A Life Cycle View of Blue Hydrogen Production

Building a net-zero future

Prof. Sean McCoy
Department of Chemical and Petroleum Engineering
Global Research Initiative on Sustainable Unconventional Resources

7 July 2022

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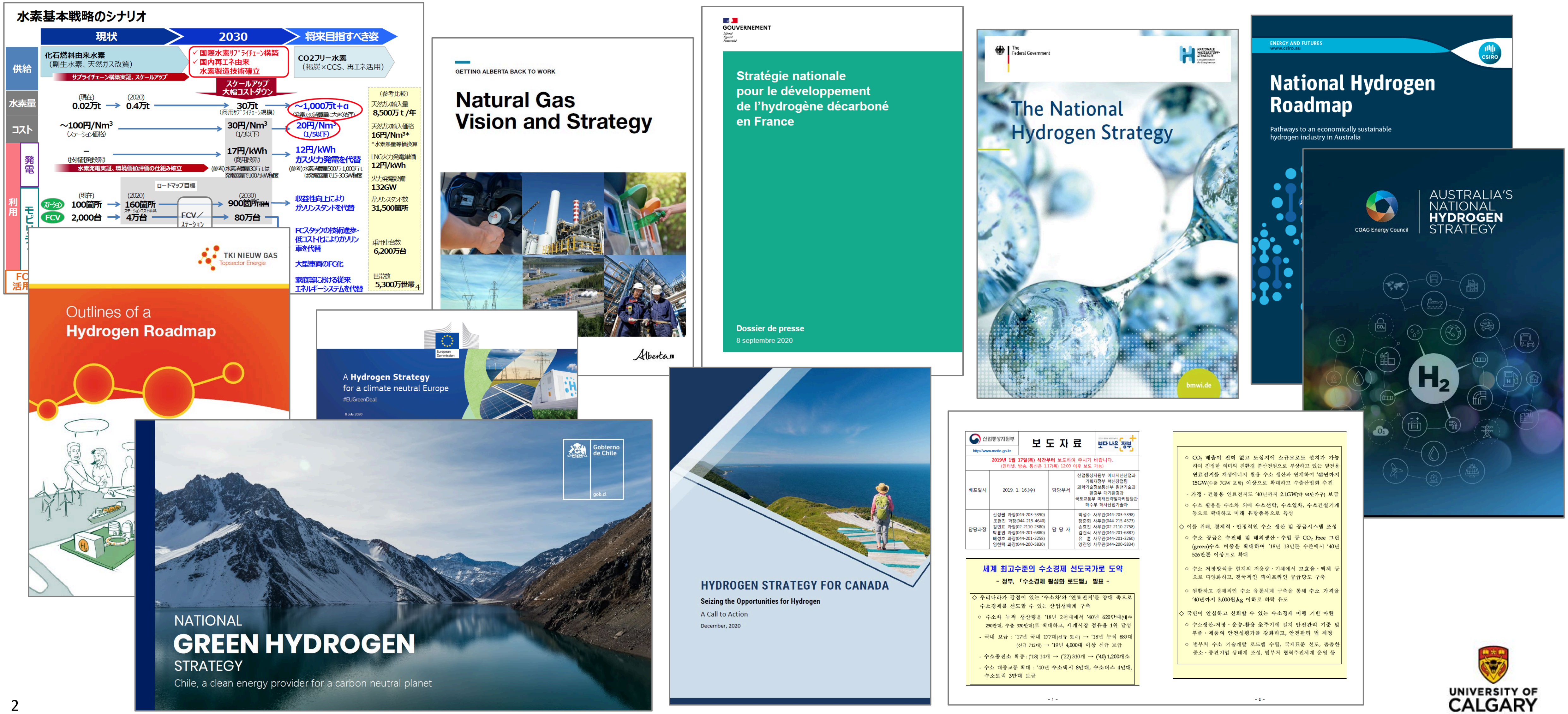
We are witnessing a hydrogen renaissance



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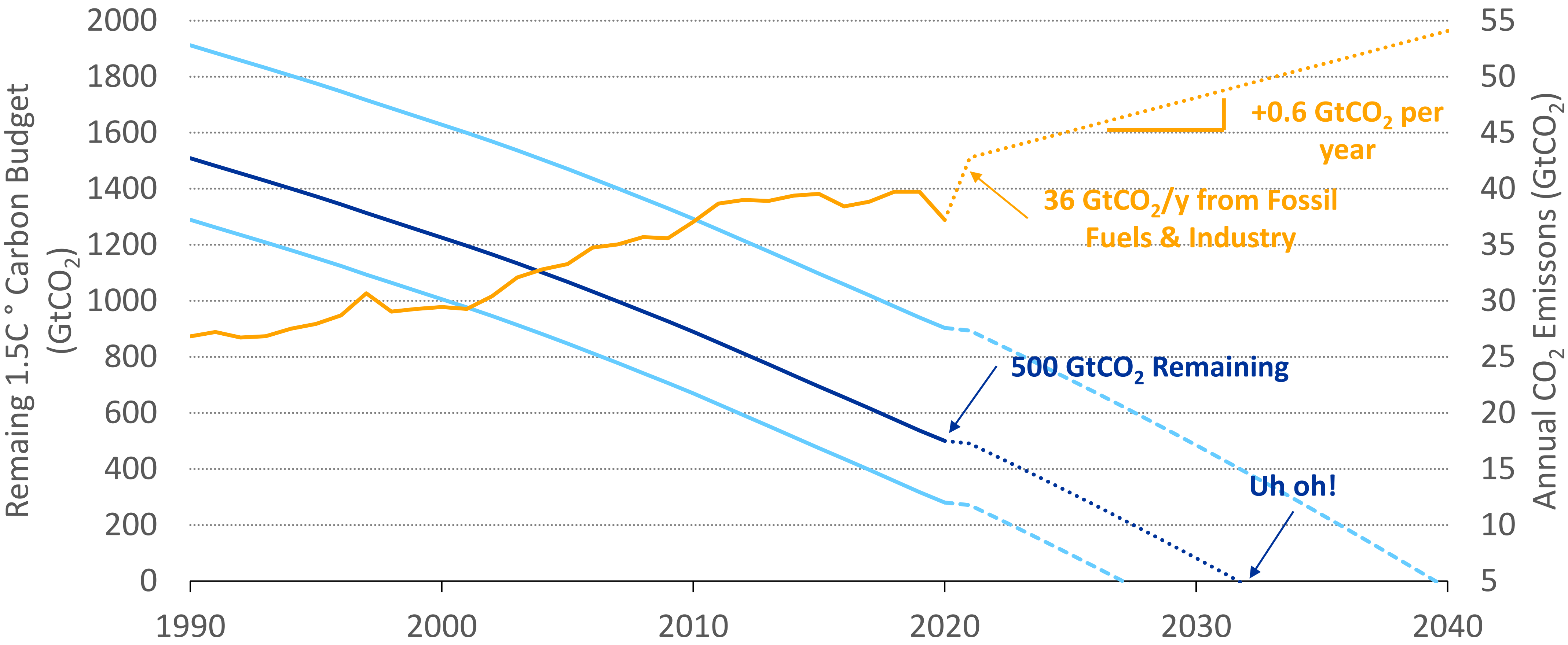
Why look at hydrogen as a fuel now?



