CICE

SKY POINT RESOURCES LTD

ORION PROJECTS

The potential for methane pyrolysis in B.C.

A techno-economic and environmental analysis of low carbon hydrogen opportunities in B.C.

PRESENTERS
Raymond Tang – Hydrogen Lead, CICE
Randy Litun – Sky Point Resources Ltd.

MAY 9, 2024 WEBINAR in support of report release

Territorial Land Acknowledgment

The B.C. Centre for Innovation and Clean Energy respectfully acknowledges that it operates on the traditional, ancestral, and unceded territories of the First Nations, Inuit, and Métis peoples.

Fast-tracking innovation like the planet depends on it.

Because it does.

Who is CICE?

- Independent not-for-profit organization
- Founded: Fall 2021
- $105M raised through public/private member partnerships and grants:
  - Government of British Columbia
  - Shell Canada
  - NRCan (Government of Canada)

Why we exist

- **Lead early-stage, catalytic seed investment**
- **Drive faster market adoption and scale-up**
- **Enable a prosperous, world-class clean economy**

CICE

CICE portfolio snapshot

$ 145M
TOTAL PROJECT FUNDING

$ 23M
INVESTMENT BY CICE

1.02MT/YR
T/YR POTENTIAL GHG ABATEMENT

BATTERY & ENERGY STORAGE

CARBON MANAGEMENT

LOW CARBON BIO & SYNTHETIC FUELS

LOW CARBON HYDROGEN

ANODYNE
ARCA
ATLAS POWER TECHNOLOGIES
Cascadia SEAWEED
Corvus Energy
DEADWOOD INNOVATIONS
EKONA
FPInnovations
H2 PORTABLE CLEAN POWER. ANYWHERE.
HTEC FUELING THE DRIVE TO HYDROGEN
hydra
HYDRON
illuming power
INNOVATREE CARBON GROUP
INVINITY ENERGY SYSTEMS
LAFARGE
Lheidli T'enneh
MANGROVE LITHIUM Unlocking a battery-powered future
Metaspectral
metrovancouver SERVICES AND SOLUTIONS FOR A LIVABLE REGION
miraterra
moment energy
Parkland
Quatern Forest Products
RAINHOUSE MANUFACTURING CANADA LTD.
TAKACHAR TECHNOLOGY • EQUITY • ENVIRONMENT

CICE

Agenda & objectives

Agenda

- Current B.C. landscape
- Methane pyrolysis technologies
- B.C. resources and infrastructure
- Techno-economic scenario analysis
- Next steps – opportunities
- Discussion & questions

Objectives

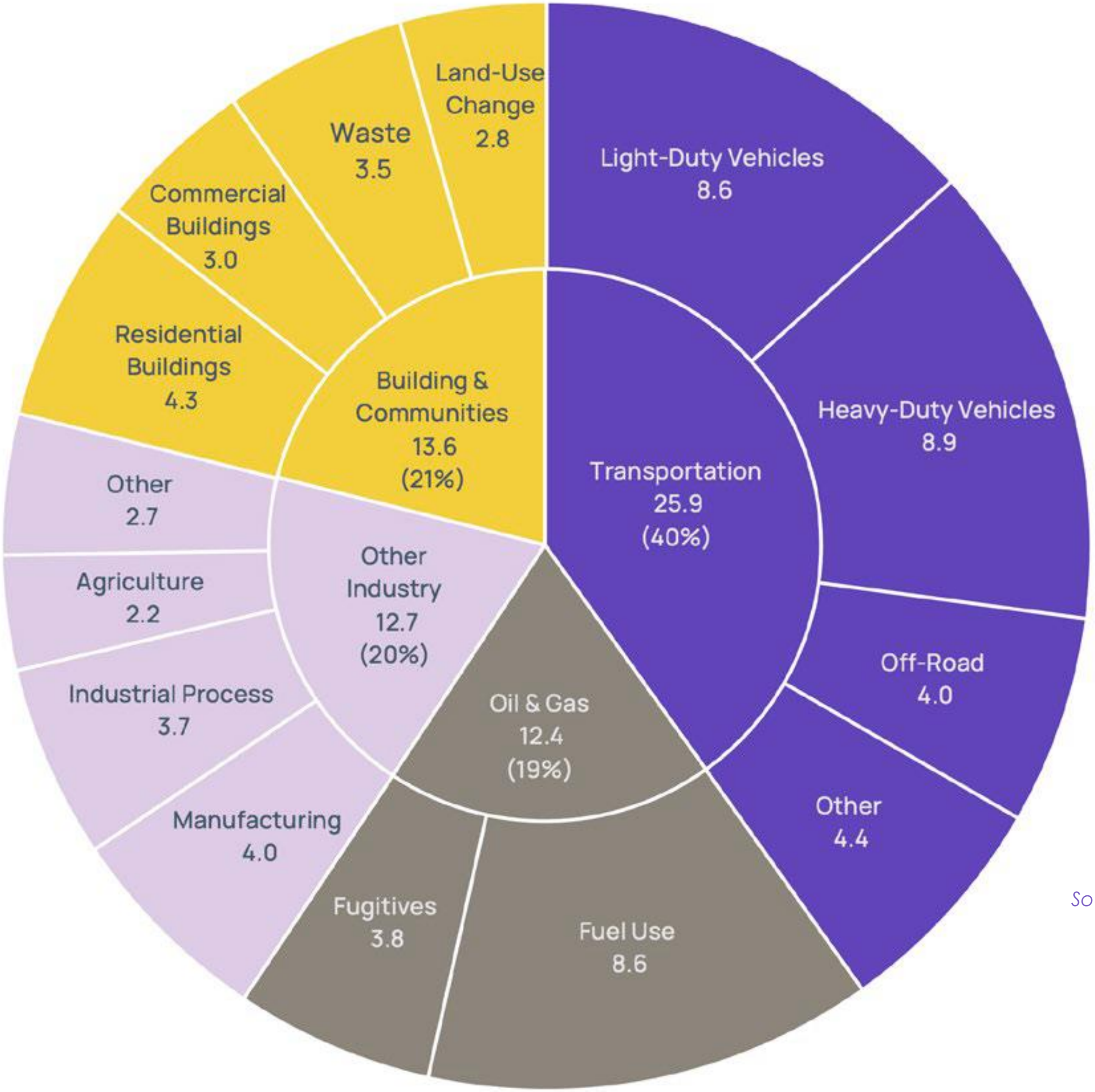
Evaluate methane pyrolysis as a decentralized low carbon hydrogen production pathway in B.C.

Techno-economic analysis of methane pyrolysis versus incumbent hydrogen technologies.

State of development of methane pyrolysis technologies, and its risks and opportunities.

Current B.C. landscape

Current B.C. energy consumption and emissions

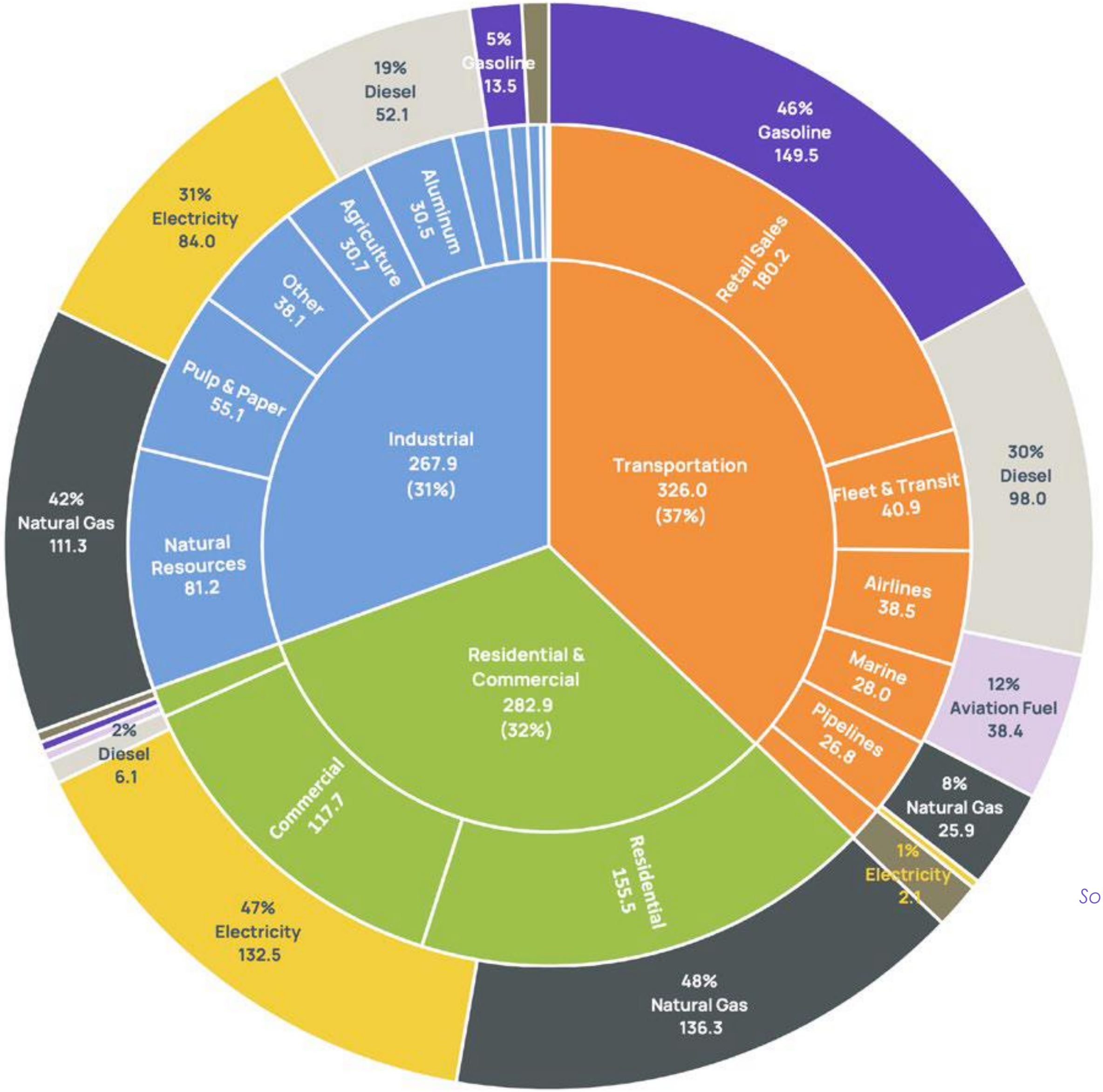


Source: Clean BC

Emissions 64.6 Mt CO_2e

CICE

Current B.C. energy consumption and emissions



Source: Stats-Can

Consumption 876.8 PJ

CleanBC Roadmap – GHG reductions of 40% below 2007 by 2030, 60% by 2040, and 80% by 2050

Transportation

2030 Target:
27-32% reduction

- Low Carbon Fuel Standard
- Zero-Emission Vehicles Act

Industry

2030 Target:
38-43% reduction

- Energy Action Framework
- Carbon Tax in alignment with Federal
- Output based emissions tax for large emitters
- Large emitter submissions for net-zero by 2050
- 100% Clean Electricity Standard by 2030

Oil & gas

2030 Target:
33-38% reduction

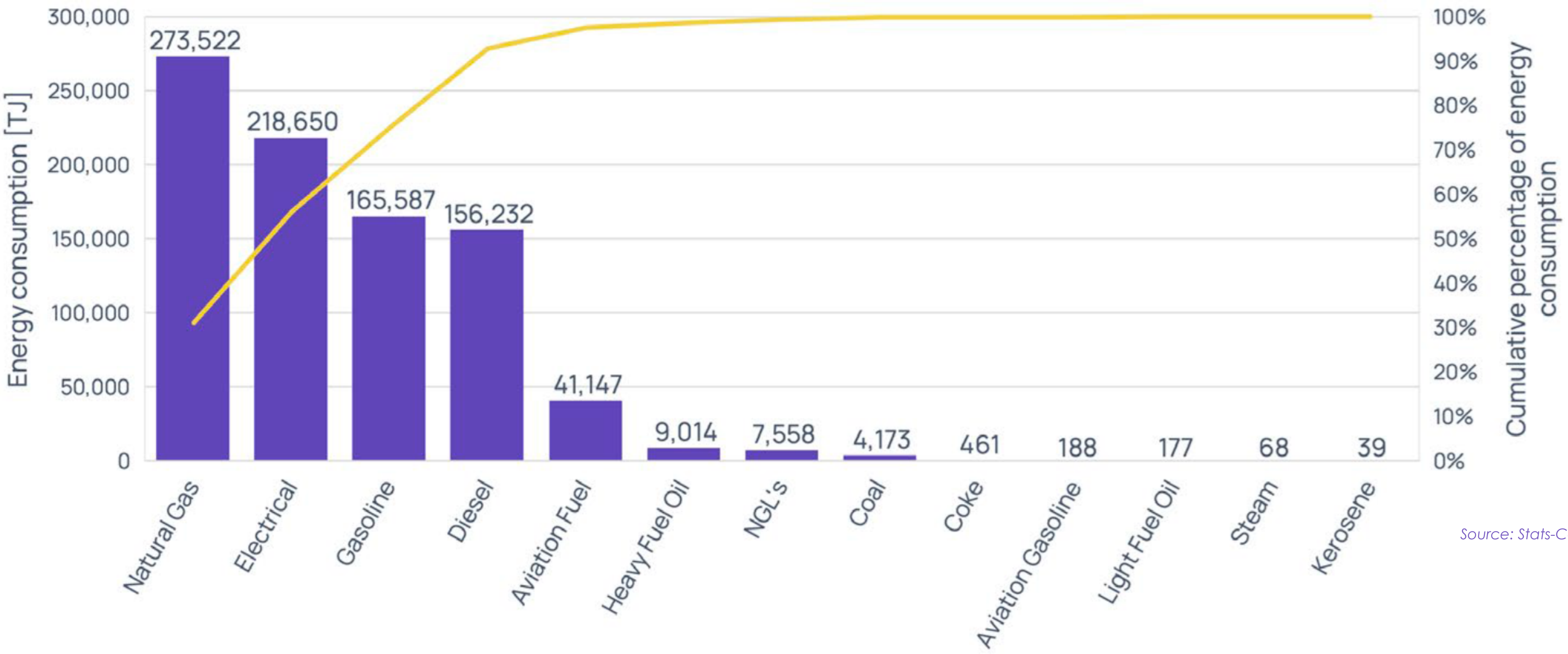
- Methane emissions reduction by 75% by 2030
- Cap on GHG emissions for natural gas utilities
- 15% target for renewable natural gas blending by 2030

