

A Life Cycle View of Blue Hydrogen Production

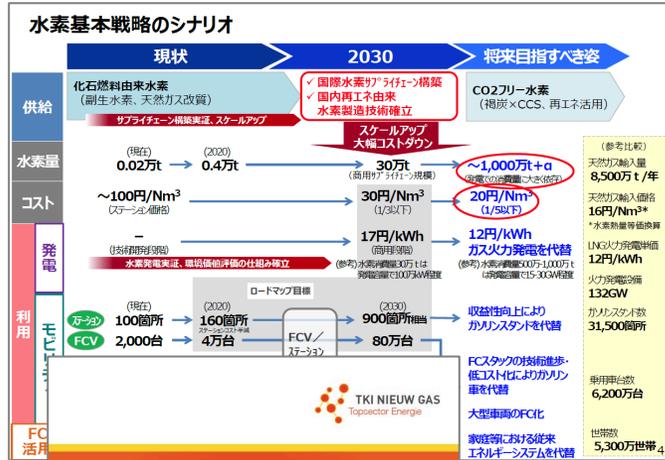
Building a net-zero future

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

7 July 2022



We are witnessing a hydrogen renaissance



Natural Gas Vision and Strategy

GETTING ALBERTA BACK TO WORK

Alberta

Stratégie nationale pour le développement de l'hydrogène décarboné en France

Dossier de presse
8 septembre 2020

The National Hydrogen Strategy

bmw.de

National Hydrogen Roadmap

Pathways to an economically sustainable hydrogen industry in Australia

AUSTRALIA'S NATIONAL HYDROGEN STRATEGY

COAG Energy Council

Outlines of a Hydrogen Roadmap

A Hydrogen Strategy for a climate neutral Europe

#EU.GreenDeal
8 July 2020

NATIONAL GREEN HYDROGEN STRATEGY

Chile, a clean energy provider for a carbon neutral planet

Gobierno de Chile

HYDROGEN STRATEGY FOR CANADA

Seizing the Opportunities for Hydrogen
A Call to Action
December, 2020

신질량연구본부 보도 자료

2019년 1월 17일(목) 석간부터 보도하여 주시기 바랍니다.
(단위: 방울, 방울은 117리터) 1200 이후 보도 가능)

배포일시	2019. 1. 14(수)	담당부서	신질량연구본부 에너지안전성과 과학기술정보정책과 환경기술과 국제교류협력팀/신질량연구본부 핵안전기술과
신질량	044-203-5390	박승민	044-203-5396
조성현	044-203-4640	김정민	044-211-4578
김정민	044-211-2380	송민진	044-211-2758
박정현	044-203-4880	김민지	044-203-4887
백정현	044-203-3258	유민	044-203-3260
김정현	044-203-5830	양정현	044-203-5834