Carbon budget based on IPCC AR6 WG1, Table 5.8 (50% TCRE solid blue; 17% and 83% dashed lines) with historical emissions on Friedlingstein, 2021. Dotted lines are based on an extension of cumulative emissions trends from 1999 to 2019.

Net-zero targets are a forcing function for hydrogen

This is *not* just a transport story, as in the past.

Myriad applications of hydrogen from multiple different sources.

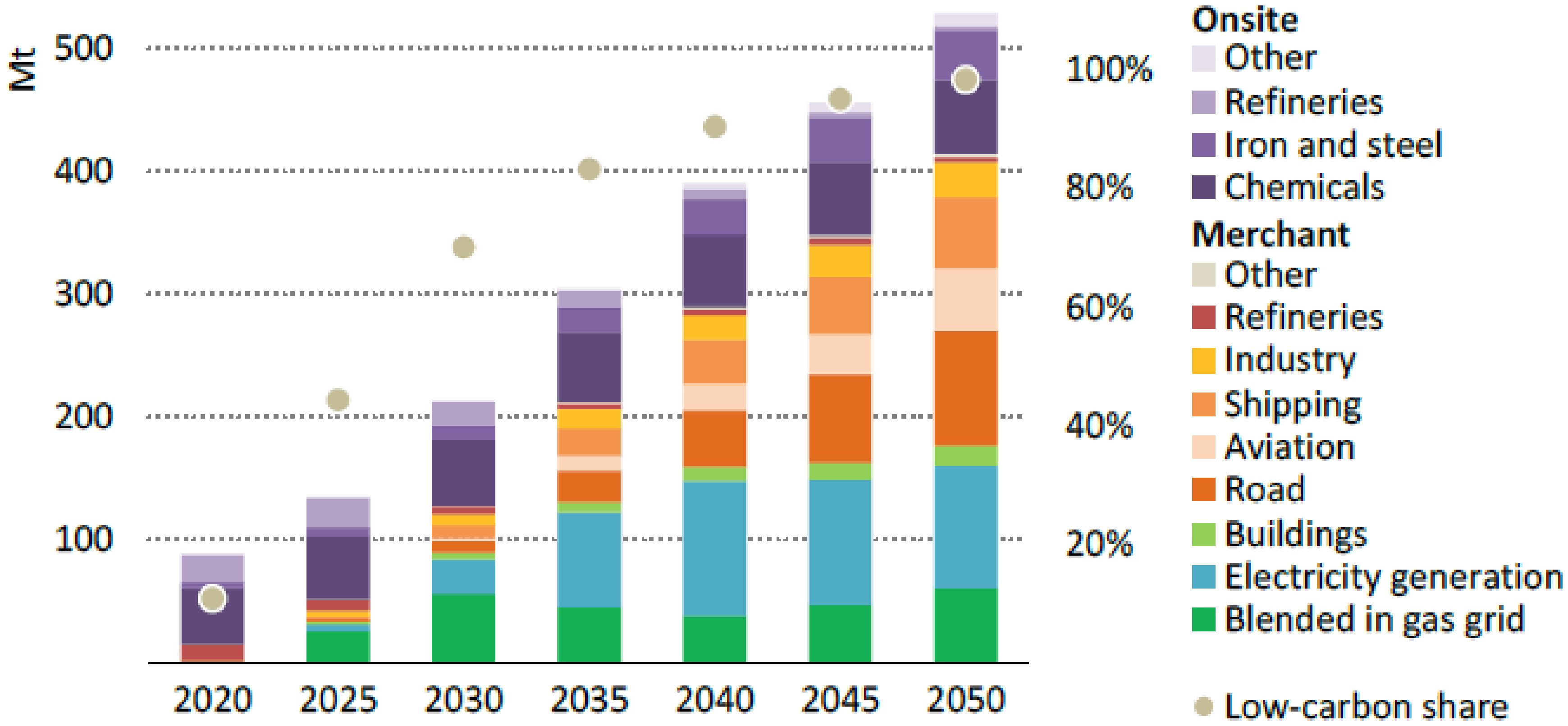


Figure 2.19, IEA NZE (2021)

Canada has grand plans for hydrogen

Targets

- 4 MtH_2/y in 2030 growing to 20 MtH_2/y in 2050
- 30% of total final energy in Canada
- Avoidance of 190 $MtCO_2e/y$

Recommendations

- Across eight pillars
- Focus on regional "blueprints" or hubs

NRCan (2021)

So, is hydrogen a “zero emission” energy carrier?

a) Yes, of course it is! Its use emits only water.
b) No, it’s not! Its production generates many environmental impacts.
c) It depends…

Key points to take from this rest of this talk…

Hydrogen is only of beneficial use in helping to meet net-zero targets if results in lower emissions, over its entire life cycle, relative to alternative fuels

1. High overall CO_2 capture rates in production are imperative to generate low-GHG intensity hydrogen *and*
2. Methane emissions upstream need to be measured and carefully controlled, regardless of whether GWP100 or GWP20 are used
3. There is an *opportunity* to demonstrate that Alberta-based producers can generate low-GHG hydrogen through certification of supply chains

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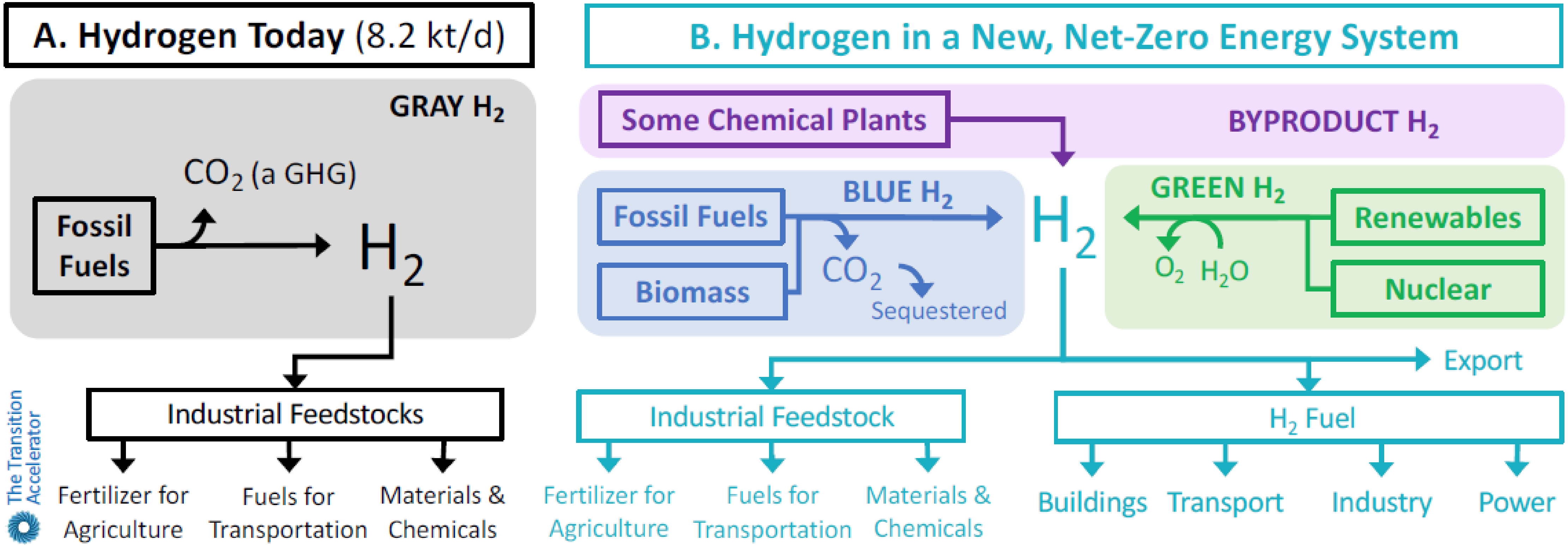
Many production routes for hydrogen, as well as uses



Alberta's hydrogen future will build off the existing 5ktH_2/d "grey" hydrogen production by adding CCS and expanding with new "blue" hydrogen capacity

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Every month, there is a new flavor…

Black or **brown** – coal gasification

Grey – natural gas reforming

Blue – natural gas reforming with CCS

Turquoise – natural gas pyrolysis

Green – water electrolysis (with renewables?)