Buildings & communities

2030 Target:
59-64% reduction

- New buildings to be zero carbon and new space and water heating to be highest efficiency by 2030
- Support of local government climate and resiliency goals

Conventional energy displacement – transition challenges



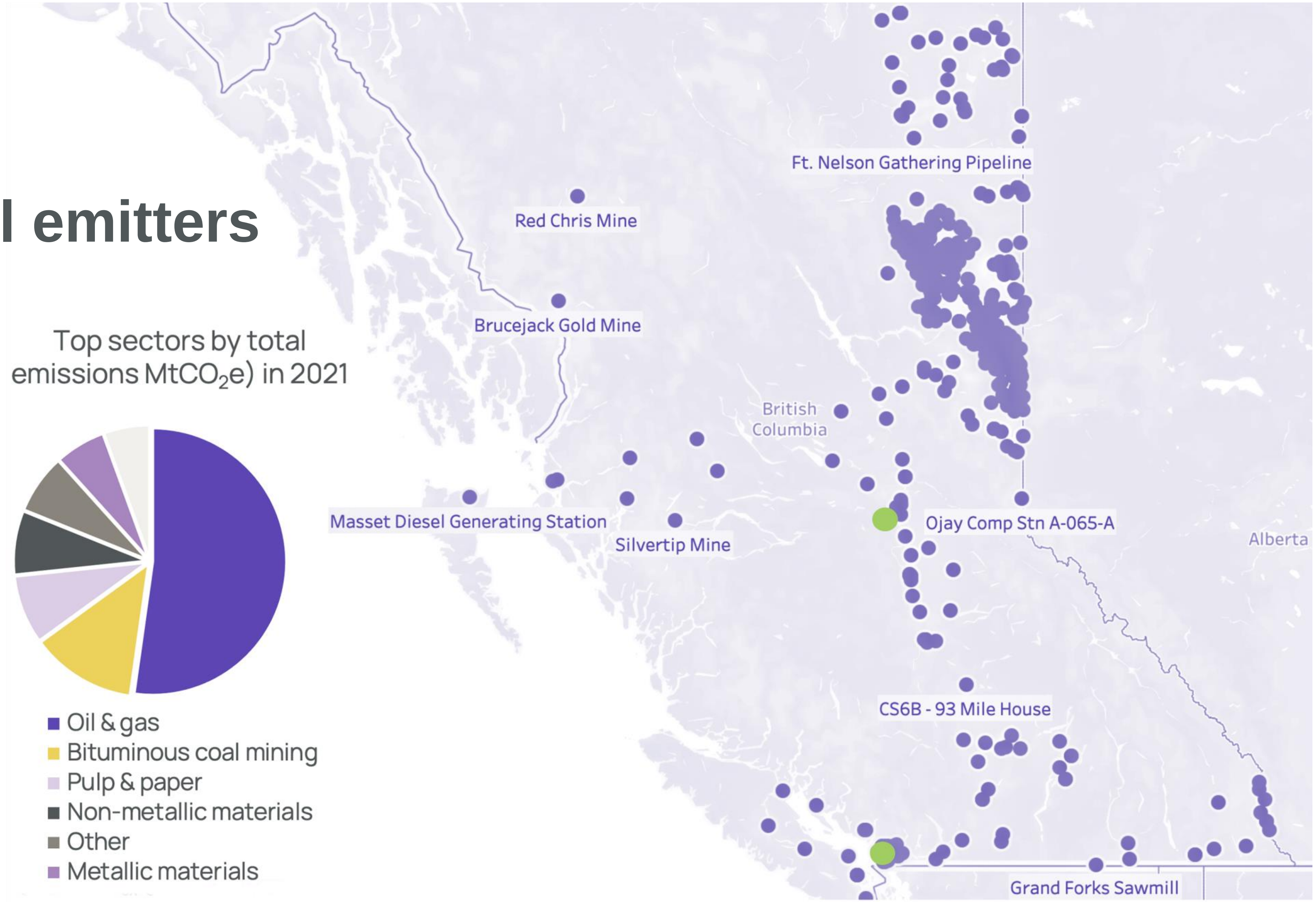
Source: Stats-Can

Natural gas, gasoline, diesel, and aviation fuel represents 75% of B.C.'s current energy use

CICE

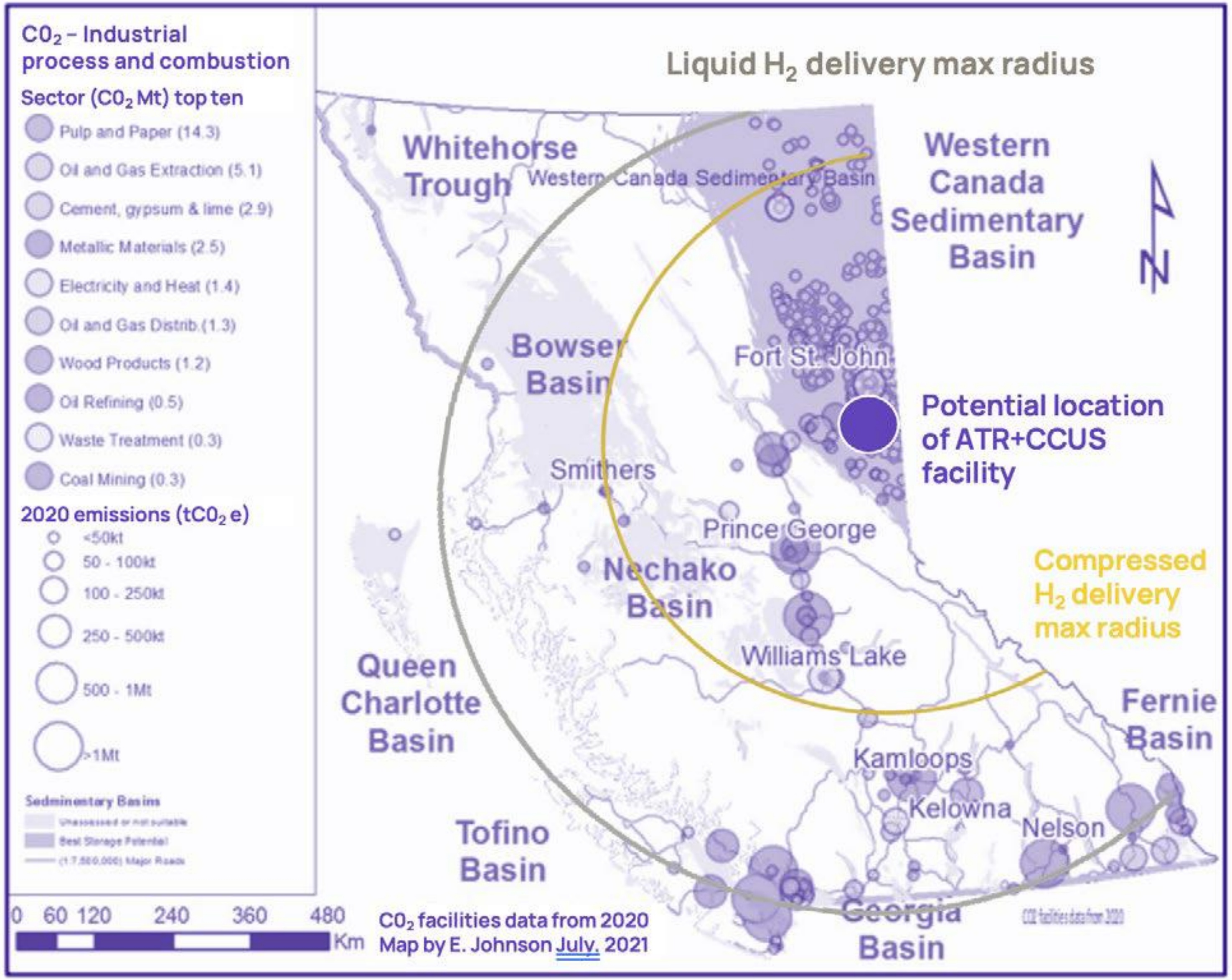
Large industrial emitters

B.C. only has 2 remaining oil refineries and no petrochemical facilities (largest direct use cases of H_2)



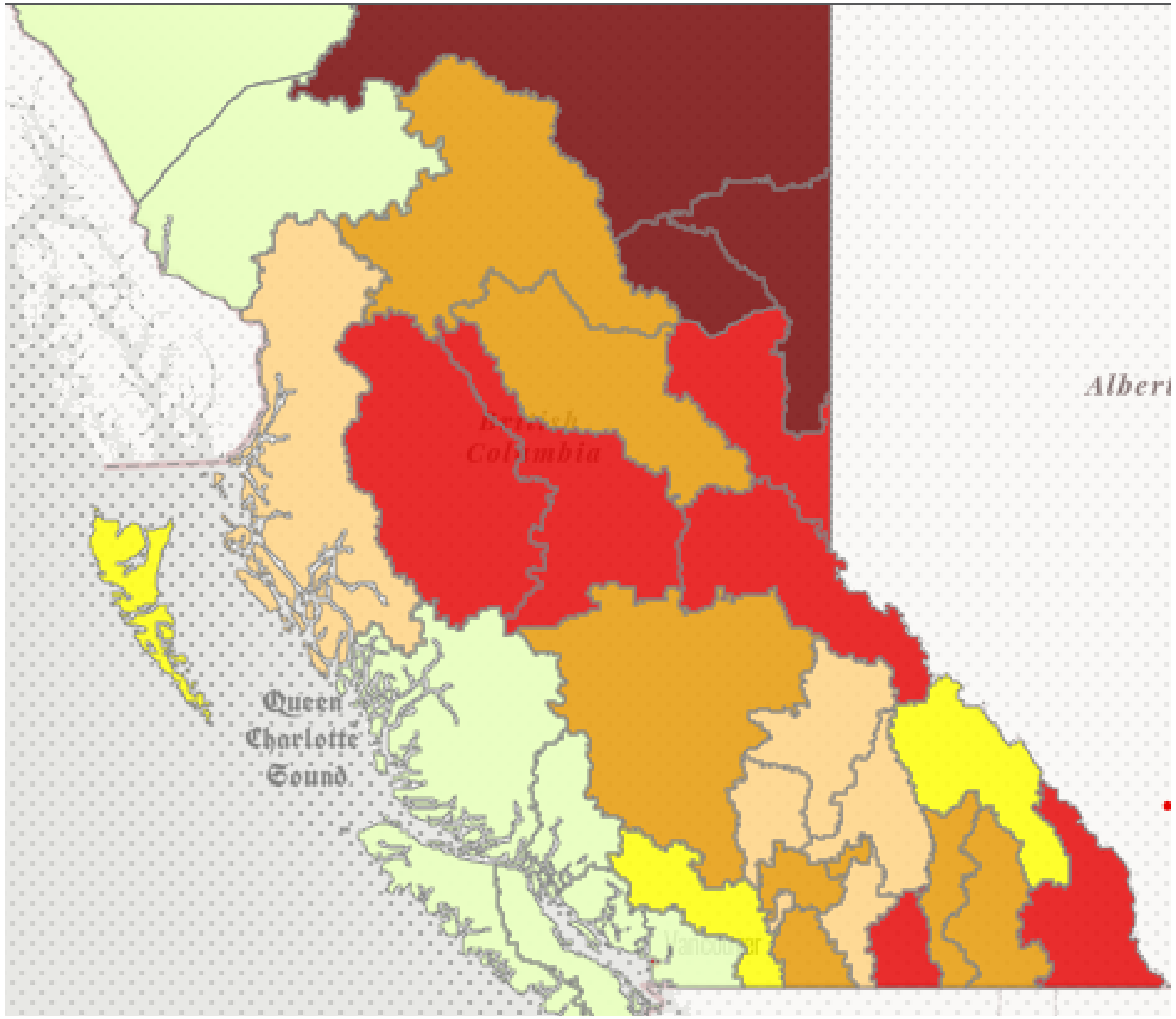
CCUS for ATR restricted to NE B.C.