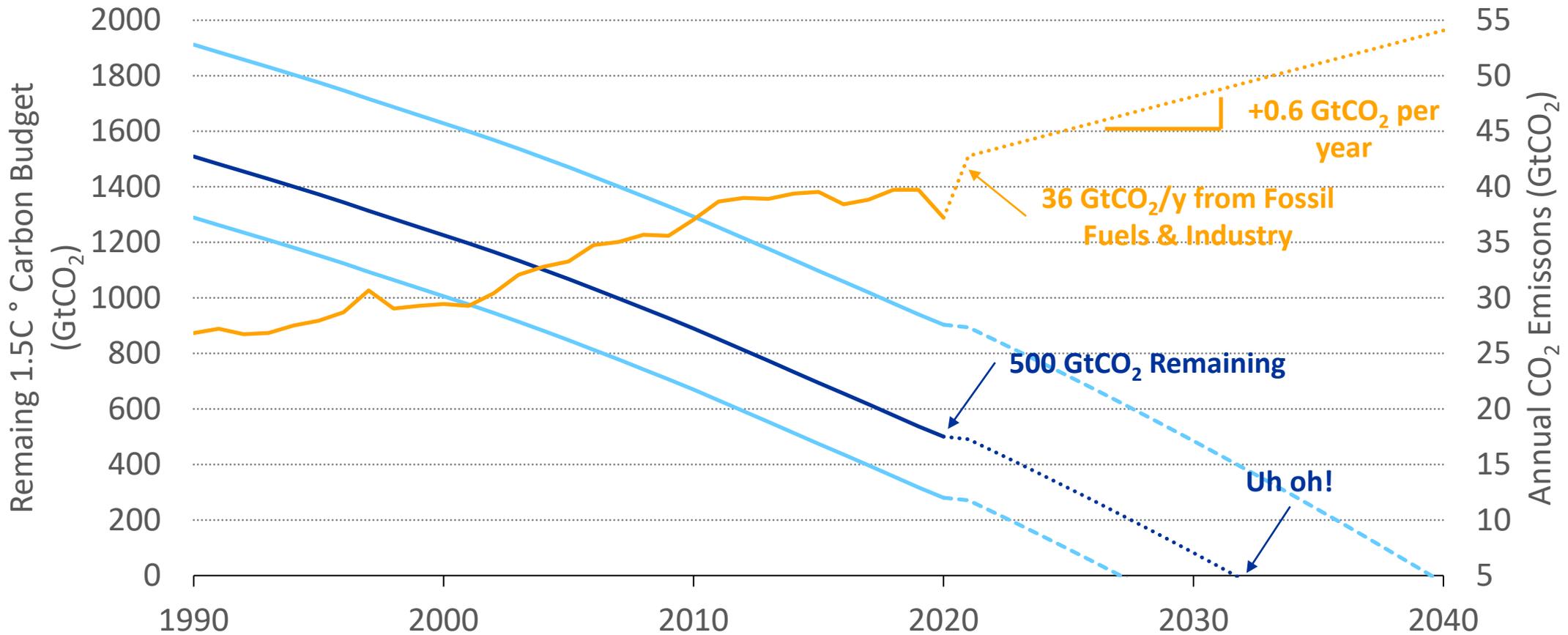
세계 최고수준의 수소경제 선도국가로 도약

- 정부, 「수소경제 활성화 로드맵」 발표 -

- 우리나라가 강점이 있는 '수소'의 '연료전지'를 통해 육으로 수소경제를 선도할 수 있는 산업생태계 구축
- 수소차 누적 생산량 18년 2천대에서 40년 620만대(내수 200만대, 수출 330만대)로 확대되고, 세계시장 점유율 1위 달성
 - 국내 보급: '17년 국내 1779(상용 51대) → '18년 누적 889대(상용 712대) → '19년 4,000대 이상 신규 보급
 - 수소중점소 차량: (18) 14기 → (22) 310기 → (40) 1,200대소
 - 수소 대중교통 확대: '40년 수소버스 8만대, 수소버스 4만대, 수소트럭 3만대 보급

- CO₂ 배출이 전혀 없고 도심지역 소규모로 설치 가능하여 진정한 의미의 친환경 완전친화적으로 부상하고 있는 밀연속 연료전지를 핵심기술로 활용 수소 생산의 연계하여 '40년까지 15GW(150만 kW) 이상으로 확대하고 수소산업의 추진
 - 가정·건물을 연료전지로 '40년까지 2.1GW(210만 kW) 보급
 - 수소 활용을 수소차 외에 수소선박, 수소열차, 수소발전기 등으로 확대하고 배후 유통망목으로 육성
- 이를 위해, 경제성·안전적인 수소 생산 및 공급시스템 조성
- 수소 공급은 수전해 및 폐회생산·수입 등 CO₂ Free 그린(green)수소 비중을 확대하여 '18년 13만톤 수준에서 '40년 520만톤 이상으로 확대
- 수소 최종발전을 원력의 저용량·저가에서 고효율·저가 등으로 다양화하고, 전국적인 하이브리드 공급망도 구축
- 친화하고 경제적인 수소 유통체계 구축을 통해 수소 가격을 '40년까지 3,000원/kg 이하로 하락 유도
- 국인이 안심하고 신뢰할 수 있는 수소경제 이행 기반 마련
 - 수소생산·저장·유통·활용 순주기적 원천안전관리 기준 및 부품·재료의 안전성평가 강화하고, 안전관리 법 제정
 - 법적 수소 기술개발 로드맵 수립, 국제표준 선도, 총출력 중소·중견기업 생태계 조성, 범부처 협력수준제 등 운영

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.

