

Hydrogen & the Hydrogen Centre of Excellence

October 11 2023

Bryan Helfenbaum
Associate Vice President,
Clean Energy




Agenda

- Hydrogen 101
- History
- Alberta Strategy
- Commercial Activities
- Hydrogen Centre of Excellence



Hydrogen 101

PERIODIC TABLE OF THE ELEMENTS



1 H Hydrogen 1,008																	18 2 He Helium 4,003
3 Li Lithium 6,941	4 Be Beryllium 9,012											13 5 B Boron 10,811	14 6 C Carbon 12,011	15 7 N Nitrogen 14,007	16 8 O Oxygen 15,999	17 9 F Fluorine 18,998	10 Ne Neon 20,180
11 Na Sodium 22,990	12 Mg Magnesium 24,305											13 Al Aluminum 26,982	14 Si Silicon 28,086	15 P Phosphorus 30,974	16 S Sulfur 32,065	17 Cl Chlorine 35,453	18 Ar Argon 39,948
19 K Potassium 39,098	20 Ca Calcium 40,078	21 Sc Scandium 44,956	22 Ti Titanium 47,867	23 V Vanadium 50,942	24 Cr Chromium 51,996	25 Mn Manganese 54,938	26 Fe Iron 55,845	27 Co Cobalt 58,933	28 Ni Nickel 58,693	29 Cu Copper 63,546	30 Zn Zinc 65,390	31 Ga Gallium 69,723	32 Ge Germanium 72,640	33 As Arsenic 74,922	34 Se Selenium 78,960	35 Br Bromine 79,904	36 Kr Krypton 83,800
37 Rb Rubidium 85,468	38 Sr Strontium 87,620	39 Y Yttrium 88,906	40 Zr Zirconium 91,224	41 Nb Niobium 92,906	42 Mo Molybdenum 94,938	43 Tc Technetium 98,000	44 Ru Ruthenium 101,070	45 Rh Rhodium 102,906	46 Pd Palladium 106,420	47 Ag Silver 107,868	48 Cd Cadmium 112,411	49 In Indium 114,818	50 Sn Tin 118,710	51 Sb Antimony 121,760	52 Te Tellurium 127,600	53 I Iodine 126,905	54 Xe Xenon 131,293
55 Cs Cesium 132,906	56 Ba Barium 137,327	57-71 Lanthanides	72 Hf Hafnium 178,490	73 Ta Tantalum 180,948	74 W Tungsten 180,948	75 Re Rhenium 186,207	76 Os Osmium 190,230	77 Ir Iridium 192,217	78 Pt Platinum 195,078	79 Au Gold 196,967	80 Hg Mercury 200,590	81 Tl Thallium 204,383	82 Pb Lead 207,200	83 Bi Bismuth 208,980	84 Po Polonium 209,000	85 At Astatine 210,000	86 Rn Radon 222,000
87 Fr Francium 223,000	88 Ra Radium 226,000	89-103 Actinides	104 Rf Rutherfordium 261,000	105 Db Dubnium 262,000	106 Sg Seaborgium 266,000	107 Bh Bohrium 264,000	108 Hs Hassium 277,000	109 Mt Meitnerium 278,000	110 Ds Darmstadtium 281,000	111 Rg Roentgenium 282,000	112 Cn Copernicium 285,000	113 Nh Nihonium 286,000	114 Fl Flerovium 289,000	115 Mc Moscovium 290,000	116 Lv Livermorium 293,000	117 Ts Tennessine 294,000	118 Og Oganesson 294,000
57 La Lanthanum 138,906	58 Ce Cerium 140,116	59 Pr Praseodymium 140,908	60 Nd Neodymium 144,240	61 Pm Promethium 145,000	62 Sm Samarium 150,360	63 Eu Europium 151,964	64 Gd Gadolinium 157,250	65 Tb Terbium 158,925	66 Dy Dysprosium 162,500	67 Ho Holmium 164,930	68 Er Erbium 167,259	69 Tm Thulium 168,934	70 Yb Ytterbium 173,040	71 Lu Lutetium 174,967			
89 Ac Actinium 227,000	90 Th Thorium 232,038	91 Pa Protactinium 231,036	92 U Uranium 238,029	93 Np Neptunium 237,000	94 Pu Plutonium 244,000	95 Am Americium 243,000	96 Cm Curium 247,000	97 Bk Berkelium 247,000	98 Cf Californium 251,000	99 Es Einsteinium 252,000	100 Fm Fermium 257,000	101 Md Mendelevium 258,000	102 No Nobelium 259,000	103 Lr Lawrencium 262,000			

1

H

Hydrogen

1,008

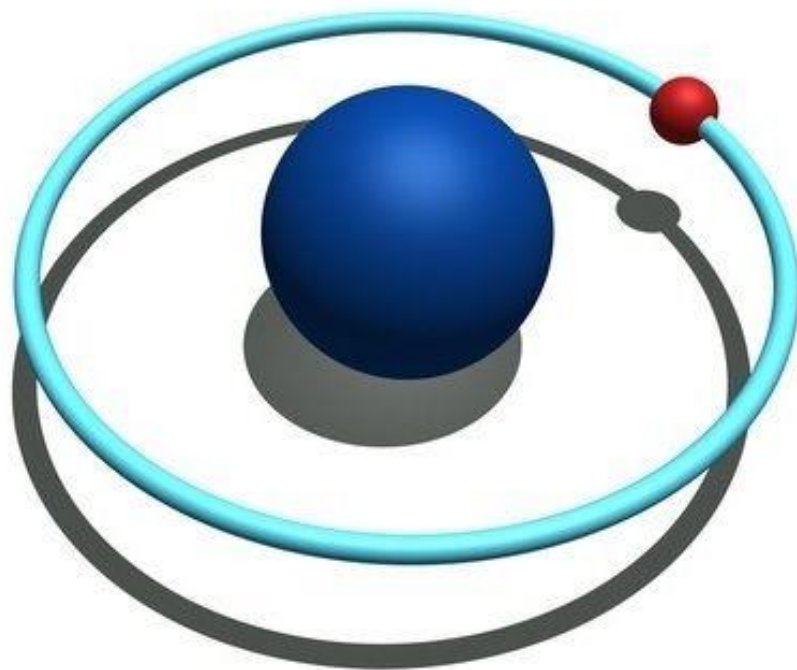
1

Atomic number

Element symbol

Element name

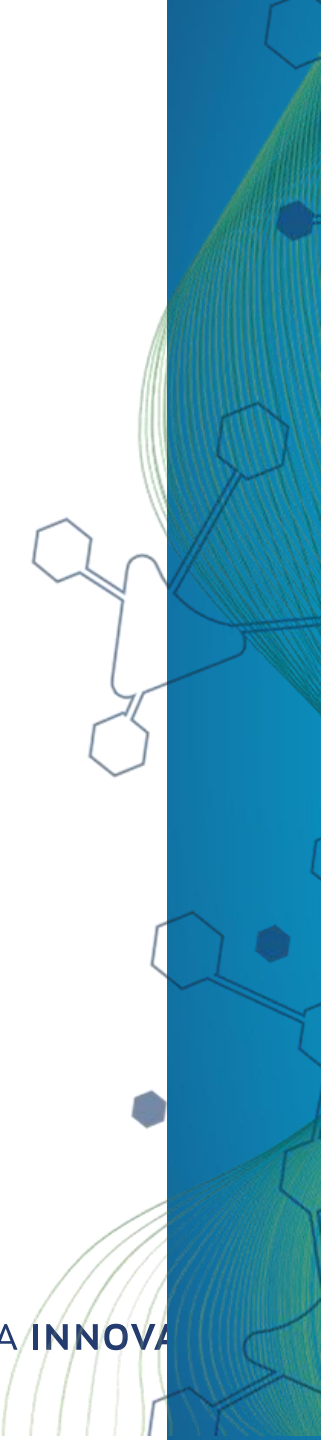
Atomic weight



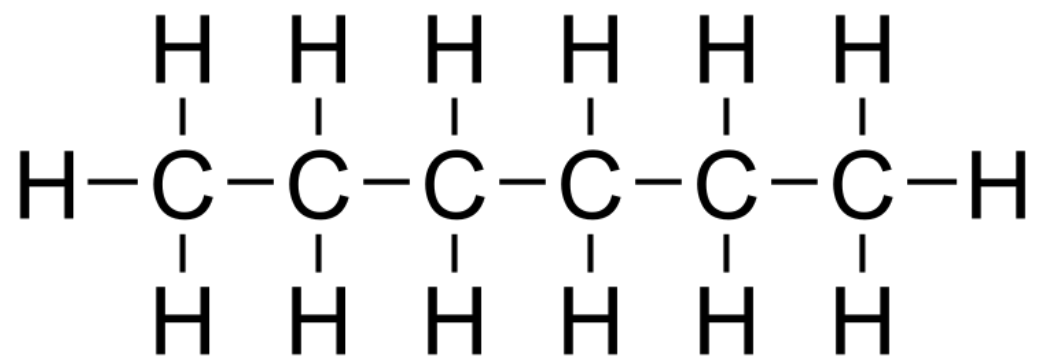
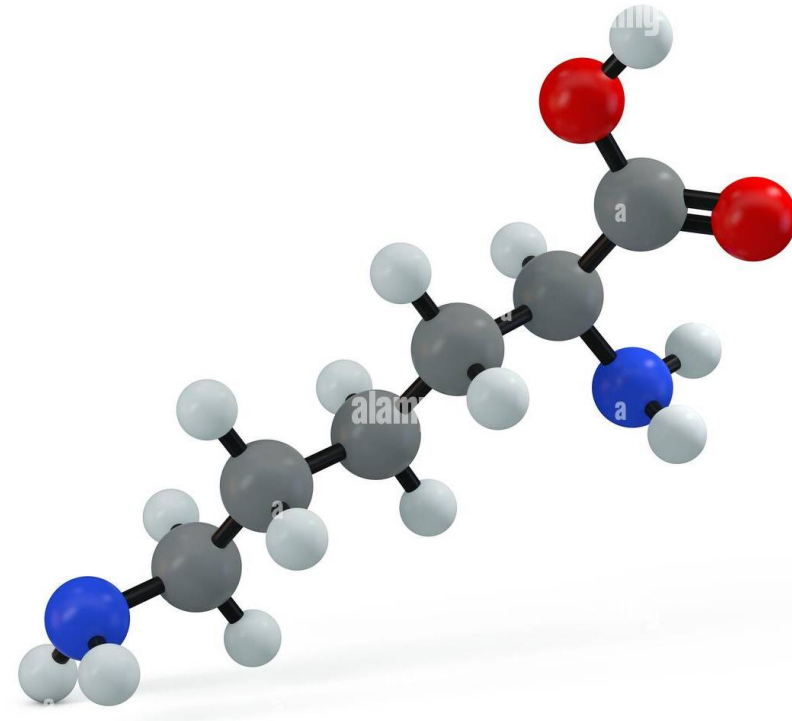
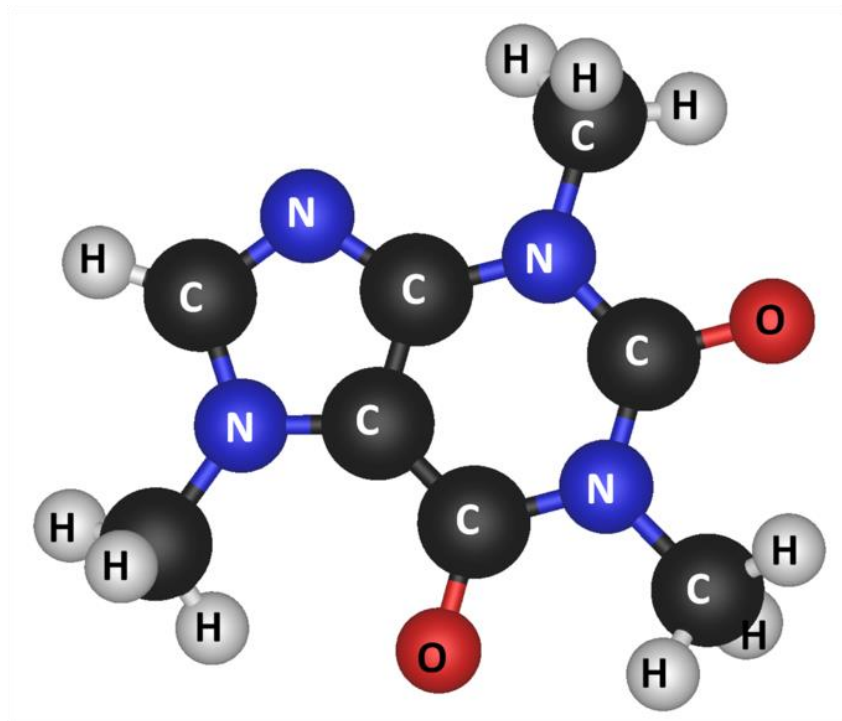






