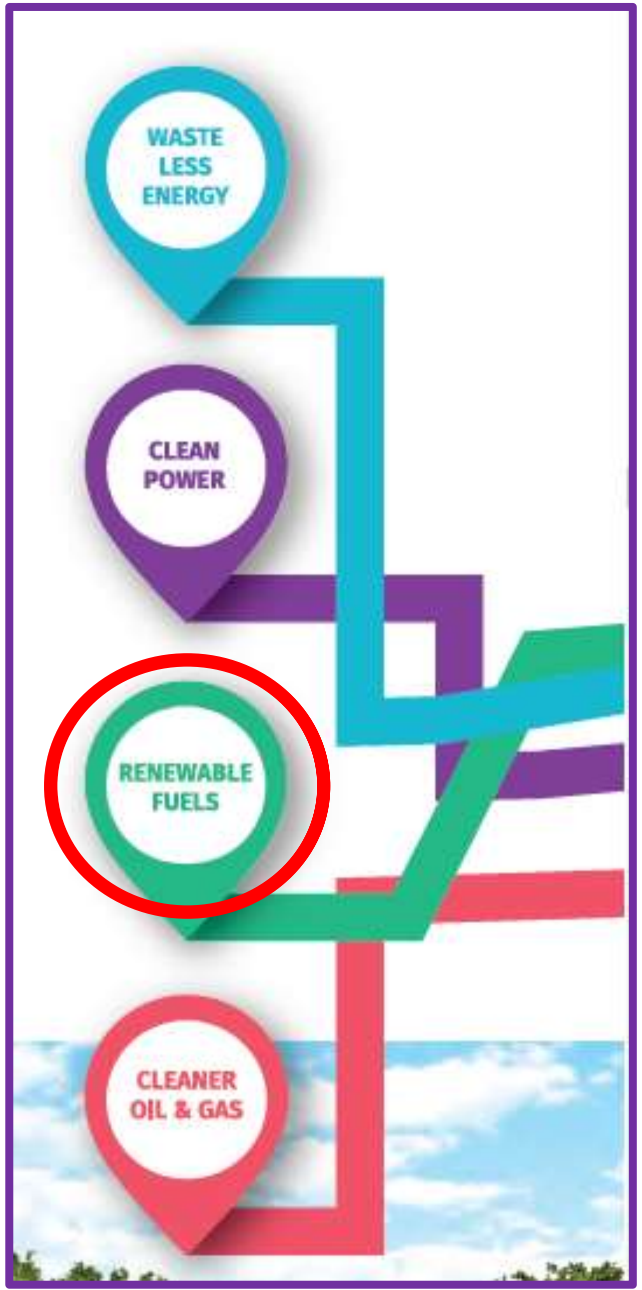
In 2017, the **Government of Canada** launched **Generation Energy** – an open and inclusive nation-wide dialogue with stakeholders, experts and over **380,000 individual Canadians** to envision what a **low-carbon energy future** would look like for Canada over the course of a generation. Building on the results of that dialogue, the Minister of Natural Resources formed the Generation Energy Council to prepare this report[1] in order to answer four crucial questions:

- What should **Canada's energy future** look like over the long term?
- What generational goals should we strive to achieve?
- What principles should guide us?
- What are the potential **pathways** and **milestones** along the way?

1. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/CoucilReport_july4_EN_Web.pdf

The four pathways to a Clean Energy Future:



