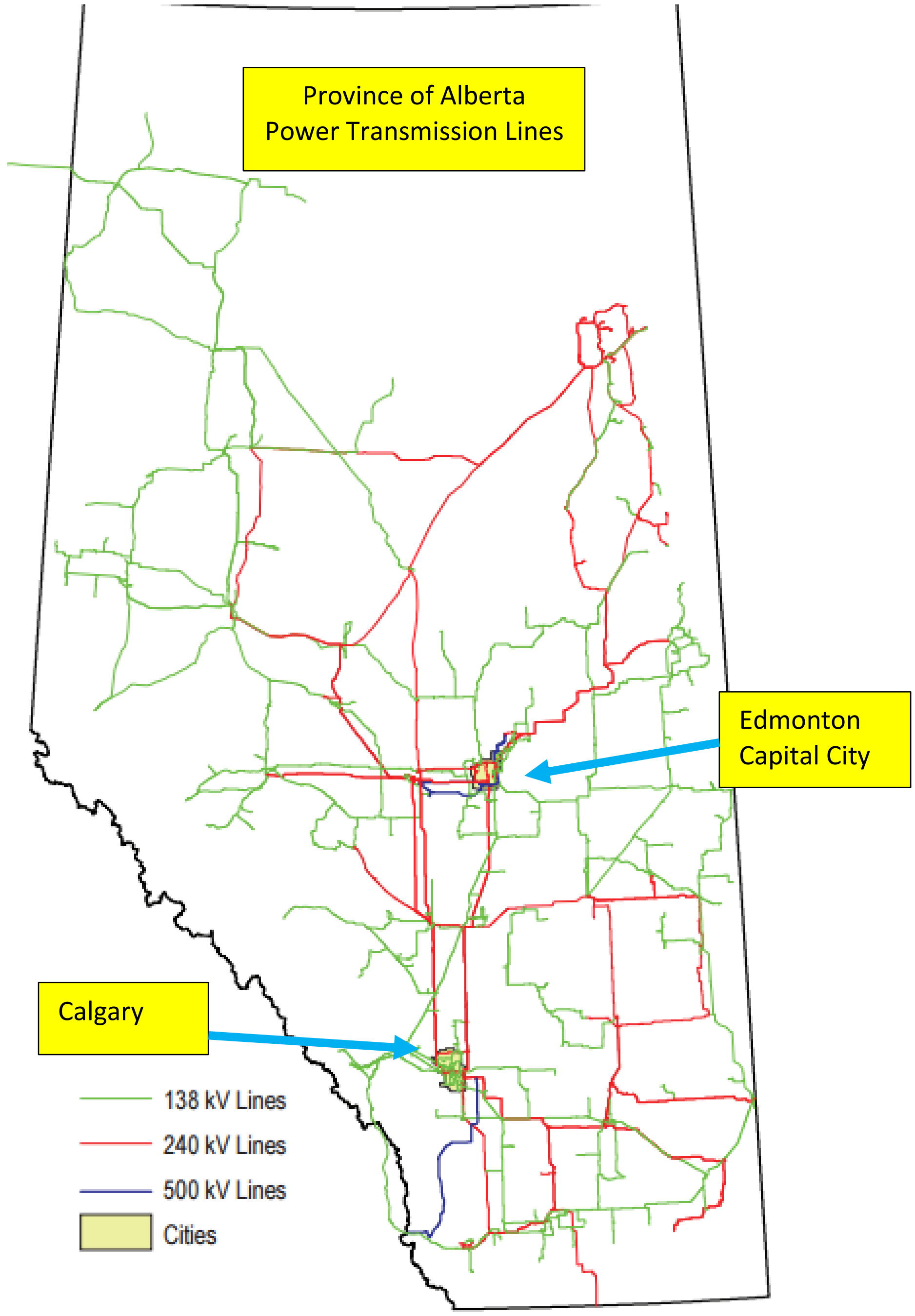
Conversations about the cost of power often address the cost of producing power by a particular type of generation, but they fail to include the distribution, integration and transmission line requirements.

This map shows Alberta's existing power transmission lines.

Of note, the 500 kilovolt (kV) line south from Calgary to Pincher Creek area windfarms cost some $2.2 Billion dollars alone. Yet wind delivers only ~5% of the power in Alberta, despite an installed name-plate capacity of some 1,445 MW. These costs have made 'free' wind quite expensive for consumers.

Until the recent downturn in the economy and oil prices, Alberta's market was expected to grow by about 2.5% every year – equivalent to adding a city the size of Red Deer (pop. ~100,000) every year. This expansion will carry its own needs, costs and grid demands.

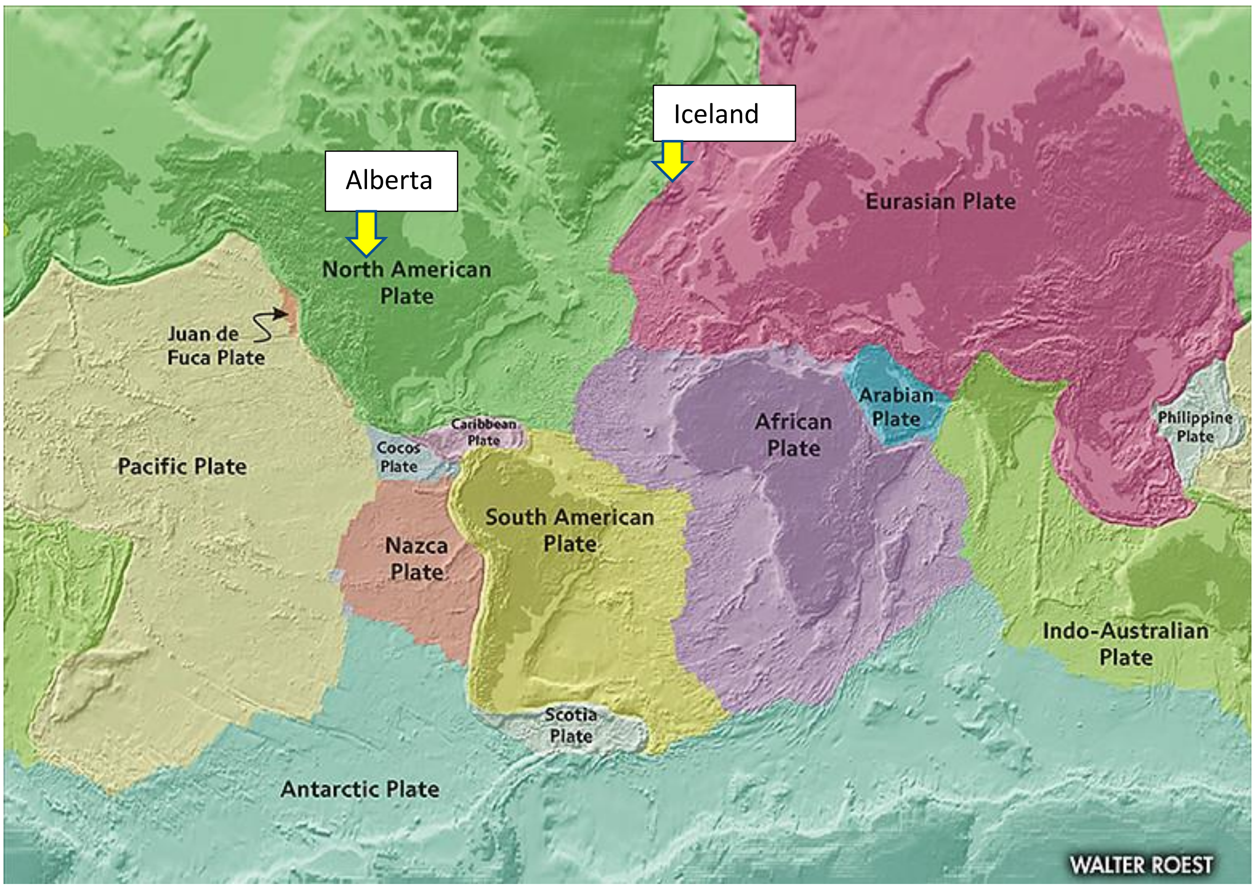
In Alberta, geothermal for commercial scale power generation would be a highly experimental exercise where there is no 'low-hanging fruit' as in Iceland. Let's discuss the challenges.