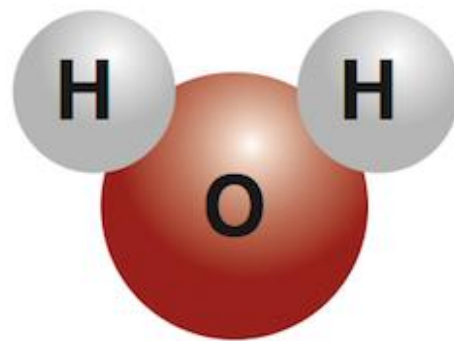




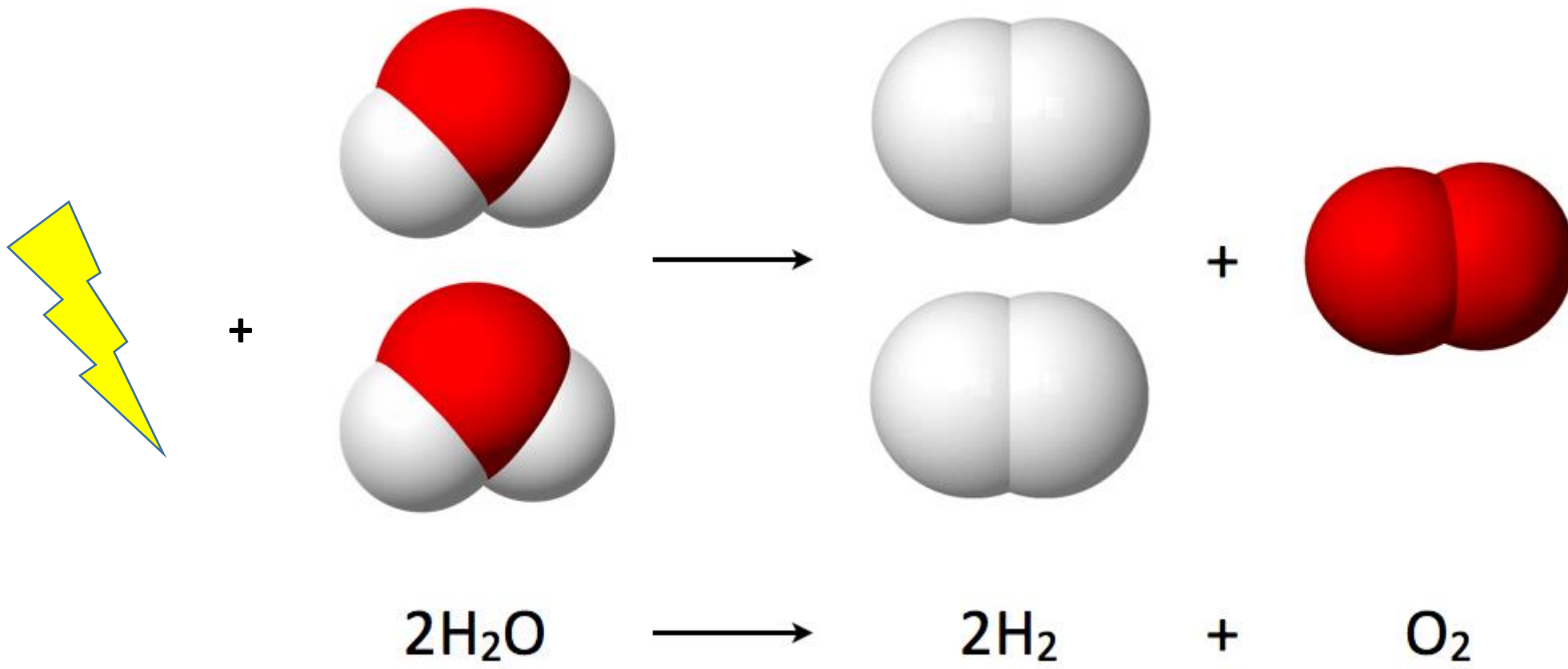




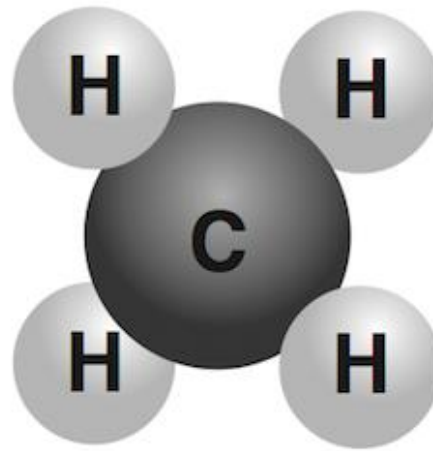
Two Practical Sources of Hydrogen



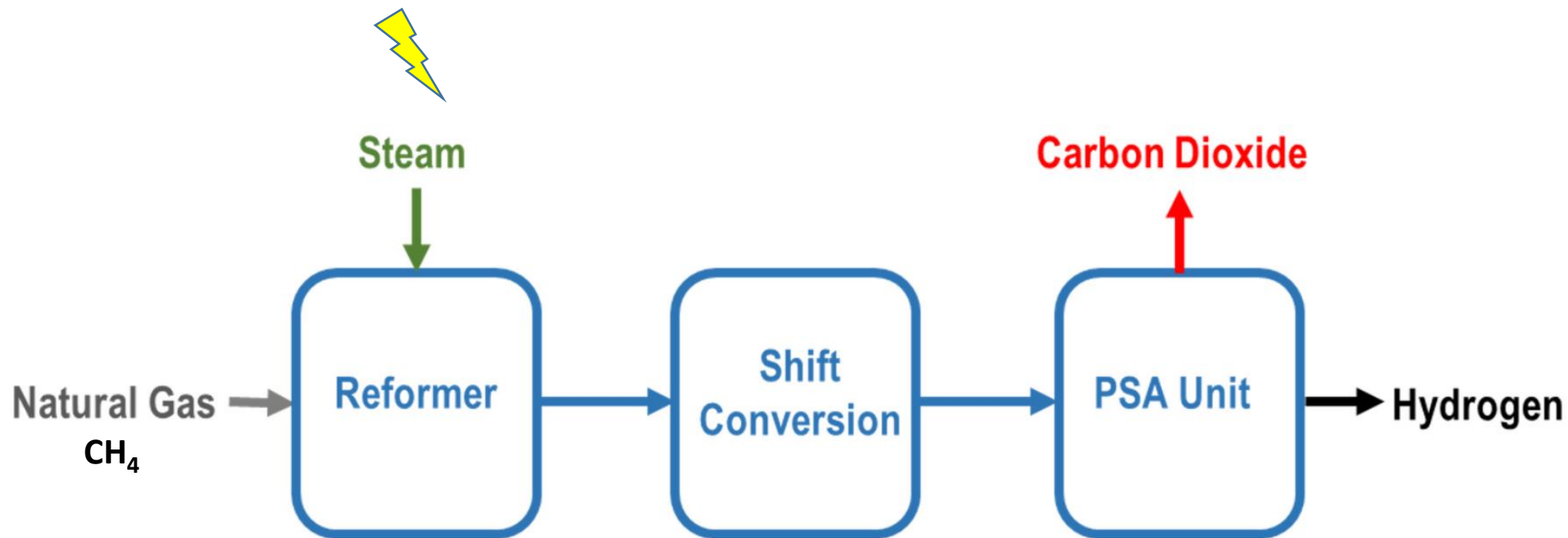
Water
 H_2O



Electrolysis



Methane
CH₄



Steam Methane Reforming

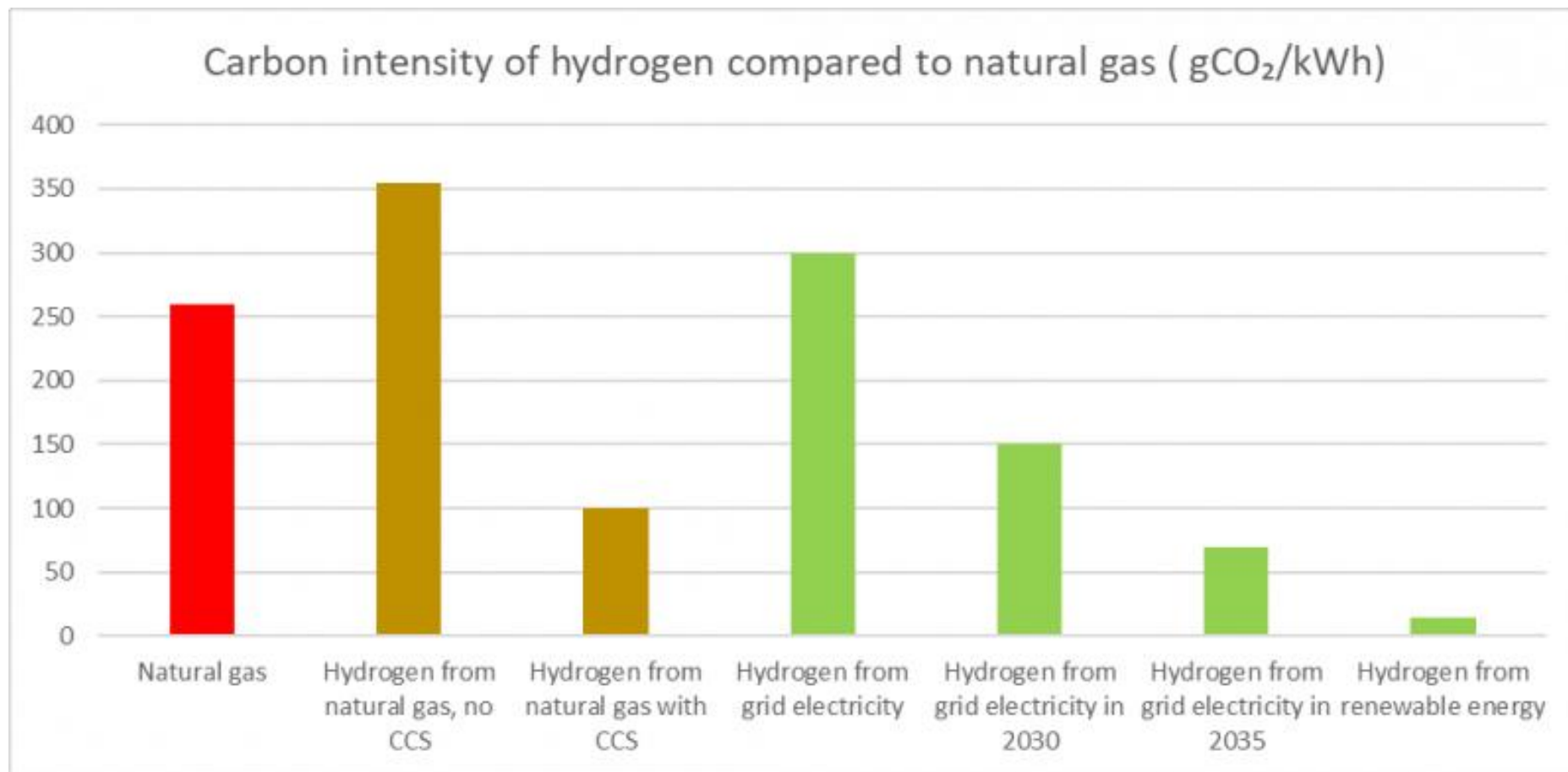
The Hydrogen Colour Spectrum

COLOUR	DESCRIPTION: FEEDSTOCK
	Grey: natural gas reforming without CCUS
	Brown: brown coal (lignite) as feedstock
	Blue: natural gas reforming with CCUS
	Green: electrolysis powered through renewable electricity
	Pink: electrolysis powered through nuclear energy
	Turquoise: methane pyrolysis
	Yellow: electrolysis powered through electricity from solar
	Orange: electrolysis powered through electricity from wind

The Hydrogen Colour Spectrum

	DESCRIPTION: FEEDSTOCK
Grey	natural gas reforming without CCUS
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Green	electrolysis powered through renewable electricity
Pink	electrolysis powered through nuclear energy
Turquoise	methane pyrolysis
Yellow	electrolysis powered through electricity
Orange	electrolysis powered through electricity from fossil fuels

Carbon Intensity of Hydrogen









edcfans EDC Folding Pocket knife: Glass Breaker, Flipper Open, Locking Liner, Sheath, Pocket Clip for...

10% off coupon

[Tools & Home Improvement](#) › [Power & Hand Tools](#) › [Hand Tools](#) › [Knives, Parts & Accessories](#) › [Knives](#) › [Pocket Knives & Folding Knives](#)

Wenger 16999 Swiss Army Knife Giant

Brand: Wenger



572 ratings

Currently unavailable.

We don't know when or if this item will be back in stock.

Product details

Brand	Wenger
Special Feature	Removable
Age Range (Description)	Adult
Handle Material	Metal
Color	Red
Blade Material	Metal

- 87 implements
- 141 functions
- Perfect for the collector
- Featured by major media outlets

Roll over image to zoom in















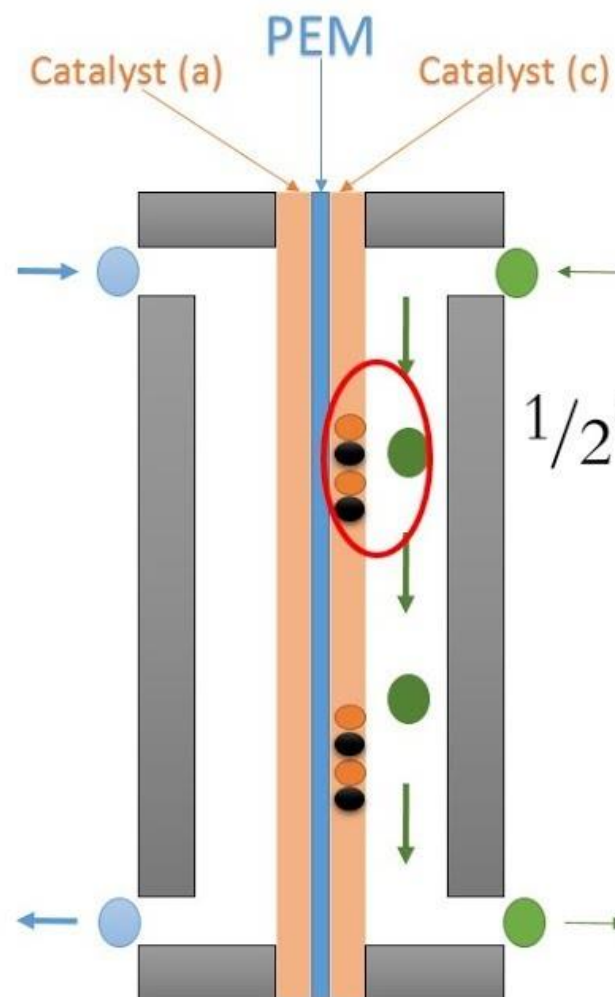


Anode

Half reaction

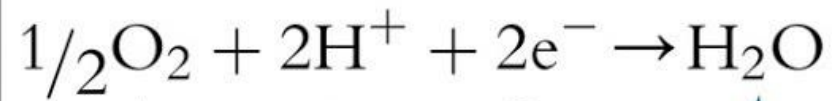


- Protons H^+
- Electrons e^-
- Hydrogen H_2



Cathode

Half reaction

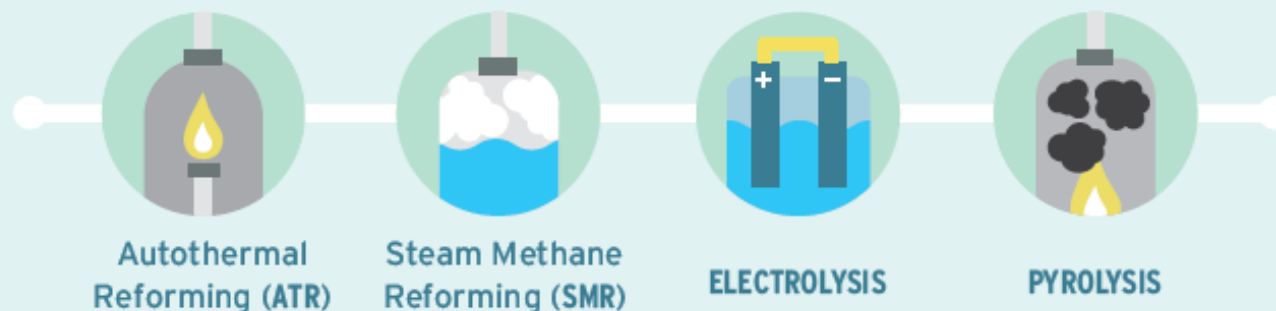


● Oxygen O_2





Numerous new hydrogen production facilities have been proposed in Alberta with a range of different technologies.