Pink – water electrolysis with nuclear

? – biomass to hydrogen

Instead, let’s focus on life-cycle greenhouse gas (GHG) intensity!

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What is Life Cycle Assessment?

A decision-making tool to identify environmental burdens and evaluate the environmental impacts of a product, process or service over its life cycle from cradle to grave.

www.nist.gov

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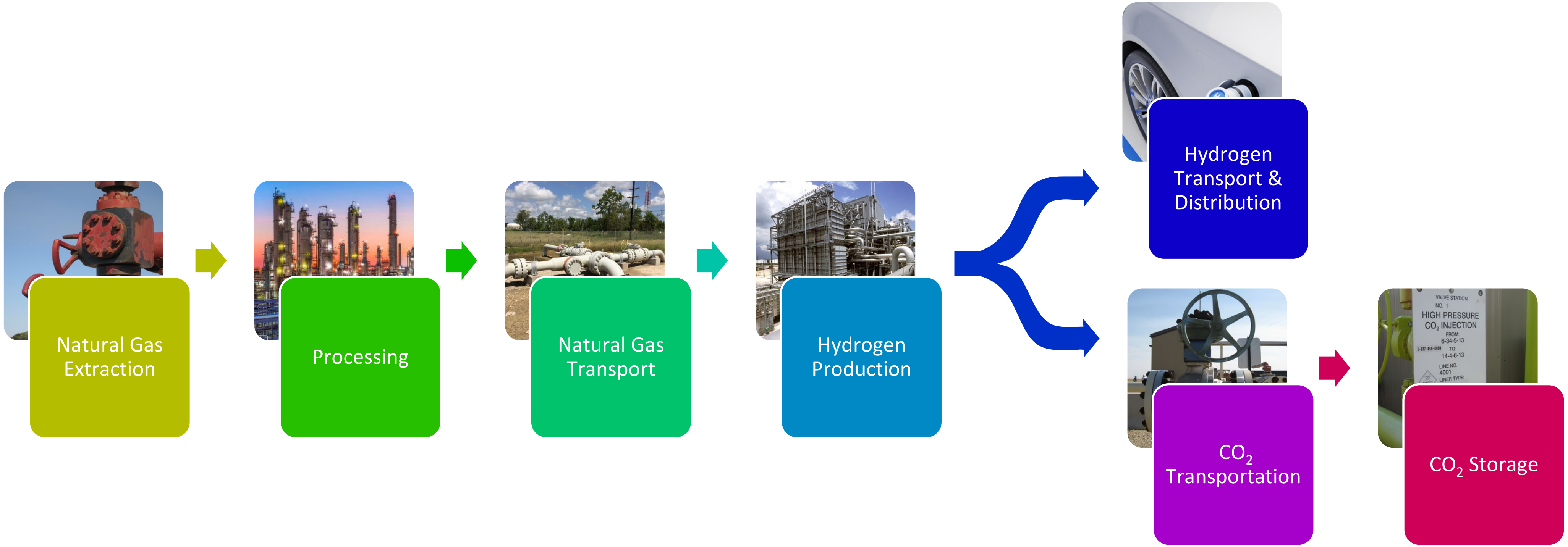
The cradle-to-grave life cycle for blue hydrogen



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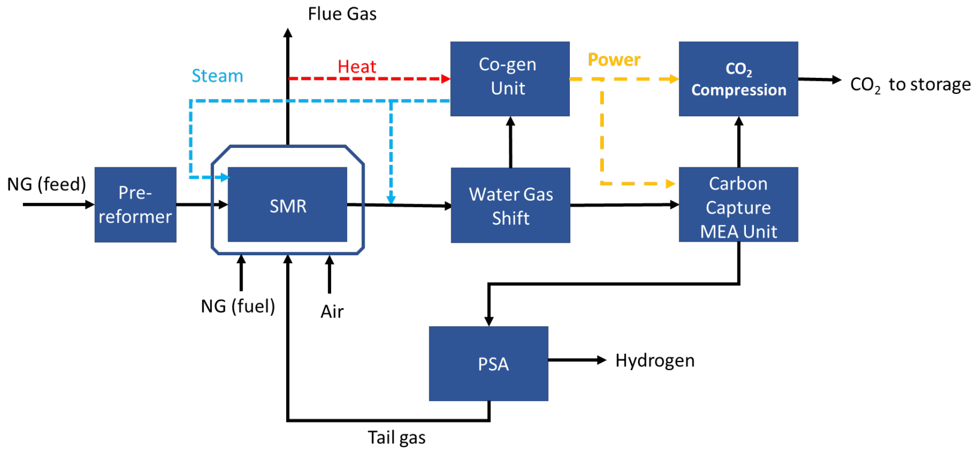
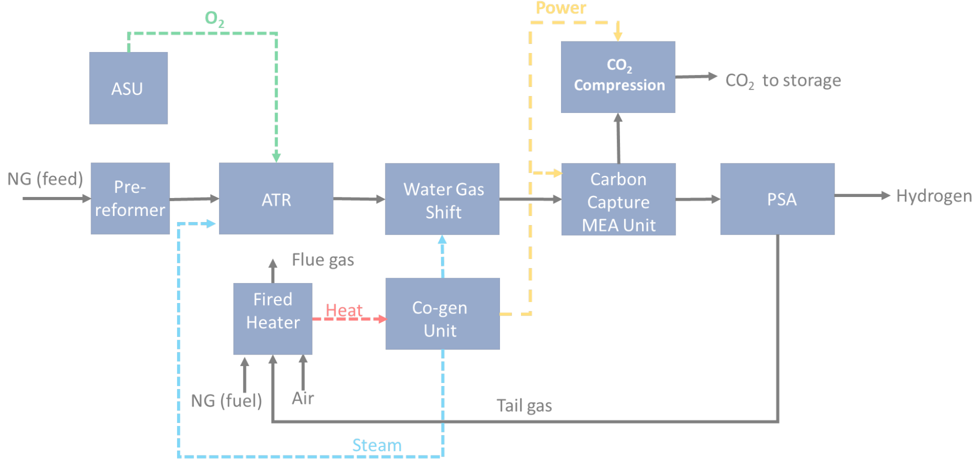
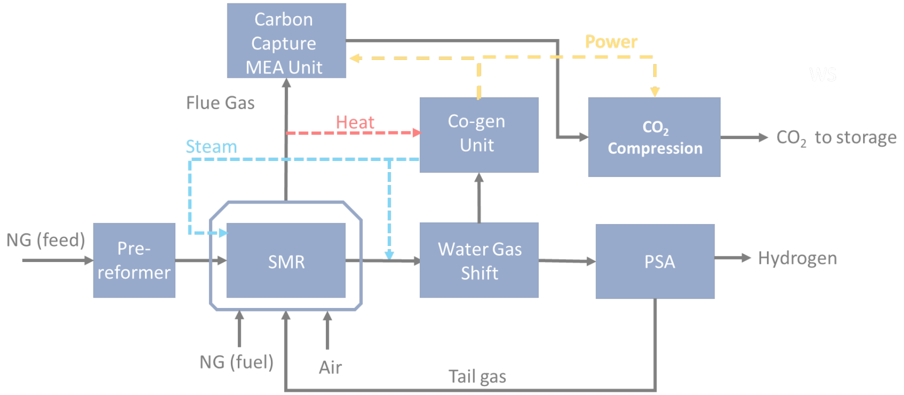
Different "direct" CO_2 emissions rates for different production technologies