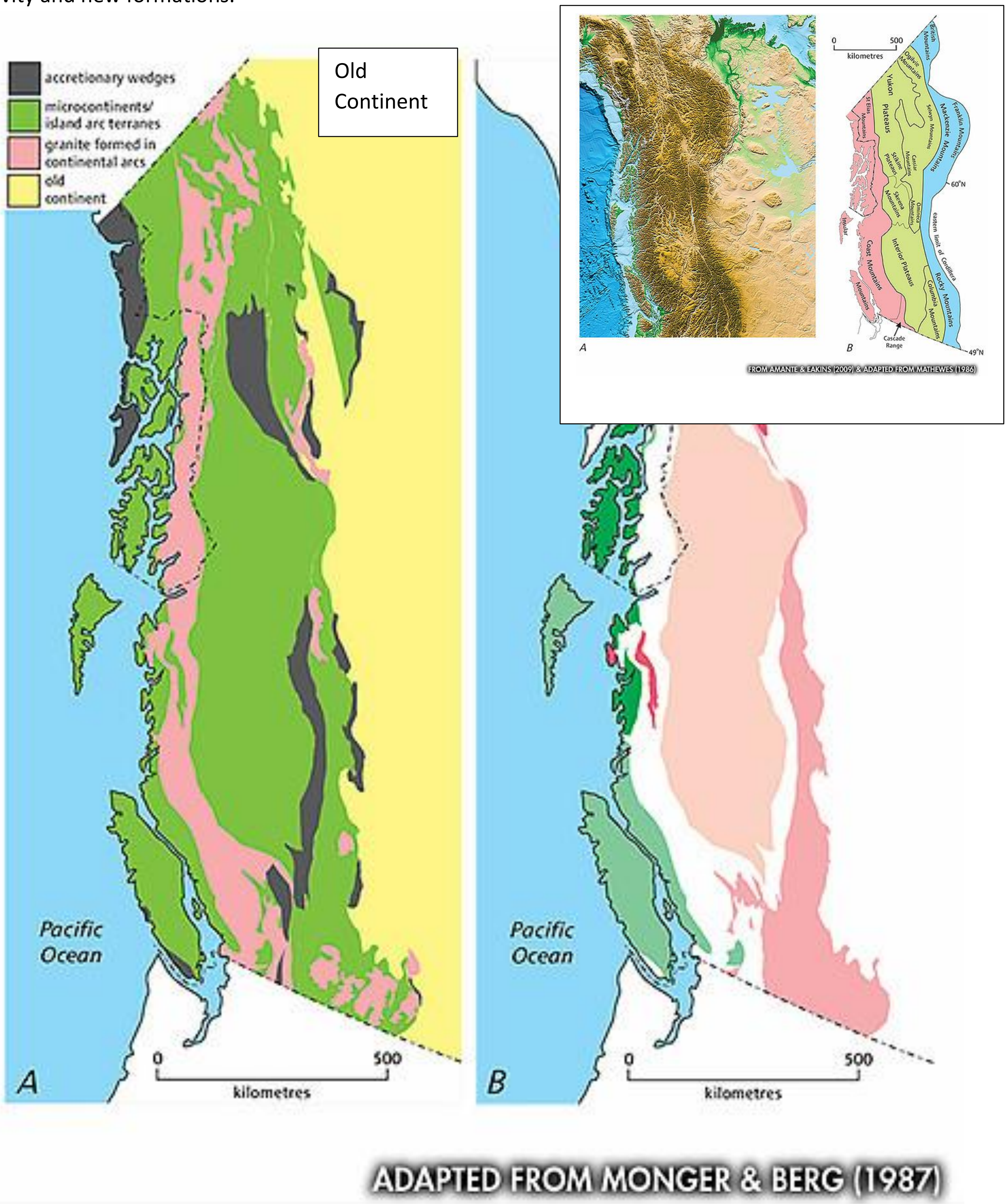
http://www.energy.alberta.ca/Electricity/pdfs/FsElectricityTransmission.pdf

5 GEOLOGY OF ALBERTA

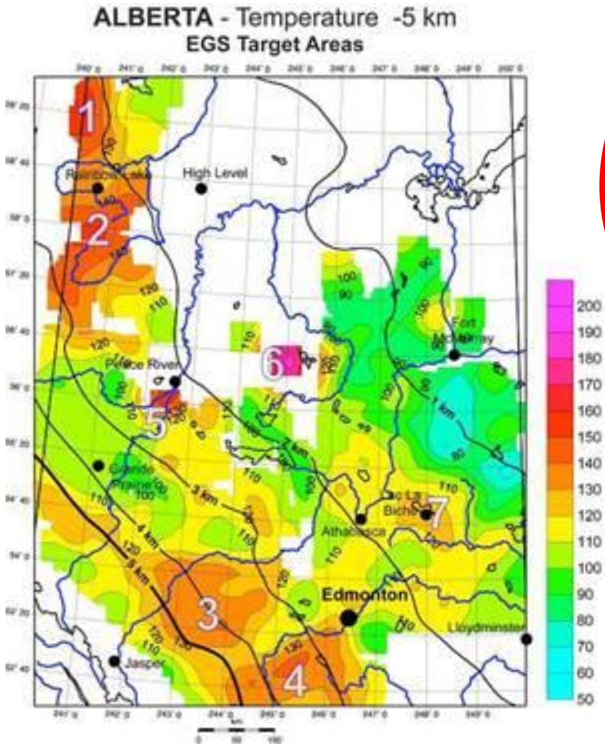
Effective, cost-efficient geothermal relies on "location, location, location" – to coin an old real estate phrase. In this context, it means you have to have a high thermal gradient (convective heat, steam or superheated water sources near surface) like Iceland has, or else you will spend a great deal of money drilling very deep wells to try and reach a suitable location with sufficient heat for geothermal production. If we return to the earth's tectonic plates, we will see that Alberta is in the middle of a solid plate, while Iceland straddles the North American and the Eurasian Plate.

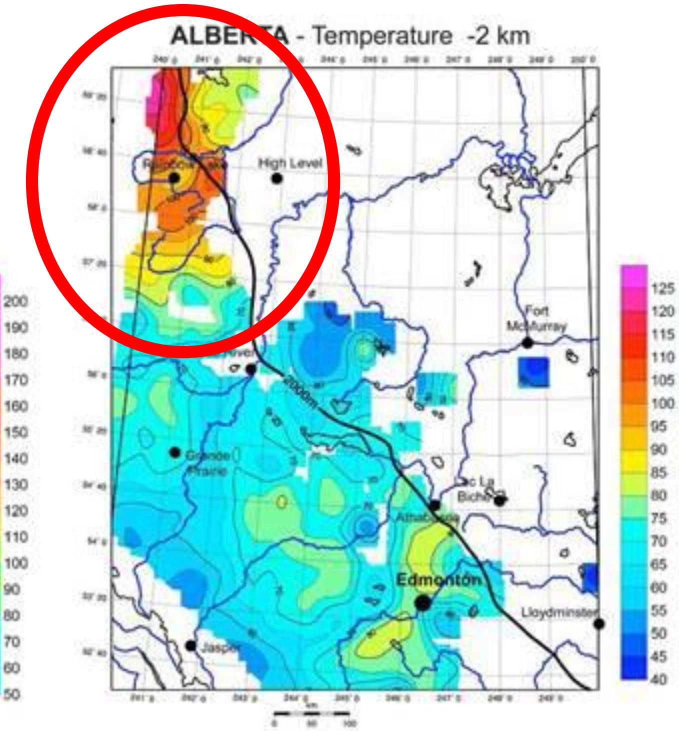


Alberta is part of the ‘old continent’ while British Columbia’s mountains and valleys illustrate tectonic activity and new formations.