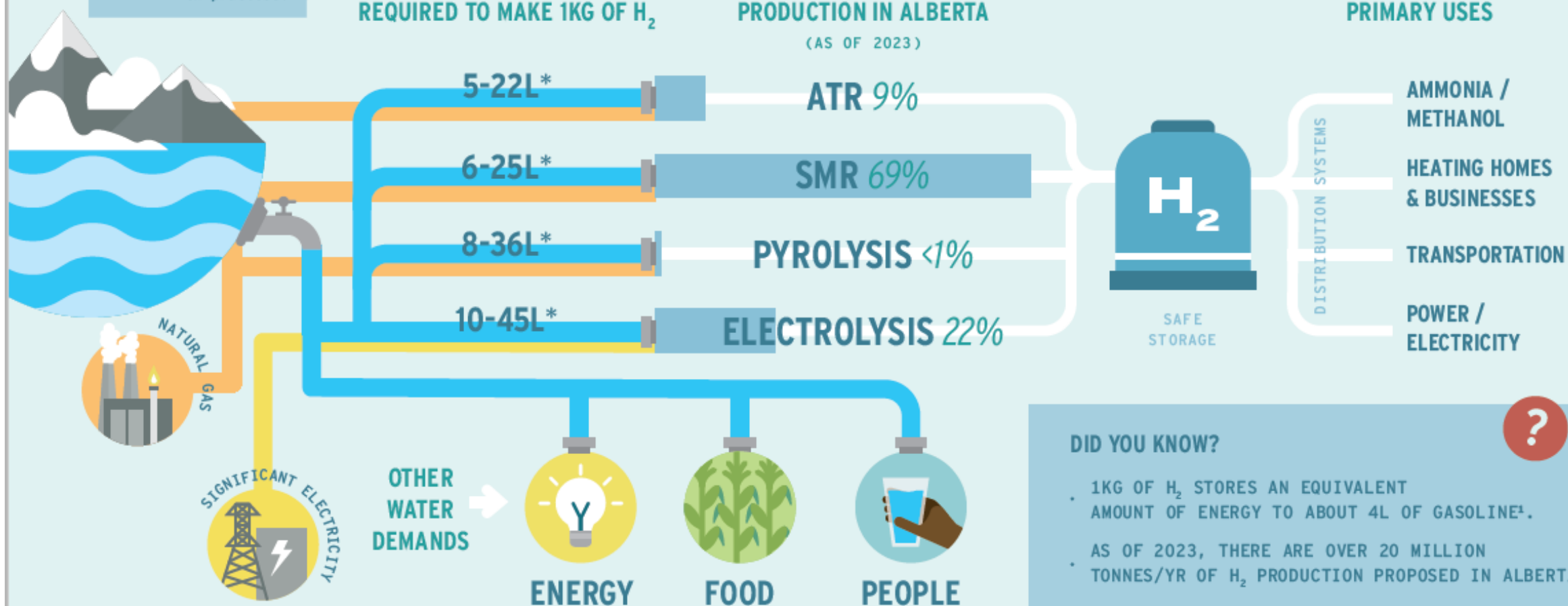
Each have different efficiencies and water consumption rates.

*The theoretical minimum water demands are lower but are difficult to achieve in practice.

LITRES OF WATER PRACTICALLY REQUIRED TO MAKE 1KG OF H_2

% OF PROPOSED PRODUCTION IN ALBERTA
(AS OF 2023)

HYDROGEN PRIMARY USES

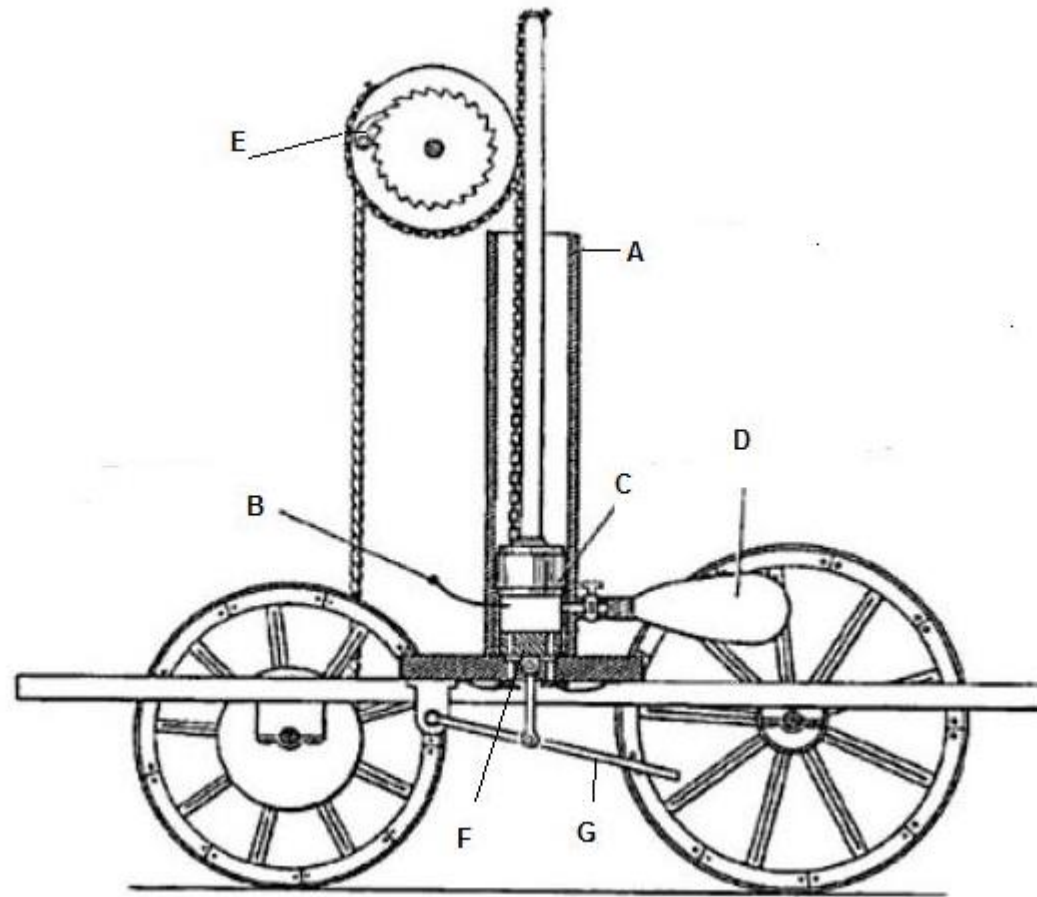


DID YOU KNOW?

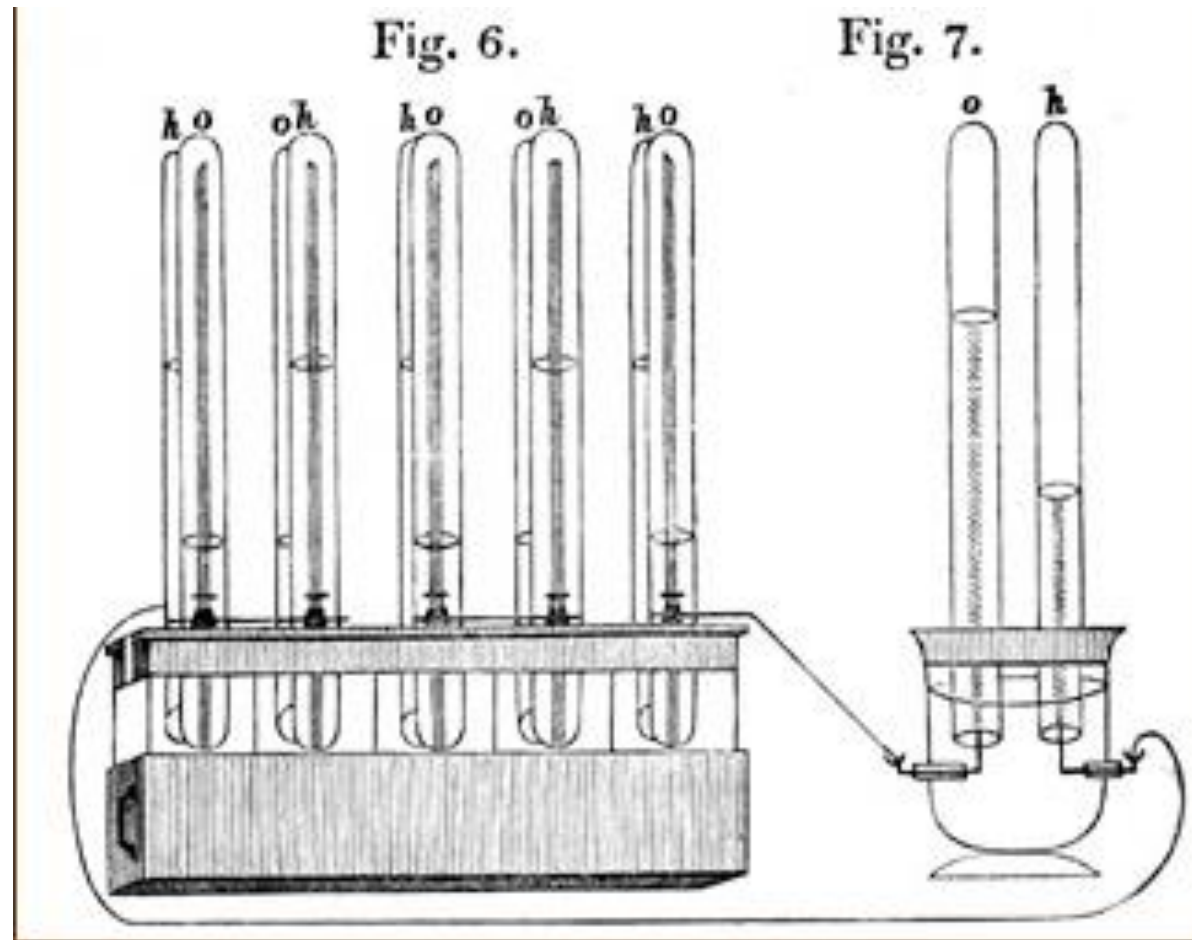
- 1KG OF H_2 STORES AN EQUIVALENT AMOUNT OF ENERGY TO ABOUT 4L OF GASOLINE¹.
- AS OF 2023, THERE ARE OVER 20 MILLION TONNES/YR OF H_2 PRODUCTION PROPOSED IN ALBERTA.

- Distance to market
- Infrastructure
- Water availability
- Electricity cost
- Natural gas cost
- Cost of competitors