Canada's Energy Future – Achieving Net-Zero Emissions

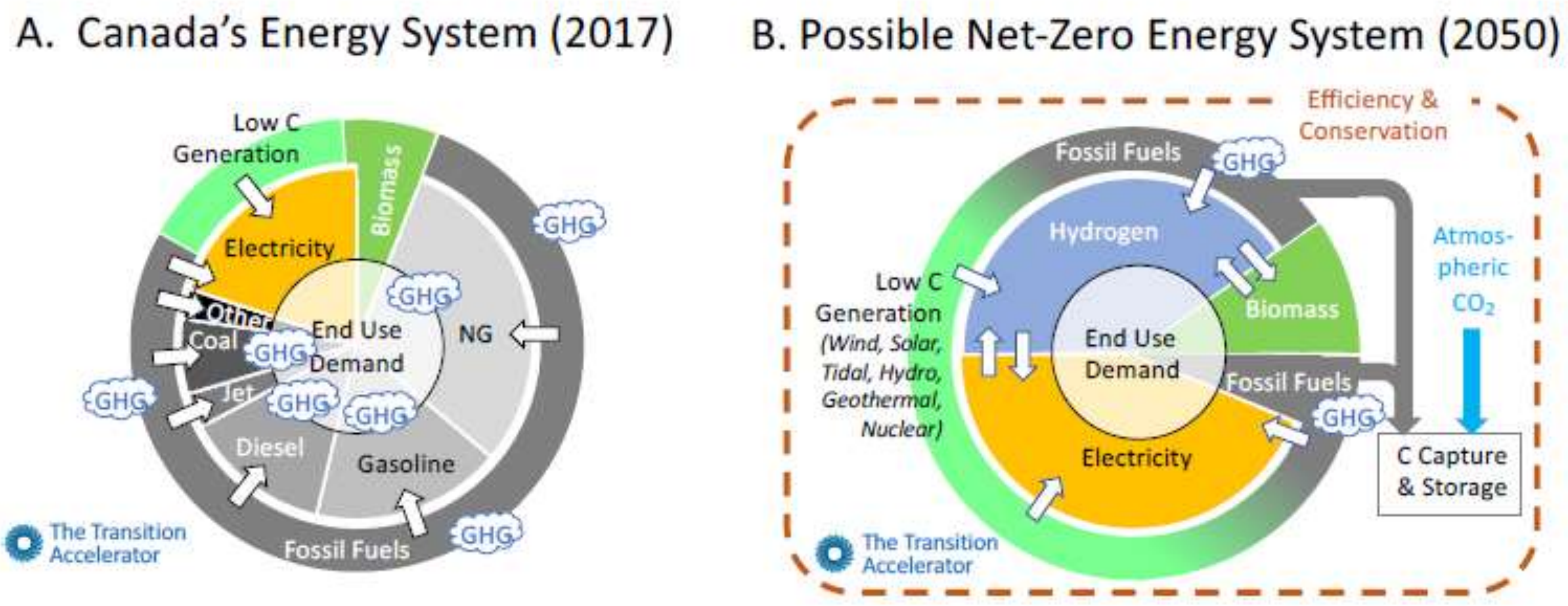


Figure 1.1. Comparison of Canada's energy system in 2017 (A), and a possible net-zero emission energy system in the future (B). End use demand for energy is provided by energy carriers that must be zero-emission in the future. The production of these energy carriers must also be greatly reduced or eliminated. GHG, greenhouse gas. Panel A from NRCan Comprehensive Energy Database. There is no consensus on the relative importance of the various energy sources or end use fuels or electricity.

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Source: Layzell DB, Young C, Lof J, Leary J and Sit S. 2020. Towards Net-Zero Energy Systems in Canada: A Key Role for Hydrogen. **Transition Accelerator Reports:** Vol 2, Issue 3. https://transitionaccelerator.ca/towards-net-zero-energy-systems-in-canada-a-key-role-for-hydroge

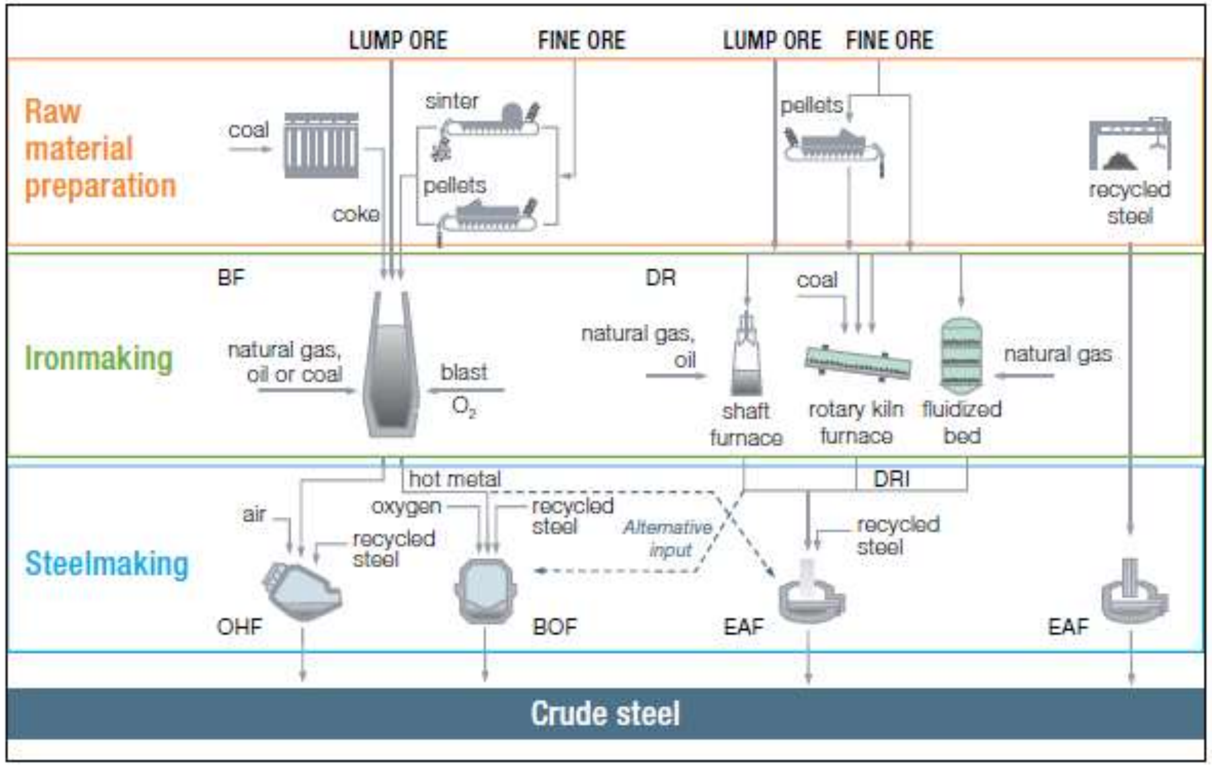
Fuels used in Steelmaking

Table 1 shows the main energy inputs of steel production and their applications as energy and reducing agents.

Energy input	Application as energy	Application as energy and reducing agent
Coal	Blast furnace (BF), sinter and coking plant	Coke production, BF pulverised coal injection
Electricity	EAF, rolling mills and motors	-
Natural gas	Furnaces, power generators	BF injection, DRI production
Oil	Steam production	BF injection