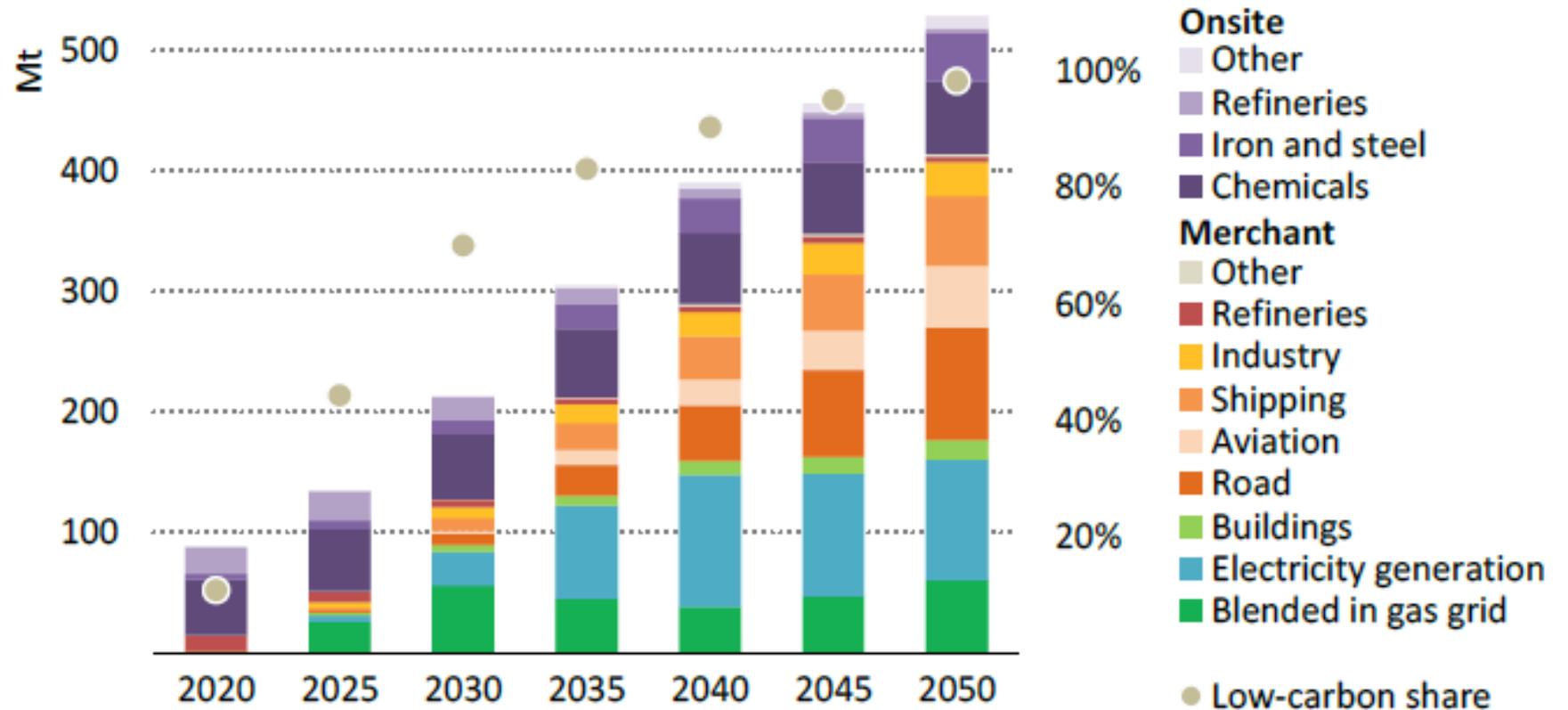


Figure 2.19, [IEA NZE \(2021\)](#)

Canada has grand plans for hydrogen



Targets

- 4 MtH₂/y in 2030 growing to 20 MtH₂/y in 2050
- 30% of total final energy in Canada
- Avoidance of 190 MtCO₂e/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...

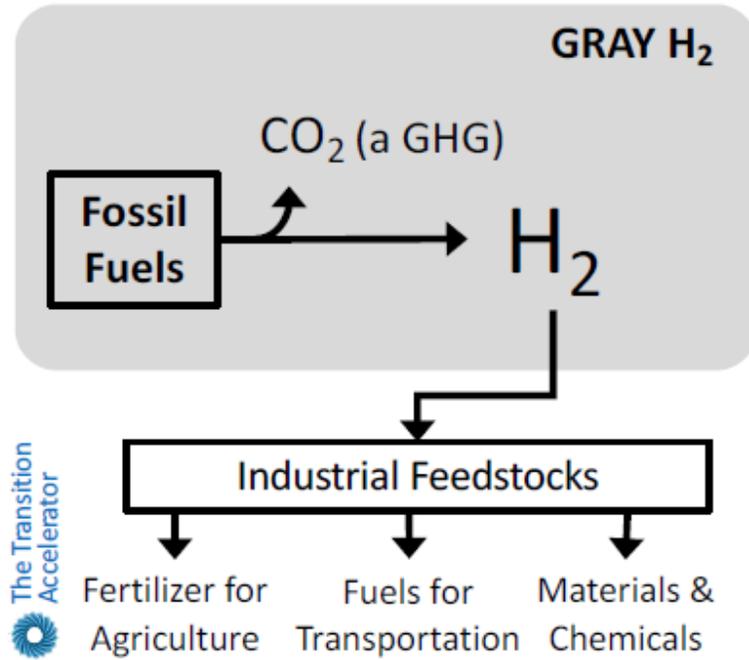
Key points to take from this rest of this talk...