History



De Rivaz's Internal Combustion Engine, 1804



William Grove's Fuel Cell, 1838



Hindenburg, 1936



Hydrogen Bomb, 1952



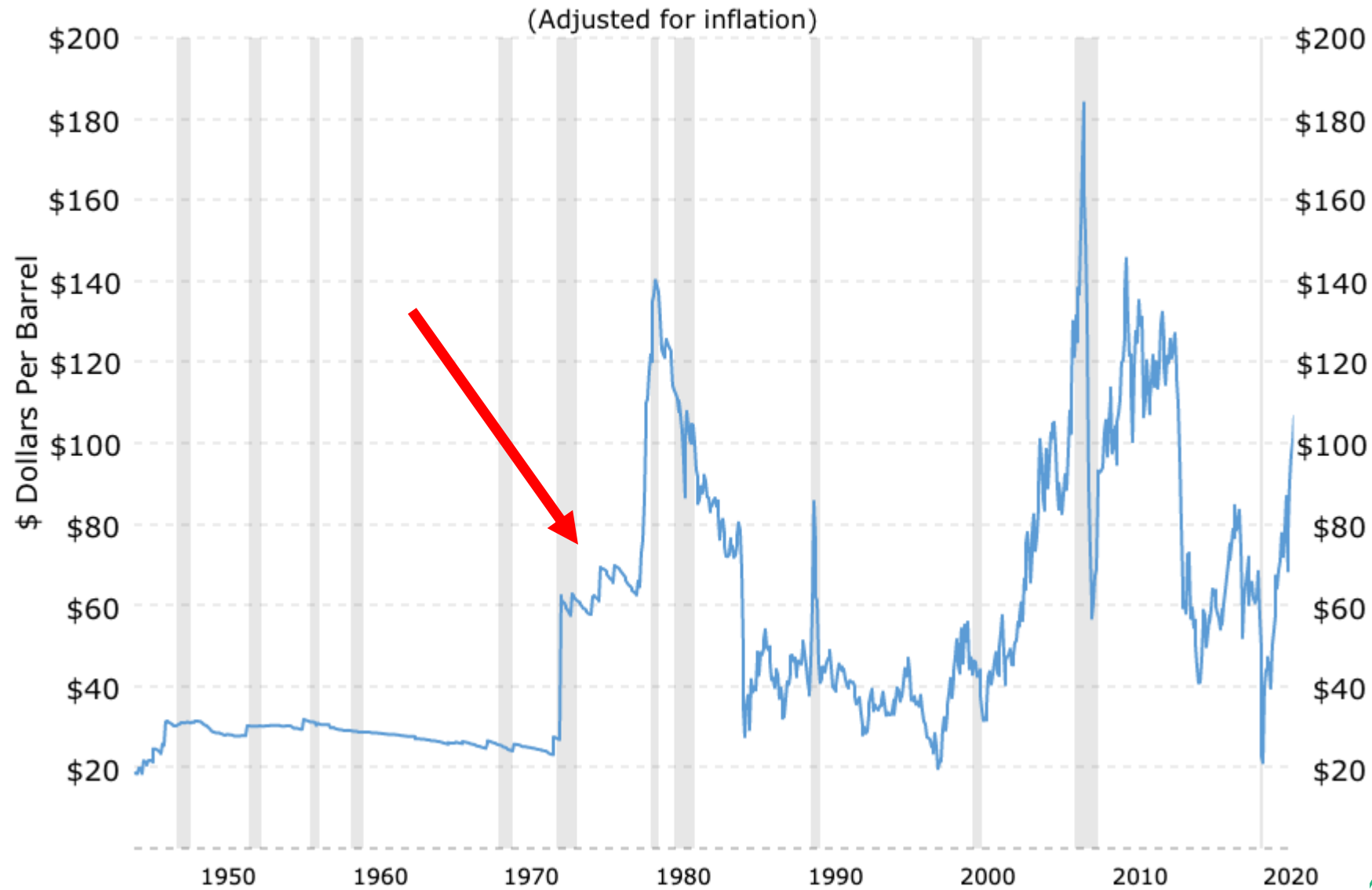
Apollo Missions, 1961 - 1972





Interest in Hydrogen Vehicles, 1973 - 1982

Price of Oil







BALLARD®
PUTTING FUEL CELLS TO WORK

Rekindled Interest in Hydrogen Vehicles, 1997 - 2002

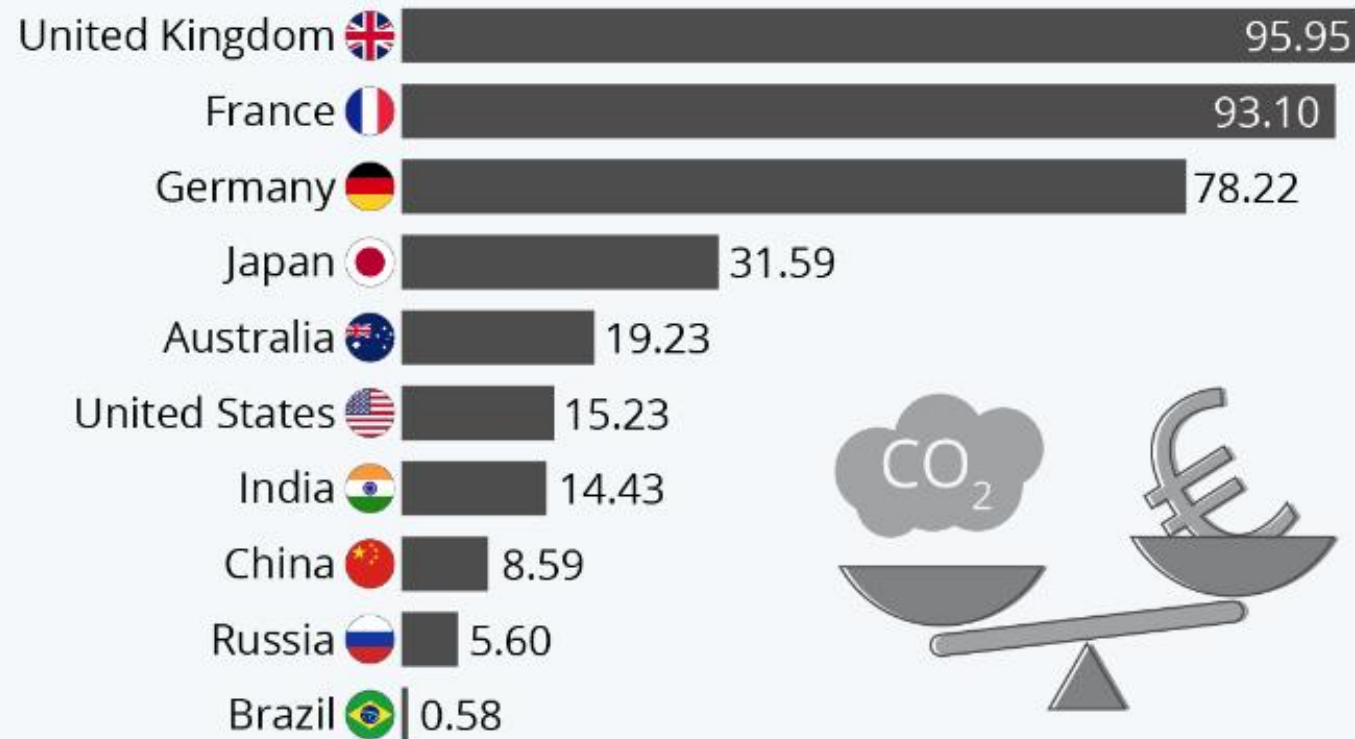


Why this time?



How the World Puts a Price on Carbon

Average carbon prices in selected countries in 2021
(EUR per tonne of CO₂)



Based on taxes applicable on 1 April 2021.
Source: OECD

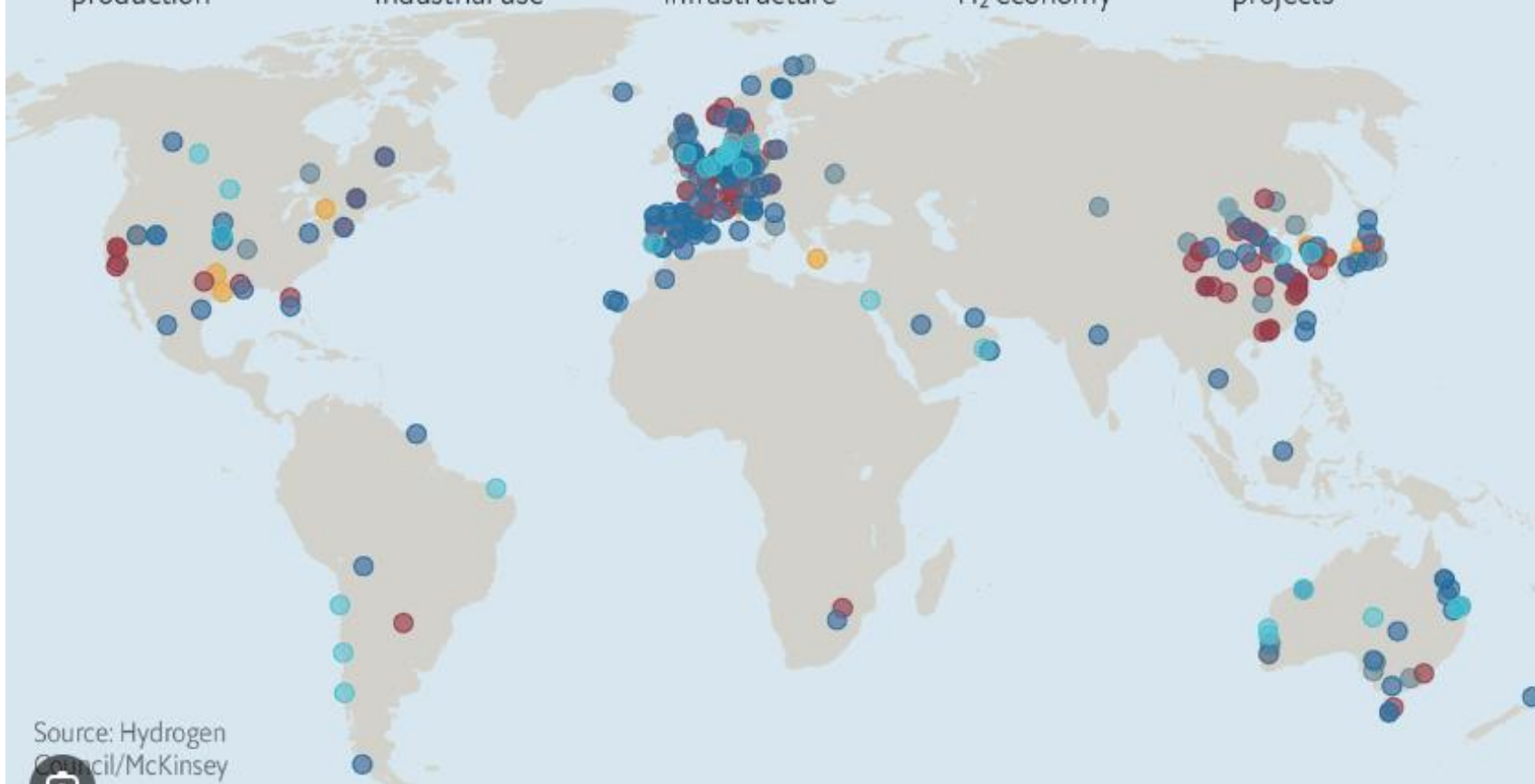
Will it last?



The world to come

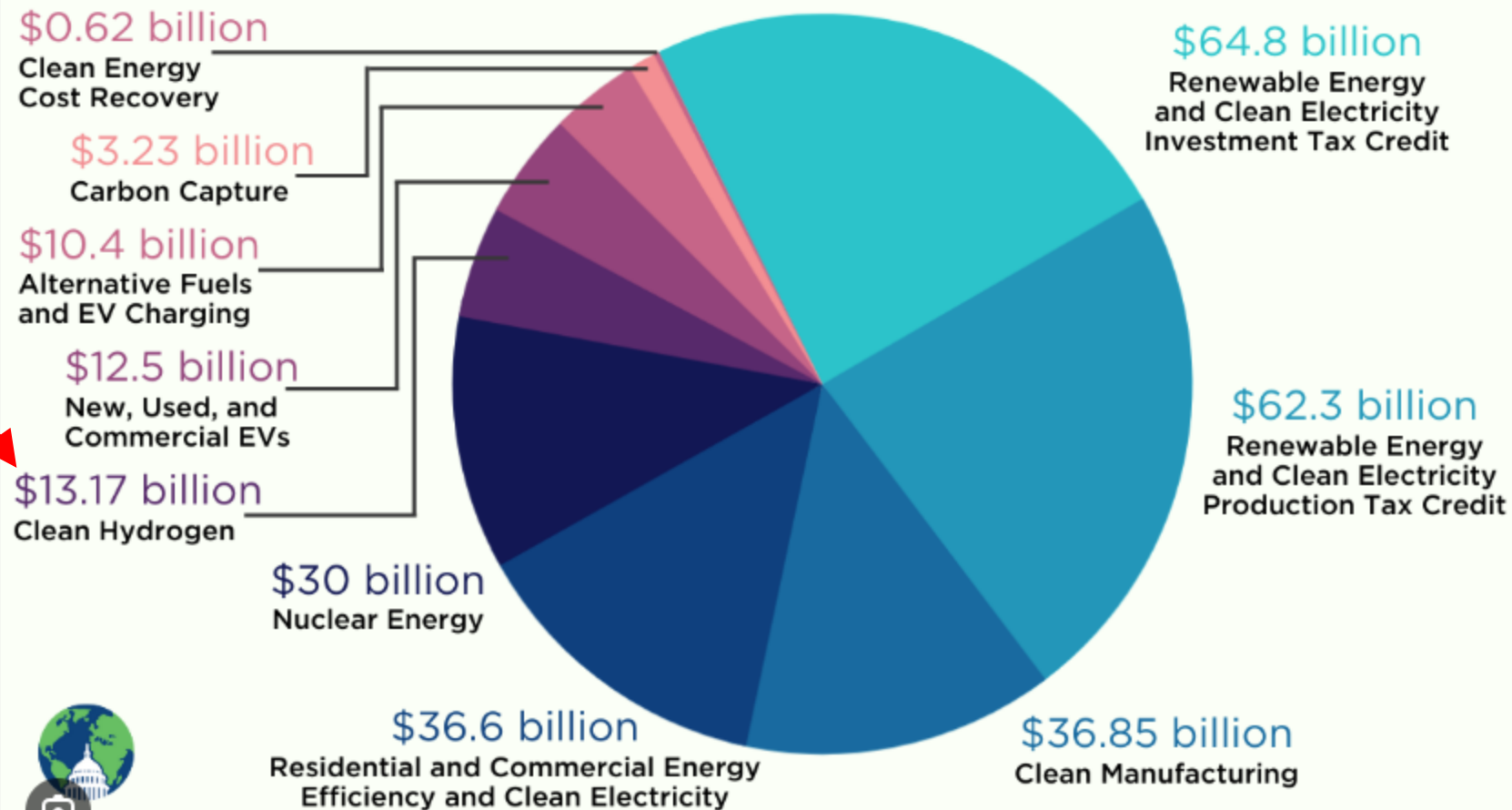
Announced large-scale hydrogen projects, by type, October 2021

- Gigawatt-scale production
- Large-scale industrial use
- Fuelling infrastructure
- Integrated H₂ economy
- H₂ infrastructure projects



Source: Hydrogen Council/McKinsey

Carrots Over Sticks: Green Tax Credits in the Inflation Reduction Act



Source: Congressional Budget Office

Graphic by: Alison Davis



ALBERTA INNOVATES

Kg of CO ₂ per kg of H ₂	Credit Value (\$)
4 - 2.5 kg CO ₂	\$0.60 / kg of H₂
2.5 - 1.5 kg CO ₂	\$0.75 / kg of H₂
1.5 - 0.45 kg CO ₂	\$1.00 / kg of H₂
0.45 - 0 kg CO ₂	\$3.00 / kg of H₂