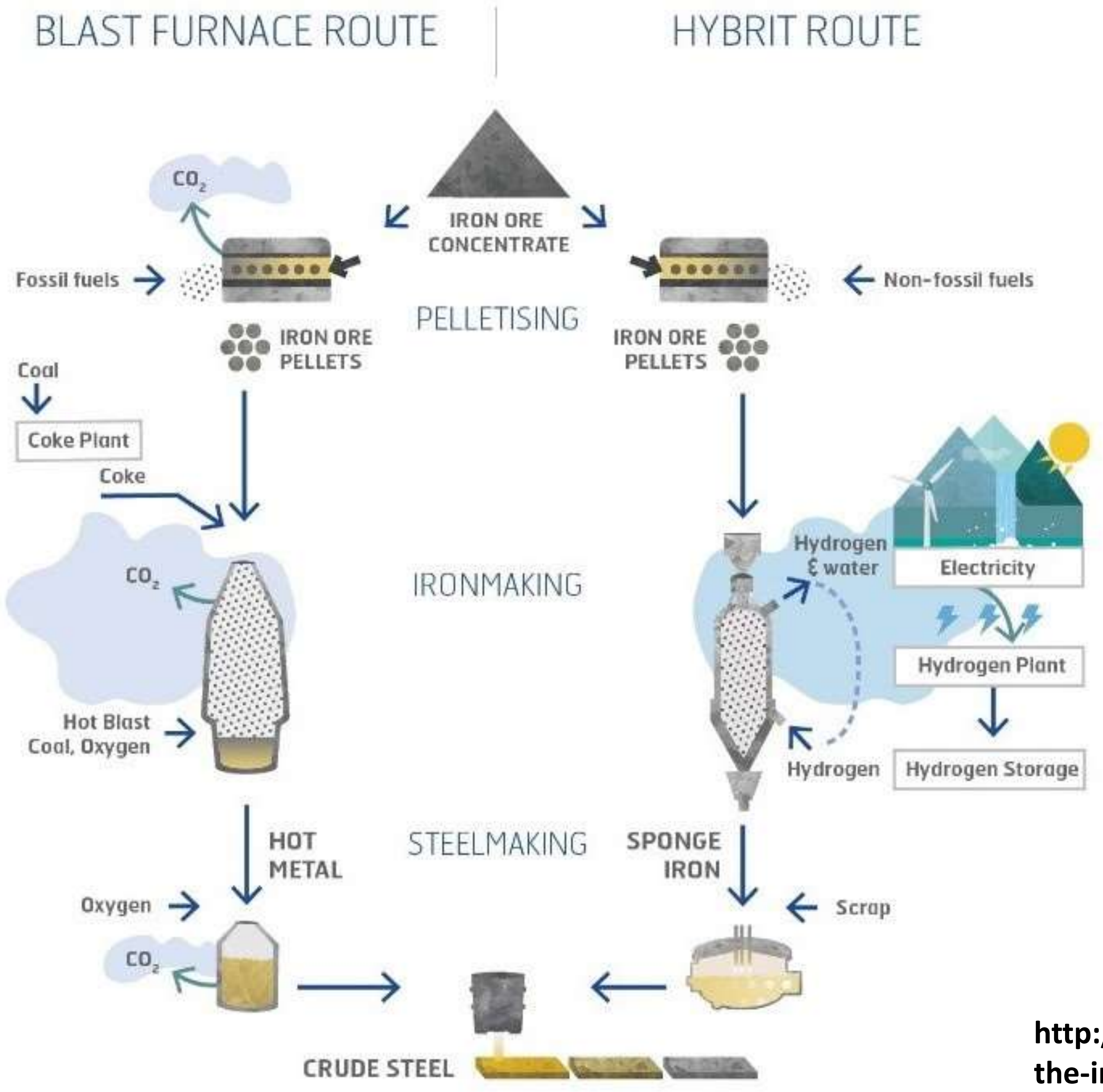
Table 1: Applications of energy inputs in steel production

Figure 2: Steelmaking routes



BF = Blast Furnace
EAF = Electric Arc Furnace
DRI = Direct Reduction Ironmaking

Source: **worldsteel.org**



Hydrogen as a Clean Alternative in the Iron and Steel Industry

Traditional iron ore reduction utilizes a chemical reaction between iron oxide and carbon monoxide sourced from heating coke fuel in a blast furnace. Coke is a hard, porous, nearly pure carbon product made by heating coal in the absence of air (in coke ovens). **Coke** acts as both a **fuel** and **reducing agent** in the blast furnace, forming carbon monoxide when burned, and **reacts with the iron oxide to produce molten pig iron and carbon dioxide**. In 2017, every ton of steel produced resulted in an average of 1.83 tons of carbon dioxide emissions. That same year saw a global production of just over 1,864 million tons of steel.

New production processes are exploring the use of **hydrogen** gas instead of coke. Hydrogen reacts with iron oxide in a similar fashion to carbon monoxide, but instead of producing carbon dioxide, the only byproduct is water vapor. When hydrogen used in this process is derived from renewable or decarbonized sources itself, **the steelmaking process can become completely emission-free, creating 'green steel.'**

http://www.fchea.org/in-transition/2019/11/25/hydrogen-in-the-iron-and-steel-industry

The Cost of Hydrogen

2.2. An International Perspective

Canada is internationally recognized as among the world's lowest cost sources of 'blue' and 'green' hydrogen. Of all pacific rim countries, Canada has been identified as the lowest cost producer of green hydrogen (**Figure 2.1**), capable of making hydrogen at an energy price equivalent to the wholesale cost of diesel.

Provinces like Quebec and Manitoba, with low-carbon, hydro-power grids that produce surplus electricity should be able achieve this price.

For the production of Blue H_2 from natural gas, the Western Canadian Sedimentary Basin (WCSB, includes Northern BC, Alberta and S Saskatchewan) is the ideal location due to the supply of low-cost natural gas, and a geology that can safely store the CO_2 byproduct safely

In this region, it should be possible to produce blue H_2 (90% capture) at a wholesale cost of C$10/GJ$_{hhv}$, one half the wholesale, and one third the retail cost of diesel (**Figure 2.1**).