Steam Methane Reforming (SMR) with partial capture
Overall capture rate: **55-70%** (at 90-98% capture efficiency)



Autothermal Reforming (ATR) with capture
Overall capture rate: **87-93%** (90-98% capture efficiency)



SMR with total capture
Overall capture rate: **89%** (at 90% capture efficiency)

Enigoumi, 2021

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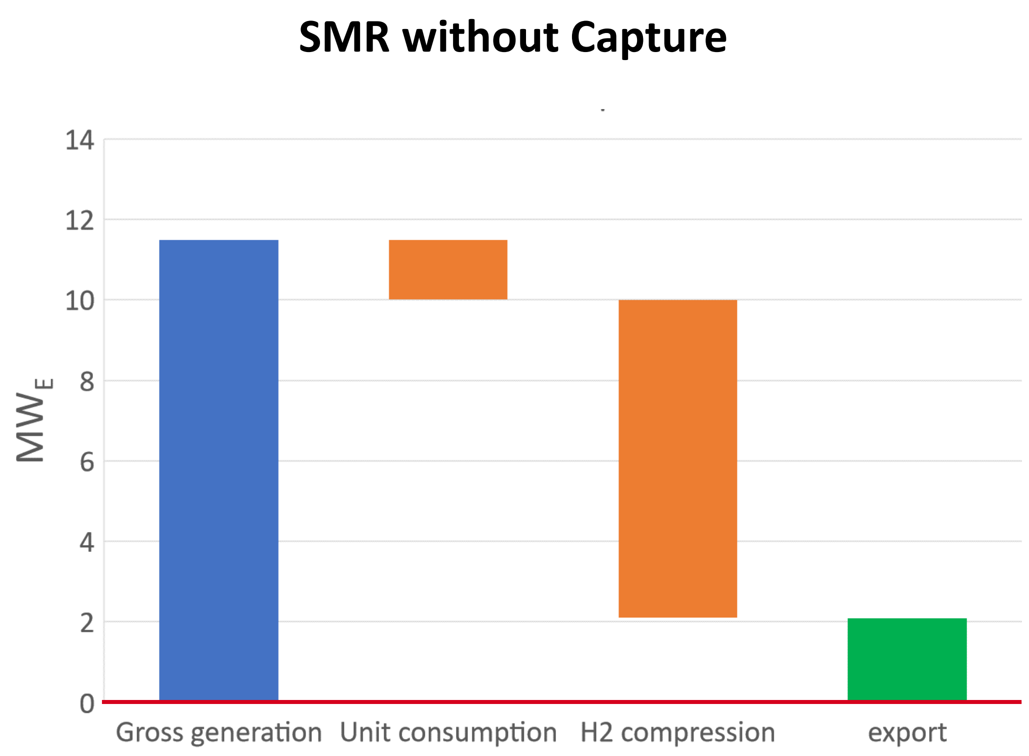
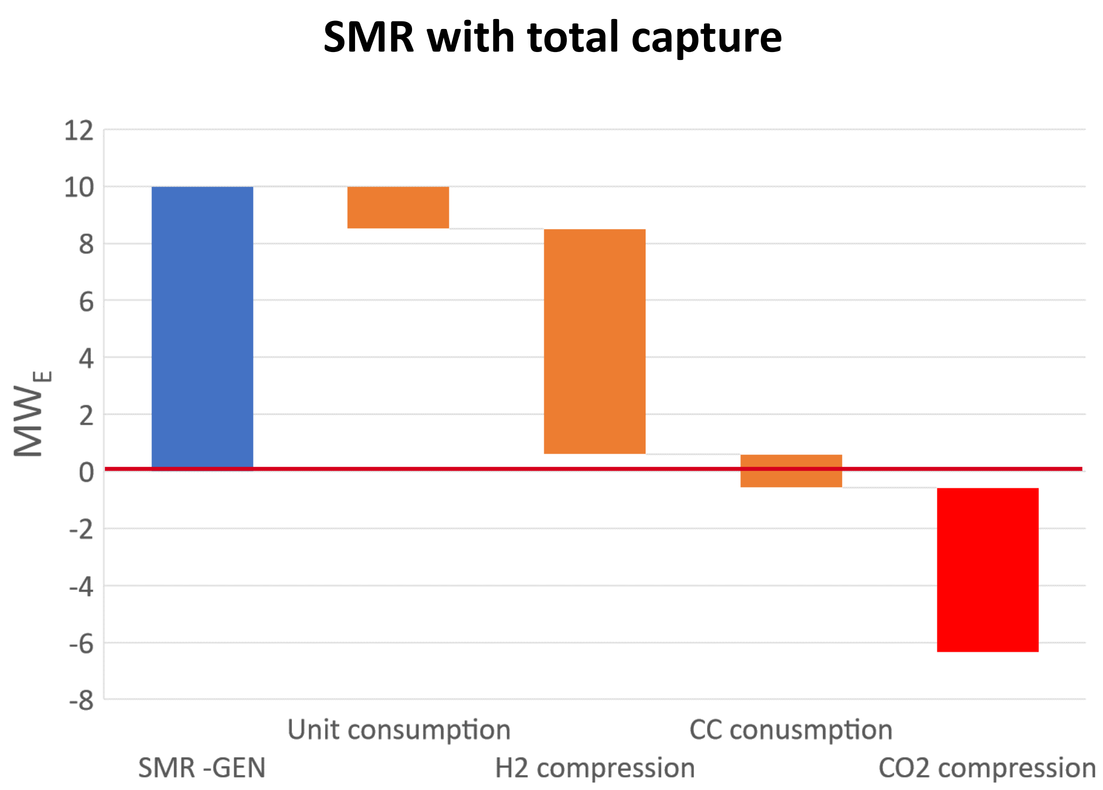
Minimizing footprint means thinking about electricity





Adding CO_2 capture and compression means traditional export of steam is eliminated; this is an issue for traditional SMR, but even more so for ATR since it is *more efficient…*

Enigoumi, 2021

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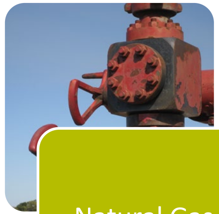
The cradle-to-grave life cycle for blue hydrogen