**BNEF: Hydrogen could account for
24% of global final energy
demand and create 5.4M jobs by
2050**



Alberta Strategy

2.5 Million tonnes per year

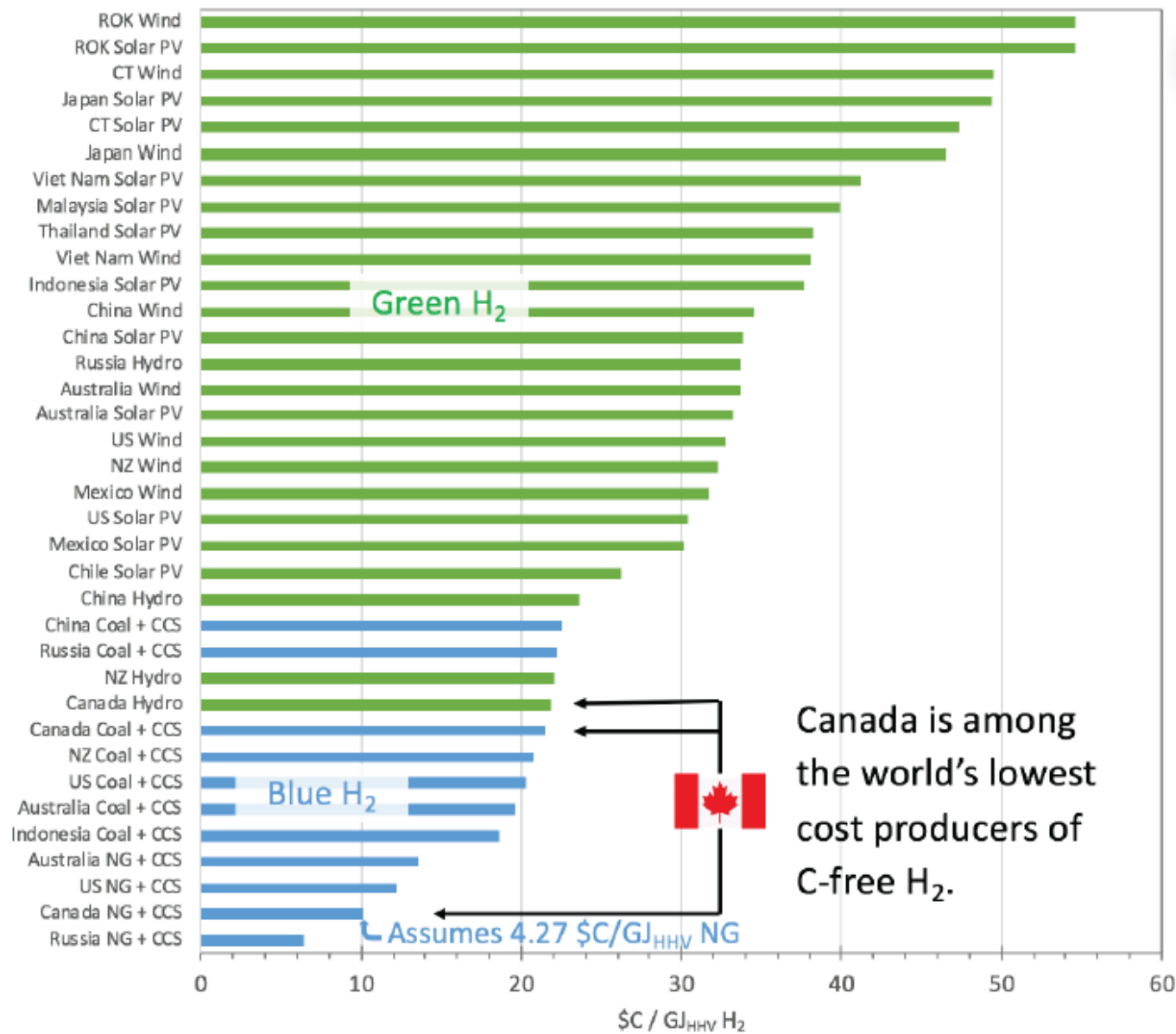
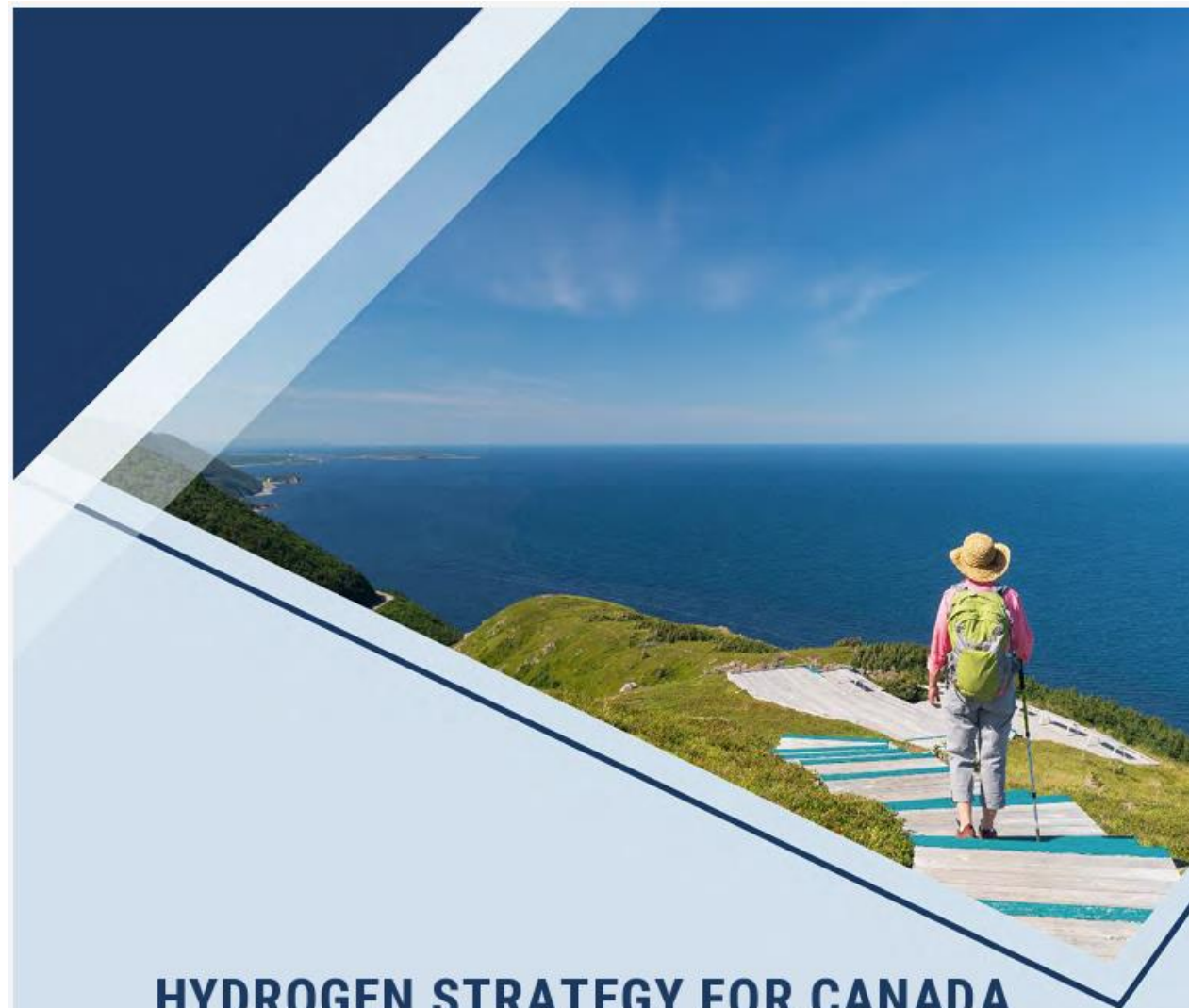


Figure 8.2. Production cost estimates of carbon free hydrogen in the APEC region in 2030. (Canadian dollars/GJ_{HHV}). Adapted from [80] assuming \$C0.80/\$US. ROK, Republic of Korea; NG, natural gas; CCS, carbon capture and storage.



HYDROGEN STRATEGY FOR CANADA

Seizing the Opportunities for Hydrogen

A Call to Action

December, 2020





Leading the way in clean hydrogen

ALBERTA'S
RECOVERY
PLAN

alberta.ca/recovery

Alberta

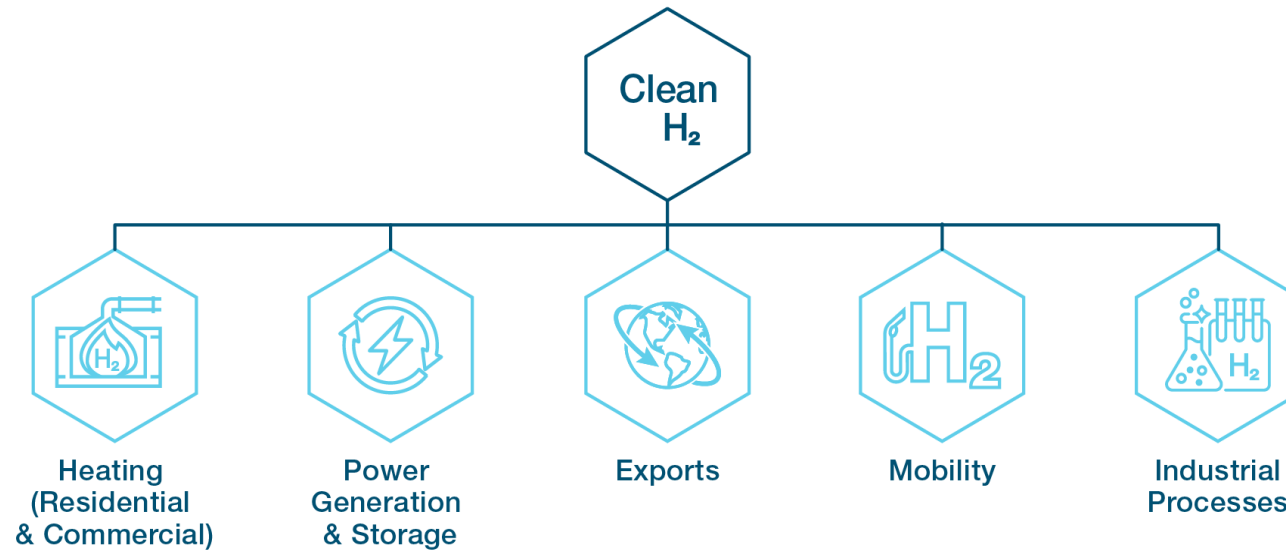
ALBERTA'S HYDROGEN AMBITION

By 2030, clean hydrogen is integrated at scale into Alberta's domestic energy system for use in mobility, heat, power generation and renewable energy storage, and industrial applications. Alberta has established itself as the global supplier-of-choice in clean hydrogen exports.

Policy Pillars



Markets



Outcomes



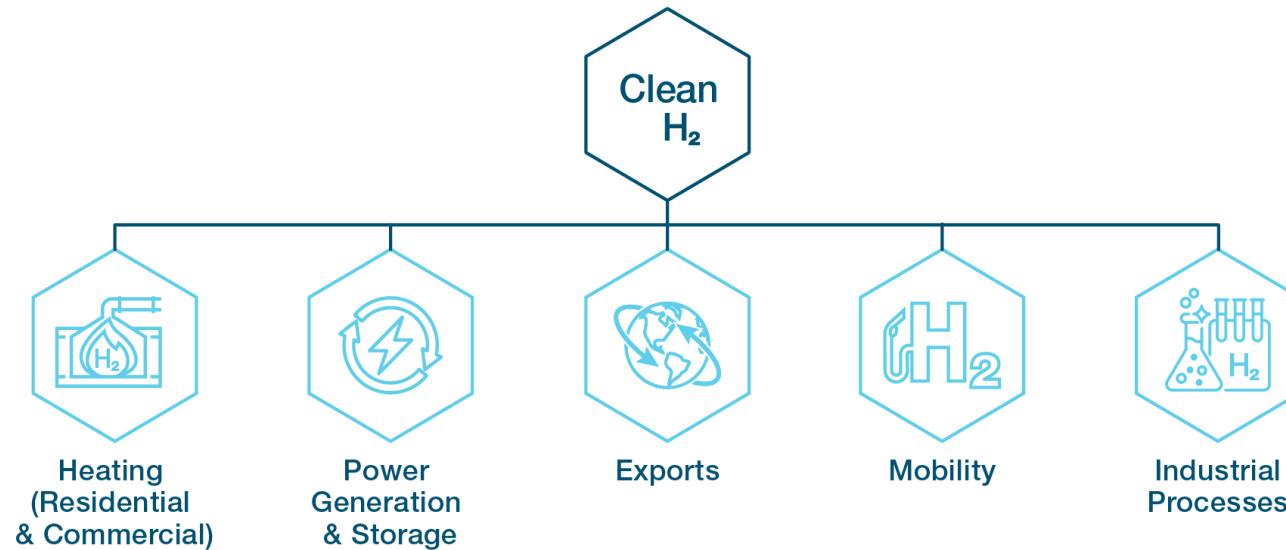
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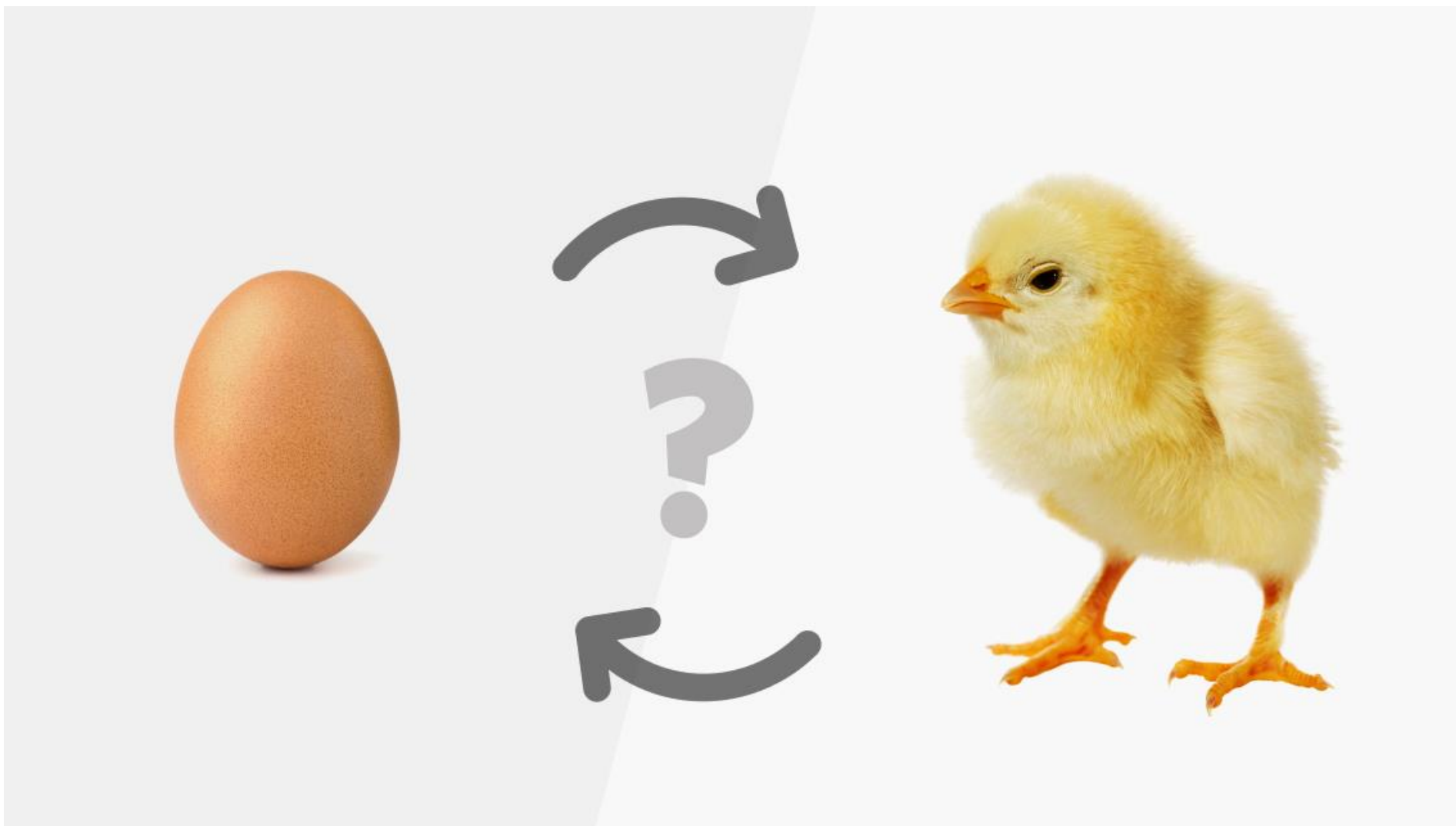