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

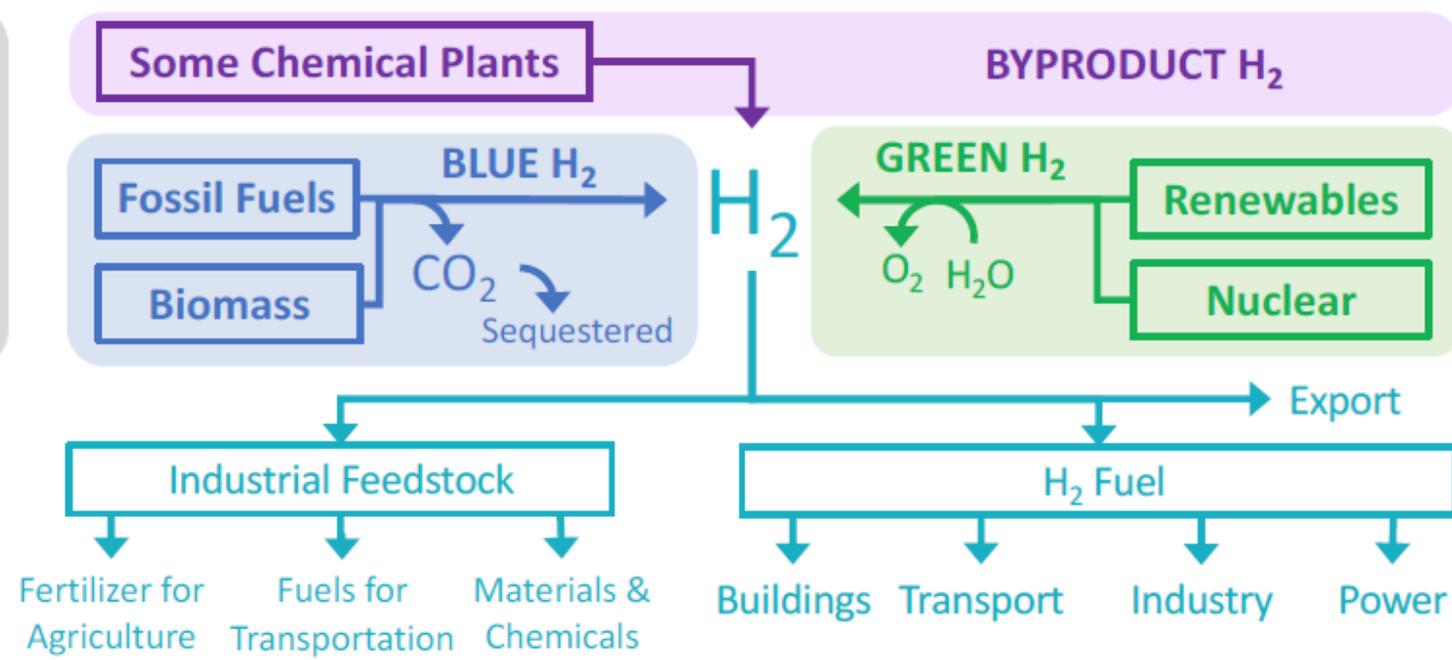
1. High overall CO₂ capture rates in production are imperative to generate low-GHG intensity hydrogen *and*
2. Methane emissions upstream need to be measured and carefully controlled, regardless of whether GWP100 or GWP20 are used
3. There is an *opportunity* to demonstrate that Alberta-based producers can generate low-GHG hydrogen through certification of supply chains

Many production routes for hydrogen, as well as uses

A. Hydrogen Today (8.2 kt/d)



B. Hydrogen in a New, Net-Zero Energy System



Alberta's hydrogen future will build off the existing 5ktH₂/d "grey" hydrogen production by adding CCS and expanding with new "blue" hydrogen capacity

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!

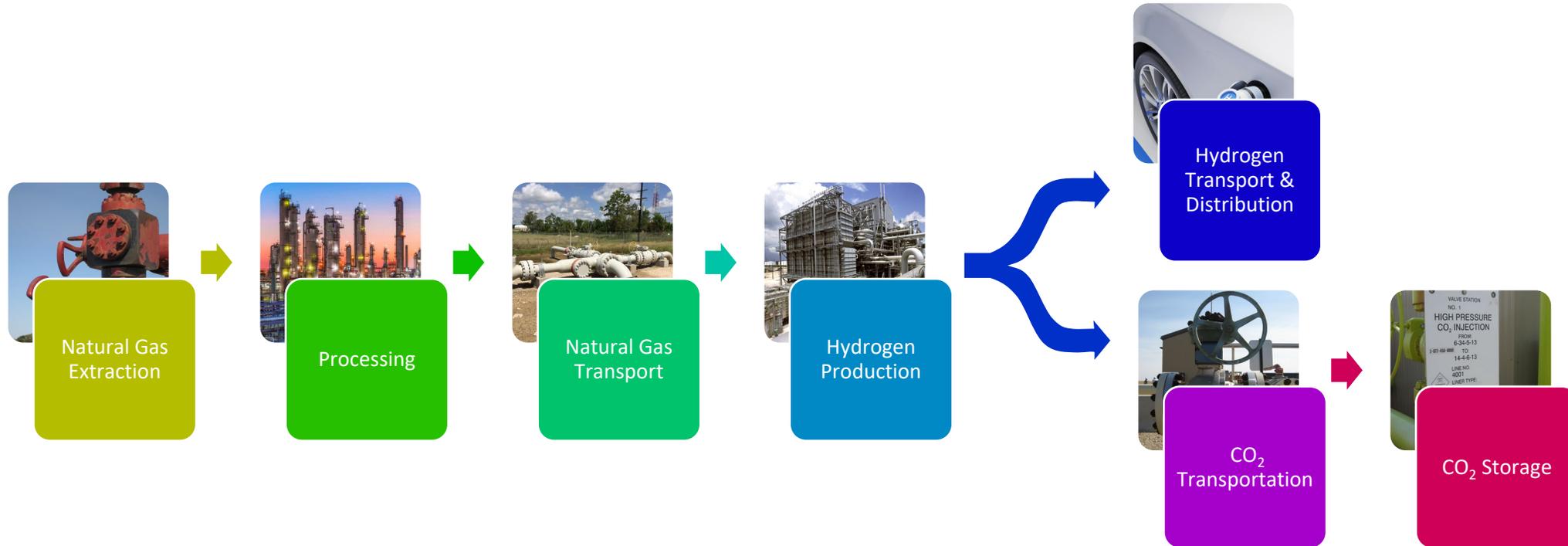
What is Life Cycle Assessment?