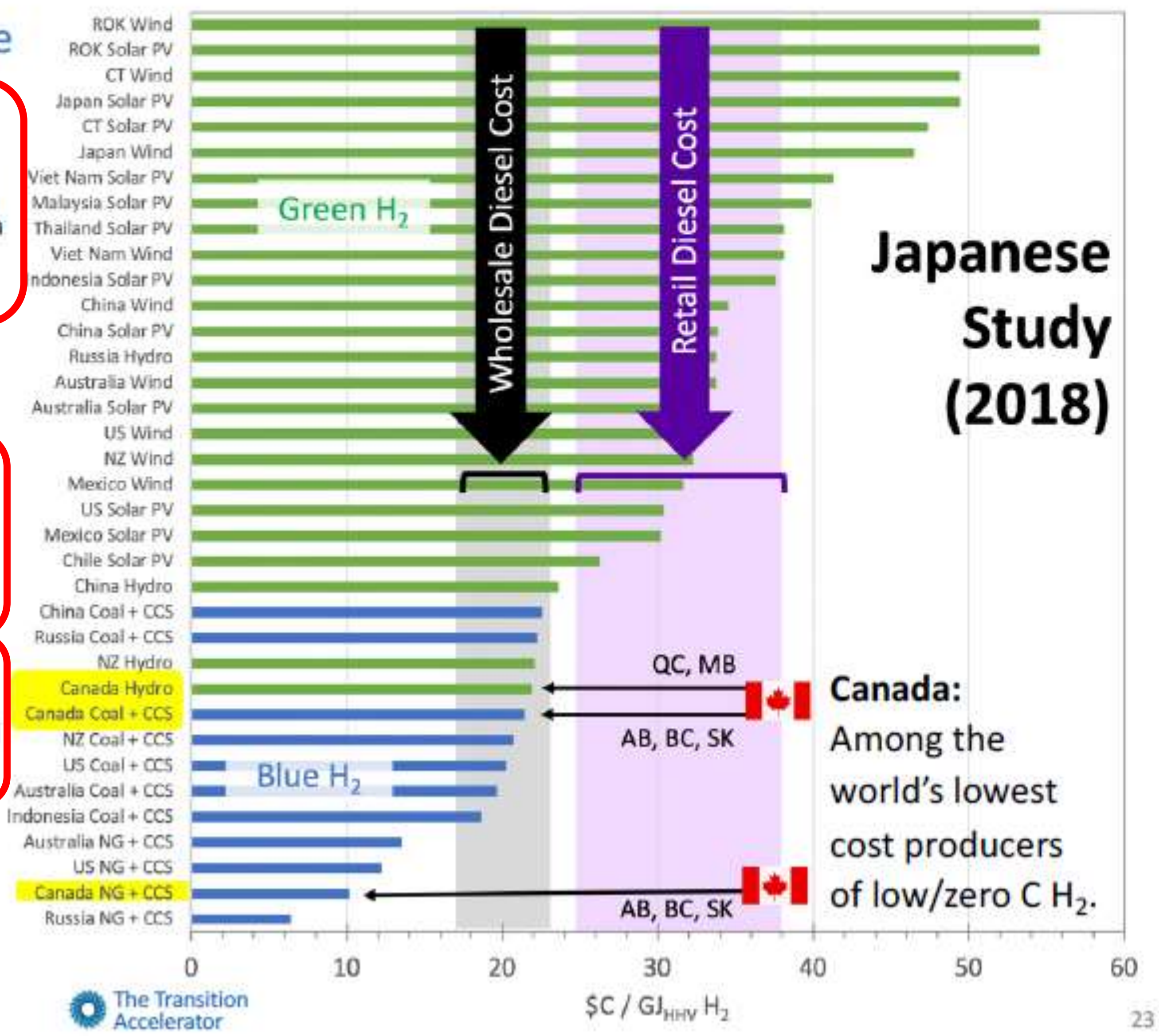


Figure 2.1. A comparison of the cost of blue or green hydrogen production from countries in the Asia-Pacific region. Adapted from Asia Pacific Energy Research Centre. 2018. Perspectives on H_2 in the APEC Region. (Figure 3.). The vertical shaded regions depict ranges for recent wholesale and retail costs of diesel use in Canada.

Source: Layzell DB, Young C, Lof J, Leary J and Sit S. 2020. Towards Net-Zero Energy Systems in Canada: A Key Role for Hydrogen. **Transition Accelerator Reports:** Vol 2, Issue 3. https://transitionaccelerator.ca/towards-net-zero-energy-systems-in-canada-a-key-role-for-hydrogen

Potential future market for Canadian Hydrogen

Table 4.1. Summary of potential North American market for blue and/or green hydrogen from Canada

Potential NA Markets	Market for H_2	H_2 Price	Market
	kt H_2/day	\$/kg H_2	\$B/yr
Domestic	63.8	\$ 2.00	\$ 46.57
USA (oil alt.)	31.0	\$ 2.00	\$ 22.60
USA (gas alt.)	26.5	\$ 2.00	\$ 19.35
Total	**121.3**		**\$ 88.50**

Total Market Value for Canadian Fuel Hydrogen > \$100bn/yr

4.3. Potential Overseas Market for Canadian Fuel Hydrogen

There is also a growing overseas market for hydrogen as countries have rolled out their hydrogen strategies. This hydrogen would need to be converted into a cryogenic liquid (LH_2) or into ammonia and put on a ship for overseas transport. For example, over the past year:

- Japan announced it aims to establish commercial supply chains that will procure 300 kt H_2/yr (822 t H_2/day) by 2030
- South Korea has projected a national demand of 5.26 Mt H_2/yr (14.4 kt H_2/day) by 2040
- Germany recently announced a national demand for about 2.5 Mt H_2/yr (7.0 kt H_2/day) by 2030.

These countries have limited domestic ability to produce hydrogen so they will be looking to import the zero-emission fuel from other nations. Assuming Canada attracts 50% of the potential market and the LH_2 sells for \$3.50/kg (a conservative price), the 11.1 kt H_2/d market would contribute C\$14.20 billion to the Canadian economy (**Table 4.2**).