Outcomes





Commercial Activities



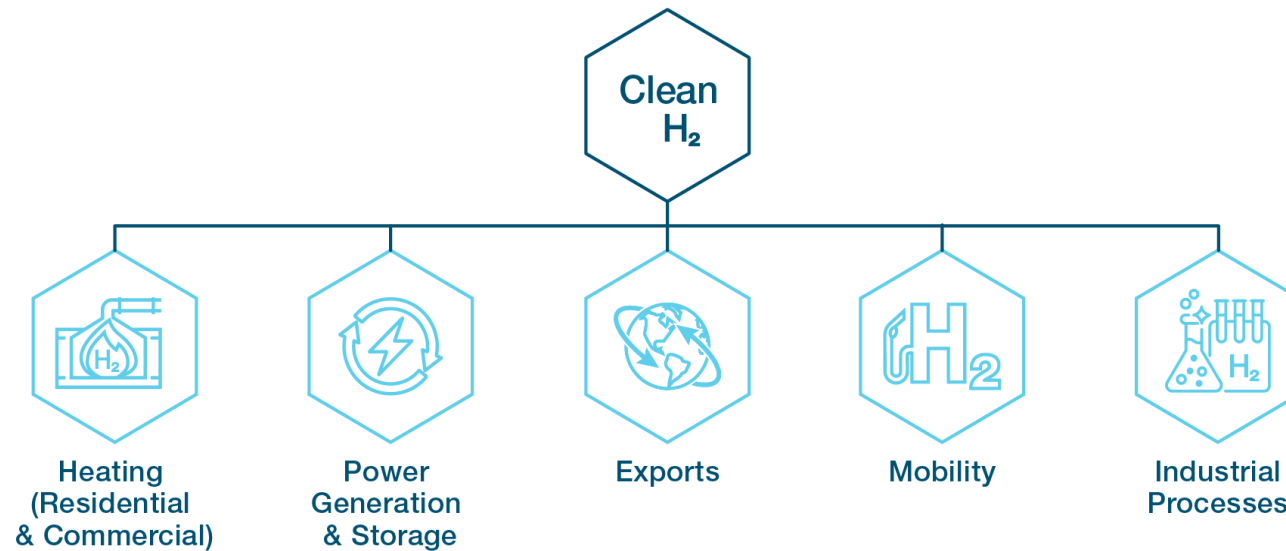
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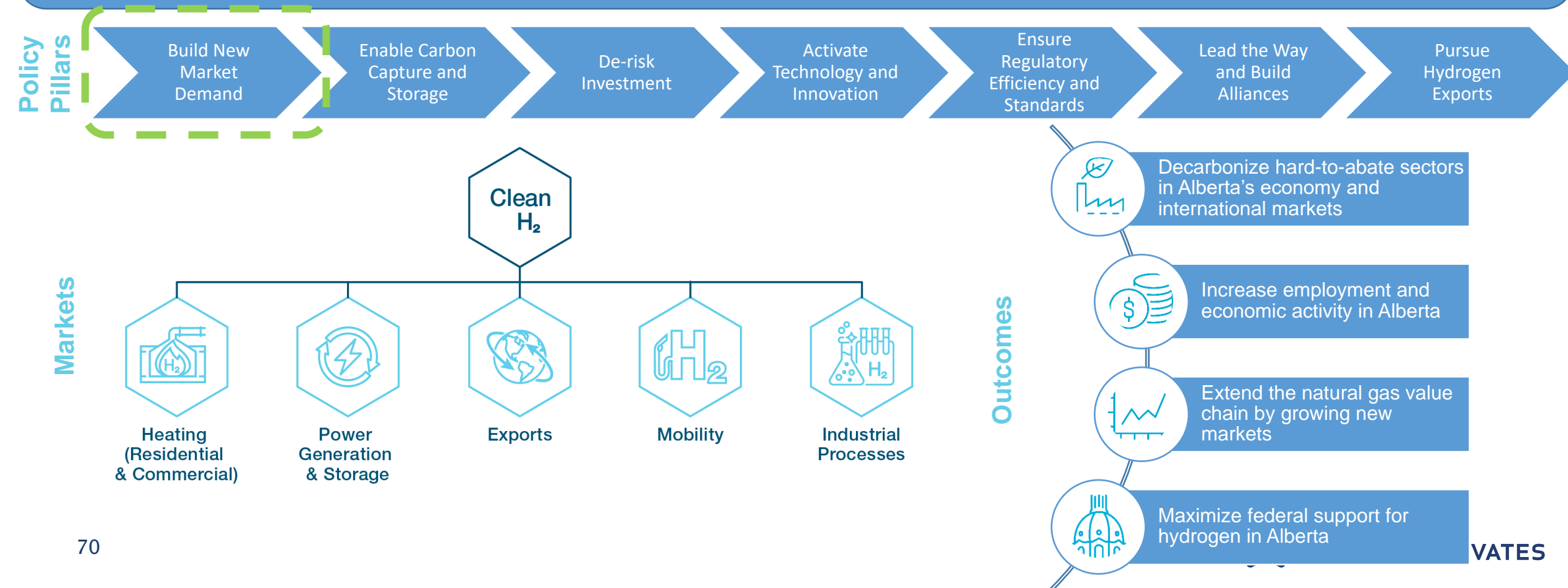


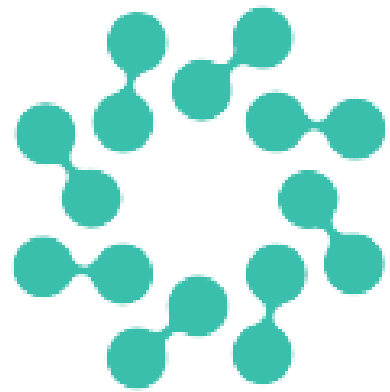
Outcomes



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EDMONTON REGION

Hydrogen HUB





Two FCEV Class 8 Trucks

- ✓ Heavy weight (63.5 t gross) B-Train
- ✓ 700 km (Edmonton → Calgary, return) between refueling
- ✓ Zero tailpipe emissions

Timetable:

- ✓ Design and Build: July 2019 to June 2021
- ✓ Test on Road: July 2021 to Dec 2022

H₂ Produced from AB natural gas:

- ✓ Steam Methane Reformed (no C mgmt)
- ✓ Cascade Refueling

Industry Led

- ✓ By Alberta Carriers under real-world conditions





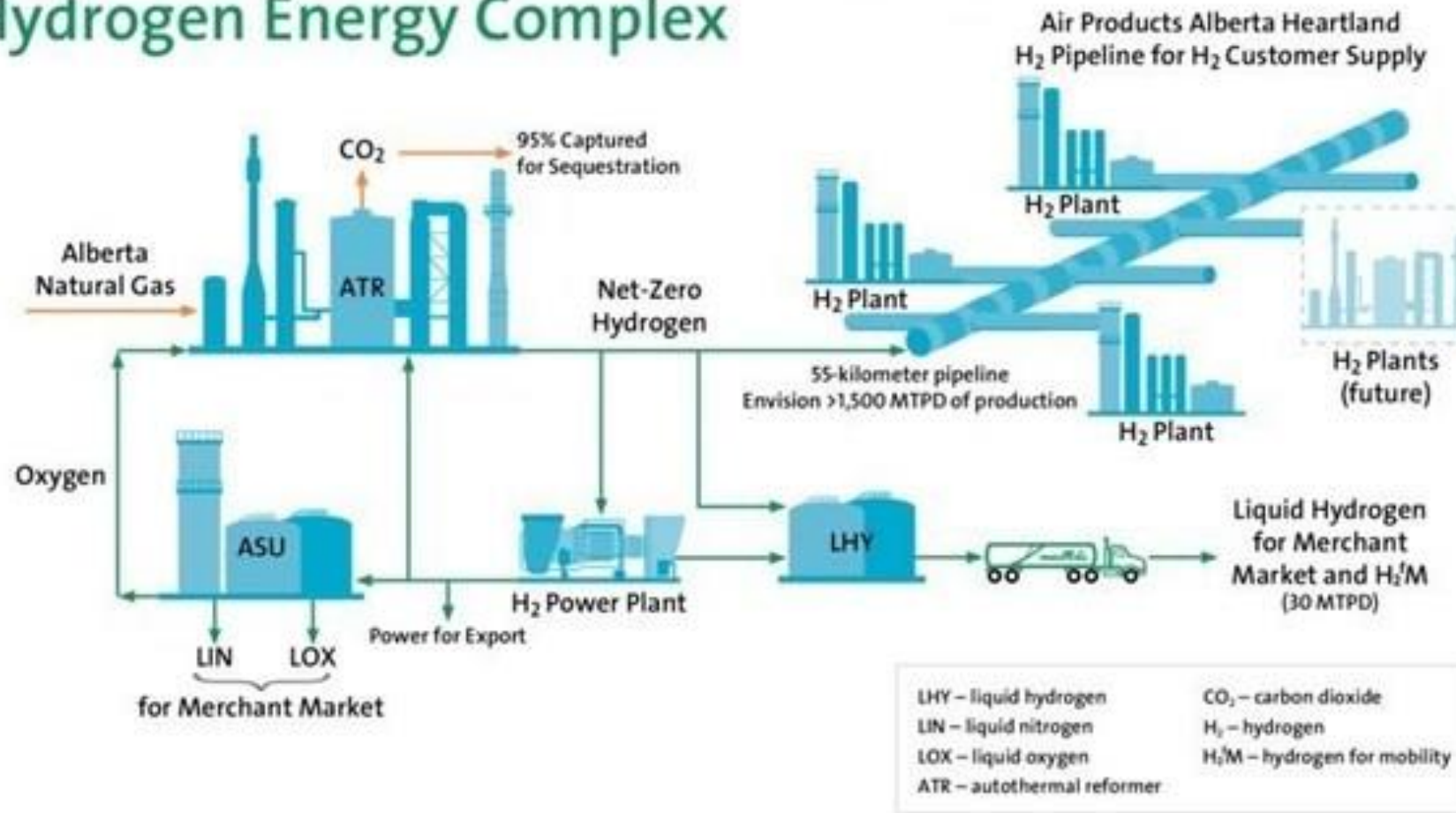


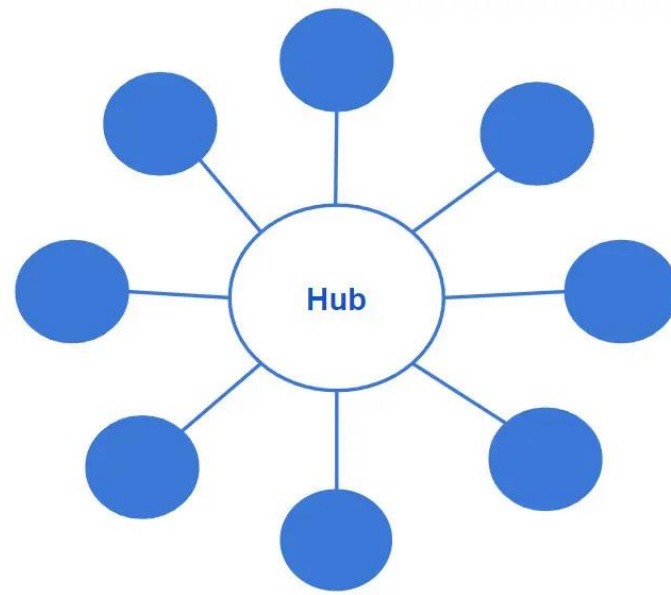


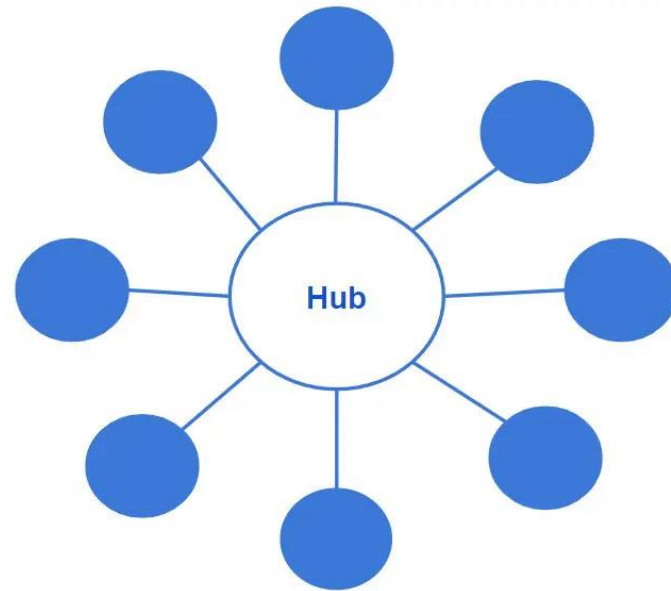
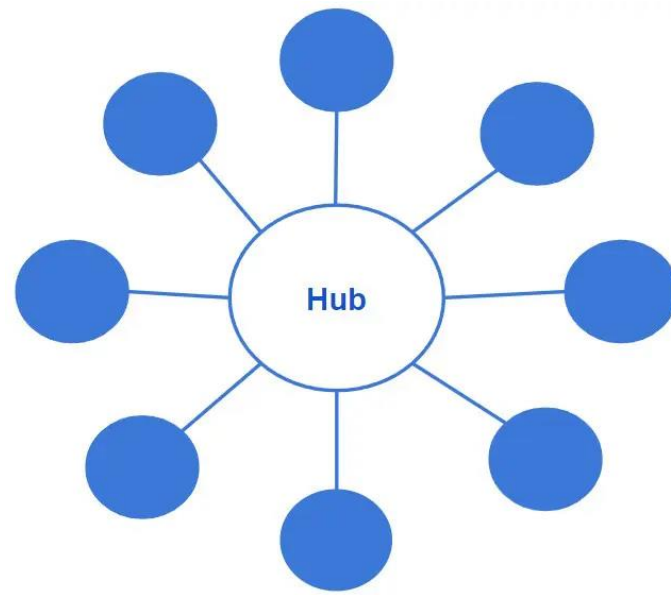


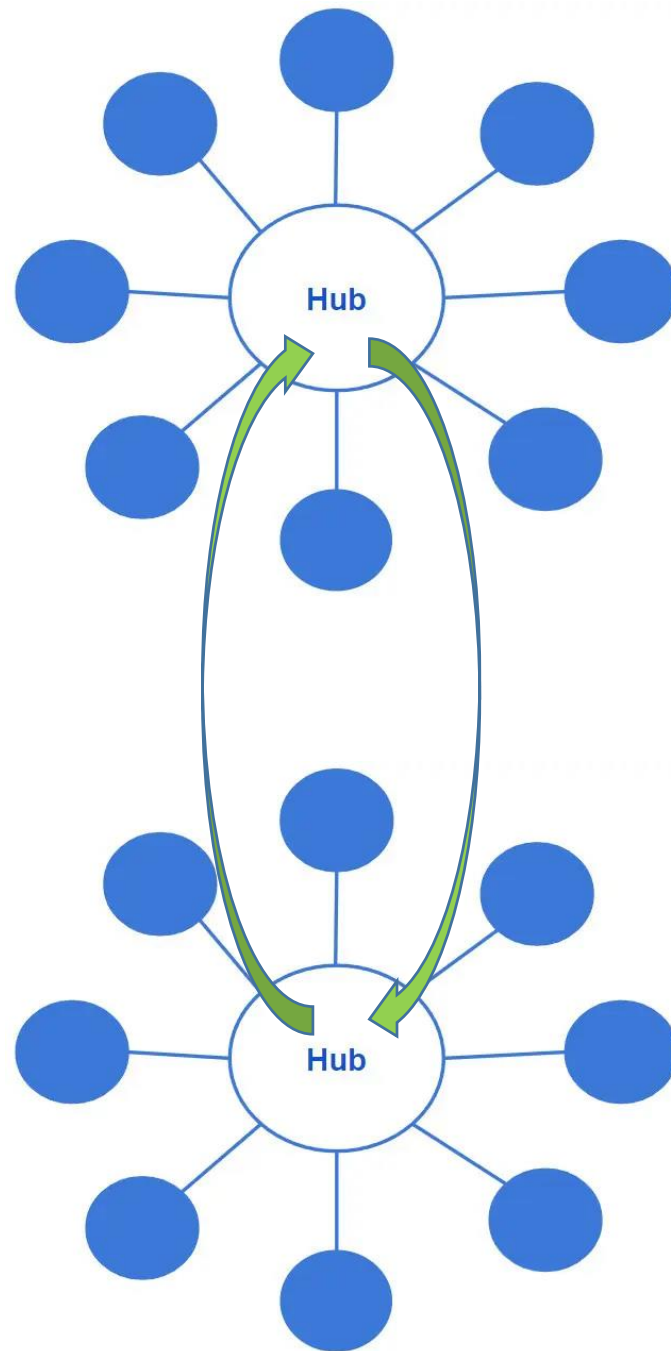


Air Products' World-Scale Net-Zero Hydrogen Energy Complex











Hydrogen Centre of Excellence

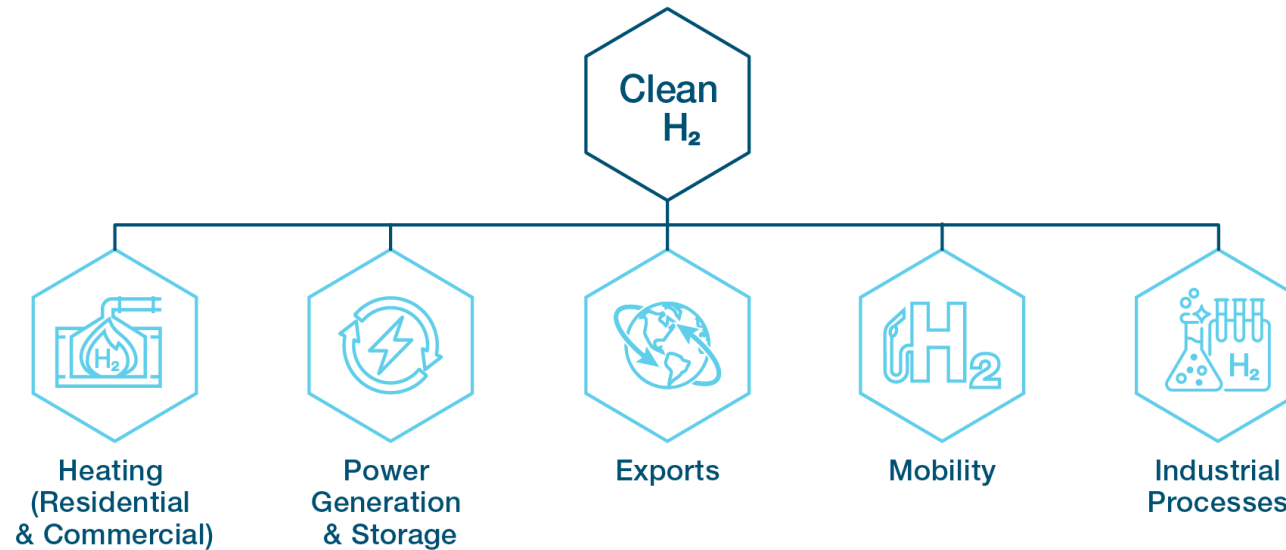
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Policy Pillars



Markets

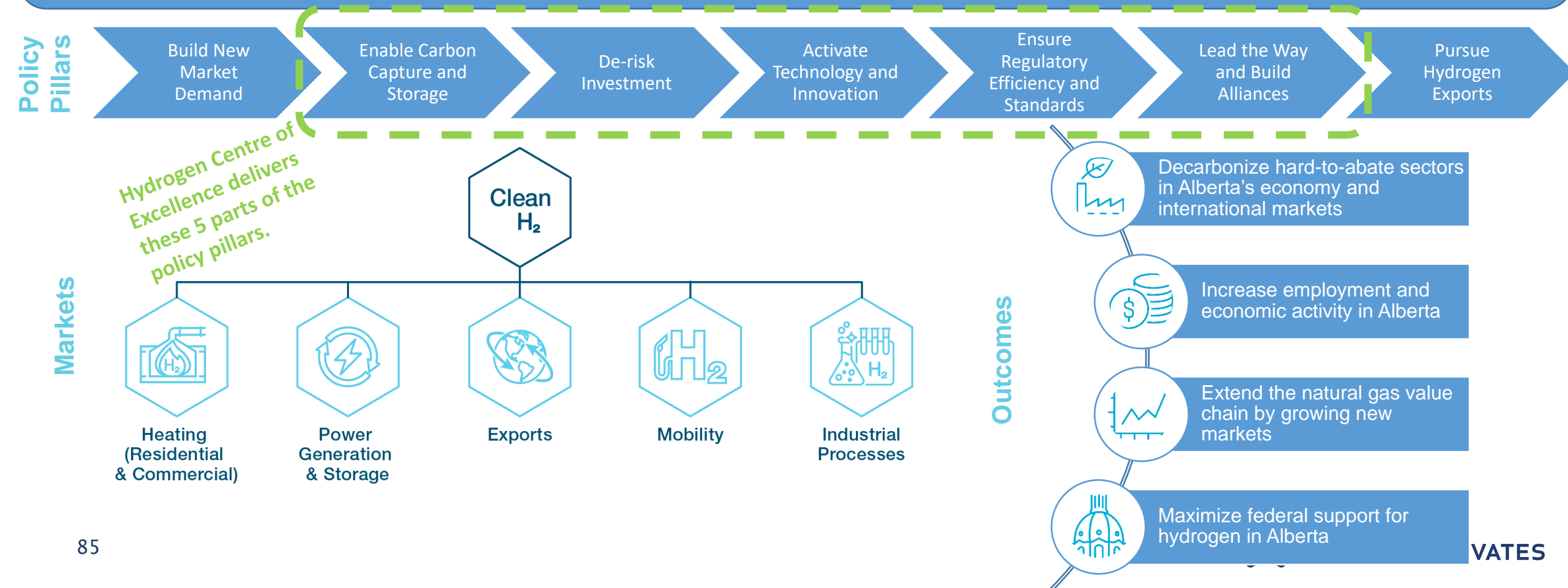


Outcomes

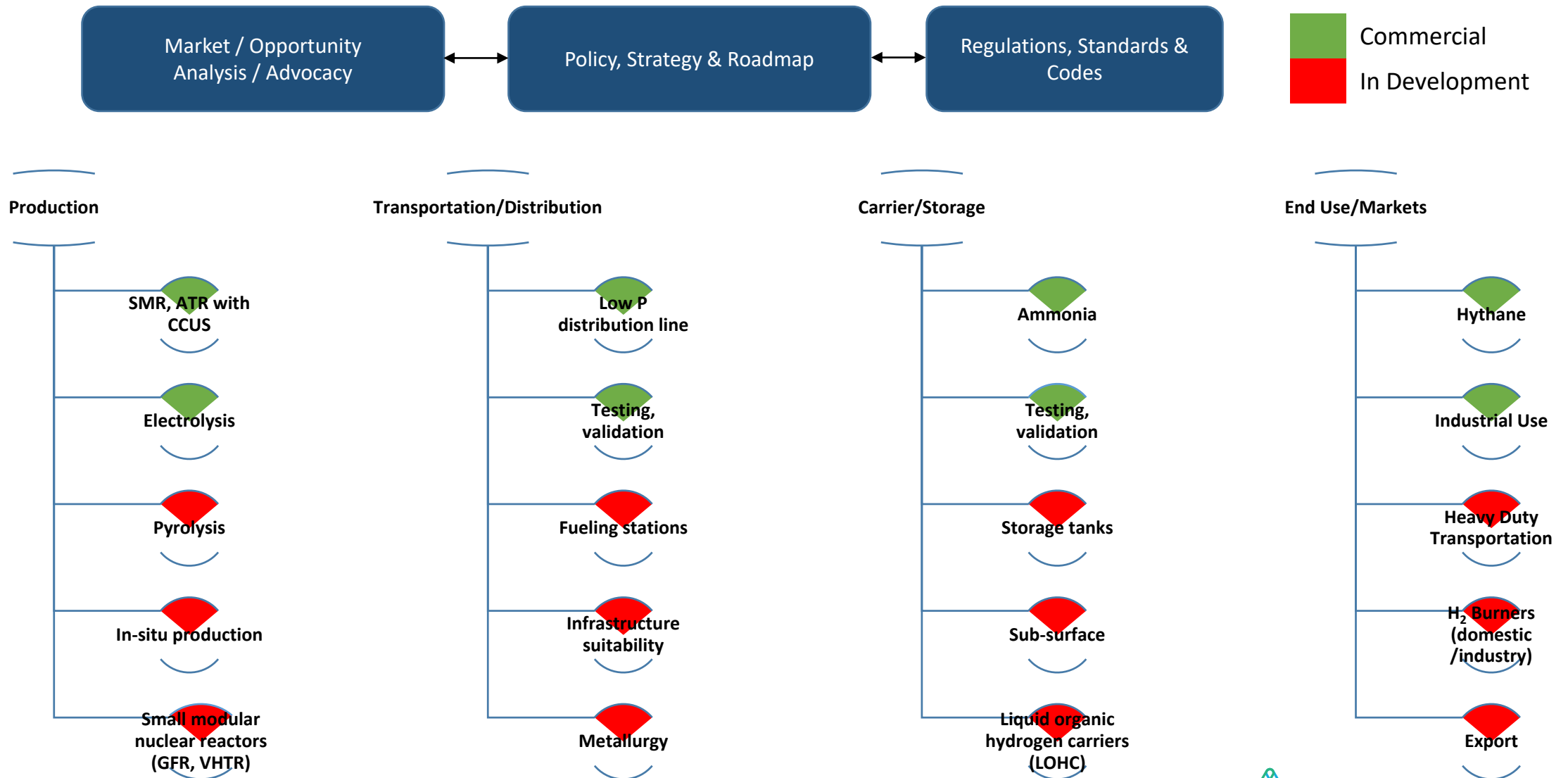


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Hydrogen Economy Ecosystem and Technology Gaps in Alberta