Would result in significant hydrogen transportation costs to demand centres far away



CICE

Water access restriction for large scale electrolysis

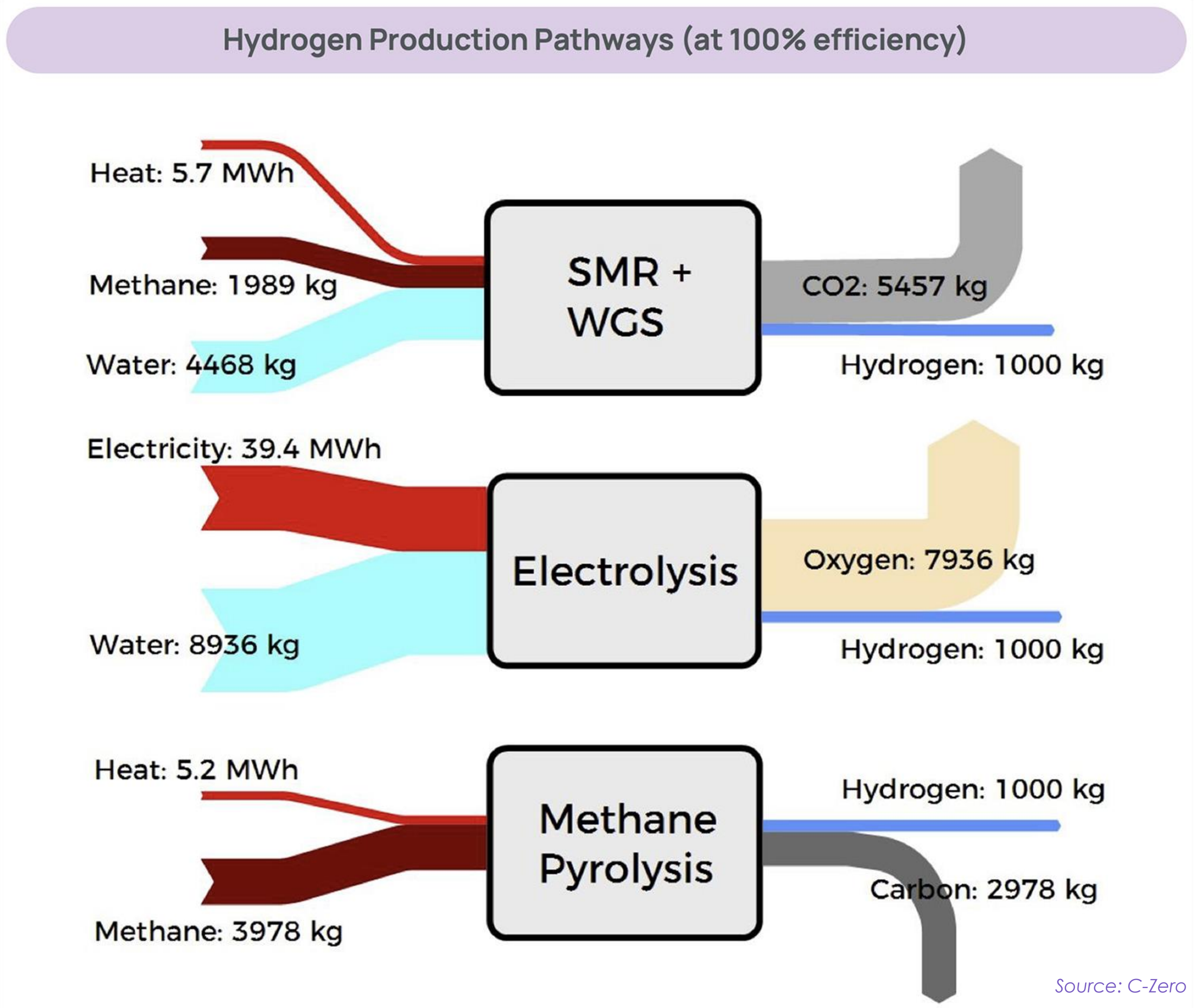


Persistent drought conditions and limited snowpack has resulted in strains on most basins throughout B.C.

Methane pyrolysis technologies

How is hydrogen generated today?

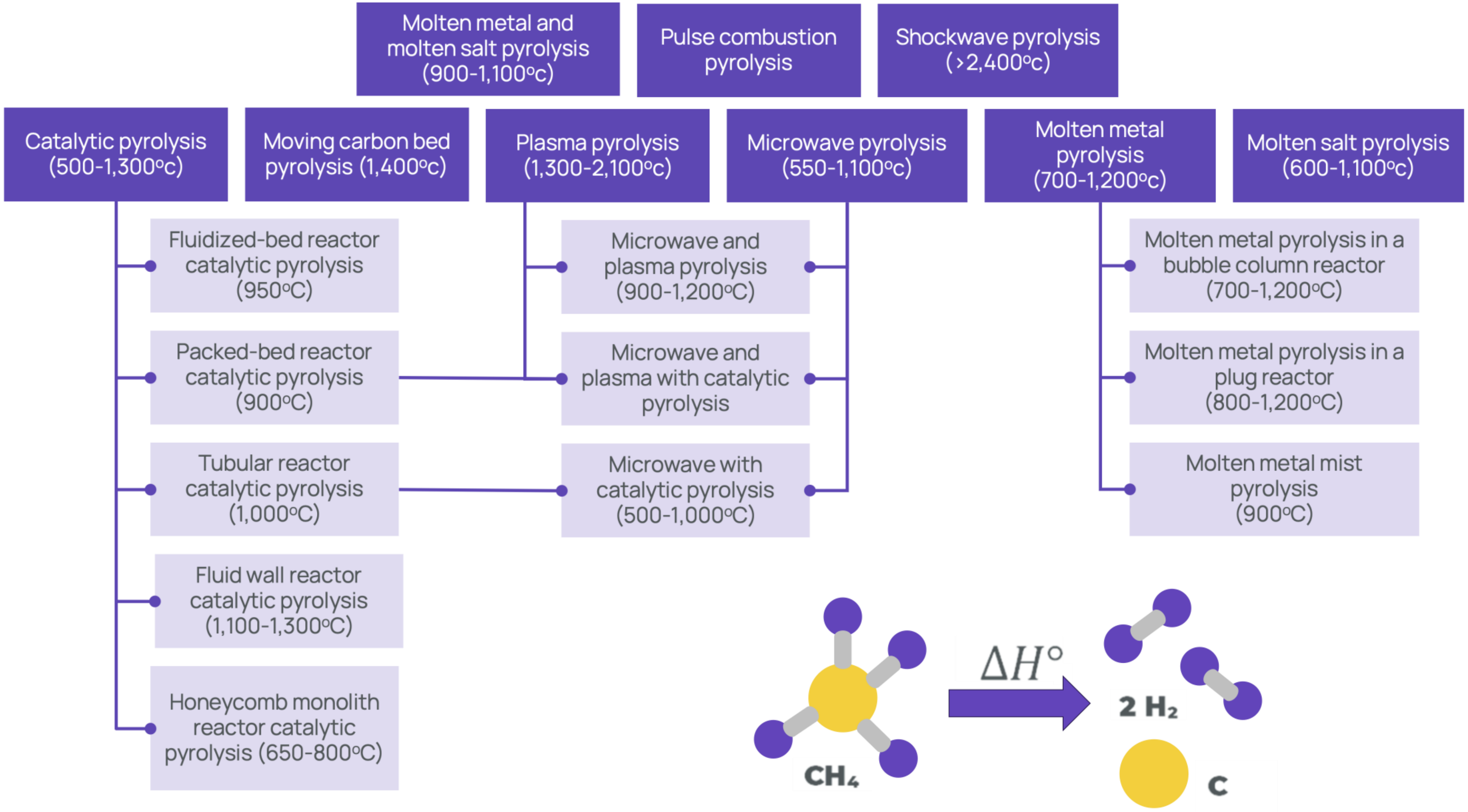
How does methane pyrolysis compare?



Hydrogen Production Pathways (at 100% efficiency)

Source: C-Zero

Methane pyrolysis – process variations



Molten metal and molten salt pyrolysis (900-1,100°c)

Pulse combustion pyrolysis

Shockwave pyrolysis (>2,400°c)

Catalytic pyrolysis (500-1,300°c)

- Fluidized-bed reactor catalytic pyrolysis (950°C)
- Packed-bed reactor catalytic pyrolysis (900°C)
- Tubular reactor catalytic pyrolysis (1,000°C)
- Fluid wall reactor catalytic pyrolysis (1,100-1,300°C)
- Honeycomb monolith reactor catalytic pyrolysis (650-800°C)

Moving carbon bed pyrolysis (1,400°c)

Plasma pyrolysis (1,300-2,100°c)

Microwave pyrolysis (550-1,100°c)

- Microwave and plasma pyrolysis (900-1,200°C)
- Microwave and plasma with catalytic pyrolysis
- Microwave with catalytic pyrolysis (500-1,000°C)

Molten metal pyrolysis (700-1,200°c)

- Molten metal pyrolysis in a bubble column reactor (700-1,200°C)
- Molten metal pyrolysis in a plug reactor (800-1,200°C)
- Molten metal mist pyrolysis (900°C)

Molten salt pyrolysis (600-1,100°c)

CICE

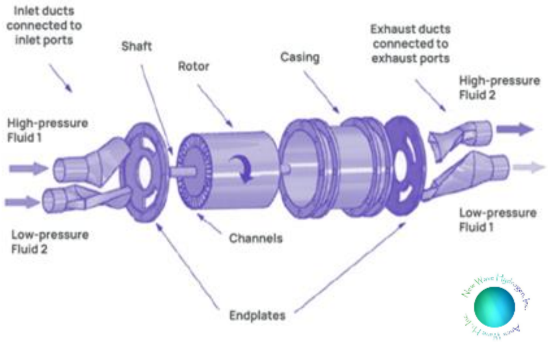
Identified methane pyrolysis technology companies

32 tech companies specific to methane paralysis identified as of Dec 2023 with more emerging every month.

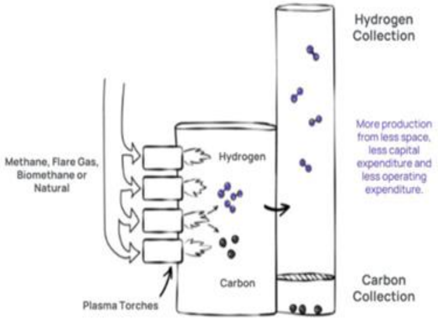
Majority of companies technology is between TRL 4 – 8 but expect many to reach TRL 8 / 9 by 2030

	Company name	Country of origin	Status	Tech
	Methane pyrolysis			
1	Monolith	US (Nebraska)	Commercial plant (13 t/d) in Nebraska 2020, expansion to 165 t/d in 2026	High temperature electric heating - plasma
2	Hazer Group	Australia (Perth)	Demo plant (275 kg/d) in Perth 2023, commerical plant (7 t/d) in BC 2025	Low temp fluid bed iron ore catalytic pyrolysis
3	C-Zero	US (Goleta, California)	Pilot plant (400 kg/d) Q4 2023, commercial plant (6 t/d) 2025	Bubble column molten metal / salt pyrolysis
4	Huntsman Nanocomp	US (Merrimack, N.H)	Bench scale (1 kg/d), pilot plant (25 kg/d) in Texas 2023, demo plant (1 t/d) in 2026	Thermal catalytic pyrolysis
5	H-Quest	US (Pittsburgh, Pa.)	Pilot plant (250 kg/d) 2023, with commercial target of 1 t/d	Microwave plasma pyrolysis
6	Hiiroc Hydrogen	UK (Kent)	2 demo plants in operation (UK), pilot plant (400 kg/d) in Germany 2023	Vortex plasma torch and molten metal pyrolysis
7	Modern Hydrogen	US (Seattle, Wash.)	2 micro demo plants (5 kg/d) 2023, pilot plant (500 kg/d) 2024	High temp pyrolysis
8	Ekona Power	Canadian (Burnaby, BC)	Bench scale reactor (200 kg/d), pilot plant (1 t/d) in Alberta 2024	Thermal pulsed methane pyrolysis
9	Hycamite	Finland (Kokkola)	Bench scale, pilot plant (5.5 t/d) 2024 (Finland)	Thermocatalytic pyrolysis
10	Levidian	UK (Cambridge)	3 demo plants (27 kg/d) in Scotland 2024 and Demo Plant (55 kg/d) in UAE 2025	LOOP - microwave plasma methane cracking
11	Plenesys	France (Valbonne)	Demo plant (150 kg/d) in Australia with commercial target of 275 kg/d and 2.7 t/d units	Hyplasma (AC plasma arc)
12	GraforcE	Berlin, Germany	Demo plant in Austria with commercial target of 1.2 t/d units	Plasmalysis - renewable electricity and plasma pyroloysis
13	Etch	US (Baltimore, Md.)	Bench scale reactor, demo plant (135 kg/d) 2023	Catalytic thermochemical redox
14	Innova Hydrogen	Canadian (Calgary, AB)	2 demo plants (2 t/d) in Alberta 2024 and pilot plant (5 t/d) in BC 2026	HIP reactor (high temp impulse) - catalytic pyrolysis
15	Aurora Hydrogen	Canadian (Edmonton, AB)	Demo plant (200 kg/d) in Alberta 2024	Microwave pyrolysis
16	Nu:Ionic Technologies	Canadian (Fredericton, NB) / US (Tulsa, Ok.)	Demo plant (2.4 t/d) in New Brunswick 2025	Microwave catalytic reforming
17	Vulcanx	Canadian (Vancouver, BC)	Pilot plant (55 kg/d) in Alberta 2023	High temp bubble column with recirculating molten metal
18	Basf	Germany (Ludwigshafen)	Bench scale reactor (11 kg/d)	High temp moving fluid bed iron ore catalytic pyrolysis
19	Hydrograph	Canadian (Toronto, ON)	Bench scale reactor, demo plant (30 kg/d) in Manhattan, KS.	Hyperion - detonation pyrolysis (graphene focused)
20	Clean Hydrogen	US (New York) / India (Arjun Datir)	Bench test	CHT - catalytic high temp plasma fluid bed pyrolysis
21	Maat Energy	US (Cambridge, Mass.) / France (Venissieux)	Bench test	AMP - atmospheric microwave plasma system
22	New Wave Hydrogen	Canadian (Calgary, AB)	Bench test	Wave rotor shockwave pyrolysis
23	Spark Hydrogen	France (Gif-sur-Yvette)	Bench test	Plasmalysis - cold nanopulsed plasma
24	Tomsk Polytechnic Institute	Russia (Tomsk)	Bench test	Microwave catalytic + cold plasma torch
25	Gasplas / University Of Cambridge, Uk	Norway (Oslo)	Conducting bench testing	Microwave plasma pyrolysis
26	Seid As	Norway (Sandnes)	Lab testing	ColdSpark (low temp pyrolysis)
27	Susteon (Palo Alto Research)	US (Palo Alto, Calif. / Cary, NC)	Lab testing	Centrifugal cascading molten zinc
28	Susteon (Stanford University)	US (Palo Alto, Calif. / Cary, NC)	Lab testing	Low temp catalytic pyrolysis
29	Susteon (Gupta)	US (Cary, NC)	Lab testing	Silicon catalytic pyrolysis
30	Thiozen	US (Beverly, Mass)	Lab testing	Thermochemical iodine sour gas pyrolysis
31	Universal Matter Advanced Materials	Canadian (Burlington, On) / US (Houston, TX) / UK (Redcar)	Lab testing	Flash pulse pyrolysis (turbostatic graphene focused)
32	Pacific Northwest National Laboratory	US (Richland, Wash)	Proof of concept	Fluidized bed bimetallic catalytic pyrolysis