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.

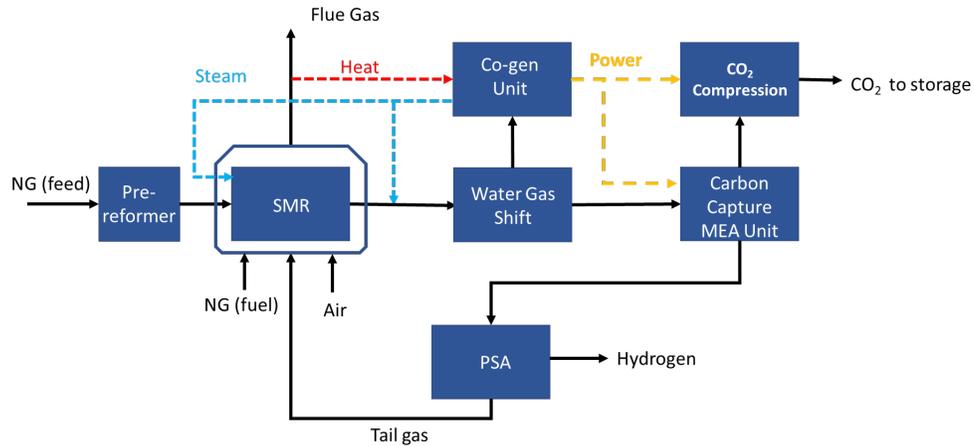


www.nist.gov

The cradle-to-grave life cycle for blue hydrogen

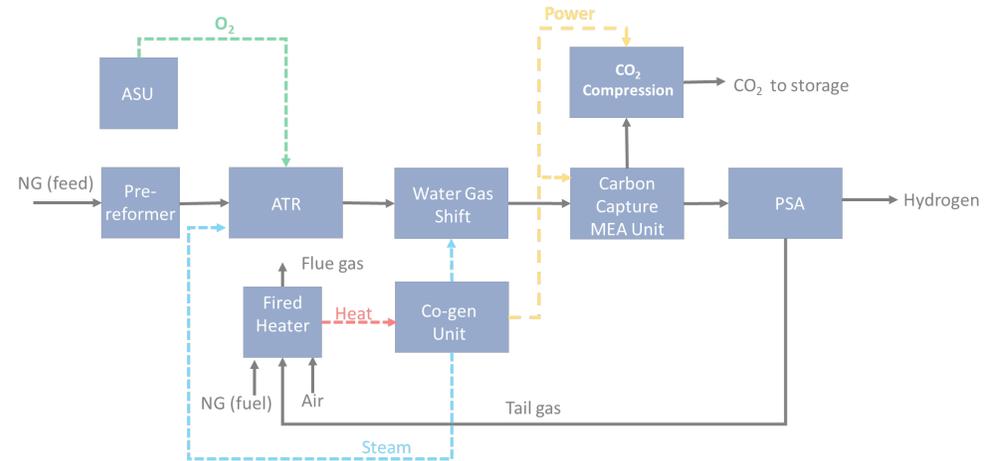


Different “direct” CO₂ emissions rates for different production technologies



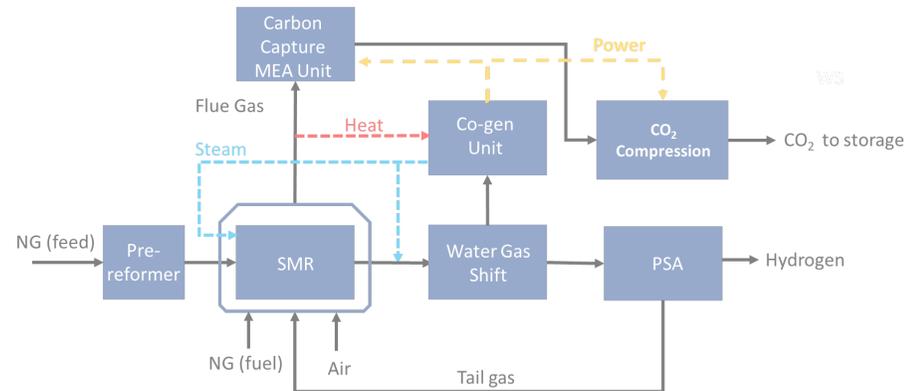
Steam Methane Reforming (SMR) with partial capture

Overall capture rate: **55-70%** (at 90-98% capture efficiency)



Autothermal Reforming (ATR) with capture

Overall capture rate: **87-93%** (90-98% capture efficiency)