Alberta's Hydrogen Centre of Excellence

Purpose

- Closes innovation and technology and support gaps where federal and provincial funding does not exist
- Innovation support across the entire hydrogen supply chain (production to end use)

Scope and Focus of Hydrogen Centre of Excellence

Ecosystem

- Opportunity Analysis



- Public Awareness



- Partnership Building



Technology

- Production



- Transportation/Distribution



- Carrier/Storage



- End Use/Markets



Service

Pilot Facilities



Testing Services



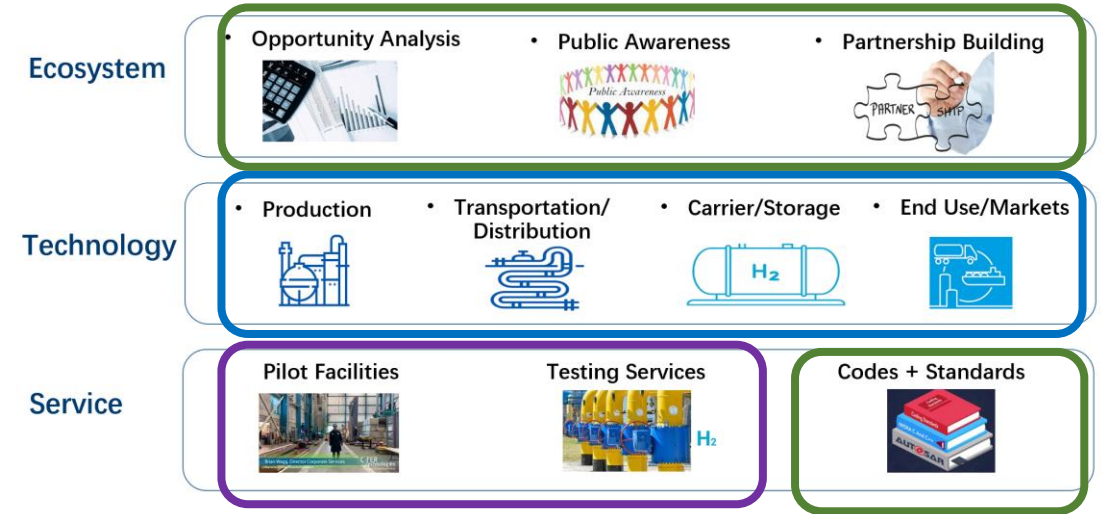
Codes + Standards



Funding Model

- \$50M from the Government of Alberta over 5 years
- \$150M Targeted Leverage from Other Sources
 - Federal Government
 - Industry
 - Applicants

Funding Allocation



- Technology & Innovation

\$35 M

- Technology development across value chain for TRL 3-6
- Includes CCUS and FEED studies for commercial-scale projects

- Capital Projects

\$10 M

- building facilities and testing capability at InnoTech and C-FER facilities

- Services Capacity

\$4 M

- Studies, analyses, codes and standards, public awareness

Technology & Innovation stream

- Competition #1 launched with \$20M available from HCOE
 - 68 Expressions of Interest received, totaling \$91M Ask for \$279M of project spend
 - 31 projects moving to Full Proposal, totalling \$38M Ask for \$146M of project spend
 - 18 projects successful, \$20.1M requested. AI contributes \$15M, NRCan \$5M
- Competition #2 launched, partnered with Emissions Reduction Alberta to expand program to service TRL 3-9
 - Sep 26 Deadline for Expressions of Interest; volume exceeded expectations

Capital Projects stream

- \$10M approved for equipment enhancements at InnoTech Alberta and C-FER Technologies
 - Procurement & installation underway
- Additional \$3M funding received from PrairiesCan for C-FER Technologies
- Provides unique testing capabilities in a Hydrogen environment
 - Generating lots of domestic and international interest

Service Capacity stream

- Scope
 - Ecosystem development
 - Codes & Standards
 - Public Awareness
 - Opportunity Analysis
 - Studies
- Funding: \$4M available
- Process
 - Continuous Intake open for submissions

Alberta Innovates

Public Perceptions of Hydrogen

Field work conducted between
November 22 and December 8, 2022

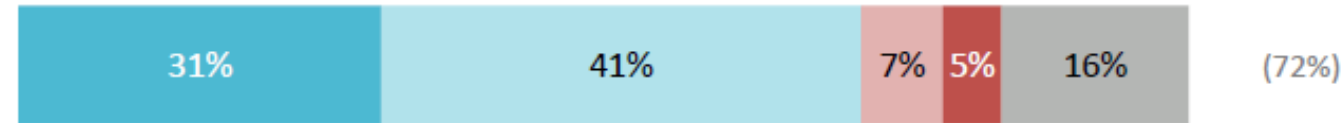
Prepared by:

Janet Brown
OPINION RESEARCH

in partnership with

Trend  **search**

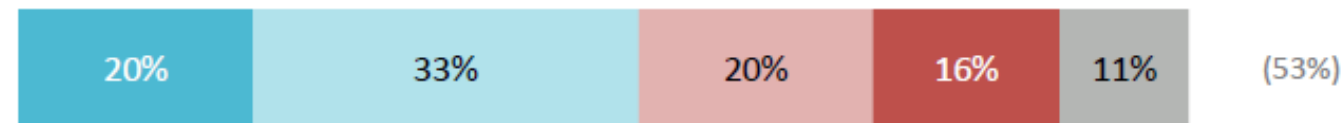
Alberta is well positioned to be an important global player in the development of hydrogen as a fuel source (Total true)



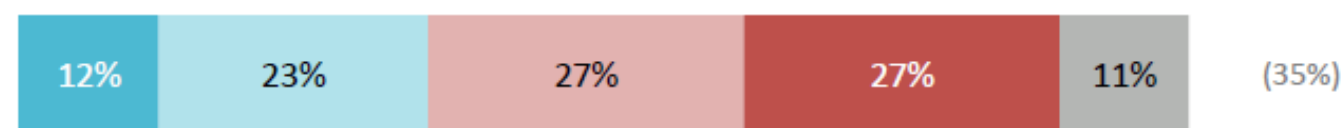
Hydrogen fuel is better for the environment than conventional fuels such as oil and natural gas



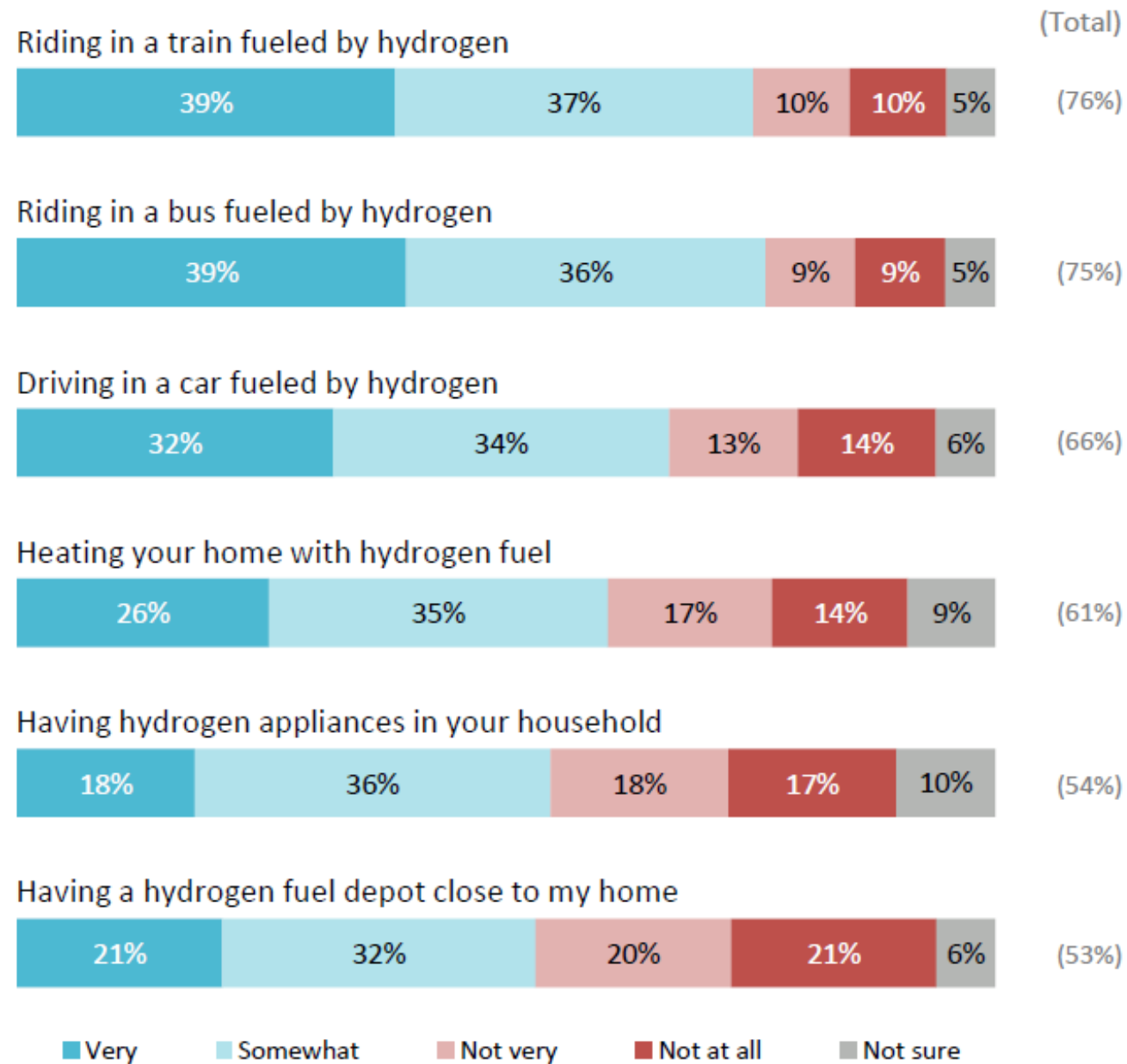
People should be concerned about the safety of hydrogen fuel



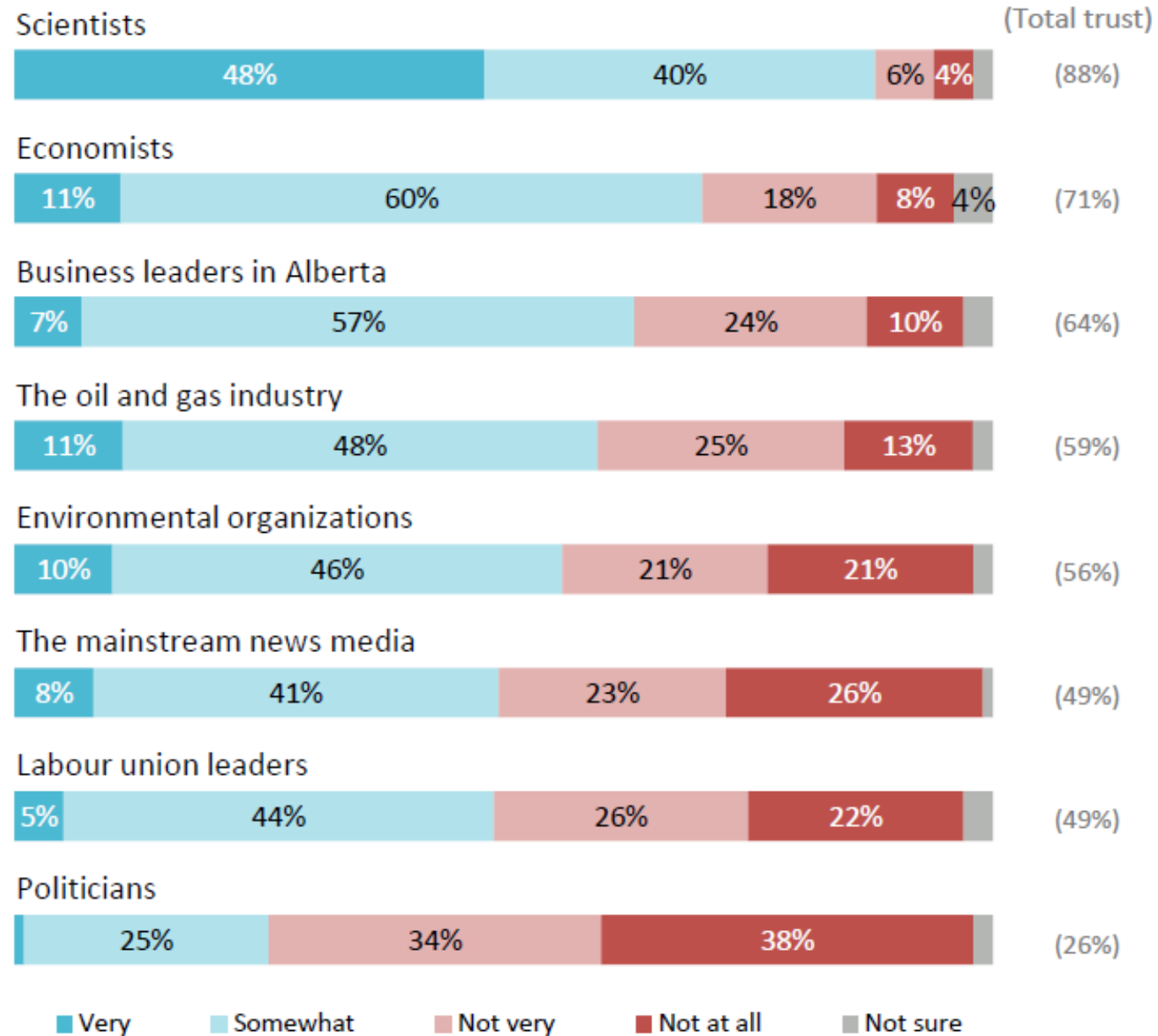
Alberta's economy will suffer if hydrogen fuel use increases around the world



Mostly true Somewhat true Somewhat false Mostly false Not sure



Public Awareness Campaign



**BNEF: Hydrogen could account for
24% of global final energy
demand and create 5.4M jobs by
2050**