The following maps give an indication of geothermal potential in Alberta at two different depths.





The most likely hot-spots at shallow depth areas of **2 km (shown on the bluish map on the right)** are in the far north west corner of the province. While this area may offer geothermal to local residents for heating, the region is too far from major population centers to offer commercial geothermal for electricity generation at large scale; the cost of transmission lines would be formidable. The **deeper areas of 5 km (shown on the left)** as "EGS" Enhanced Geothermal[22] would require more expensive drilling operations and are also relatively far from major urban centers or suitable transmission lines.

In very simplified terms, the EGS method attempts to replicate Mother Nature's 'wet' geothermal resources by drilling a bore hole where there is 'dry' hot rock below and inject cold water from above to get a similar effect as natural 'wet' geothermal.

There are two ways to tap a geothermal heat source: firstly, if the rock has little or no porosity/permeability, a bore hole is drilled where there is 'dry' hot rock below. The rock is then fractured (fracked)* to create greater surface contact area for the injected cold water, which would make super-heated steam as it contacts the hot rocks. Nearby, another bore hole (or several) would be drilled to uptake the resulting steam heat. The exuded steam drives a turbine facility at the surface where power is generated. This is known as a 'closed loop' as the water cycles through the input and uptake pipes as water or steam.

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[22] http://energy.gov/eere/geothermal/how-enhanced-geothermal-system-works

A second method can be considered where the geothermal rock has porosity/permeability. If the well bore encounters a porous/permeable (usually sandstone or dolomite) water bearing zone, such as the Leduc reefs north of Edson, and pumps water up from it, and return it (to the same reservoir) several miles away. The produced water can be used for both heat and electricity, but it normally requires heating a second gas (via heat exchangers) to run a generator, hence a binary system.

**In oil drilling 'fracking' means high pressure injection of fluid that turns the rock to rubble; in geothermal, depending upon the company's process, the more appropriate term is 'hydroshearing' wherein existing small cracks in the rock are expanded to create more surface contact area for the injected cold water. Hydroshearing is discussed in this paper: http://pubs.geothermal-library.org/lib/grc/1028449.pdf*

Currently, Deep Earth Energy is drilling a geothermal well in Saskatchewan near Boundary Dam. According to the Estevan Mercury of Dec. 11, 2015: *"The estimated cost to get the five-megawatt demonstration project going is $40 million"*[23] [5 MW would serve about 5,000 houses] Taxpayers may be concerned about a statement in the article regarding the project's financing: *"The idea is once we're bankable**, then continued federal funding can support this project….***"*

Cost of geothermal is a factor in Alberta when compared to affordable, abundant coal and natural gas reserves. It should be unnecessary for any provincial or federal tax funding to be "continued federal funding …support" for any such project. Alberta generates much of its power from coal because Alberta has rich, high quality, low-sulfur coal resources that are near the surface and easy to mine and reclaim. Likewise, high efficiency, low-emissions power plants and stringent air quality standards have made coal the driver of Alberta's affordable power prices for decades.

> *Alberta has vast resources of coal and natural gas but very limited easily accessible geothermal energy resources and since CO_2 emissions from burning fossil fuels neither cause severe global warming nor harm the environment in any way; there is no sound environmental or economic reason for switching from either coal or natural gas to geothermal power generation." -Norman H. Kalmanovitch P. Geoph.*

Light pink indicates areas with coal reserves in Canada

Image Source: Coal Association of Canada

However, geothermal that is cheap and accessible in Iceland, is not so in North America, even in locations where the thermal gradient is favorable.

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[23] http://www.estevanmercury.ca/news/business-energy/deep-earth-energy-corp-moves-closer-to-its-objective-1.2128276#sthash.V8xCWG1u.dpuf

According to a CBC report of July 1, 2015:

> *Geothermal power plants cost more money than natural gas facilities. For some perspective, consider the Neal Hot Springs plant in Oregon that was constructed in 2012 for **$139 million for 22 megawatts of production**.*
>
> *The Shepard natural gas power plant in Calgary began operating this year with a total cost of **$1.4 billion for 800 megawatts of electricity**. In this comparison, the **geothermal facility costs three times as much per megawatt of power.***

Todd Hirsch, Chief Economist of ATB Financial is supportive of efforts to develop geothermal in Alberta, though he acknowledges that it is presently a 'marginal resource' and that drilling would necessarily be 4 km deep or more.[24]

Even if the technology is workable – and that remains an "if" until one or more pilot geothermal projects are up and operational – the question is the cost-benefit, and also what are the safety concerns in light of Alberta's geological structure which is fraught with risks of toxic hydrogen sulfide (H2S) gas releases.

The stratigraphy of wells deep enough to be at the 125°C temperature requirement for conventional geothermal power generation is problematic in Alberta.

Deep wells will bottom in the Devonian which has many stratigraphic levels comprised of anhydrite which is calcium sulphate. At temperatures well below this level anhydrite reacts with methane (natural gas) to produce deadly hydrogen sulfide (H_2S).

Geothermal power generation using the highly saline H_2S laden water from the Devonian[25] will bring large volumes of this deadly H_2S to the surface where it will pose a threat to life if any leak occurs. Let's not forget that the Pembina Institute, ironically a proponent of geothermal, got its name from the Pembina area where the 1982 Lodgepole Blowout which spewed deadly H_2S, and where Pembina Institute made a name for itself then, as a public defender.

A further challenge for geothermal development in Alberta is that of overpressure in these deep wells:

> ***"Abnormally high pressure**, **sour**, carbonate Devonian reefs have **caused drilling and completion difficulties** since the West Pembina, Alberta, Field was discovered in 1977. This work deals with the practical aspects of **the kill operations under sour gas conditions**. These sealed Devonian Nisku Reefs vary in pore pressure from normal gradients to in excess of 1900 kg/cu m. **The depth of burial ranges between 2500 to 4000 m**, and each reef exhibits different degrees from sweet to **42% H_2S**.**Reef penetration is hazardous** due to unpredictable pore pressure, sour gas, low fracture gradients above the reef, and apparent lack of drilling indicators of impending over pressure in the carbonate transition zone above the reefs."*[26]

Another factor is that once drilled, there may not be suitable geothermal resources. This is the kind of 'dry hole' that oil and gas companies frequently encounter. Their development losses

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[24] http://www.cbc.ca/news/business/geothermal-pitched-as-alberta-s-next-big-energy-source-1.3132416

[25] http://ags.aer.ca/document/Table-of-Formations.pdf

[26] https://www.researchgate.net/publication/241906765_Pembina%27s_high-pressure_sour_reefs_need_special_drill_in_procedures

are written off and the company moves on, financed by cash flow from previous successes or from interests in 'future plays' of potential reserves. Despite the fact that there are existing drilled wells and a great deal of information about the substrate, the geothermal venture in Alberta will still be highly experimental at best.

However, since investor interest in marginal power generation is low (see following section), geothermal hopefuls have difficulty keeping the faith of investors, especially in geology that is not suited to geothermal.

> *"To date, it is mostly the challenges that have been at the forefront of development in B.C.. Developers poured millions of dollars into geothermal exploration at Meager Creek north of Pemberton and tapped temperatures high enough to generate power, but couldn't find the hot water that it needed to flow.*
>
> *In it's last integrated resource plan, BC Hydro identified potential for just 780 megawatts of geothermal power from 16 potential sites….*
>
> *And in November, Energy and Mines Minister Bill Bennett said B.C. is still a long way from having usable geothermal power, because the market has "been slow to pick it up."*[27]

Australia's Geodynamics did a very thorough test case at Cooper Basin.[28]

The following chart compares the costs of that 'dry rock' Enhanced Geothermal System (ESG) project with a number of other methods of geothermal exploitation in other parts of the world known as "Flash," "Dry Steam," "Binary" and some combination versions.