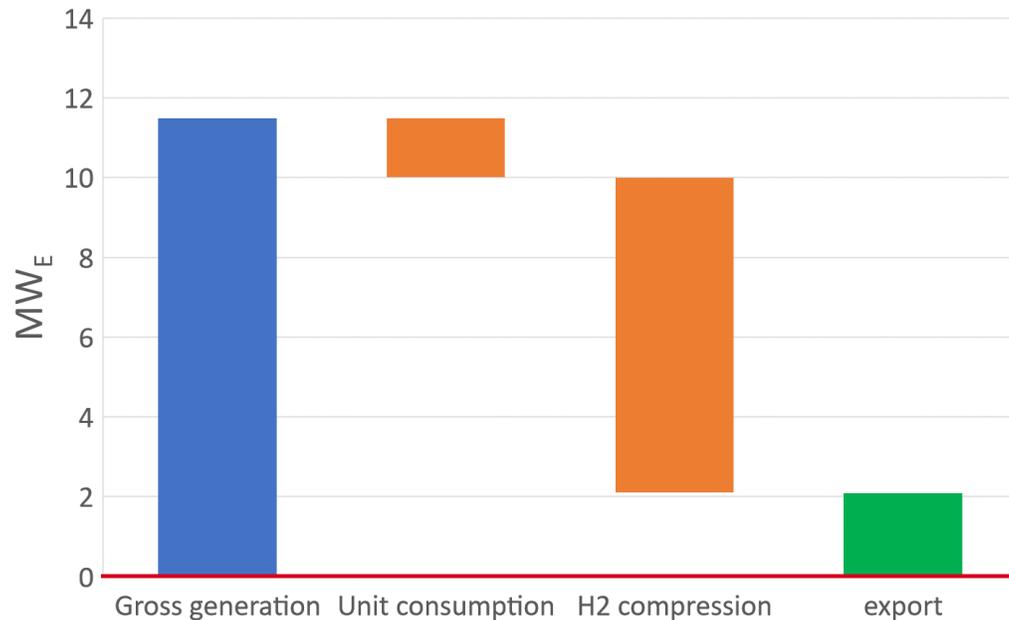


SMR with total capture

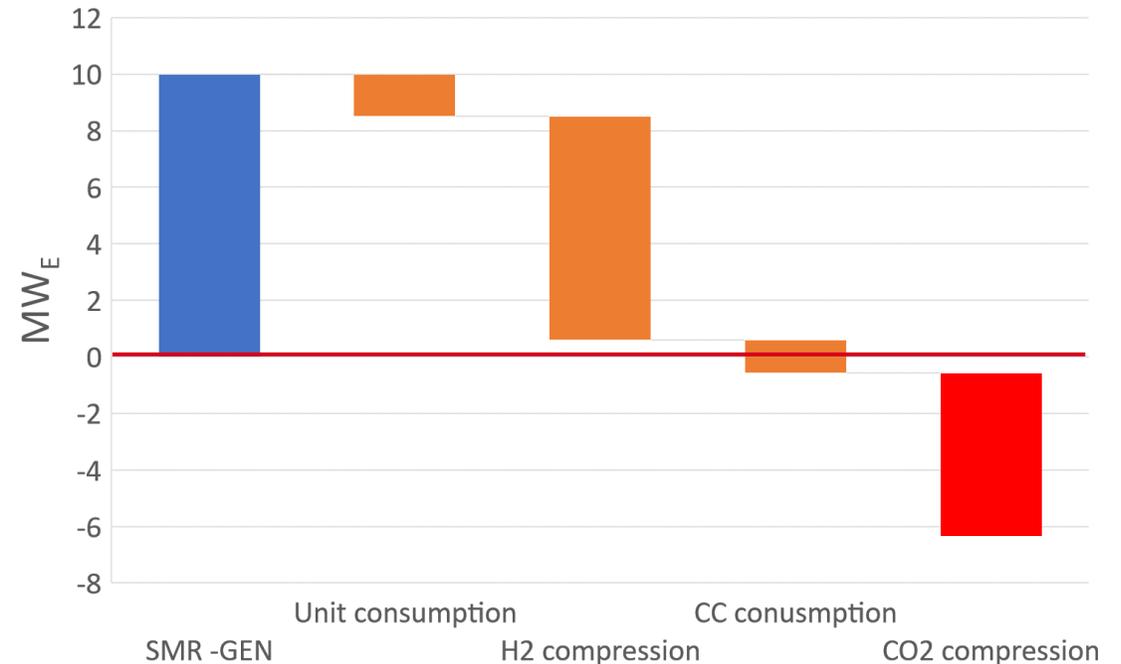
Overall capture rate: **89%** (at 90% capture efficiency)