Natural Gas Extraction

Processing

Natural Gas Transport

Hydrogen Production

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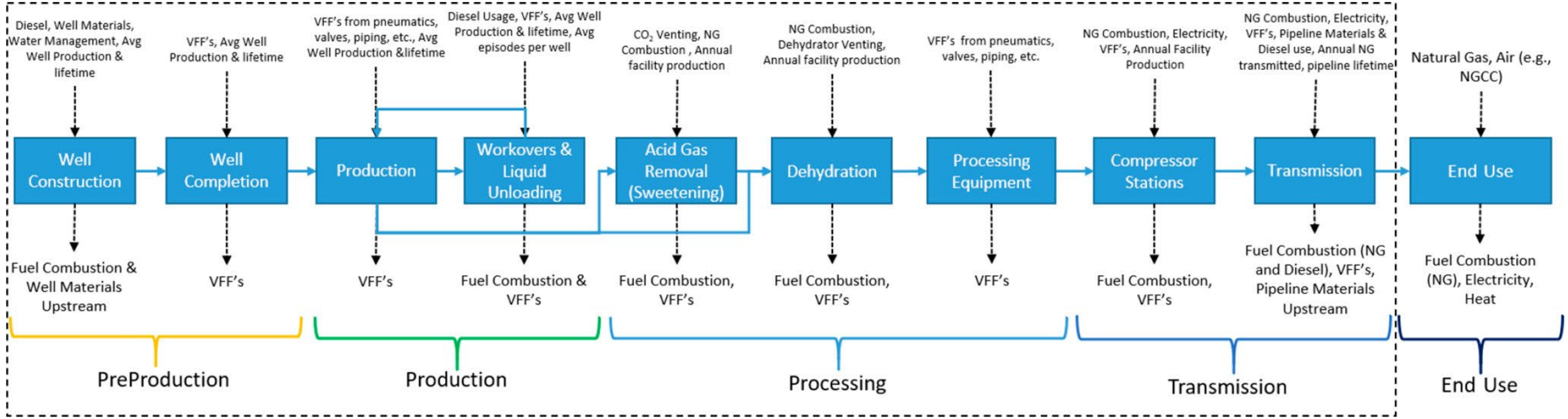
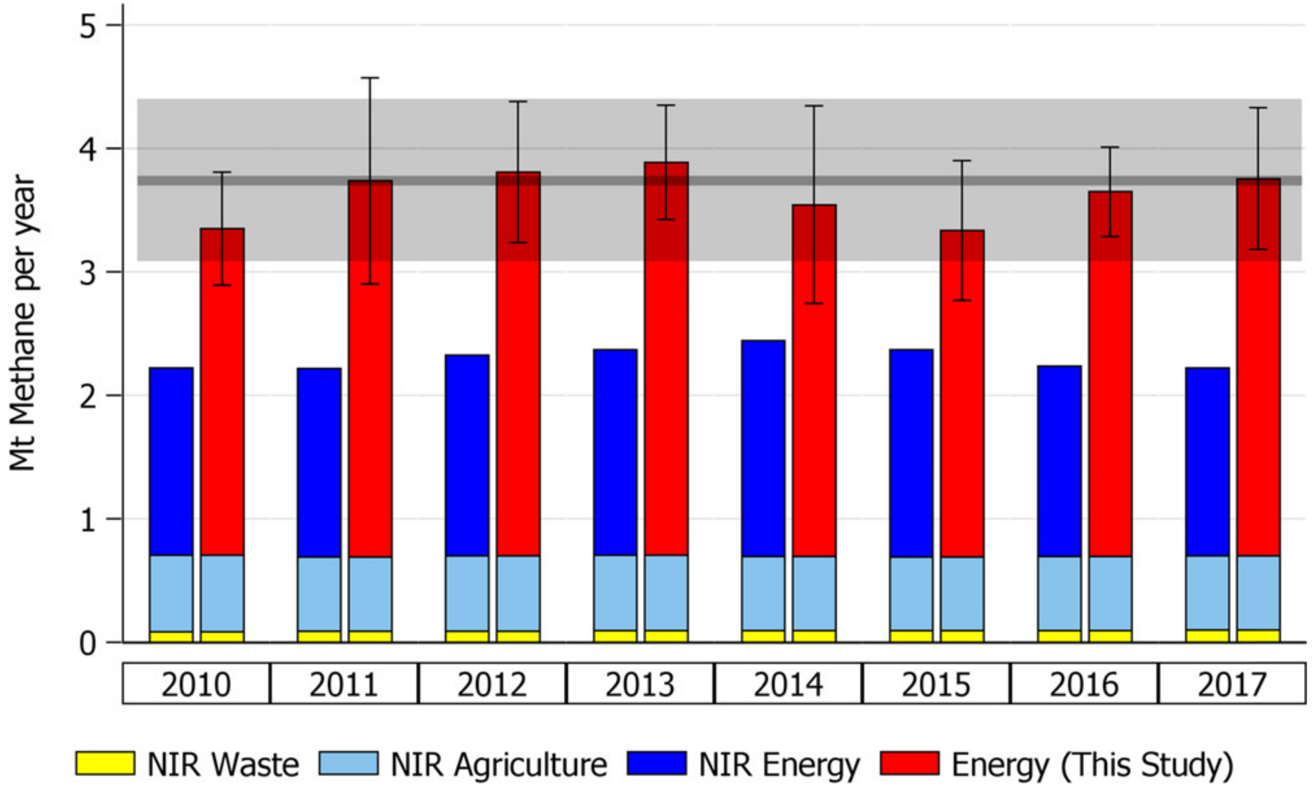
The life cycle includes production, processing and transmission, too



Liu et al. (2021)

Upstream methane emissions are poorly constrained today



Many studies of gas producing regions, such of Alberta and Saskatchewan (e.g., Chan et al., 2020), have shown that national inventories (e.g., Canada's NIR) chronically underestimate methane emissions. Much more work is needed in the field if we are to get an accurate estimate of methane emissions.

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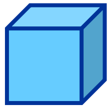
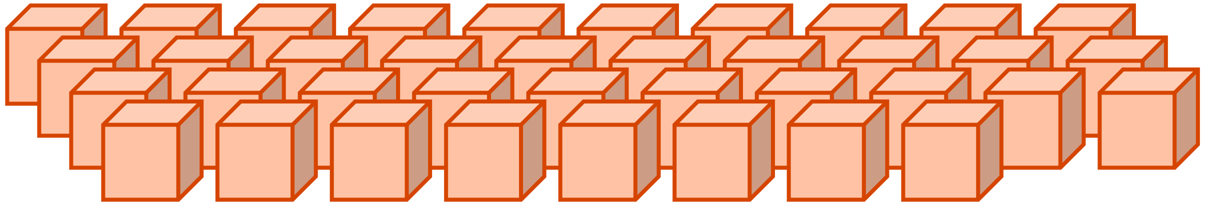
How do we compare the climate impacts of different greenhouse gases?