Geodynamics found that the cost of drilling was the most expensive part of the project. That would seem to support the CANGEA proposal to repurpose existing wells in Alberta. However, the Cooper Basin project was geographically too far away from demand centers, as is the most suitable place in Alberta for geothermal – the far north west corner of the province. Transmission lines would make the power too costly. Likewise, despite dedicated work and a great deal of knowledge of the substrate of Cooper's Basin, they had trouble producing power, experienced one explosion, and found it to be very expensive even compared to other conventional geothermal operations. Power prices in Australia were also too low to make the project viable.

> *"Australia's flagship geothermal developer, Geodynamics, has written down the value of its Cooper Basin operations and plant assets, citing the subdued outlook for electricity demand in Australia.*

[27] http://www.vancouversun.com/technology/geothermal+advocates+keep+heat+campaign+promote+energy+potential/10926651/story.html

[28] http://www.geodynamics.com.au/Geodynamics/media/GDY-PDF/Announcements%202014/COM-FN-OT-PLN-01166-1-0-HGP-Field-Development-Plan-for-General-Distribution.pdf

*The decision to **write $88.8 million off** its Cooper Basin assets comes as the company completes a trial of its 1MW Habanero pilot plant near Innamincka, which sourced energy from super-heated rocks 4.2kms below the surface – deeper than any other geothermal plant in the world.”* [29]

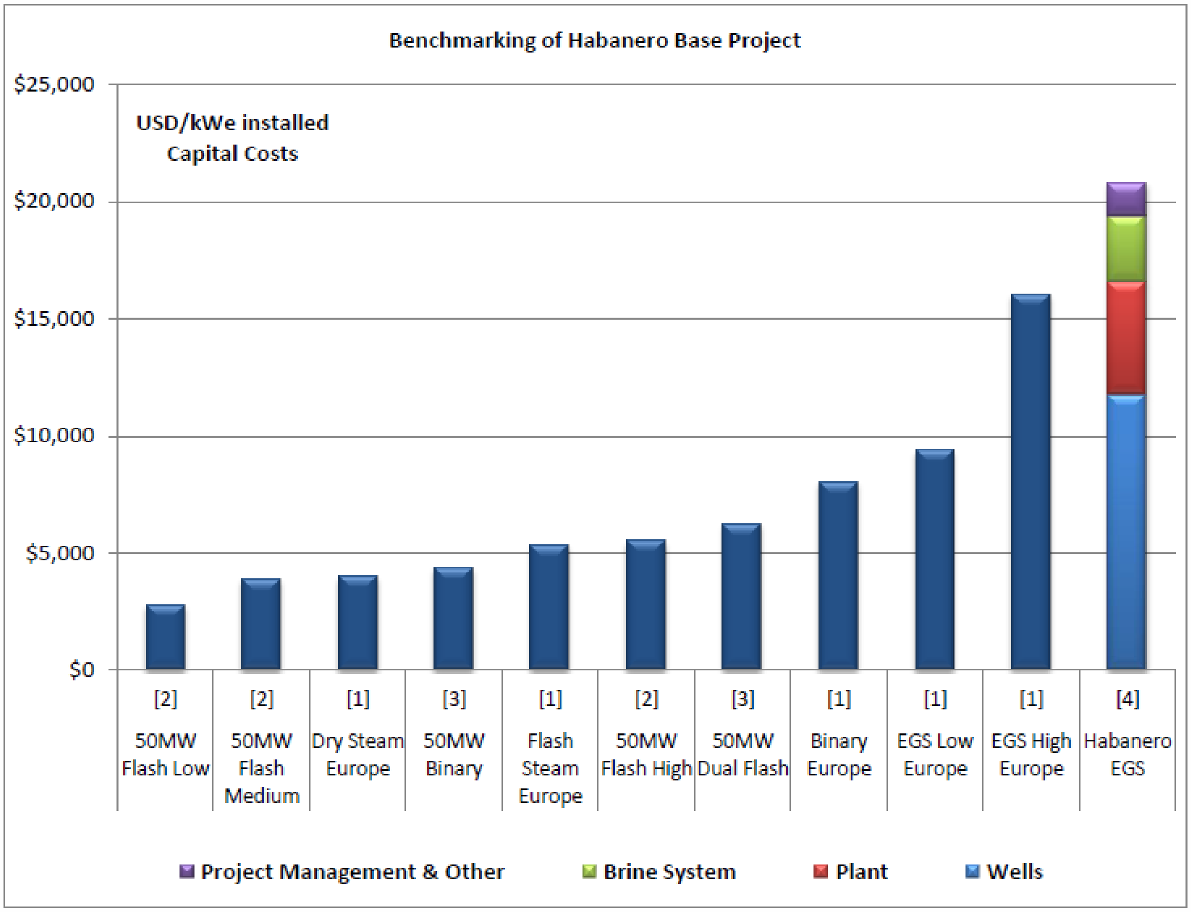

Figure 10-2: Benchmarking of Habanero Base Project (Sources: [1] European Geothermal Energy Council (EGEC), July 2013; [2] World Bank (ESMAP), June 2012; [3] US-EIA, April 2013; [4] GDY)

Europe is proposing to do an extremely deep drilling for supercritical heat, fronted by ENEL[30] as reported in Sept, 2010[31] by SINTEF – the independent Scandinavian research organization. As reported by Science Daily on Oct. 23, 2015, the DESCRAMBLE (Drilling in dEep, Super-CRitical AMBients of continentaL Europe) project encountered unusual challenges related to the qualities of supercritical steam and deep earth pressure.[32]

"One of the major uncertainties is the presence of what we call supercritical fluids," explains physicist Roar Nybø at SINTEF Petroleum Research. At depths of two to three kilometres in the Earth's interior, ambient physical conditions change dramatically. Temperature increases. And so does the pressure. Something very special happens when

[29] http://reneweconomy.com.au/2013/geodynamics-writes-cooper-basin-geothermal-assets-40047
[30] https://www.enelgreenpower.com/en-gb/Documents/plants/geotermia.pdf
[31] http://www.sintef.no/en/latest-news/energy-underfoot/
[32] https://www.sciencedaily.com/releases/2015/10/151023094414.htm

temperatures reach 374 degrees and the pressure 218 times the air pressure at the surface. We encounter what we call supercritical water.

It isn't a liquid, and nor is it steam. It occurs in a physical form incorporating both phases, and this means that it takes on entirely new properties. Supercritical water behaves like a powerful acid, and will attack anything -- including electronics and drilling equipment."

This type of deep well with supercritical fluids is **not the focus of CANGEA's Alberta proposals**, as we understand it. The article and the SINTEF research highlight both the great potential and the many challenges of geothermal in unconventional venues, and the need for cautious exploration.

Other challenges facing geothermal development include:

- Corrosion of piping or blocking of pipes due to rock slurry or calcified mineral deposits
- Loss of pressure,[33] resulting in inexplicable/unrecoverable loss of productivity
- Reduction in temperature below suitable operating levels due to the flooding of the substrate with cold water overriding the very slow rise of conductive head
- Potential for explosion of part or all of the facility, depending on gases and facility failure or human error (as with any industrial operation) [34] [35] [36] [37]
- Fracturing the rock (fracking) in some formations may lead to seismic activity; a Basel, Switzerland facility was abandoned due to induced earthquakes [38]
- Some projects are substantially underwritten by subsidies and tax benefits; it is not clear they would have commercial merit without these financial supports [39]

Indeed, it is the cost and uncertainty of suitable outcomes that have prevented the development of geothermal. According to Jeremy Shere's book "Renewable," as early as 1972 Joseph Barnea, then director of resources and transportation for the UN, claimed the US would be powered by geothermal electricity to the order of some 395 million kilowatts by 2020.