Table 4.2. Summary of potential Overseas market for blue and/or green hydrogen from Canada

Country with H_2 Import Plan	Market for LH2		Liquid H_2 Price	Market
	Kt LH_2/day	**% Mkt Share**	\$/kg LH2	\$B/yr
Japan (2030)	0.822	50%	\$ 3.50	\$ 0.53
South Korea (2040)	14.4	50%	\$ 3.50	\$ 9.20
Germany (2030)	7.0	50%	\$ 3.50	\$ 4.47
Total	**22.2**			**\$ 14.20**

Proton Technologies

A Calgary company currently producing Hydrogen from abandoned oilfields

www.proton.energy

An interview with Dr. Ian Gates, Head of Chemistry and Petroleum Engineering, University of Calgary (2mins):-
https://youtu.be/vFo3FE-SRoI

Proton is testing its zero-emissions technology on a well in Saskatchewan that could reach output of as much as 20 tons of hydrogen a day this fall, Chief Executive Officer Grant Strem said in an interview. A facility the company aims to build in the next two years could produce **500 tons per day** at a cost of about **C$100 a ton**, compared with **$1000 to $3000 per ton** for the currently cheapest method, he said.

Source: https://www.bloomberg.com/news/articles/2020-08-13/home-of-the-oil-sands-eyes-cleaner-future-as-hydrogen-superpower

The countries who buy Canada's coal are turning away from fossil fuels

Canadian exports and imports of coal, 2019 (95% metallurgical)

On 3 September 2016, **China** [ratified the Paris Agreement] and submitted its NDC (Nationally Determined Contribution) to the UNFCCC, which includes several elements:

- Peak CO_2 emissions by **2030**, or earlier if possible;
- Lower the **carbon intensity** of GDP by **60% to 65%** below 2005 levels by **2030**;

Japan's NDC includes an **emissions reduction** target of **26%** below 2013 levels in **2030** (Government of Japan, 2017)

South Korea signed the Paris Agreement on 22 April 2016 and ratified it on 3 November 2016. Its NDC proposes an economy-wide target to **reduce GHG emissions by 37%** below business-as-usual (BAU) emissions of 857 $MtCO_2e$/year in **2030**

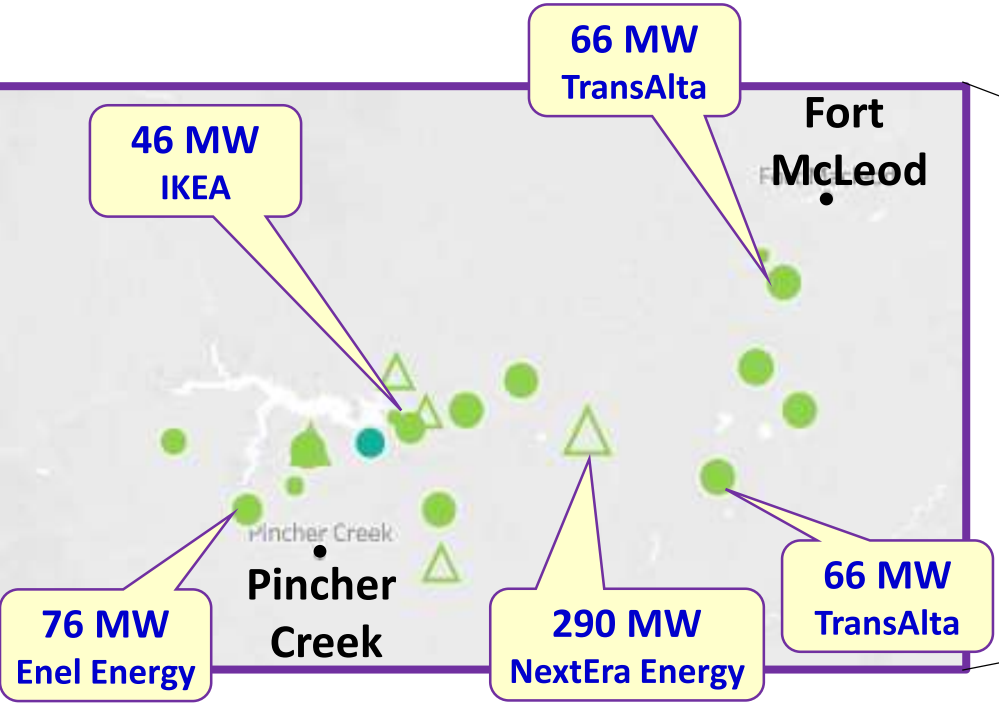
India ratified the Paris Agreement exactly one year after the submission of its Intended Nationally Determined Contribution (INDC), on 2 October 2016. It contains the following main elements (Government of India, 2015):