1 kg CH_4

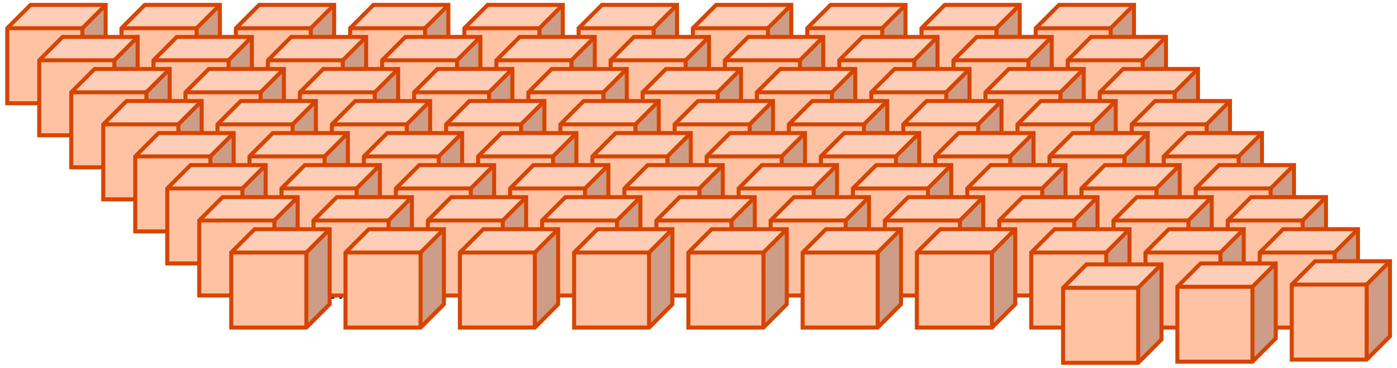


Has the same global warming potential (GWP) as….

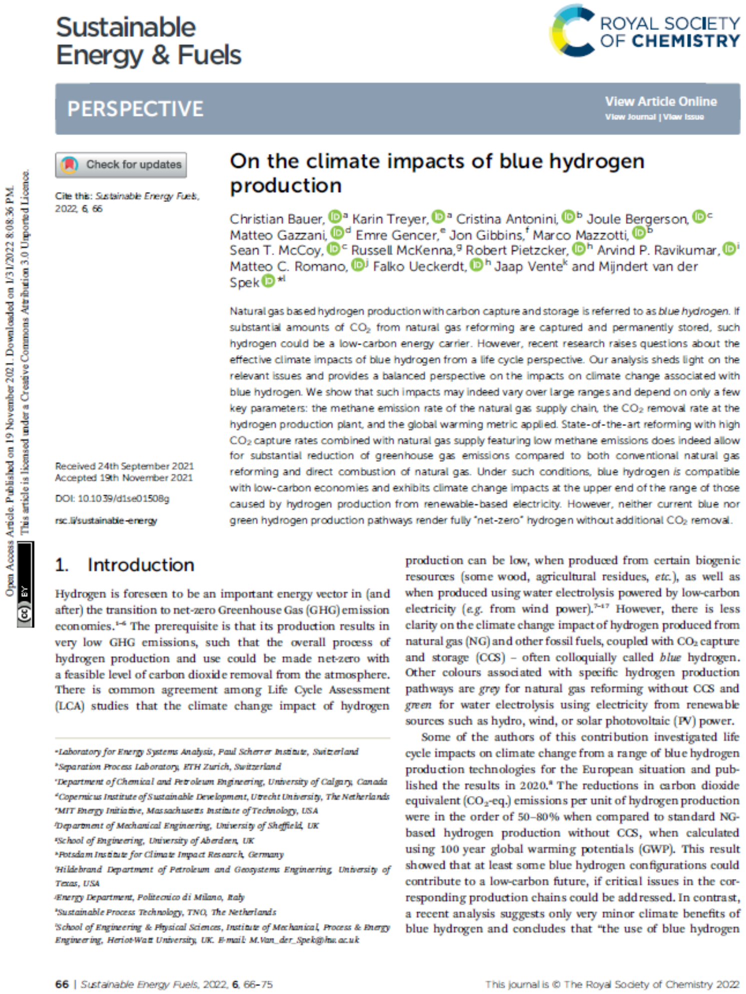
30 kg CO_2 (measured over a 100-year period, GWP100)



83 kg CO_2 (measured over a 20-year period, GWP20)



Cradle-to-grave assessment of GWP for hydrogen



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Cite this: *Sustainable Energy Fuels*, 2022, 6, 66

On the climate impacts of blue hydrogen production

Christian Bauer,[a] Karin Treyer,[a] Cristina Antonini,[b] Joule Bergerson,[c] Matteo Gazzani,[d] Emre Gencer,[e] Jon Gibbins,[f] Marco Mazzotti,[b] Sean T. McCoy,[c] Russell McKenna,[g] Robert Pietzcker,[h] Arvind P. Ravikumar,[i] Matteo C. Romano,[j] Falko Ueckerdt,[h] Jaap Vente[k] and Mijndert van der Spek*[l]

Natural gas based hydrogen production with carbon capture and storage is referred to as *blue hydrogen*. If substantial amounts of CO_2 from natural gas reforming are captured and permanently stored, such hydrogen could be a low-carbon energy carrier. However, recent research raises questions about the effective climate impacts of blue hydrogen from a life cycle perspective. Our analysis sheds light on the relevant issues and provides a balanced perspective on the impacts on climate change associated with blue hydrogen. We show that such impacts may indeed vary over large ranges and depend on only a few key parameters: the methane emission rate of the natural gas supply chain, the CO_2 removal rate at the hydrogen production plant, and the global warming metric applied. State-of-the-art reforming with high CO_2 capture rates combined with natural gas supply featuring low methane emissions does indeed allow for substantial reduction of greenhouse gas emissions compared to both conventional natural gas reforming and direct combustion of natural gas. Under such conditions, blue hydrogen *is* compatible with low-carbon economies and exhibits climate change impacts at the upper end of the range of those caused by hydrogen production from renewable-based electricity. However, neither current blue nor green hydrogen production pathways render fully "net-zero" hydrogen without additional CO_2 removal.

Received 24th September 2021
Accepted 19th November 2021

DOI: 10.1039/d1se01508g

rsc.li/sustainable-energy

1. Introduction

Hydrogen is foreseen to be an important energy vector in (and after) the transition to net-zero Greenhouse Gas (GHG) emission economies.[1–6] The prerequisite is that its production results in very low GHG emissions, such that the overall process of hydrogen production and use could be made net-zero with a feasible level of carbon dioxide removal from the atmosphere. There is common agreement among Life Cycle Assessment (LCA) studies that the climate change impact of hydrogen production can be low, when produced from certain biogenic resources (some wood, agricultural residues, *etc.*), as well as when produced using water electrolysis powered by low-carbon electricity (*e.g.* from wind power).[7–17] However, there is less clarity on the climate change impact of hydrogen produced from natural gas (NG) and other fossil fuels, coupled with CO_2 capture and storage (CCS) – often colloquially called *blue* hydrogen. Other colours associated with specific hydrogen production pathways are *grey* for natural gas reforming without CCS and *green* for water electrolysis using electricity from renewable sources such as hydro, wind, or solar photovoltaic (PV) power.