Despite millions of dollars pumped into the Fenton Hill Dry Rock Project, hoping to replicate Mother Nature's 'wet' geothermal by pumping water down onto hot rocks, the project was fraught with unexpected failures – and constantly **"ran up against the unsettling reality that engineering a geothermal system was much, much more difficult than it may have at first appeared."** (pg 221) Fenton Hill was shut down for good in 2000.

An MIT review of geothermal came to these conclusions[40]

> "The most important conclusion from all this prior work regarding the development of EGS as a power-producing technology is that we can probably form an EGS reservoir at any depth and anywhere in the world that has both a temperature high enough for

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[33] http://amarillo.com/stories/2001/04/14/usn_calgeo.shtml#.V167n_krIdU

[34] http://www.pennenergy.com/articles/pennenergy/2014/02/ngawha-geothermal-power-plant-declared-safe-following-explosion-scare.html

[35] https://www.newscientist.com/article/dn17042-geothermal-explosion-rocks-green-energy-hopes/

[36] http://www.popsci.com/environment/article/2009-06/icelands-power-down-below

[37] http://blogs.discovermagazine.com/80beats/2009/04/28/geothermal-explosion-highlights-a-downside-of-a-leading-alt-energy-source/#.V17CSPkrIdU

[38] http://www.nytimes.com/2009/12/11/science/earth/11basel.html?_r=0

[39] http://www.usgeothermal.com/projects/2/Neal%20Hot%20Springs

[40] https://mitei.mit.edu/system/files/geothermal-energy-4-6.pdf

> energy conversion and sufficient far-field connectivity through existing natural fractures. **Nonetheless, uncertainties still exist, for example, regarding the natural state of stress and rock properties, even within well-characterized geologic regions.** Most important, the existence of anisotropic stresses in the rock as a prerequisite for stimulation by shear failure is fundamentally different than normal practice in oil- and gas-bearing formations. Other aspects of the reservoir structure may cause operational problems down-hole, such as mapping existing major faults and fractures that may act as flow barriers or conduits – and cause problems for our system."

Shere reports that MIT found **"we cannot predict the long-term effect of injecting water…into the reservoir."** He further explains **"<u>And not being able to predict how much energy an engineered geothermal reservoir will produce is anathema to investors and utilities</u>, which typically insist on knowing precisely how much power will come out of a power plant, and at what cost."**

May we add that Alberta taxpayers, reliant on power in a province that features extreme cold and short days/long dark nights for about half the year, must know the costs and reliability of such proposed power generation projects.

The voice of experience of mining expert and renewables advocate Ross Beaty's explains the relative costs in trying to tap geothermal in B.C. offers some cost comparisons:

> "By Beaty's calculations, geothermal power costs about $5 million to create each megawatt of electricity, compared with hydro, wind and solar capital costs "in the range of $3 million to $5 million per megawatt" and coal/gas power plants at around $1 million to $2 million per megawatt."[41]

6 CANGEA CLAIMS ARE BIG – BUT NOT ONE OPERATIONAL PILOT …YET

CANGEA materials indicate that they are interested in using existing drilled wells for Enhanced Geothermal Systems (EGS), possibly to minimize the costs of drilling everything from anew. As noted in Geodynamics Ltd. Review of their Cooper Basin "Habanero" project, the cost of drilling wells was by far the greatest expense, and that **"the drilling of the wells at Habanero alone is more expensive than most geothermal projects in their entirety."** (pg165)[42]

CANGEA claims that its members will recycle old wells and put thousands of oil workers on the job in a new 'green' industry. Geodynamics "lessons learned" points out that drilling deep wells with high pressure is extremely challenging. Oil rig crews must be retrained to deal with some of the anomalies of how drilling fluids react differently and various extreme safety issues (one Cooper Basin project exploded). Likewise, rig equipment, materials and casings respond differently to high pressure high temperature. Reworking old gas wells as geothermal power generators may have unexpected outcomes or unintended consequences too.

[41] https://www.biv.com/article/2014/7/drilling-down-to-the-economic-realities-of-geother/

[42] http://www.geodynamics.com.au/Geodynamics/media/GDY-PDF/Announcements%202014/COM-FN-OT-PLN-01166-1-0-HGP-Field-Development-Plan-for-General-Distribution.pdf

As we understand it from their materials and various news reports, CANGEA claims it is possible to generate heat or power at lower temperatures (at ~ 90°C rather than the conventional 126°C) using novel processes, and apparently relying on the potential value of Renewable Energy Certificates (REC) (as noted by Majorowicz and Moore)[43] to arrive at cost-competitiveness).

To taxpayers, RECs means subsidies - money from your wallet - to support a marginal, untested method of power generation that carries identifiable public health risks.

CANGEA claims that oil and gas operators get government subsidies that are denied to geothermal proponents, but this is not the case as demonstrated in Friends of Science Society's report "Keep Canada in the Black." [44]

CANGEA also claim they can put thousands of oil workers back to work in a similar field. This might be conceivable if a test operation could show demonstrable results. But as with the 'rush-to-renewables' in the European Union, if anything we should learn to properly test alternative energy generation, before going full speed ahead.[45] No demo site, no cost-benefit analysis based on actual operations, no reasonably long-term evidence of successful operation… fools rush in.

One important test is the Energy Return on Energy Invested (EROI). The graph below illustrates that most alternative forms of power generation have virtually no return on energy invested and are, in fact, huge consumers of valuable materials and precious fossil fuels.

Energy Return on Energy Invested is described by Cambridge University's Prof. Michael J. Kelly:[46]
"Weißbach et al. 23 have analysed the EROI for a number of forms of energy production and their principal conclusion is that nuclear, hydro-, and gas and coal-fi red power stations have an EROI that is much greater than wind, solar photovoltaic (PV), concentrated solar power in a desert or cultivated biomass: see Fig. 2 [next page]. In human terms, with an EROI of 1, we can mine fuel and look at it—we have no energy left over. ***To get a society that can feed itself and provide a basic educational system we need an EROI of our base-load fuel to be in excess of 5****, and for a society with international travel and high culture we need EROI greater than 10. The new renewable energies do not reach this last level when the extra energy costs of overcoming intermittency are added in. In energy terms the current*

[43] http://www.sciencedirect.com/science/article/pii/S0960148114000159
[44] https://friendsofsciencecalgary.wordpress.com/2016/03/15/keep-canada-in-the-black/
[45] http://www.finadvice.ch/files/germany_lessonslearned_final_071014.pdf
[46] http://journals.cambridge.org/download.php?file=%2FMRE%2FMRE3%2FS2329222916000039a.pdf&code=3d91fd3be30433d400062d1042e9273c

generation of renewable energy technologies alone will not enable a civilized modern society to continue!."

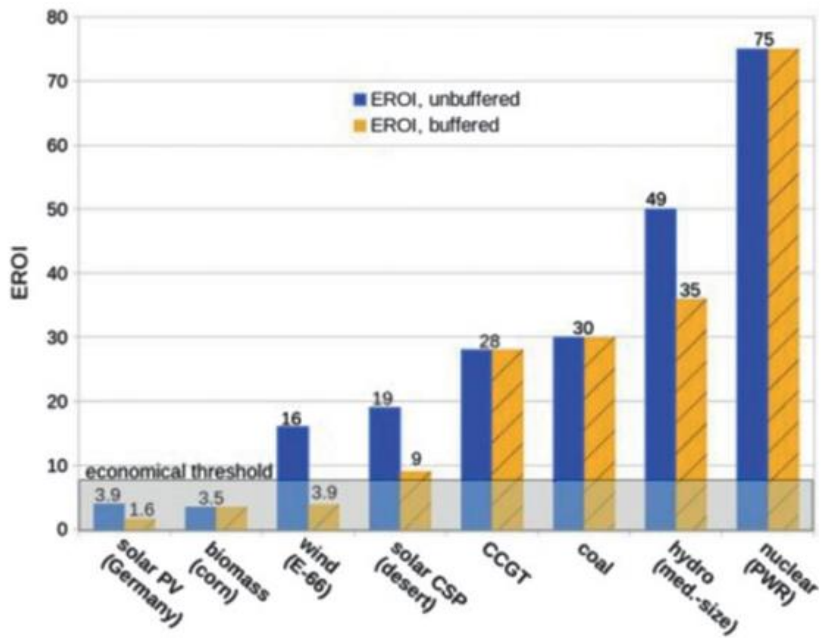


Figure 2. The energy return on energy invested for various forms of energy generation with the threshold for supporting a modern economy indicated across the bottom.[23] The advantages of fossil fuels and nuclear energy are very clear. Reprinted from Ref. 23, with permission from Elsevier.