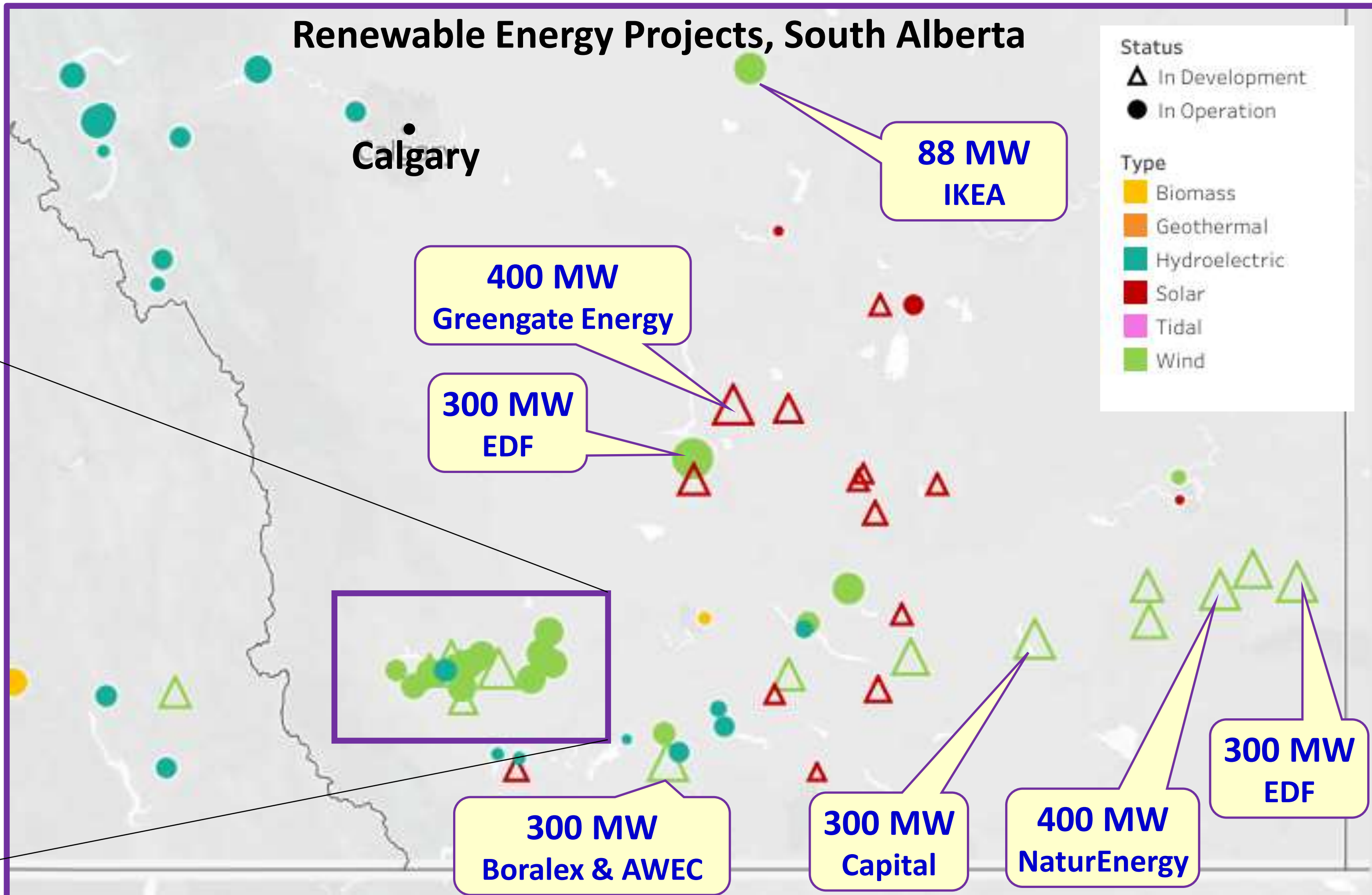
- To **reduce the emissions** intensity of GDP by **33%–35% by 2030** below 2005 levels;

Sources: https://www.nrcan.gc.ca/science-data/data-analysis/energy-data-analysis/energy-facts/coal-facts/20071
https://climateactiontracker.org/countries/

Opportunities for employment in the Renewable Energy sector in southern Alberta

Source:
https://www.futureenergysystems.ca/resources/renewable-energy-projects-canada