Some of the authors of this contribution investigated life cycle impacts on climate change from a range of blue hydrogen production technologies for the European situation and published the results in 2020.[8] The reductions in carbon dioxide equivalent (CO_2-eq.) emissions per unit of hydrogen production were in the order of 50–80% when compared to standard NG-based hydrogen production without CCS, when calculated using 100 year global warming potentials (GWP). This result showed that at least some blue hydrogen configurations could contribute to a low-carbon future, if critical issues in the corresponding production chains could be addressed. In contrast, a recent analysis suggests only very minor climate benefits of blue hydrogen and concludes that "the use of blue hydrogen

[a] Laboratory for Energy Systems Analysis, Paul Scherrer Institute, Switzerland
[b] Separation Process Laboratory, ETH Zurich, Switzerland
[c] Department of Chemical and Petroleum Engineering, University of Calgary, Canada
[d] Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands
[e] MIT Energy Initiative, Massachusetts Institute of Technology, USA
[f] Department of Mechanical Engineering, University of Sheffield, UK
[g] School of Engineering, University of Aberdeen, UK
[h] Potsdam Institute for Climate Impact Research, Germany
[i] Hildebrand Department of Petroleum and Geosystems Engineering, University of Texas, USA
[j] Energy Department, Politecnico di Milano, Italy
[k] Sustainable Process Technology, TNO, The Netherlands
[l] School of Engineering & Physical Sciences, Institute of Mechanical, Process & Energy Engineering, Heriot-Watt University, UK. E-mail: M.Van_der_Spek@hw.ac.uk

In response to problematic representations of the GHG intensity of hydrogen, we set out to identify the conditions under which "blue hydrogen" could truly be a low-carbon energy carrier…

Technical assumptions and scenarios

- 99.9% hydrogen at 200 bar (gas)
- Electricity imports (or credit for displacement) at European average (ENTSO-E) of 0.42 $kgCO_2e/kWh$
- Electrolyzer comparisons at 55kWh/kg H_2 (including compression to 200 bar)
- CO_2 separation using methyl diethanolamine (MDEA)
- Two CO_2 capture cases:
  - ***CCS-low:*** SMR with "partial capture" (90% CO_2 removal from syngas, 55% overall capture of CO_2 at the plant)
  - ***CCS-high:*** ATR with two shift reactors (98% CO_2 removal from syngas, 93% from overall plant)

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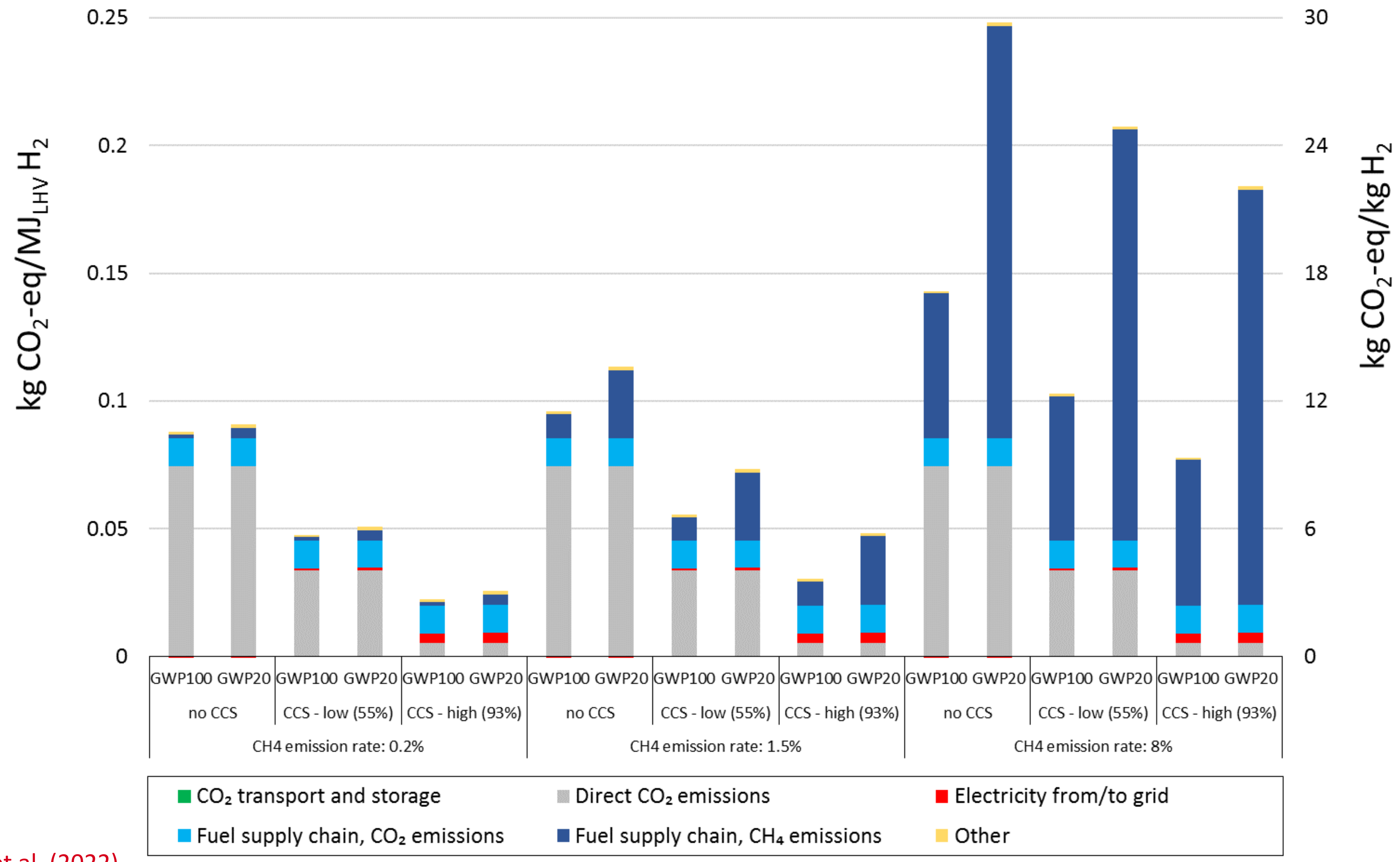

Bauer et al. (2022)