Professor Kelly dispels other magical thinking about the Energy Return on Energy Invested regarding the graph above, saying: *"It is often said that a new large-scale battery technology would transform the role of renewable energy, but in Fig. 2 we see the potential limitations. The reference to **buffered energy** systems based on a renewable energy source shows the degradation in terms of energy return on investment, when additional batteries are used to provide access to the renewable energy on demand, or as baseload. This feature is rarely described in debates on large scale energy storage."*

AJ Mansure looks at the EROI of geothermal, though not in marginal fields like those of Alberta.[47]

What of return on financial investment?

In fact, the 2012 Morrison Park Advisors[48] report for the Market Surveillance Authority of Alberta indicates there is little desire to invest in baseload power in Alberta because the market prices for electricity are so low.

[Note: your Alberta power bill may be quite high, but look at the **cost of power- in Alberta it is low**; much of the additional costs are related to distribution and transmission {new power lines, some for wind which provides little power return to the grid]

[47] https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2011/mansure.pdf

[48] http://albertamsa.ca/uploads/pdf/Archive/2012/Investor%20Perspectives%20Report%20to%20MSA%20-%2017%20Augus.pdf

Here follows a review by Morrison Park Advisors in discussion with investors as to whether or not they would invest in these various power generation forms in Alberta.

In the table below, the different categories of power generation units are described, by their use within the power system. ***Baseload*** *refers to the minimum level of 24/7 power demand, typically from the least expensive, most reliable source of generation. In Alberta that is coal.* ***Co-generation*** *is where what would be waste heat from an industrial operation is used as a source for power generation. In Alberta, many oil sands operations provide co-generated power.* ***Mid-merit*** *refers to a power plant type that fills the gap between base load and peak load and adjusts its output throughout the day to respond to demand periods. This would be a simple cycle natural gas plant.* ***Peaking*** *is a special natural gas plant that, like a giant gas stove, can quickly power up or down in seconds to respond to generate power to fill the gap of a surge or drop of wind and solar power.* ***Intermittent*** *power generation comes from wind and solar as they only generate power when the wind blows at the right speed or when the sun shines. Their output can radically surge or drop off completely with little warning. Without peaking plants, and special grid infrastructure, these erratic surges can damage 'power quality' or even cause the grid to black-out. (NOTE: AESO previously informed Friends of Science that no blackouts in Alberta have been ever been caused by wind/solar to date. However, this problem has been an issue in Bulgaria where the government was driven out of office after violent riots over power prices, power blackouts and foreign power companies.*[49] [50]*)*

Investor Interest in the Alberta Power Market: (2012)

Type of Plant	General View
Baseload	Recent prices in the Alberta electricity market have not been sufficiently high to support investment
Co-generation	Investment depends on the terms of the contract with the steam host, more than it does on the Alberta electricity market
Mid-merit	Recent prices in the Alberta electricity market have not been sufficiently high to support investment
Peaking	Prices, and the volatility of prices in the market, have been sufficiently high to allow several investors to consider construction
Intermittent	Recent prices in the Alberta electricity market have not been sufficiently high to support investment

Investor Perspectives on the Attractiveness of Alberta's Electricity Generation Market Prepared by Morrison Park Advisors For Alberta's Market Surveillance Administrator Pg. 18

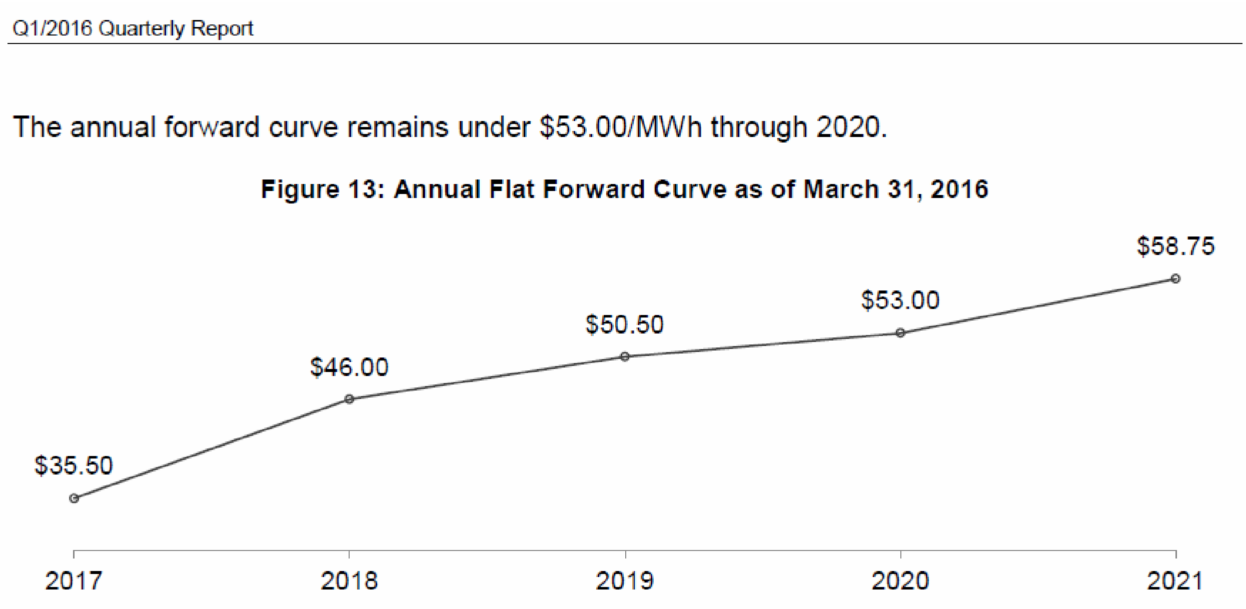
[49] http://www.economist.com/news/europe/21572252-bulgarian-prime-minister-unexpectedly-resigns-power-protests

[50] http://instituteforenergyresearch.org/analysis/germanys-green-energy-destabilizing-electric-grids/

Geothermal was not a specific power generation source reviewed in the Morrison Park study, however as **<u>an untested form of baseload power generation in Alberta</u>**, the above indicates no investor interest in baseload power. Until one or more geothermal demonstration sites are in operation so that the cost-benefits could be assessed, investor interest appears to be low for baseload power.

Despite the foregoing, on CANGEA's website "Fact Sheet"[51] they claim that they can "produce $4.4 billion/yr in power sales." This appears to be based on GWH per year which comes from 5000 MW capacity times 365 days, times 24 hours, then divide that into the projected power sales revenues. This also uses 100% availability or service factor with no downtime during the year for planned maintenance or unscheduled outages.

A review of the 2016 Market Surveillance Authority (MSA) First Quarter Report[52] suggests that the forward prices are under $53.00 MWh to 2020.



Source: MSA 1st Quarter report 2016 pg. 9

Consequently, it appears that CANGEA may be anticipating substantial subsidies or RECs to arrive at their target price of $100.00. This can only come from tax subsidies, not the market, according to the MSA forecast. Are Albertans willing to underwrite an untried venture for billions that has faced numerous challenges and failures elsewhere in the world? CANGEA claims it would solve high energy costs. The evidence presented here does not support that claim.