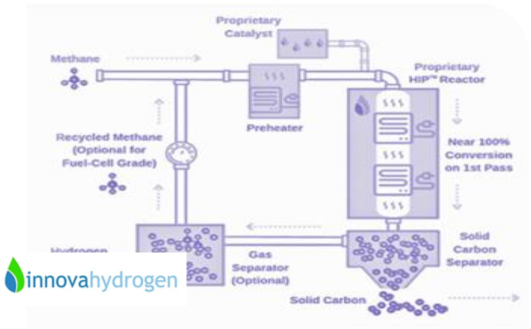
Selected existing technologies – Canada well represented



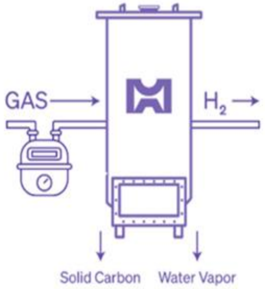
Rotary shock wave



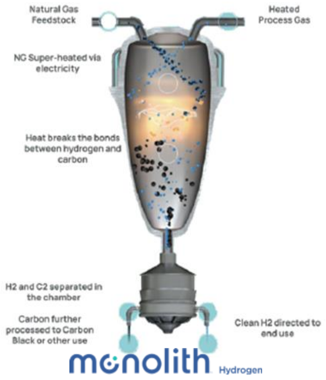
Plasma – molten metal



Low temp – catalytic

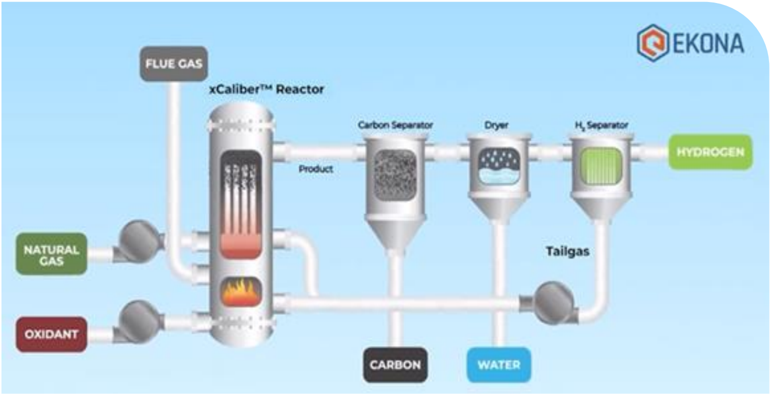


Concurrent combustion

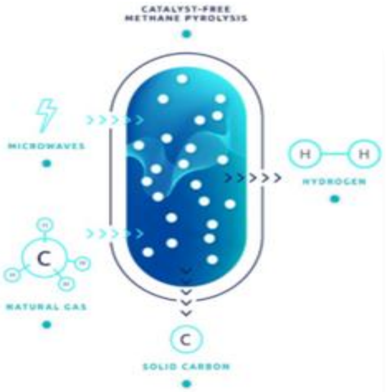


Plasma

Molten metal



Thermal pulse



Microwave

Not just in the lab!

Commercial Unit	
Production Rate	Hydrogen Production: ~600 kg/h
Operation	2020 - present
Location	Nebraska, United States
Technology	Full commercial scale unit

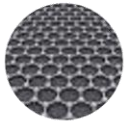
Monolith Corp. – Olive Creek Plant phase 1
Hallam, Nebraska

Hazer Group commercial demonstration plant Perth, Australia

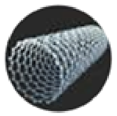
Valuable co-product stream

Carbon black

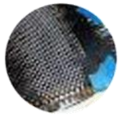
Graphite



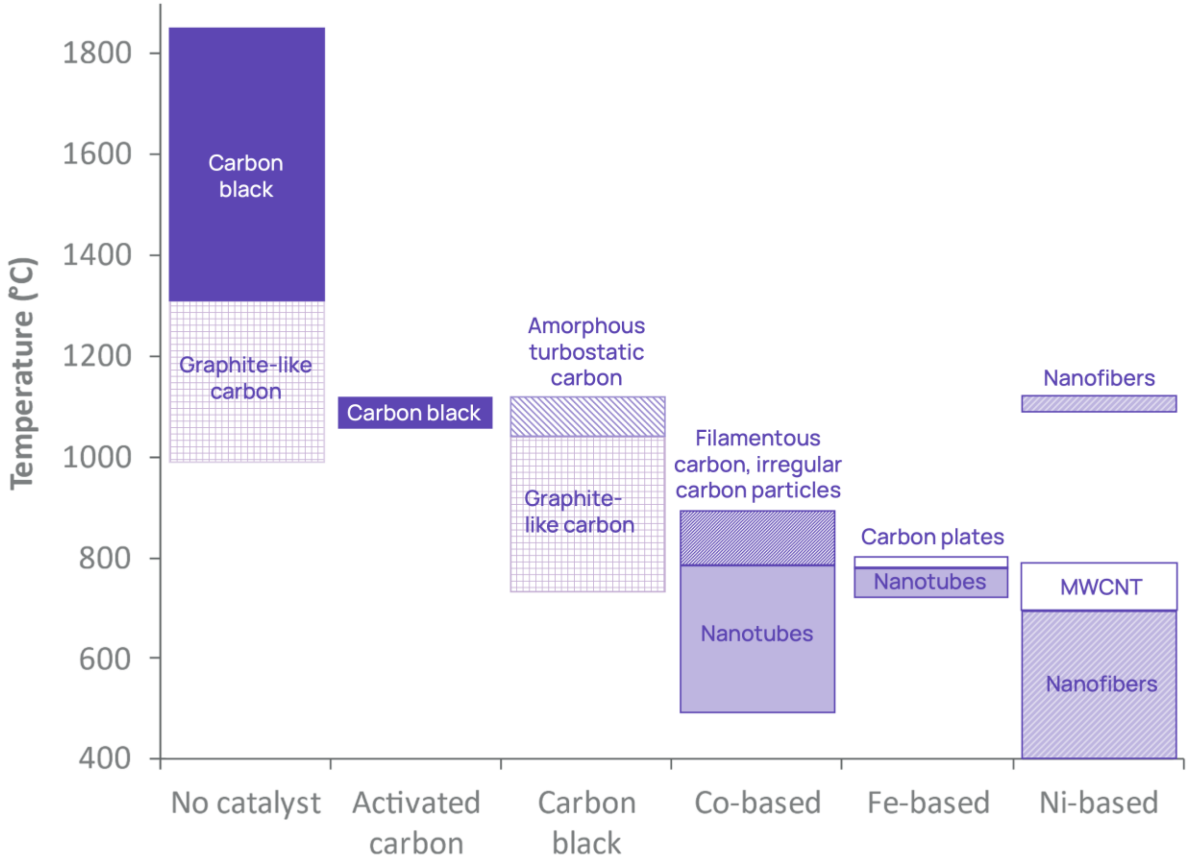
Graphene



Carbon nanotube

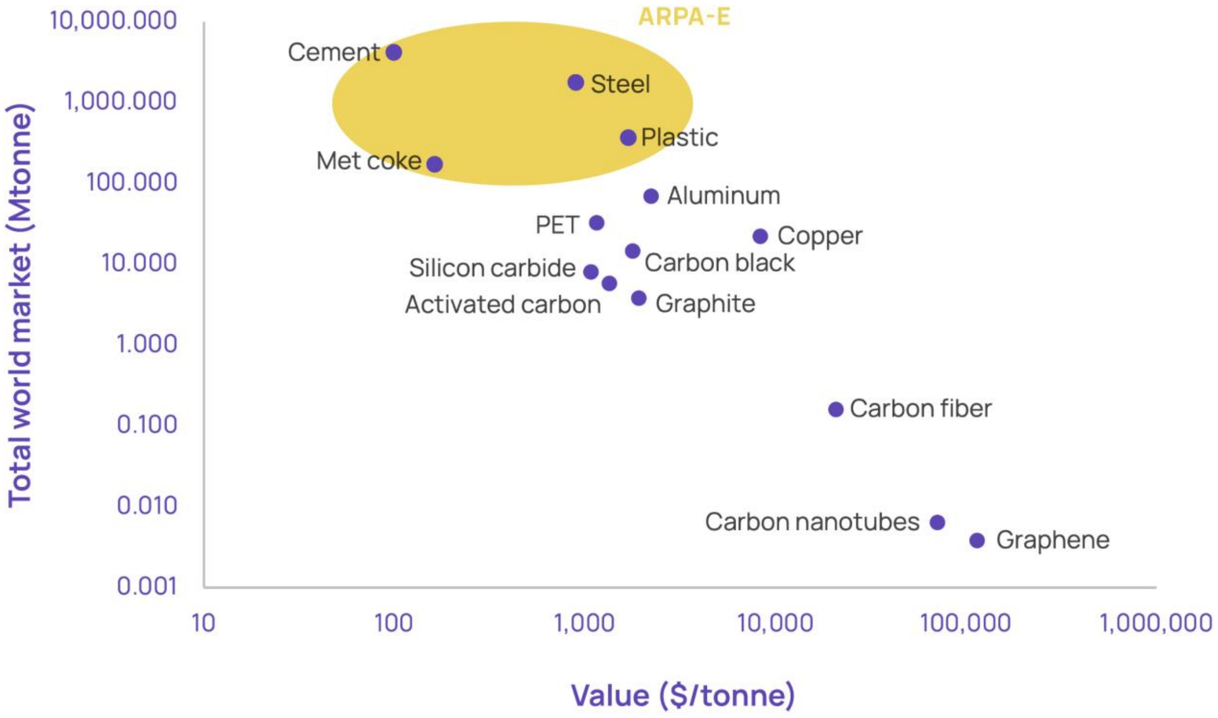


Carbon fibers



Different pyrolysis conditions dictate the carbon allotrope created and the properties of the carbon.

Source: Keipi, et al, "Thermo-catalytic decomposition of methane: The effect of reaction parameters on process design and the utilization of possibilities of the produced carbon", 2016

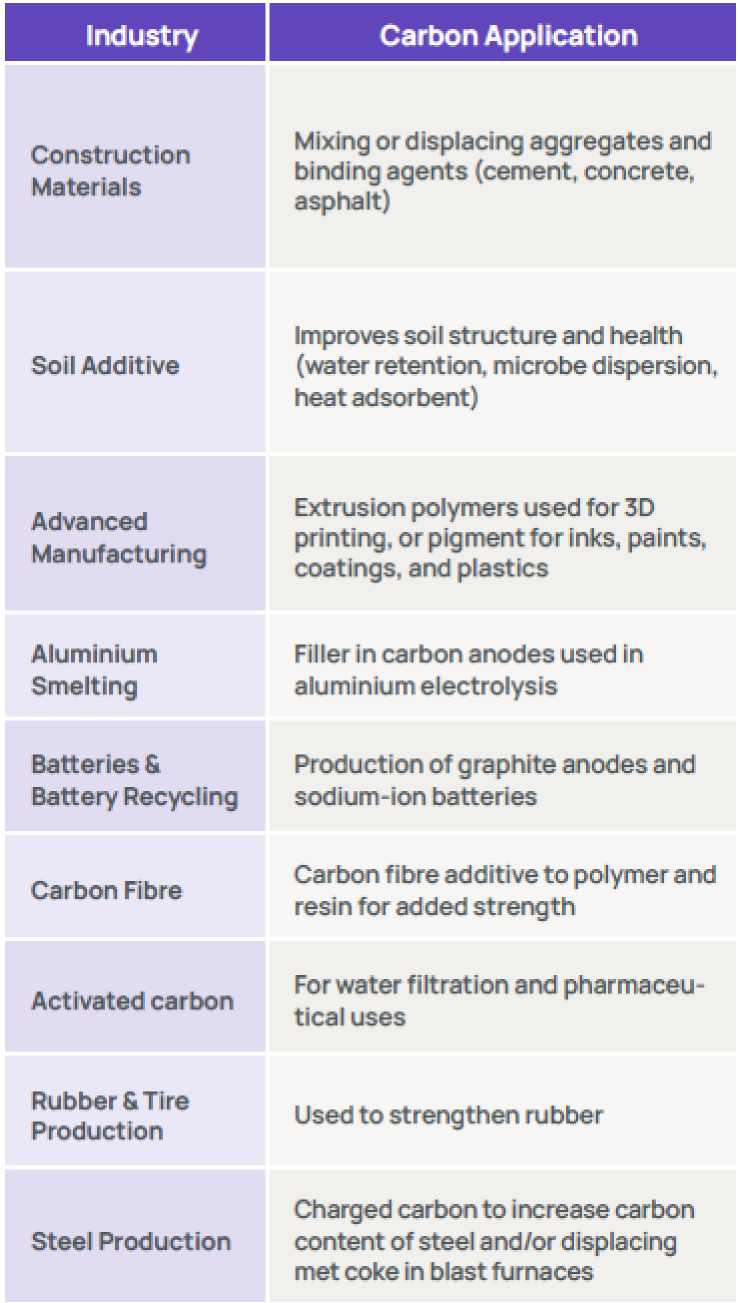


Wide range of value for different allotropes with market size inversely proportional to value.