Supplementary Information

4.1. Potential Markets for Fuel Hydrogen in Canada

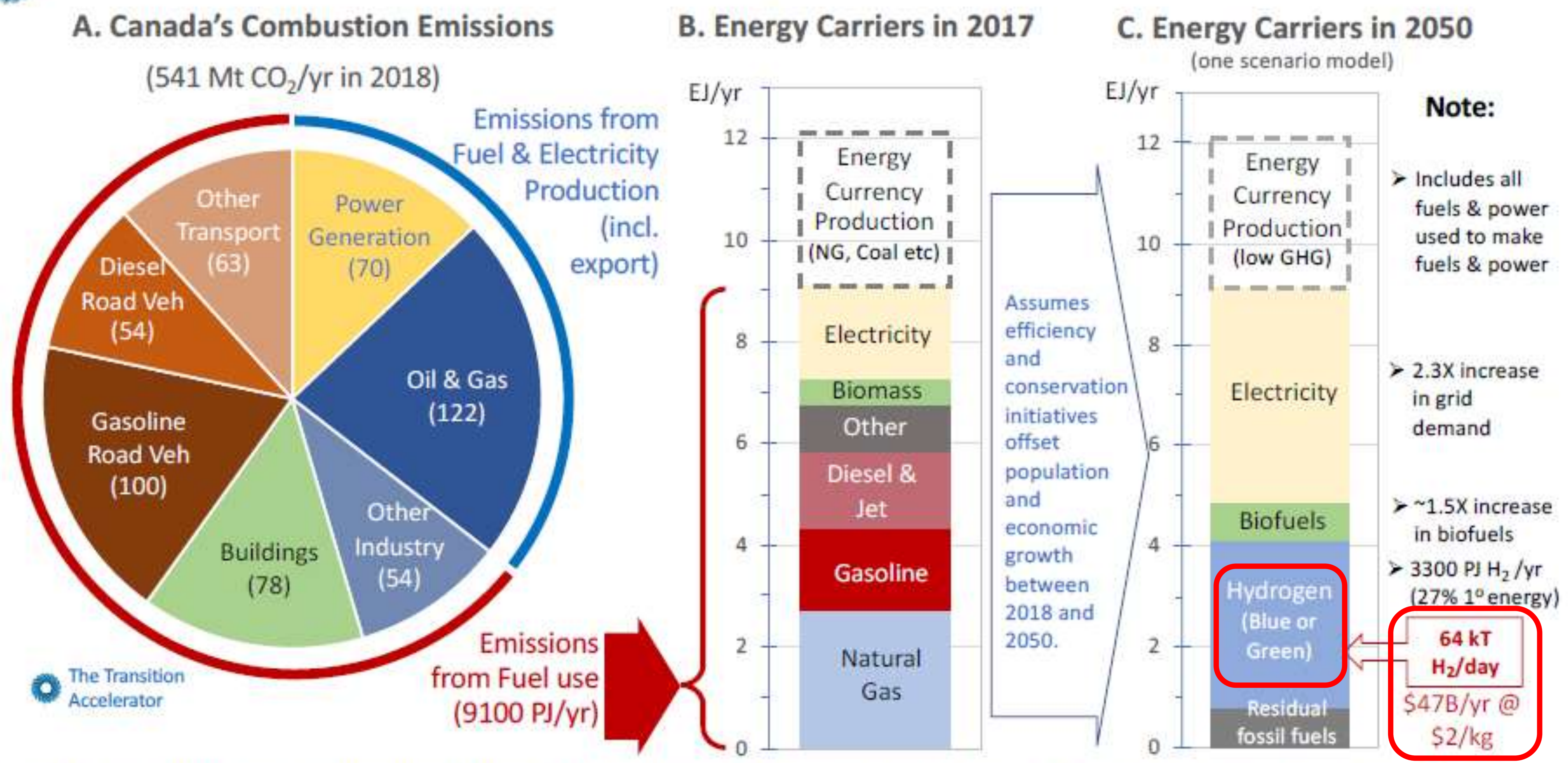


Figure 4.1. A scenario projection for the potential market for fuel hydrogen and low or zero carbon electricity in Canada in a net-zero emission energy system in 2050. Panel A from the National Inventory Report 2020. Panel 2 from the NRCan comprehensive energy database.

4.1. Potential Markets for Fuel Hydrogen in Canada (Continued)

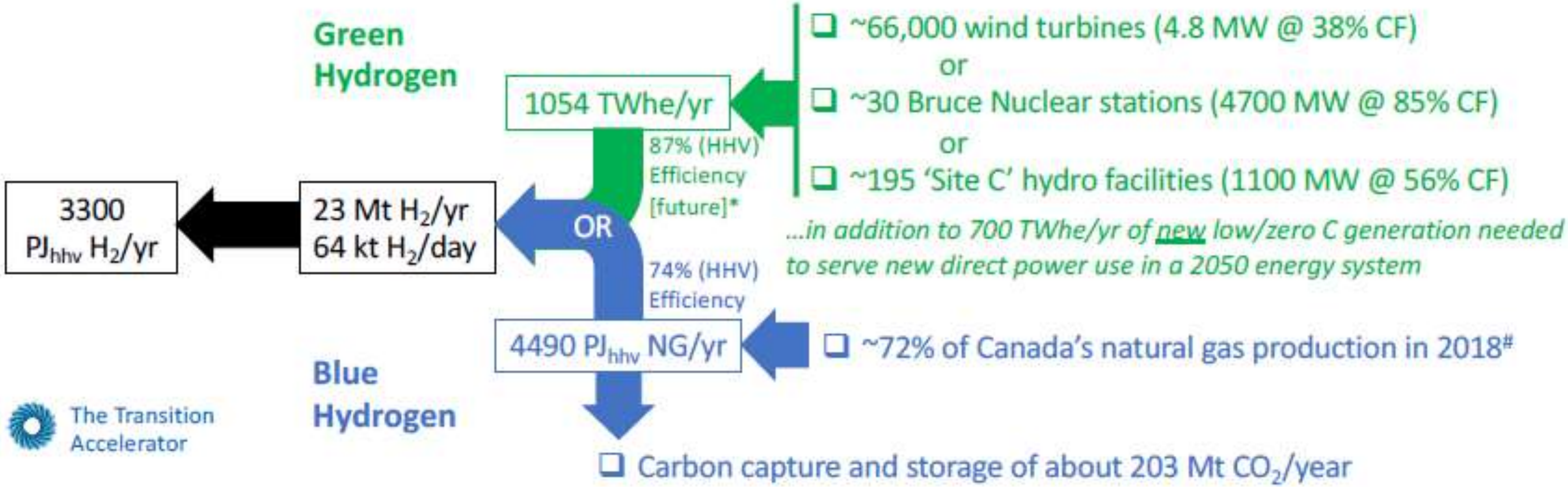


Figure 4.2. A summary of the strategies that Canada could use to provide 64 kt H_2/day from very low or zero emission energy resources. For the green hydrogen alternatives, an 87% (electricity to HHV H_2) conversion efficiency is assumed, reflecting the projected future technological advances in water electrolysis (see **Figure 2.2C**). *, future electrolysis efficiency projected by IEA Future of Hydrogen (2017) report; #, 16.2 Bcf natural gas/day from Canadian Energy Regulator.