[51] http://www.cangea.ca/geothermal-fact-sheet.html

[52] http://albertamsa.ca/uploads/pdf/Archive/0000-2016/2016-04-29%20Q1%20Quarterly%20Report.pdf

7 GLOBAL GEOTHERMAL

According to energy economist Robert Lyman's recent report "Why Renewable Energy Cannot Replace Fossil Fuels by 2050"[53] geothermal is a minor player in the global energy mix, making it questionable as to how it could become a major player in Alberta where the geology is unfavorable.

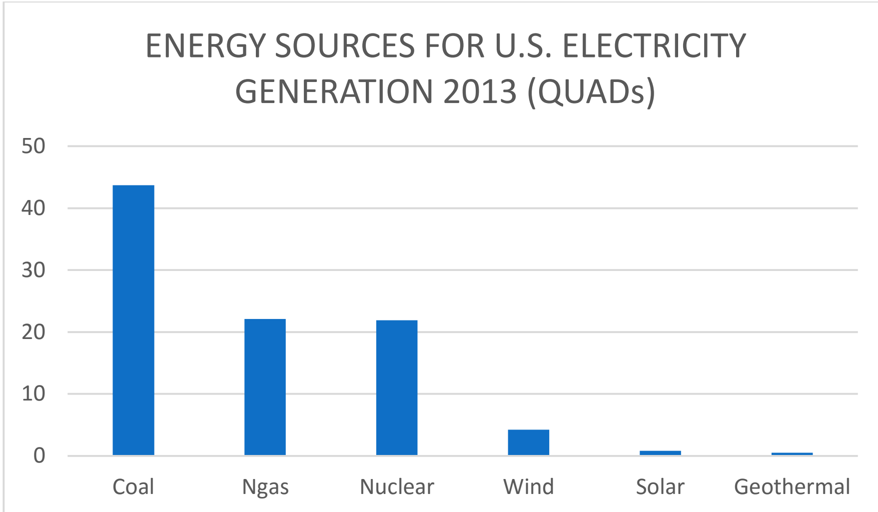
The U.S. Lawrence Livermore National Laboratory has produced a detailed breakdown, in the form of a flow chart, of the current sources and uses of energy in the United States in 2013. The Laboratory produced a similar flow chart for the world in 2011. The flowing table summarizes the current sources of electrical generation in terms of quadrillion BTU's ("quads"). (see Table 4)

Table 4
ENERGY SOURCES FOR U.S. ELECTRICITY GENERATION 2013
(QUADs)

Energy Source	Use	Percentage
Coal	16.5	43.7
Natural Gas	8.34	22.1
Nuclear	8.27	21.9
Wind	1.60	4.2
Solar	0.32	0.8
Geothermal	**0.20**	**0.5**
Totals	**37.76**	**100**

Note here that fossil fuels (coal and natural gas) constitute 65.8 % of the energy for electricity generation, whereas wind, solar and geothermal sources combined constitute only 5.5%. Reversing this relationship is a tall order indeed.

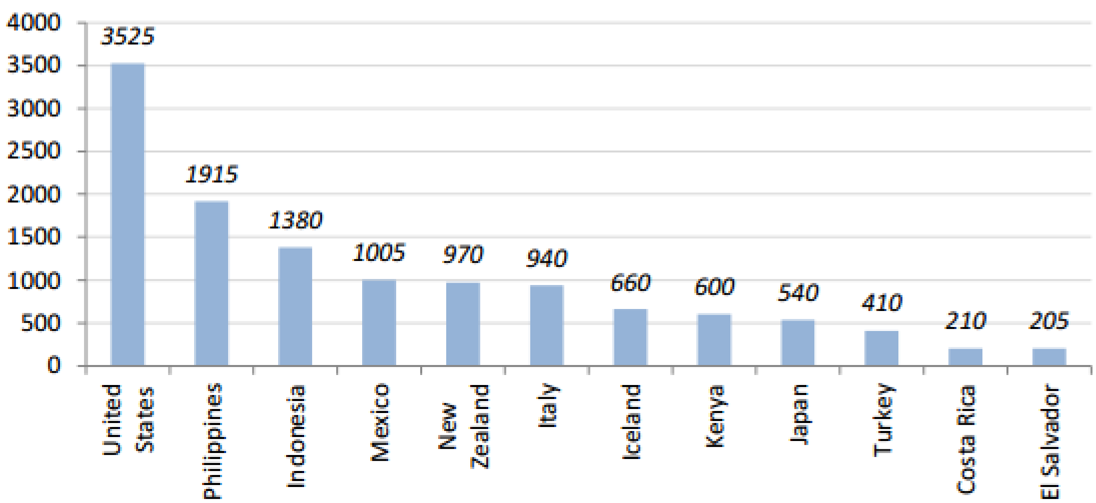
[53] https://friendsofsciencecalgary.wordpress.com/2016/05/31/why-renewable-energy-cannot-replace-fossil-fuels-by-2050/



By percentage

Thus, it seems unlikely that geothermal could replace 29%, or any portion of present coal-fired generation in Alberta, unless there is a true breakthrough technology in terms of CANGEA's EGS. Breakthrough technologies often take decades to implement. In the US, the world leader in geothermal power generation, the contribution of geothermal to the power mix is so small. No breakthroughs appear to be on the horizon there.

Figure 3: Established Geothermal Power Markets Installed Capacity (MW)



As shown in the chart above from the 2015 Global Geothermal Energy Org Annual Report, all of the geothermal installed capacity in the US is less than half of the installed coal-fired capacity in Alberta. Note that all of the countries listed here happen to be in areas which are naturally favored by geothermal resources, unlike AB where we are blessed with abundant, clean, economic fossil fuels.

8 IPCC – To Decarbonize or Not To Decarbonize

The main driver behind the development of unconventional geothermal resources at this point in time is related to climate change and the perceived need to reduce human emissions of carbon dioxide, along with an intention to make use of earth's natural heat source for heating or power generation, while preserving fossil fuels for humankind's portable fuel needs.

However, it should be made clear that the Intergovernmental Panel on Climate Change (IPCC) does not *recommend* going off fossil fuels like coal – in fact Mr. Jonathan Lynn, Head of Communications and Media Relations of the WMO/IPCC wrote to Friends of Science Society and said: *"…the IPCC does not make recommendations on any topic and you will not find any recommendations in any of our reports."* [54]

This seems to suggest that the IPCC recognizes that every country in the world has its own set of best-use assets – in Iceland, that would be natural geothermal; in Alberta the obvious asset for power generation is coal, followed by natural gas. Geothermal would not be recognized as a native asset to Alberta for power generation except in a few remote locations. Whether local exploitation there would be cost-effective is not the subject of this review.

9 Social Costs of Carbon are Net Beneficial

The thinking behind providing Renewable Energy Certificates as an inducement to industry and investors to get into renewable energy projects that otherwise are not cost-competitive or profitable is based on the idea that carbon dioxide emissions have a negative impact on climate change and long-term stability of climate and human survival.

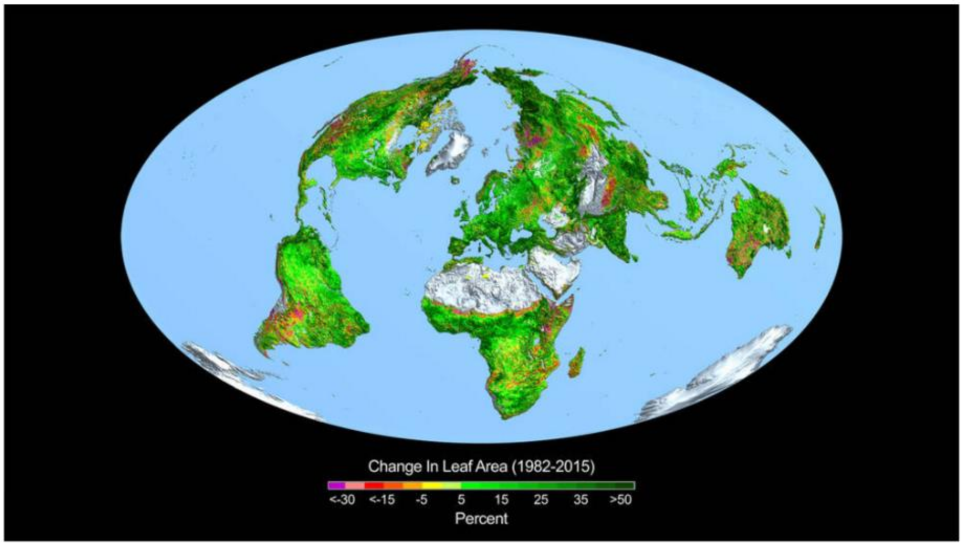
The idea of 'carbon taxes' is based on the principle that 'polluter pays' – however the evaluation of Social Costs of Carbon are based on an outdated formula that is calibrated to early IPCC 'climate sensitivity' (effect) of carbon dioxide on warming.