Minimizing footprint means thinking about electricity

SMR without Capture



SMR with total capture

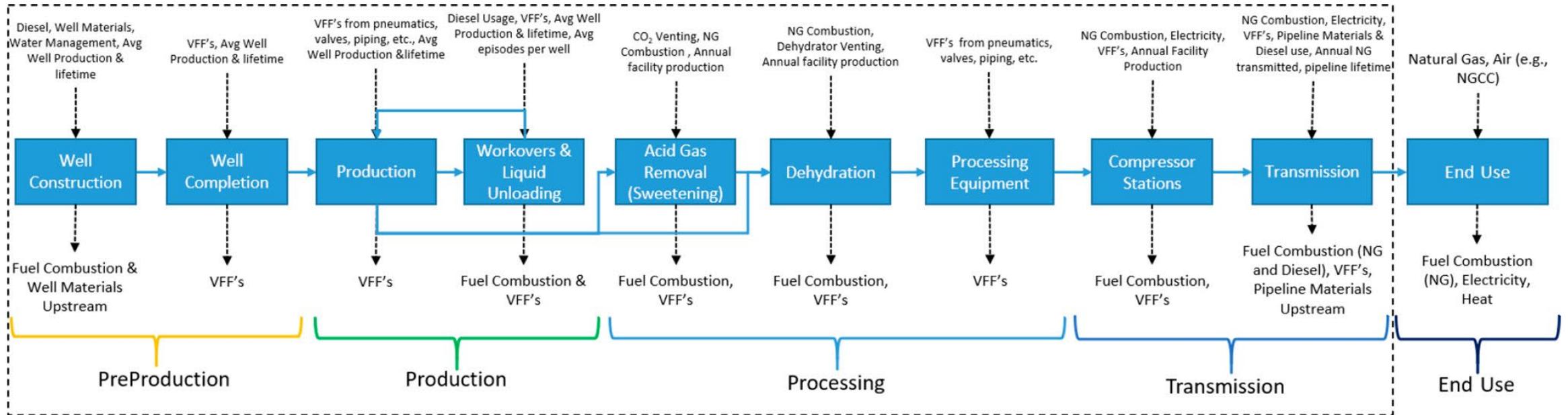


Adding CO₂ capture and compression means traditional export of steam is eliminated; this is an issue for traditional SMR, but even more so for ATR since it is *more efficient*...

The cradle-to-grave life cycle for blue hydrogen

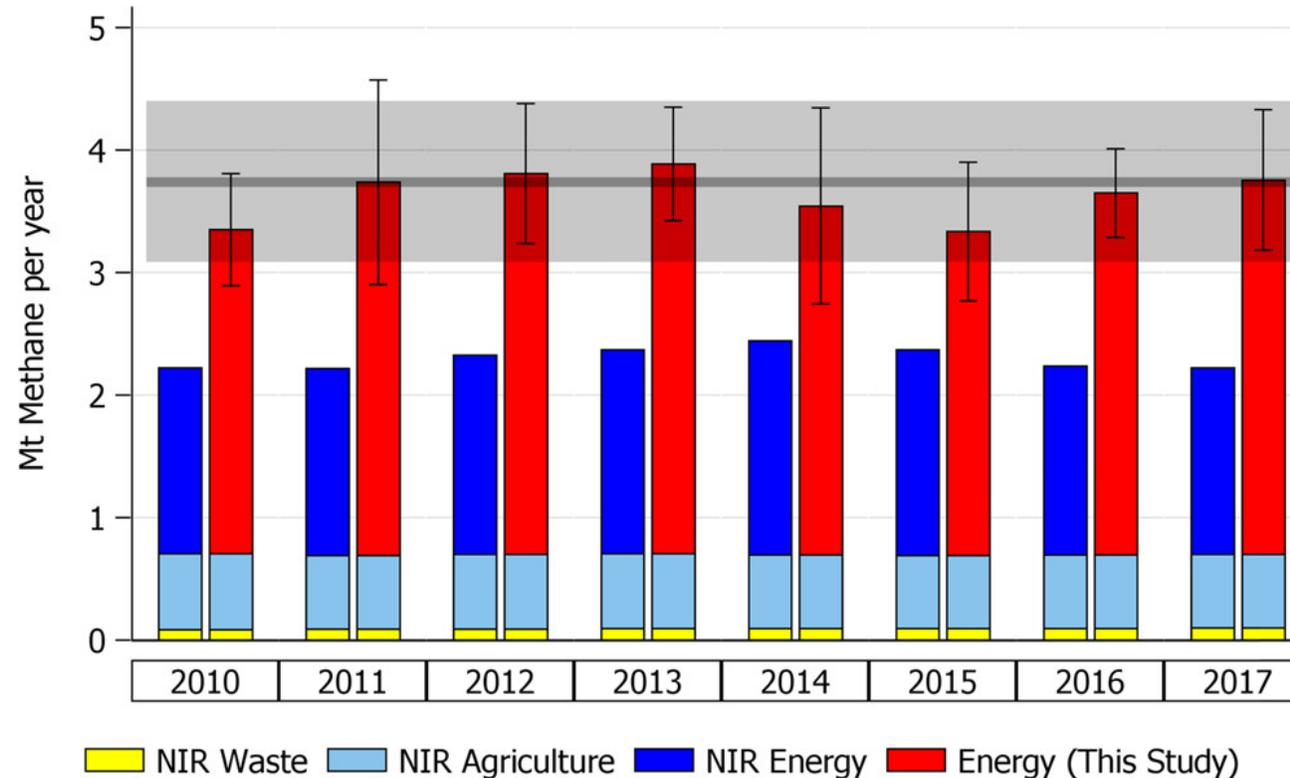


The life cycle includes production, processing and transmission, too



Liu et al. (2021)

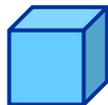
Upstream methane emissions are poorly constrained today



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.