CICE

Carbon utilization in B.C.

B.C. has the potential to take a leadership position in developing adoption of carbon from methane pyrolysis within a new advanced materials economy



Industry	Carbon Application
Construction Materials	Mixing or displacing aggregates and binding agents (cement, concrete, asphalt)
Soil Additive	Improves soil structure and health (water retention, microbe dispersion, heat adsorbent)
Advanced Manufacturing	Extrusion polymers used for 3D printing, or pigment for inks, paints, coatings, and plastics
Aluminium Smelting	Filler in carbon anodes used in aluminium electrolysis
Batteries & Battery Recycling	Production of graphite anodes and sodium-ion batteries
Carbon Fibre	Carbon fibre additive to polymer and resin for added strength
Activated carbon	For water filtration and pharmaceutical uses
Rubber & Tire Production	Used to strengthen rubber
Steel Production	Charged carbon to increase carbon content of steel and/or displacing met coke in blast furnaces

CICE

B.C. resources and infrastructure

Electrical + natural gas infrastructure

Electrical Infrastructure composed of ~ 90,000 km of wire with 19.1 GW (86% hydro) capacity with 1.1 GW Site C in service 2024/25.

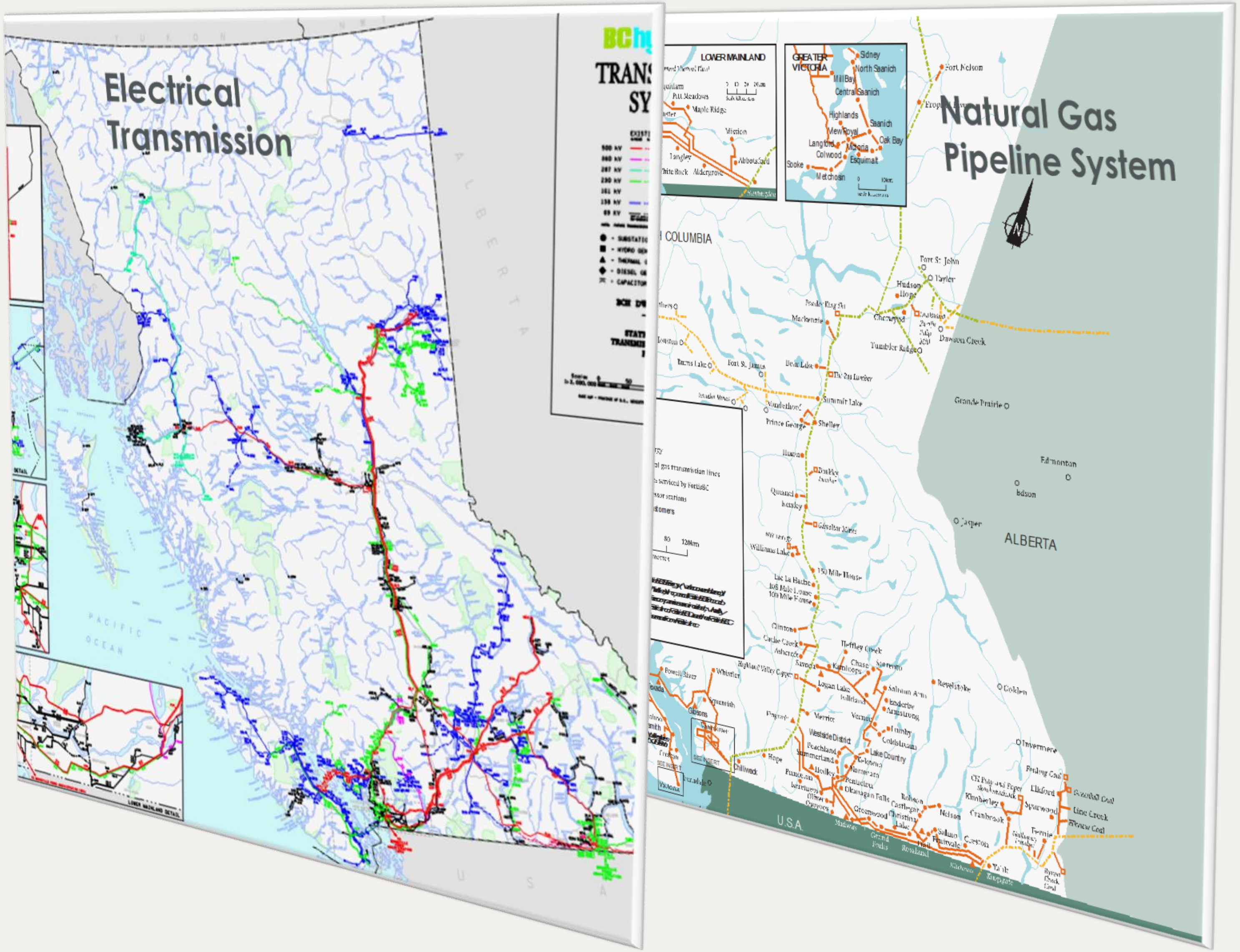
BC Hydro main producer and distributer with Fortis BC and Independent generators.

Identified transmission constraints for North Coast, East Kootenays, Lower Mainland, and Vancouver Island

Natural Gas infrastructure composed of major export transmission lines plus local distribution network.

Alliance Pipeline & TC Energy's North Montney & Coast Gas link provide export capacity

Enbridge (Spectra), Pacific Northern Gas (PNG), and FortisBC provide internal transmission and distribution services.



Natural Gas Resource

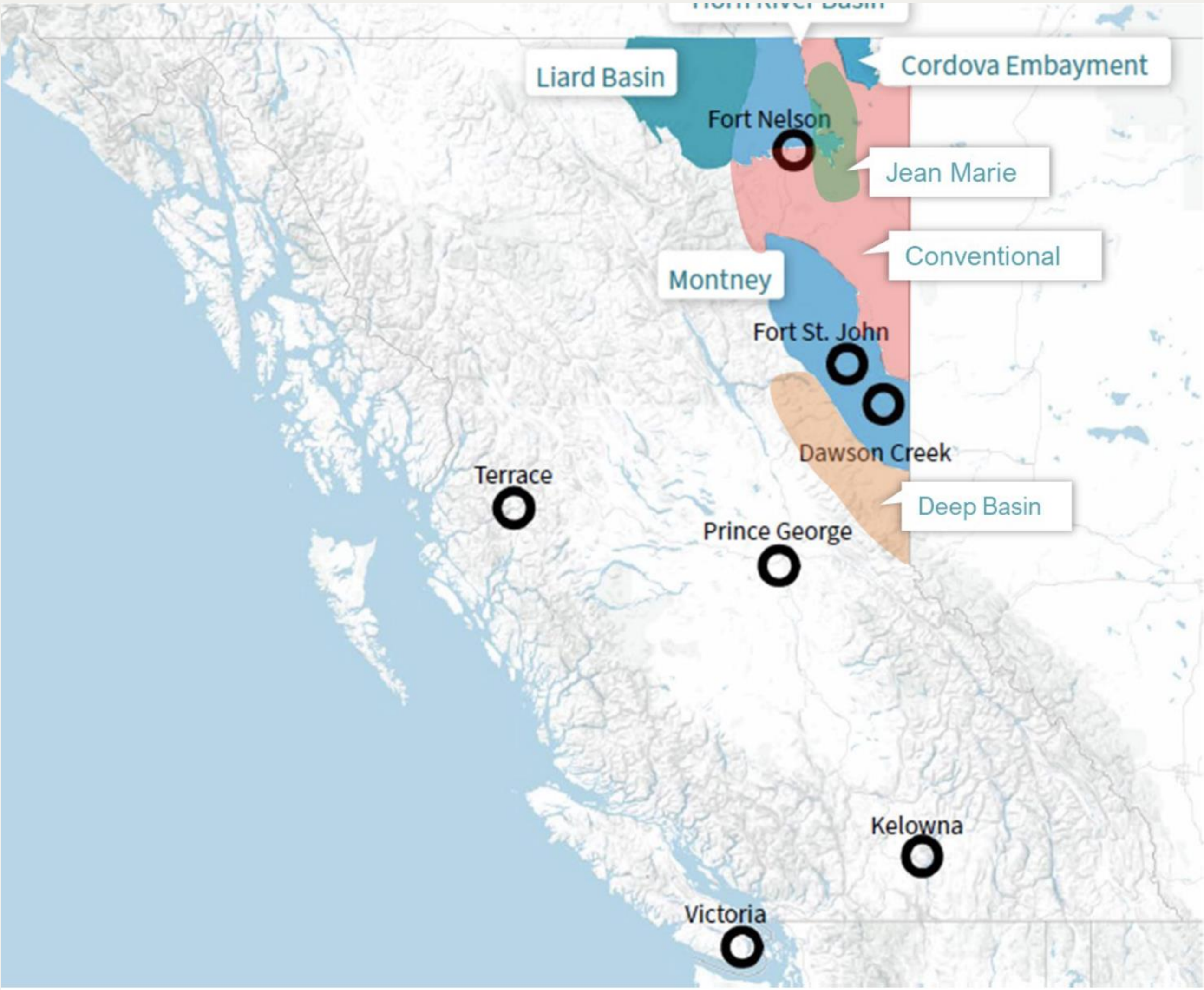
Reserves & Resource (Dec 31, 2022)

- *87.8 TCF* of natural gas reserves
  - 93% attributable to the Montney unconventional reservoir
- *532 TCF* of marketable resources
  - Predominately in the Montney
  - 248 TCF in the Liard / Horn River Basins

Production (2022)

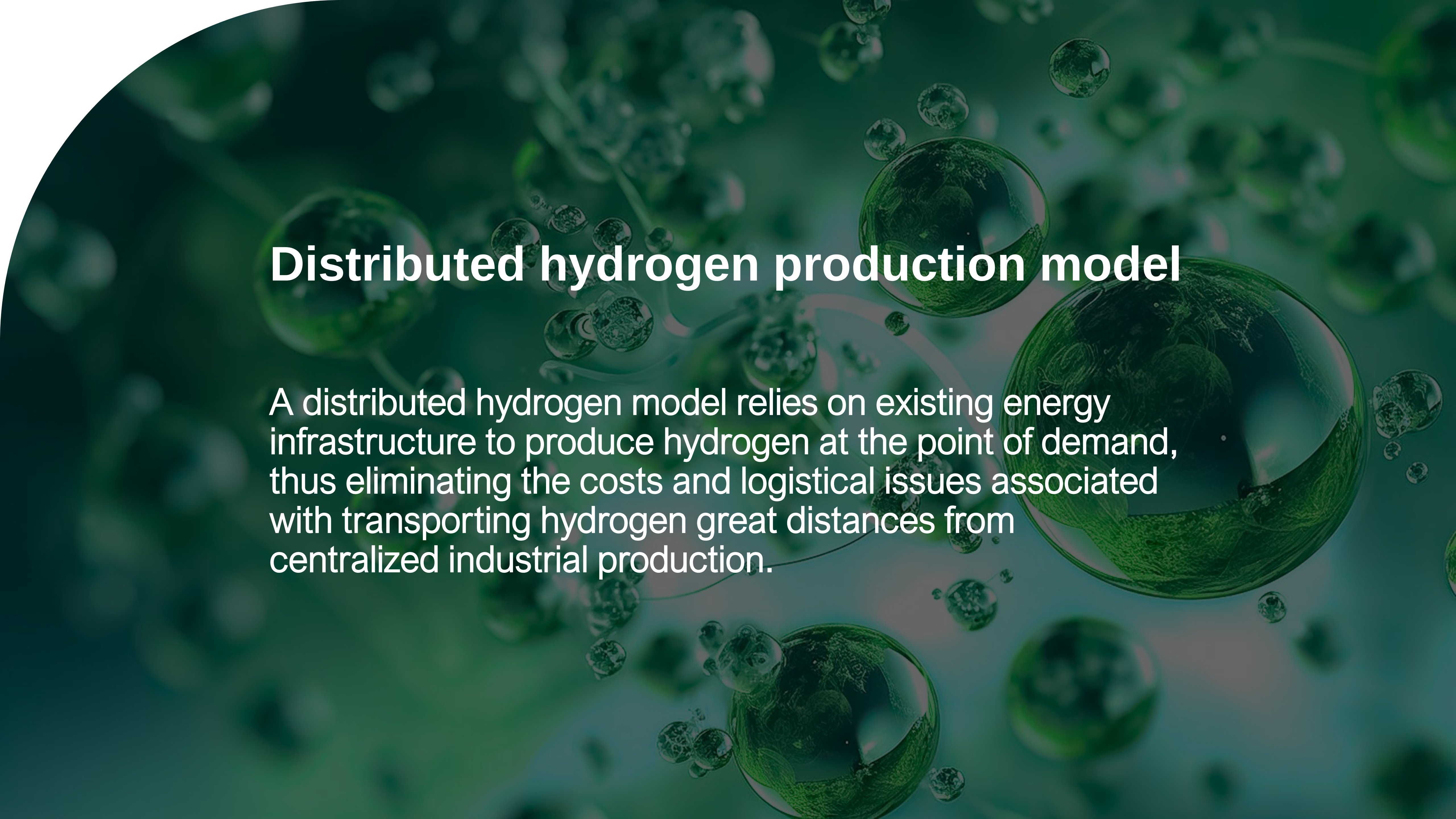
- *2.5 TCF*
  - 90% exported outside of B.C.