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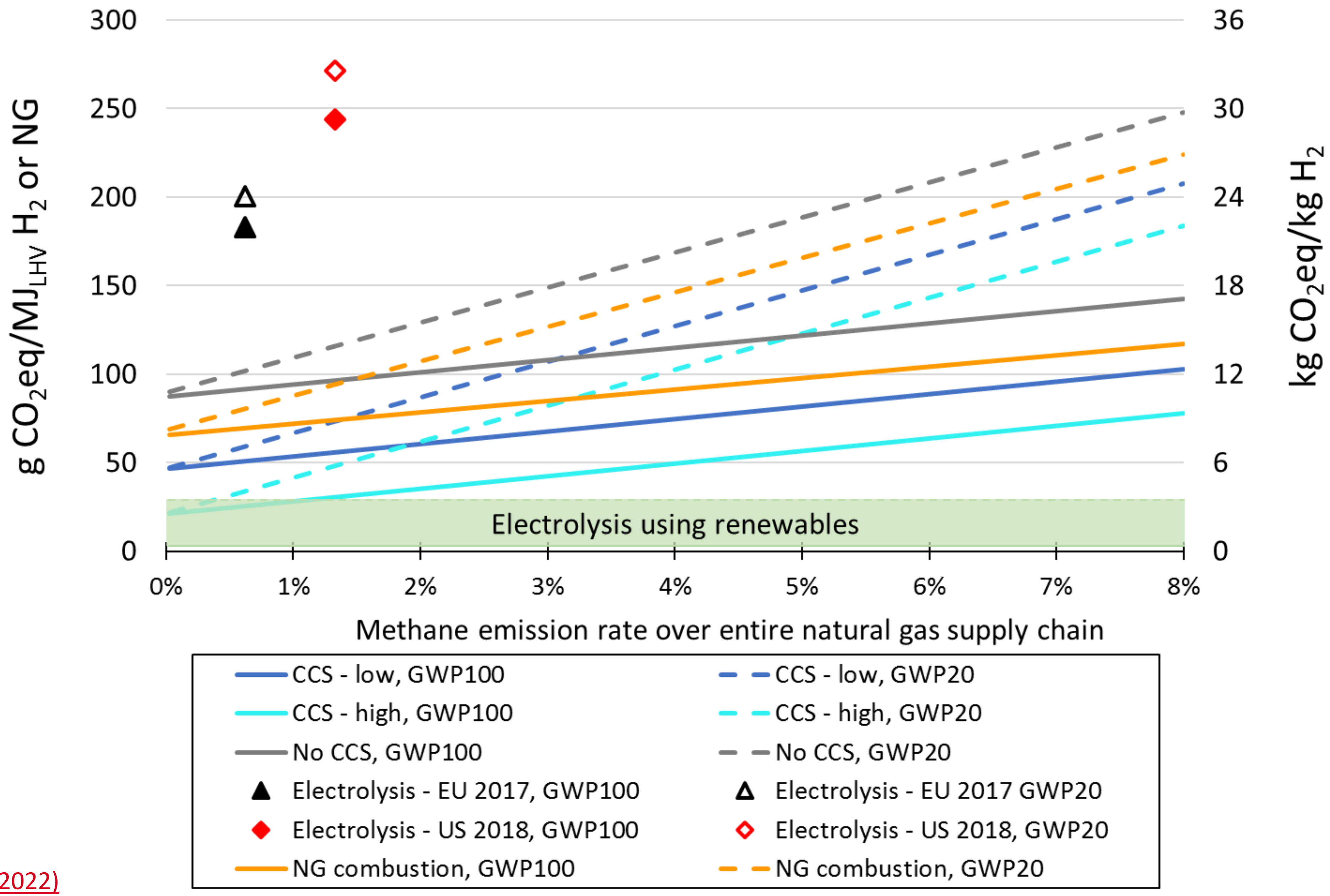

Bauer et al. (2022)

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What does this mean for hydrogen and Alberta?

1. High overall CO_2 capture rates in production are imperative to generate low-GHG intensity hydrogen *and*
2. Methane emissions upstream need to be measured and carefully controlled, regardless of whether GWP100 or GWP20 are used
3. There is an *opportunity* to demonstrate that Alberta-based producers can generate low-GHG hydrogen through certification of supply chains

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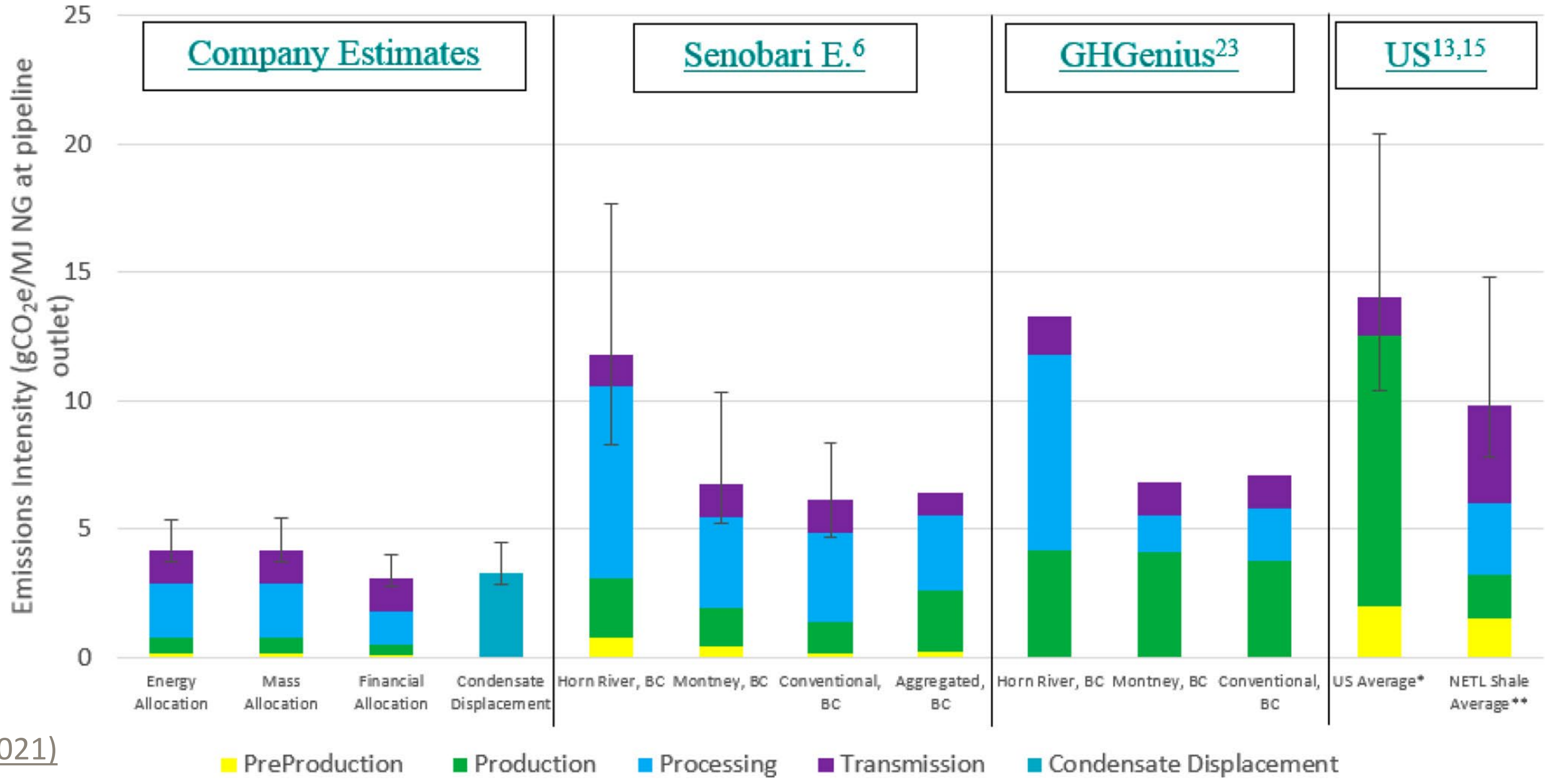
Work suggests that emissions could be low in Alberta



Liu et al. (2021)

On top of actions to reduce venting, flaring, and fugitives, *more* spatially and temporally resolved emissions monitoring data must be collected and made publicly available

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Challenges for the hydrogen economy in Alberta

- Build hydrogen plants with high levels of CCS (and consider electricity system interactions)
- Measure upstream emissions and create confidence in reported GHG intensities for hydrogen
- Drive upstream emissions down faster than those for electrolytic hydrogen
- Be cost competitive
- Oh, and… research suggests hydrogen has a GWP that is 5 or more, so measure and control downstream leakage

…Easy, right!?

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Acknowledgements

- Abdalla Elnigoumi, MSc
- Dr. David Layzell, The Transition Accelerator
- Financial support from the **Canada First Research Excellence Fund (CFREF)**

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Questions?

Sean T. McCoy, Ph.D.
sean.mccoy@ucalgary.ca | +1 (403) 220-3178
https://schulich.ucalgary.ca/contacts/sean-mccoy

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