4.2. Potential US Market for Canadian Fuel Hydrogen

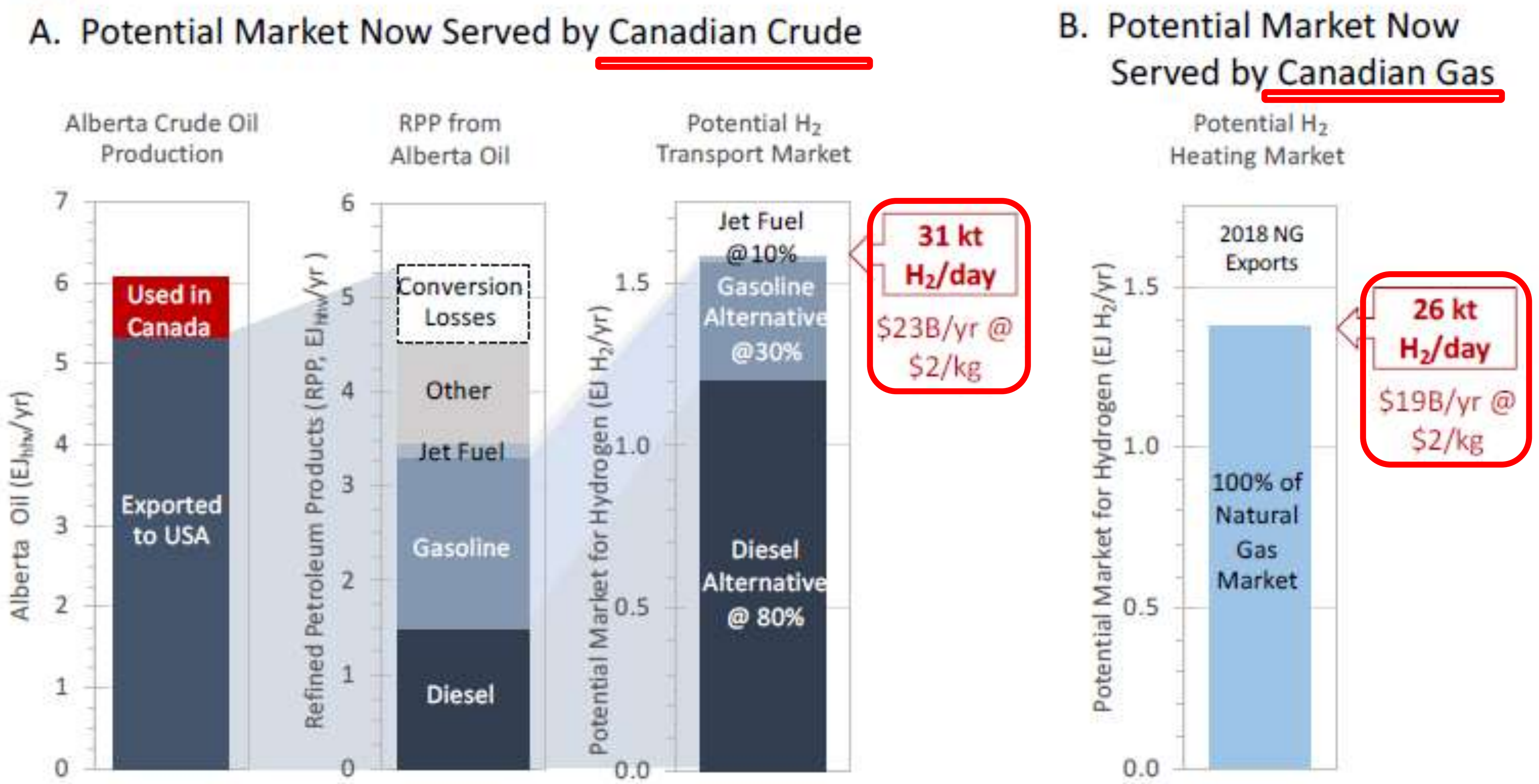


Figure 4.3. Calculation of hydrogen export potential associated with shifting to hydrogen, current U.S. markets for either Canadian crude oil (A) or Canadian natural gas (B).

How to produce Hydrogen from an abandoned oilfield

https://proton.energy/proton-process/

In simple terms, advanced technology allows for a two-step process: i) heating the reservoir to create free hydrogen, and ii) extracting pure hydrogen gas, heat and other valuables.

In practice, a functioning facility or 'Trove' will include a series of connected processes, beginning with the production of oxygen-enriched air and ending with storage and distribution of hydrogen.

The most innovative part of these Trove technologies is the patented combination of heating reservoirs with *Oxinjection wells* and harvesting the hydrogen with *Hygeneration wells*. Both types of wells adapt existing equipment to new purpose.

1. CREATING PURE HYDROGEN WITH OX-INJECTION WELLS

Oxygen-enhanced air is produced at the wellhead, and then injected deep into the reservoir through an '*Oxinjection Well*'. Gases, coke and heavier hydrocarbons are oxidized in place (a process known as *In-Situ Combustion*). Targeted portions of the reservoir become very warm. Where necessary, the temperatures are heightened further through radio frequency emissions.

Eventually, oxidation temperatures exceed 500°C. This extreme heat causes the nearby hydrocarbons, and any surrounding water molecules, to break apart. Both the hydrocarbons and the H_2O become a temporary source of free hydrogen gas. These molecular splitting processes are referred to as thermolysis, gas reforming and water-gas shift. They have been used in commercial industrial processes to generate hydrogen for more than 100 years. In HEE these processes are controlled through the timing and pattern of oxygen injection and external heating.

2. HARVESTING PURE HYDROGEN THROUGH HY-GENERATION WELLS

After creating free hydrogen, one or more Hygeneration wells extracts the elemental hydrogen, using Proton's patented *Hygenerator*. The Hygenerator is a dynamic down-hole device that uses feedback from inside the wells to intelligently locate hydrogen. A selective membrane inside the Hygenerator filters the gases, and a pump moves pure hydrogen gas up to the wellhead.

The Hygenerator is an adaptation of hydrogen-selective filters used in steam-methane reformers (SMRs). Over 95% of the world's hydrogen comes from splitting natural gas, above ground, in SMRs. For a Trove to work, the Hygenerator membrane must be encased in a robust cartridge system that can be placed into a bendy well, and function for long periods despite high pressures and temperature.

Hy-generation wells are sometimes referred to as 'mother wells' since they have potential to produce a stream of other valuable resources: steam for electricity generation, helium gas, syngas, and low-grade thermal energy. Everything else, including carbon, can be left in the ground.

A small part of the energy extracted from the reservoir – as hydrogen, heat or syngas – may be used directly at the wellhead to produce the oxygen-enhanced air, and to operate the pumps.

If syngas is harvested, HEE may release small quantities of carbon into the atmosphere, or recirculate CO2 into the reservoir, as a way to relieve pressure.

In most cases HEE will be completely clean and green, producing pure hydrogen continuously and in massive quantities.