> 250 years of natural gas production



Source: BCER

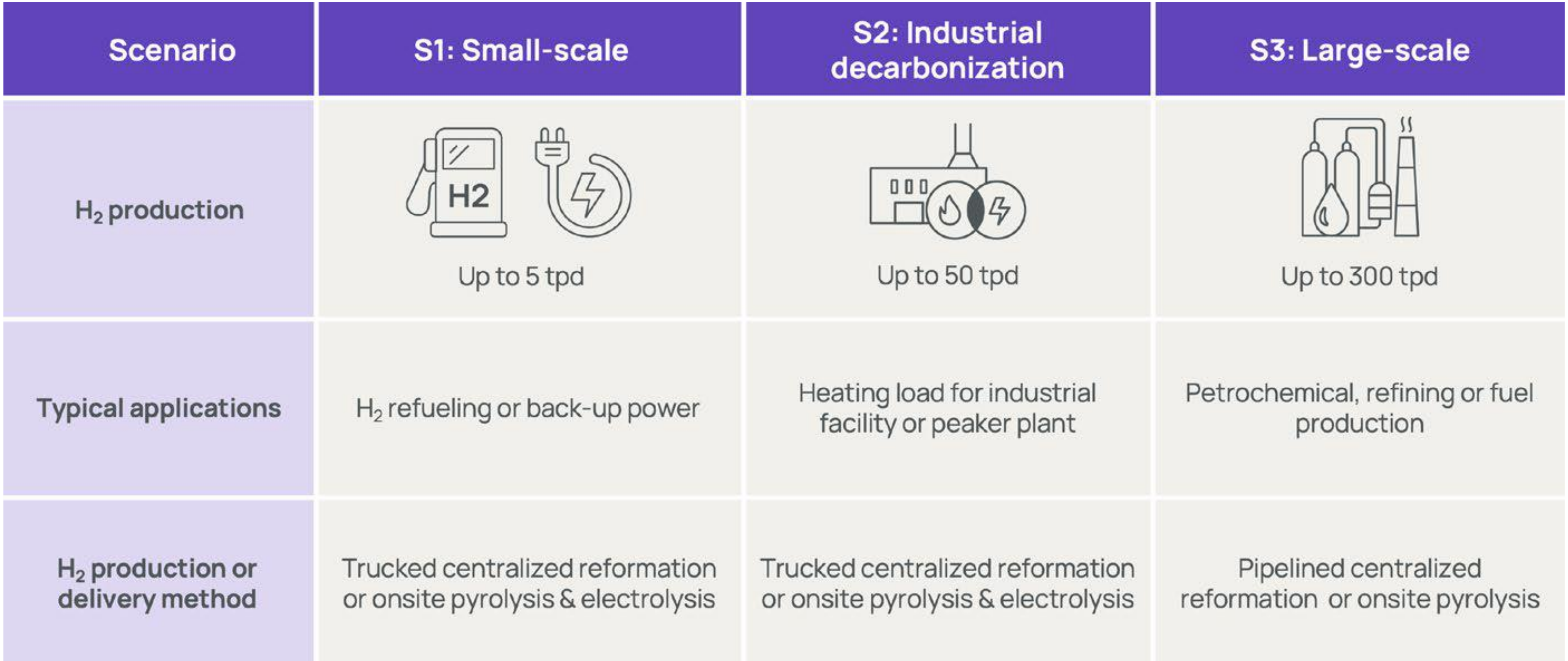
Techno-economic scenario analysis



Distributed hydrogen production model

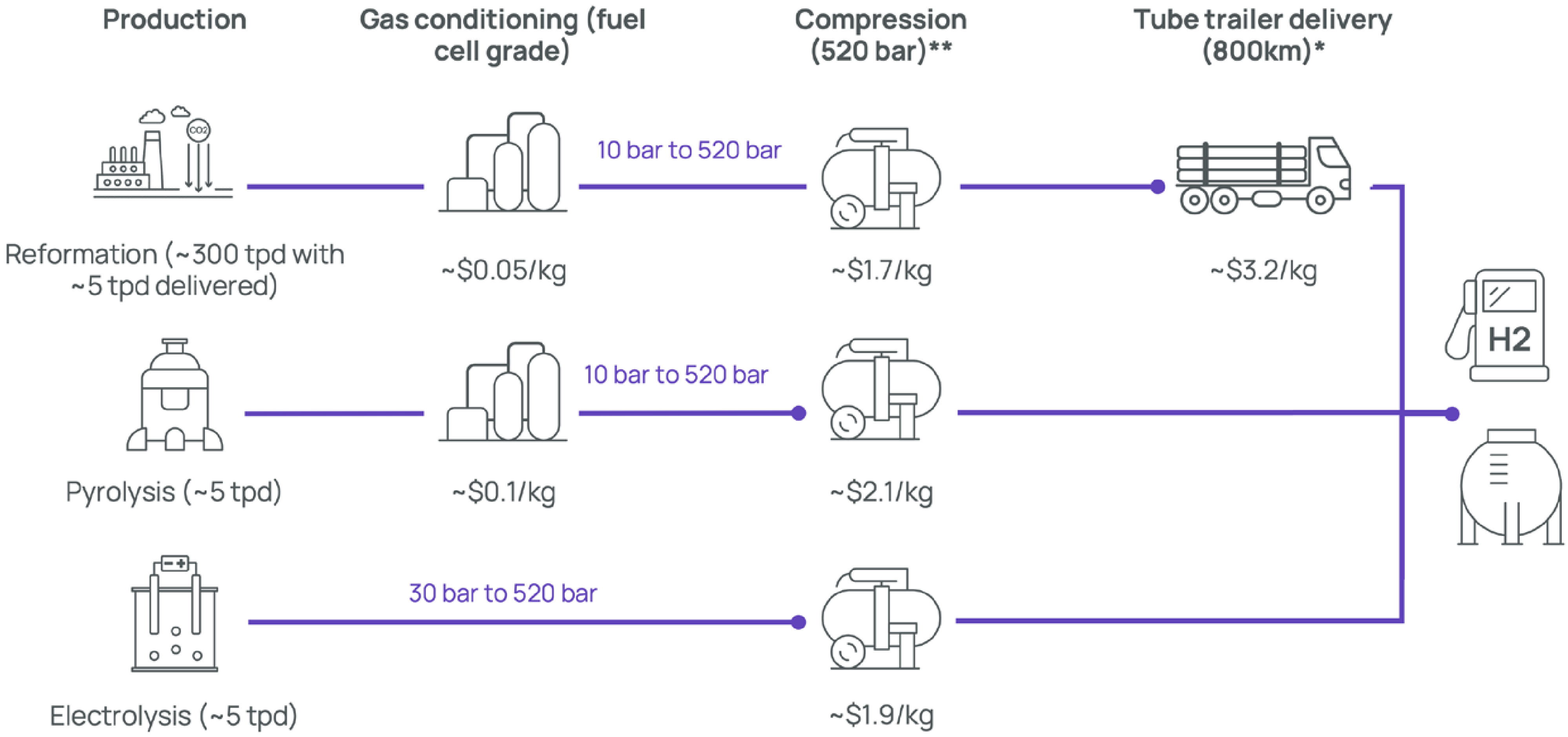
A distributed hydrogen model relies on existing energy infrastructure to produce hydrogen at the point of demand, thus eliminating the costs and logistical issues associated with transporting hydrogen great distances from centralized industrial production.

Techno-economic scenarios



Scenario	S1: Small-scale	S2: Industrial decarbonization	S3: Large-scale
H_2 production	Up to 5 tpd	Up to 50 tpd	Up to 300 tpd
Typical applications	H_2 refueling or back-up power	Heating load for industrial facility or peaker plant	Petrochemical, refining or fuel production
H_2 production or delivery method	Trucked centralized reformation or onsite pyrolysis & electrolysis	Trucked centralized reformation or onsite pyrolysis & electrolysis	Pipelined centralized reformation or onsite pyrolysis

Scenario 1: Small-scale production for FCEV fueling or H_2 storage



Production

Gas conditioning (fuel cell grade)

Compression (520 bar)**

Tube trailer delivery (800km)*

Reformation (~300 tpd with ~5 tpd delivered)

~$0.05/kg

10 bar to 520 bar

~$1.7/kg

~$3.2/kg

Pyrolysis (~5 tpd)

~$0.1/kg

10 bar to 520 bar

~$2.1/kg

Electrolysis (~5 tpd)

30 bar to 520 bar

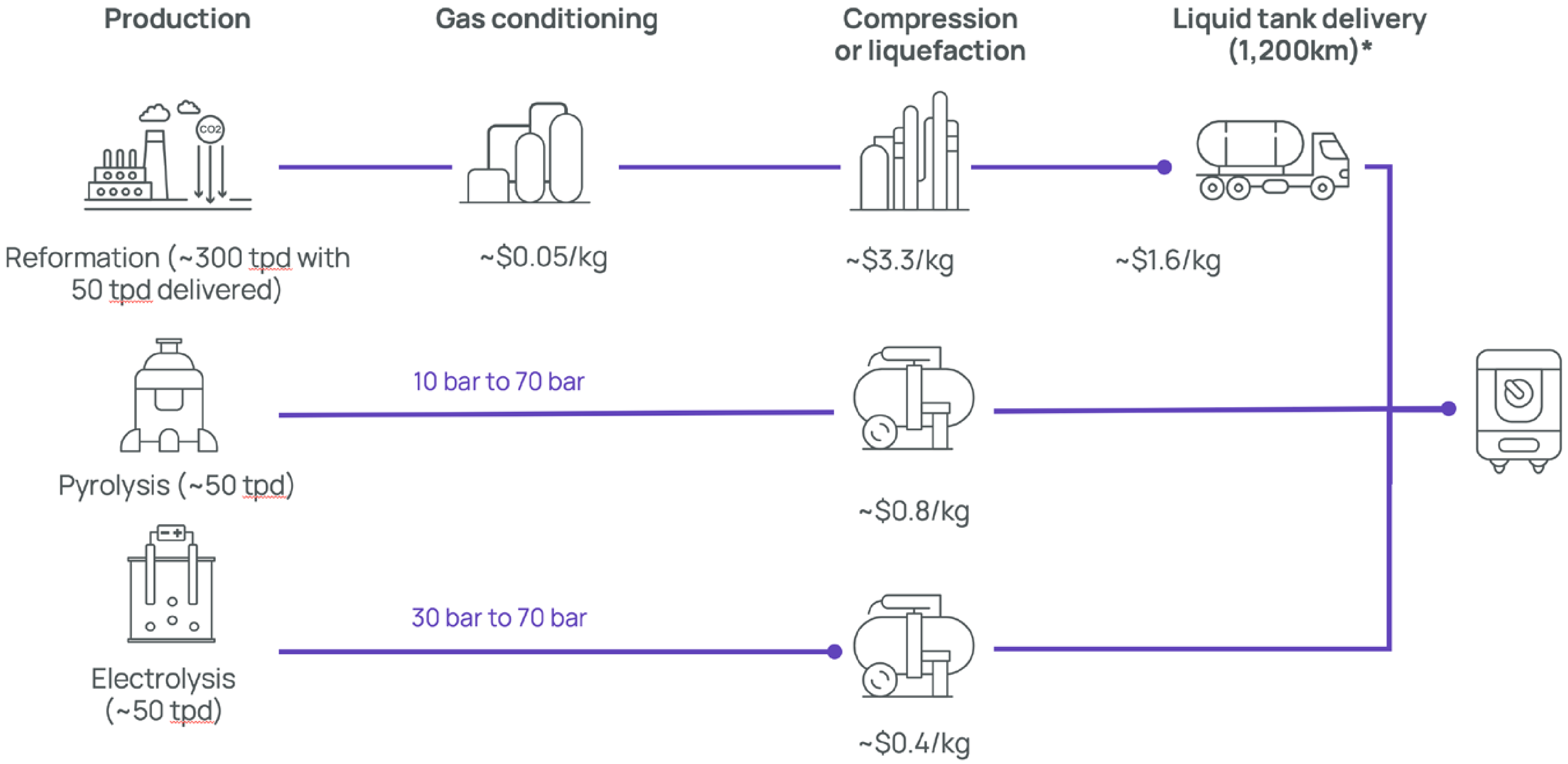
~$1.9/kg

* Based on production in NE B.C. with delivery to mid-province

** Compression cost variability depends on economies of scale at larger sizes or compression differential between starting and end point

CICE

Scenario 2: Medium-scale production for industrial facility heating load



Production

Gas conditioning

Compression or liquefaction

Liquid tank delivery (1,200km)*

Reformation (~300 tpd with 50 tpd delivered)

~$0.05/kg

~$3.3/kg

~$1.6/kg

Pyrolysis (~50 tpd)

10 bar to 70 bar

~$0.8/kg

Electrolysis (~50 tpd)