There has been a significant rise in carbon dioxide concentrations in the atmosphere over the past 18 years, but there has been no coincident rise in temperature as previously predicted/modelled by the IPCC. Consequently, numerous scientists now conclude that the warming effect of carbon dioxide has been greatly exaggerated and that natural factors like the sun's cycles, oceanic currents and atmospheric oscillations and their interactions, are more influential on climate change.

A recalculation by Dayaratna et al (2016) has recently shown a **net benefit of carbon,**[55] and indeed, previous calculations excluded the social benefits of carbon, meaning the "Social Costs of Carbon" was an entirely one-sided evaluation.

[54] https://friendsofsciencecalgary.wordpress.com/2015/11/05/a-matter-of-public-interest-on-the-ipcc-does-it-recommend-or-not-recommend-that-is-the-question/

[55] Dayaratna, Kevin, Ross McKitrick and David Kreutzer (2016) Empirically-Constrained Climate Sensitivity and the Social Cost of Carbon. SSRN Discussion Paper 2759505



This image shows the change in leaf area across the globe from 1982-2015.
Credits: Boston University/R. Myneni

NASA satellite imagery has also shown that the world has been greening – often in desertified spots - with the increased carbon dioxide (known as CO2 fertilization).

http://www.nasa.gov/feature/goddard/2016/carbon-dioxide-fertilization-greening-earth/

As economist Richard Tol has said about **climate policy, the first rule should be to do no harm to the economy.**

Unfortunately, extreme climate policies, often obsessed with reducing carbon dioxide or incenting renewable energy at taxpayers' expense, have turned people's lives upside down across Europe, leading to masses of formerly middle class people being pushed into heat-or-eat poverty, and industry moving offshore to more favorable, less regulated countries, thus leading to job loss and a further blow to the economy.

In a rebuttal to a criticism of Tol's perspective that climate change impacts are nominal compared to destruction of economies, Tol writes:

> *"The twenty-two studies cited above all agree **that the impact of climate change is small relative to economic growth.** This was found in studies by Professor William Nordhaus and Professor Samuel Fankhauser. It was confirmed by the Intergovernmental Panel on Climate Change from its Second Assessment Report, in a chapter led by the late Professor David Pearce, to its Fifth Assessment Report, in a chapter led by me. Even the highest estimate, the 20% upper bound by Lord Professor Nicholas Stern of Brentford, has that a century of climate change is not worse than losing a decade of economic growth.*
>
> *Over the years, many people have objected to these estimates. Tellingly, not a single one of these people have published an estimate that strongly deviates from existing estimates. On the contrary, a number of people have set out to prove Nordhaus and Fankhauser wrong, only to find estimates of a similar magnitude.*
>
> *In sum, **climate change is a problem but not the biggest problem in the world**. "* [56]

[56] http://www.lse.ac.uk/GranthamInstitute/news/the-economic-impacts-of-climate-change-richard-tol/

10 CONCLUSION

CANGEA presents Albertans with a potential novel form of electrical power generation or ground heat exchange. At present, The Living Energy Project[57] has a single ground heat exchange project in pilot mode, with assorted additional renewables at the Leduc #1 exhibition facility on the outskirts of Edmonton, however to scale up from one ground heat exchange project to the CANGEA claims of substituting substantial amounts, even claiming replacement of 29% of Alberta's existing coal-fired power generation capacity through EGS is naïve and overly-optimistic.

There may be potential in the novel approach of low temperature EGS in Alberta, but it would only be fair to taxpayers to properly pilot this project and carefully assess the cost-benefit of the proposal before going ahead on any large scale, or before offering any substantial promise of subsidies in any form or Renewable Energy Certificates for unproven technology.

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[57] http://www.albertaoilmagazine.com/wp-content/uploads/2016/04/Living-Energy-Project.pdf
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End Notes

Alberta's Electricity Generation - 2014

Generation	Gigawatt Hour (GWh)	Generation Share By Fuel
Coal	44,442	55%
Natural Gas	28,136	35%
Hydro	1,861	2%
Wind	3,471	4%
Biomass	2,060	3%
Others*	373	0%
Total	**80,343**	**100%**

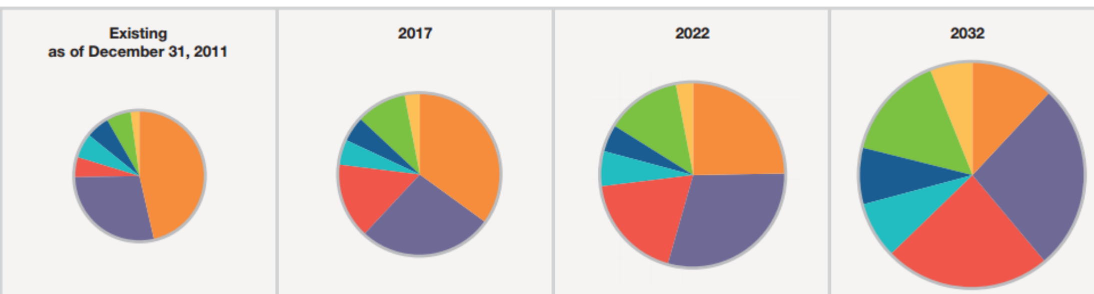
Source: Alberta Utilities Commission (AUC)

*Others include fuel oil and waste heat

i

In 2014, 90% of Alberta's power generation came from fossil fuels in the form of coal and natural gas. Below, 2013 plan of AESO for power grid mix. A diversified grid is more flexible and not reliant on a monopoly source of supply.

Figure 5.3.5–1: Generation Outlook – Installed Capacity (MW)



Existing as of December 31, 2011			2017			2022			2032		
46%	Coal	6,242	**35%**	Coal	5,900	**25%**	Coal	4,832	**12%**	Coal	2,876
28%	Cogeneration	3,782	**27%**	Cogeneration	4,619	**30%**	Cogeneration	5,770	**27%**	Cogeneration	6,365
5%	Combined Cycle	750	**15%**	Combined Cycle	2,518	**19%**	Combined Cycle	3,668	**24%**	Combined Cycle	5,568
6%	Simple Cycle	827	**5%**	Simple Cycle	901	**6%**	Simple Cycle	1,176	**8%**	Simple Cycle	1,826
6%	Hydro	879	**5%**	Hydro	879	**5%**	Hydro	979	**8%**	Hydro	1,979
6%	Wind	865	**10%**	Wind	1,694	**13%**	Wind	2,544	**15%**	Wind	3,578
2%	Other	314	**3%**	Other	445	**3%**	Other	585	**6%**	Other	1,385
	Total	**13,659**		**Total**	**16,956**		**Total**	**19,554**		**Total**	**23,577**

Source: AESO

This report was compiled by Friends of Science Society's communications team with contributions from energy experts. It was reviewed for accuracy by Professional Geophysicists, Professional Geologists, Professional Engineers, energy executives and economists.

About

Friends of Science Society has spent a decade reviewing a broad spectrum of literature on climate change and have concluded the sun is the main driver of climate change, not carbon dioxide (CO2). Friends of Science is made up of a growing group of earth, atmospheric and solar scientists, engineers, and citizens.

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