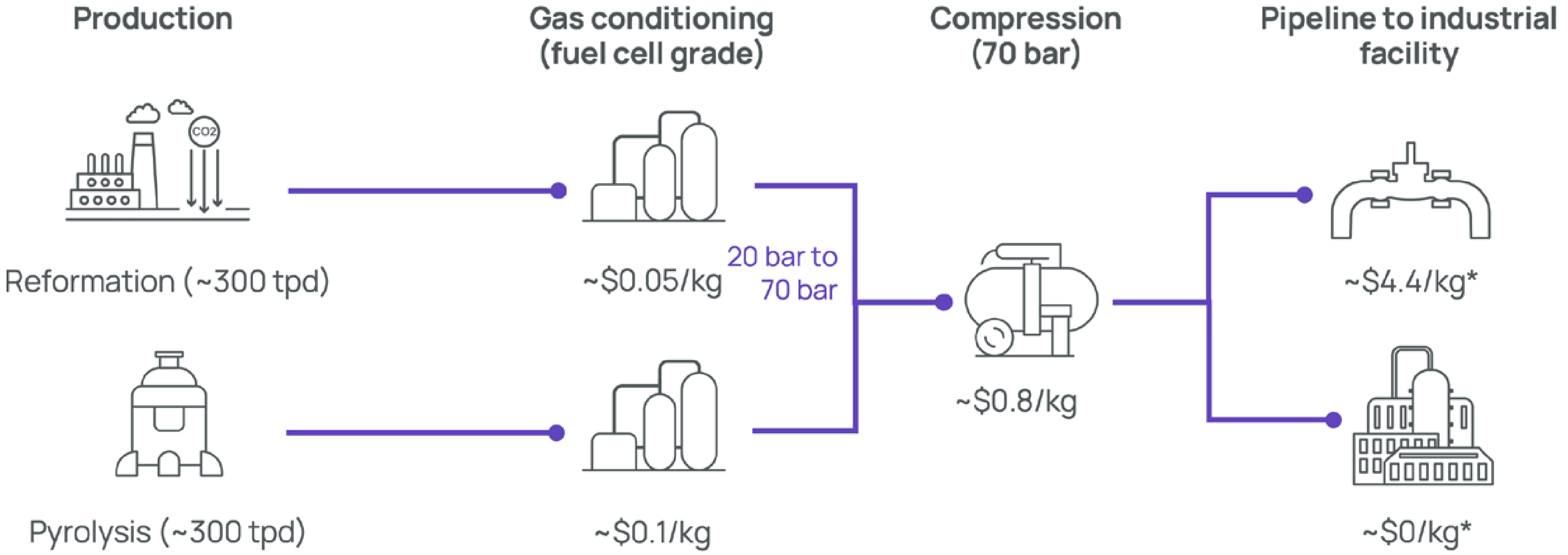
30 bar to 70 bar

~$0.4/kg

* Based on production in NE B.C. with delivery to lower mainland

** Compression cost variability depends on economies of scale at larger sizes or compression differential between starting and end point

Scenario 3: Large-scale production for refining or fuel production



Production

Reformation (~300 tpd)

Pyrolysis (~300 tpd)

Gas conditioning (fuel cell grade)

~$0.05/kg

~$0.1/kg

20 bar to 70 bar

Compression (70 bar)

~$0.8/kg

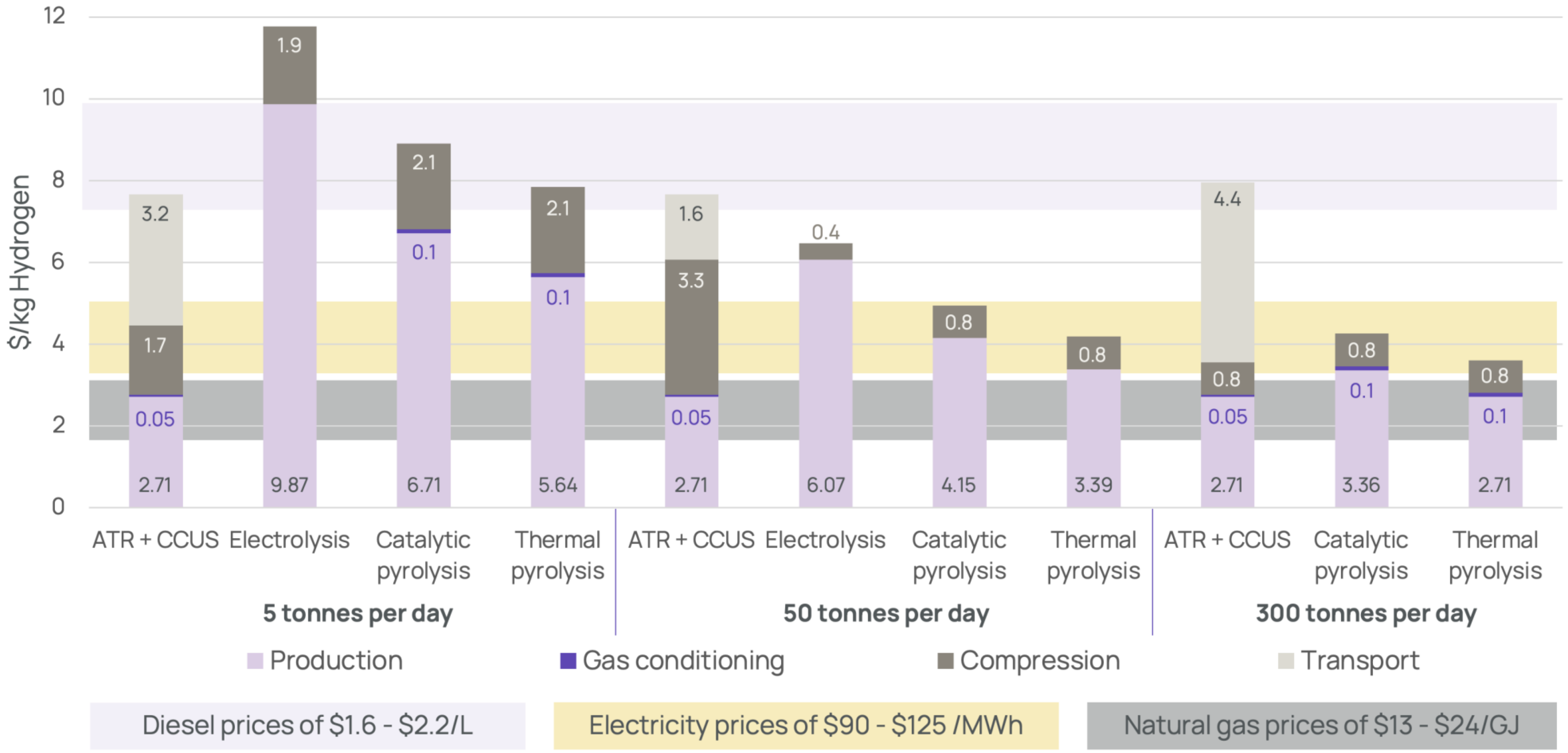
Pipeline to industrial facility

~$4.4/kg*

~$0/kg*

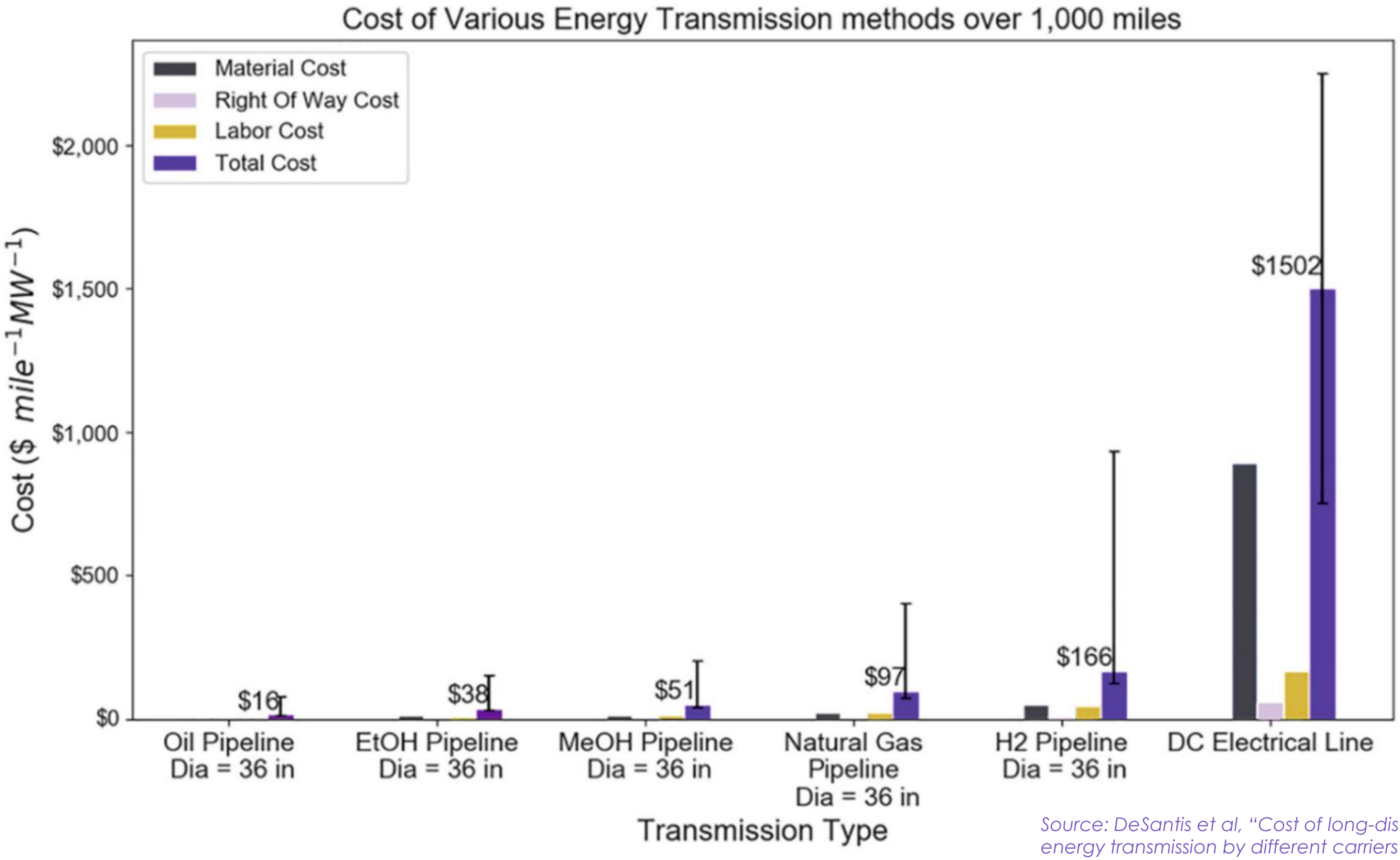
* Reformation facility based on pipeline transport of 1,200 km and pyrolysis facility based on co-located demand whereby pipeline transport costs are negligible

Scenario summary – Levelized Cost Of Hydrogen (LCOH)



- Energy prices inclusive of carbon tax of $170/tCO_2$
- Energy prices factored for changes in energy efficiency of displaced fuels: 1.06 GJ_{H2} / GJ_{NG}, and 0.86 GJ_{H2} / GJ_{DIESEL}

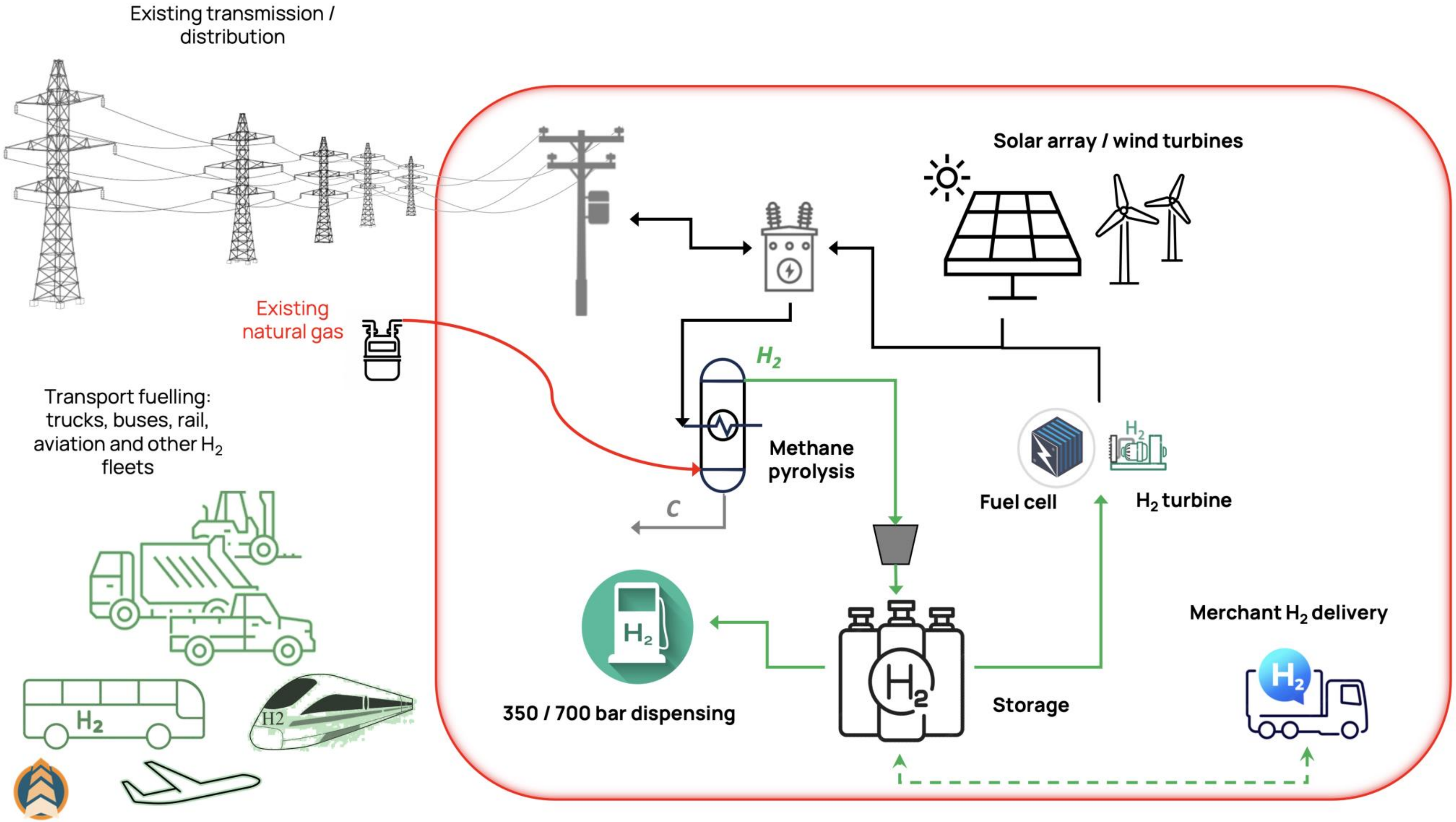
Cost to transmit energy



Source: DeSantis et al, "Cost of long-distance energy transmission by different carriers", 2021

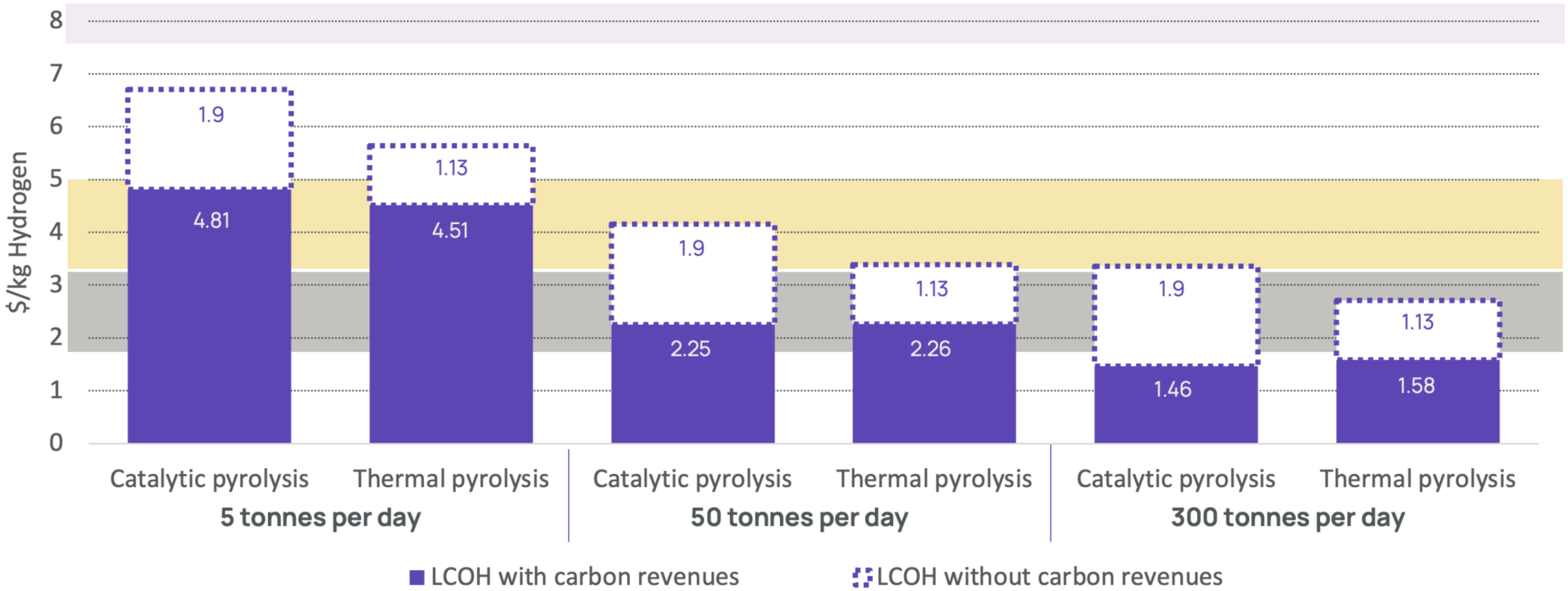
Numerous reports have demonstrated that transmitting energy as an electron is upwards of 10X more expensive on a capital basis as an equivalent molecule

Distributed hydrogen can result in a wide-spread robust network capable of addressing transportation and the creation of micro-grids to support and stabilize the local electrical system.



CICE

Impact on LCOH for methane pyrolysis with inclusion of carbon value



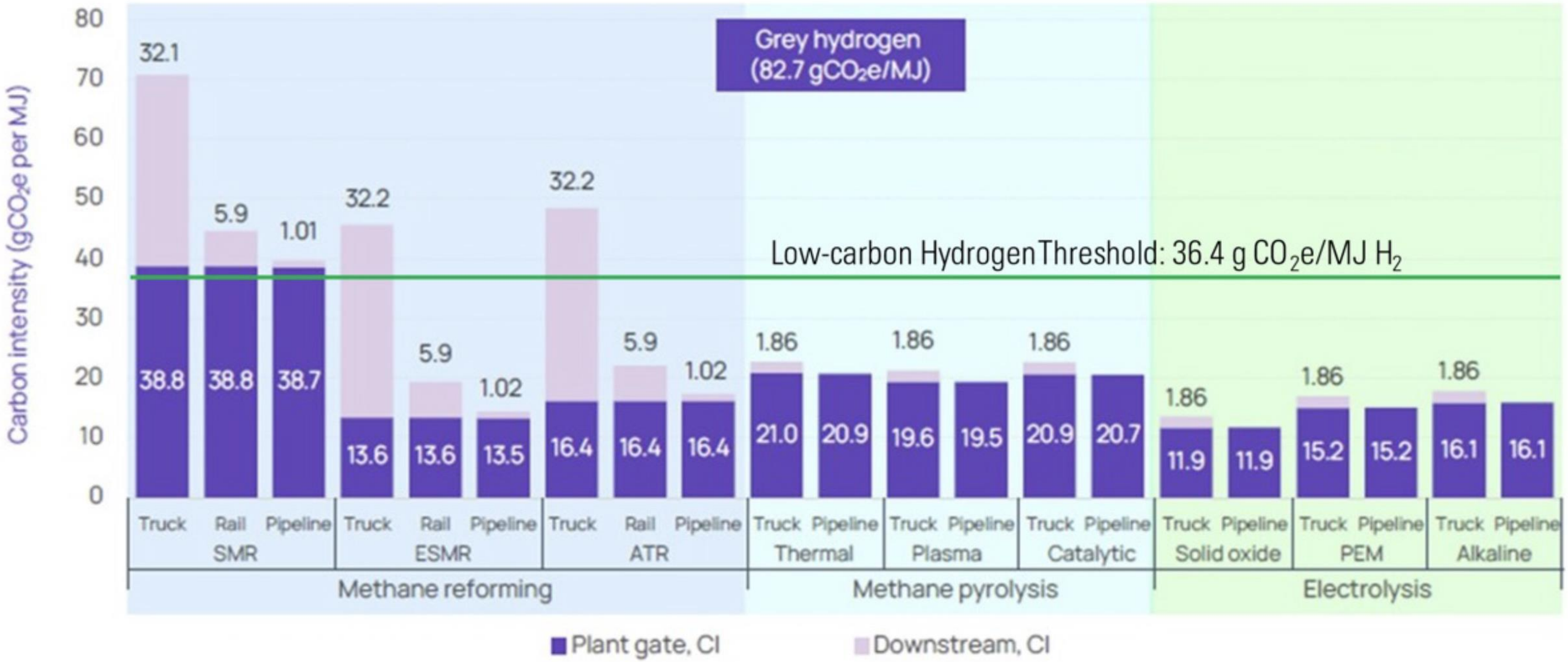
Diesel prices of $1.6/L

Electricity prices of $90 - $125 /MWh

Natural gas prices of $13 - $24/GJ

- Catalytic carbon sales price: $500/t Thermal carbon sales price: $250/t
- Energy prices factored for changes in energy efficiency of displaced fuels: 1.06 GJ_{H2} / GJ_{NG}, and 0.86 GJ_{H2} / GJ_{DIESEL}

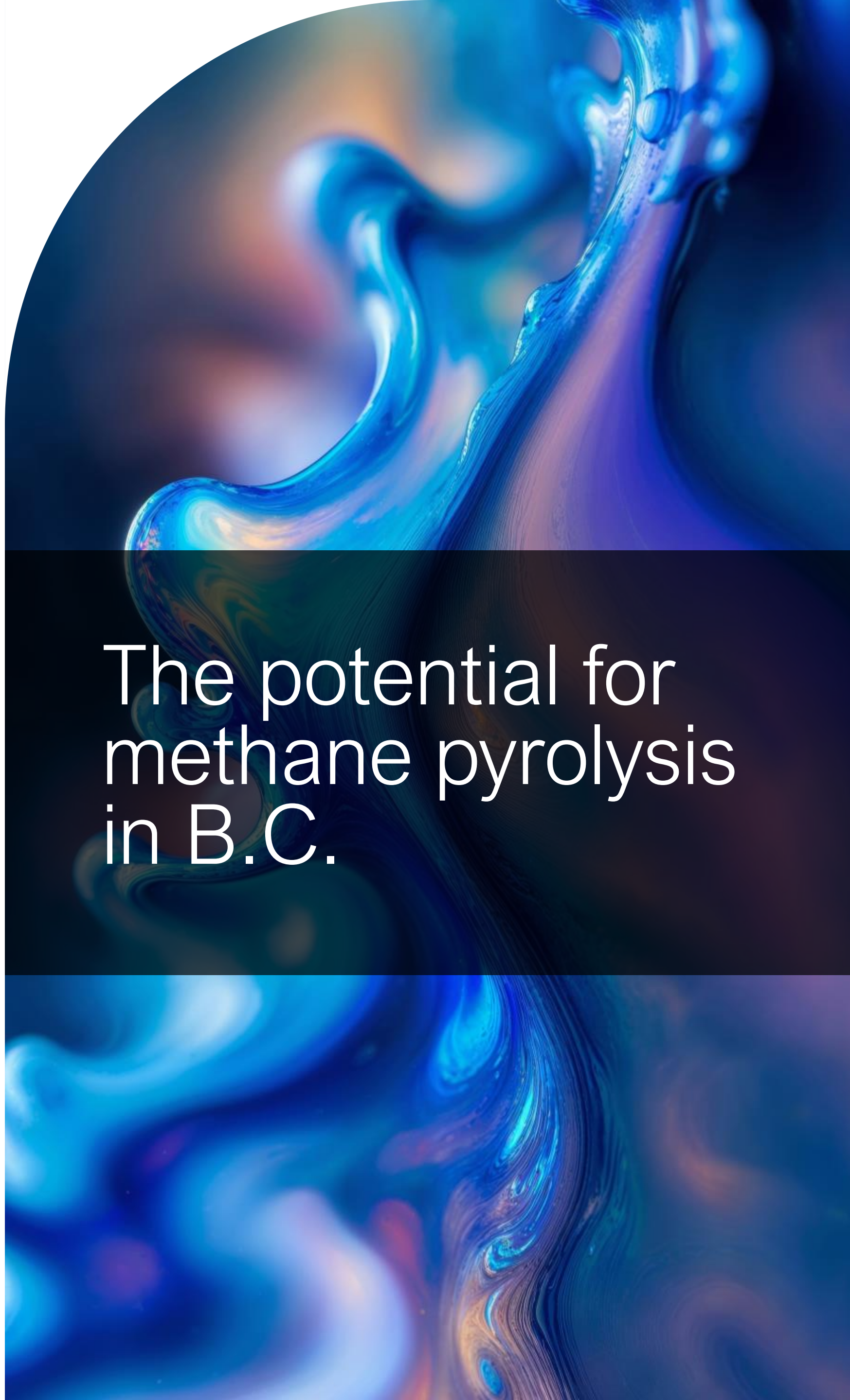
Previous CICE report *“Carbon Intensity of Hydrogen Production Methods”* demonstrated how technology, when utilized in B.C. can result in low-carbon hydrogen. Methane pyrolysis, when carbon sales are accounted for, could realize carbon intensity of 8.2 g CO_2e/MJ or lower.



CICE   SKY POINT RESOURCES LTD   ORION PROJECTS

Key takeaways

- Methane pyrolysis is a cost-effective, low carbon intensity hydrogen production method that could result in **rapid wide-spread hydrogen deployment** across B.C.
- Methane pyrolysis can **leverage B.C.'s existing natural gas** resources and infrastructure to develop a **distributed** hydrogen network.
- By 2030 delivered hydrogen from methane pyrolysis could cost **less than fossil fuels** in B.C.
- Regulation is needed to **support methane pyrolysis** as a means of H_2 generation, emissions reduction, and CO_2e sequestration.



The potential for methane pyrolysis in B.C.

Next steps – opportunities

Next steps

1

Commercialize methane pyrolysis

Provide funding to commercialize technology for distributed H_2 production

2

Be agnostic

Utilize the right technology for the right application

3

Deploy microgrids

Embrace electrical transmission efficiency – performance & capital

Next steps

4

Utilize natural resources

Unleash the economic value of an abundant resource without CO_2 emissions

5

Amend regulations

Gain acceptance for solid carbon as an equivalent means of CO_2 sequestration and GHG reduction.

6

Build a new economy

Establish an Advanced Material Carbon Hub to valorize the potential of solid carbon.

CICE 2024 – Potential Investment Priorities

Utilization of solid carbon from methane pyrolysis

Hydrogen use in industrial applications

LOW CARBON HYDROGEN

Discussion & questions

CICE

SKY POINT
RESOURCES LTD

ORION PROJECTS

Any other questions?

Raymond Tang: raymond.tang@cice.ca

Randy Litun: rlitun@skypointres.com

Daniel O’Connor: doconnor@orion-projects.ca

Ahsan Syed: asyed@orion-projects.ca

DOWNLOAD THE REPORT → [The Potential for Methane Pyrolysis in B.C.](https://cice.ca/low-carbon-hydrogen/)

https://cice.ca/low-carbon-hydrogen/