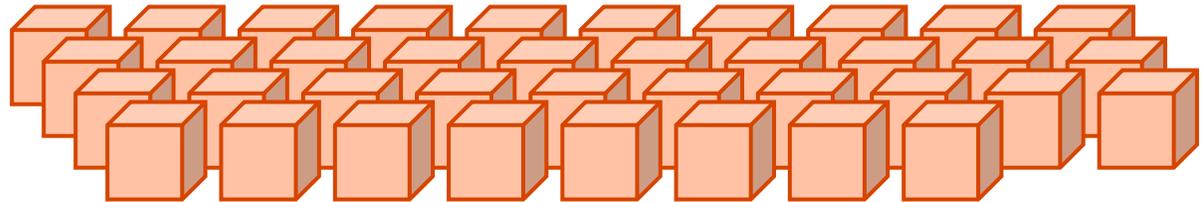
How do we compare the climate impacts of different greenhouse gases?

1 kg CH₄

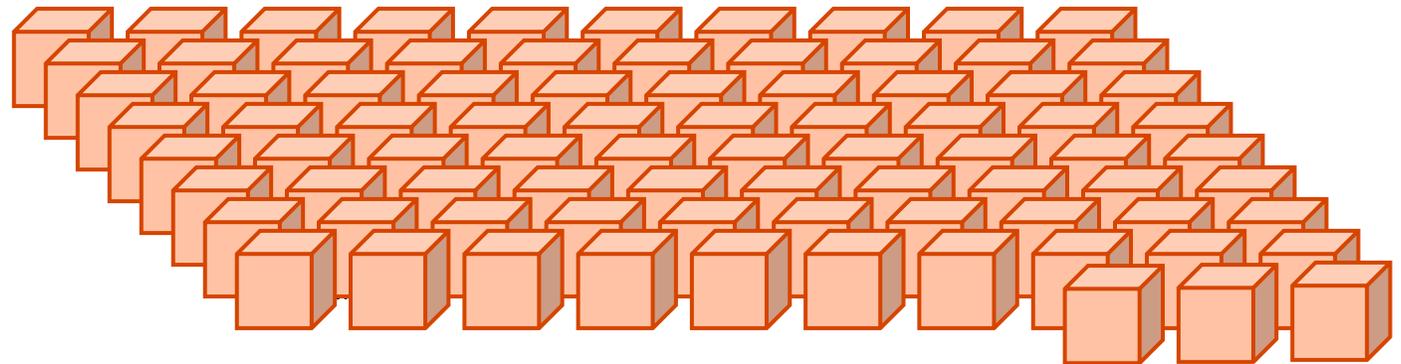


Has the same global warming potential (GWP) as....

30 kg CO₂ (measured over a 100-year period, GWP100)



83 kg CO₂ (measured over a 20-year period, GWP20)



Cradle-to-grave assessment of GWP for hydrogen

Sustainable
Energy & Fuels



PERSPECTIVE

View Article Online

View Journal | View Issue

Check for updates

On the climate impacts of blue hydrogen production

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

Natural gas based hydrogen production with carbon capture and storage is referred to as *blue hydrogen*. If substantial amounts of CO₂ 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 CO₂ removal rate at the hydrogen production plant, and the global warming metric applied. State-of-the-art reforming with high CO₂ 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 CO₂ removal.

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

Received 24th September 2021
Accepted 19th November 2021

DOI: 10.1039/d1se01508g

rsos.royalsocietypublishing.org

1. Introduction

Hydrogen is foreseen to be an important energy vector in (and after) the transition to net-zero Greenhouse Gas (GHG) emission economies.^{1–4} 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).^{5–17} However, there is less clarity on the climate change impact of hydrogen produced from natural gas (NG) and other fossil fuels, coupled with CO₂ 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 (CO₂-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

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...

^aLaboratory for Energy Systems Analysis, Paul Scherrer Institute, Switzerland

^bSeparation Process Laboratory, ETH Zurich, Switzerland

^cDepartment of Chemical and Petroleum Engineering, University of Calgary, Canada

^dCopernicus Institute of Sustainable Development, Utrecht University, The Netherlands

^eMIT Energy Initiative, Massachusetts Institute of Technology, USA

^fDepartment of Mechanical Engineering, University of Sheffield, UK

^gSchool of Engineering, University of Aberdeen, UK

^h Potsdam Institute for Climate Impact Research, Germany

ⁱHildebrand Department of Petroleum and Geosystems Engineering, University of Texas, USA

^jEnergy Department, Politecnico di Milano, Italy

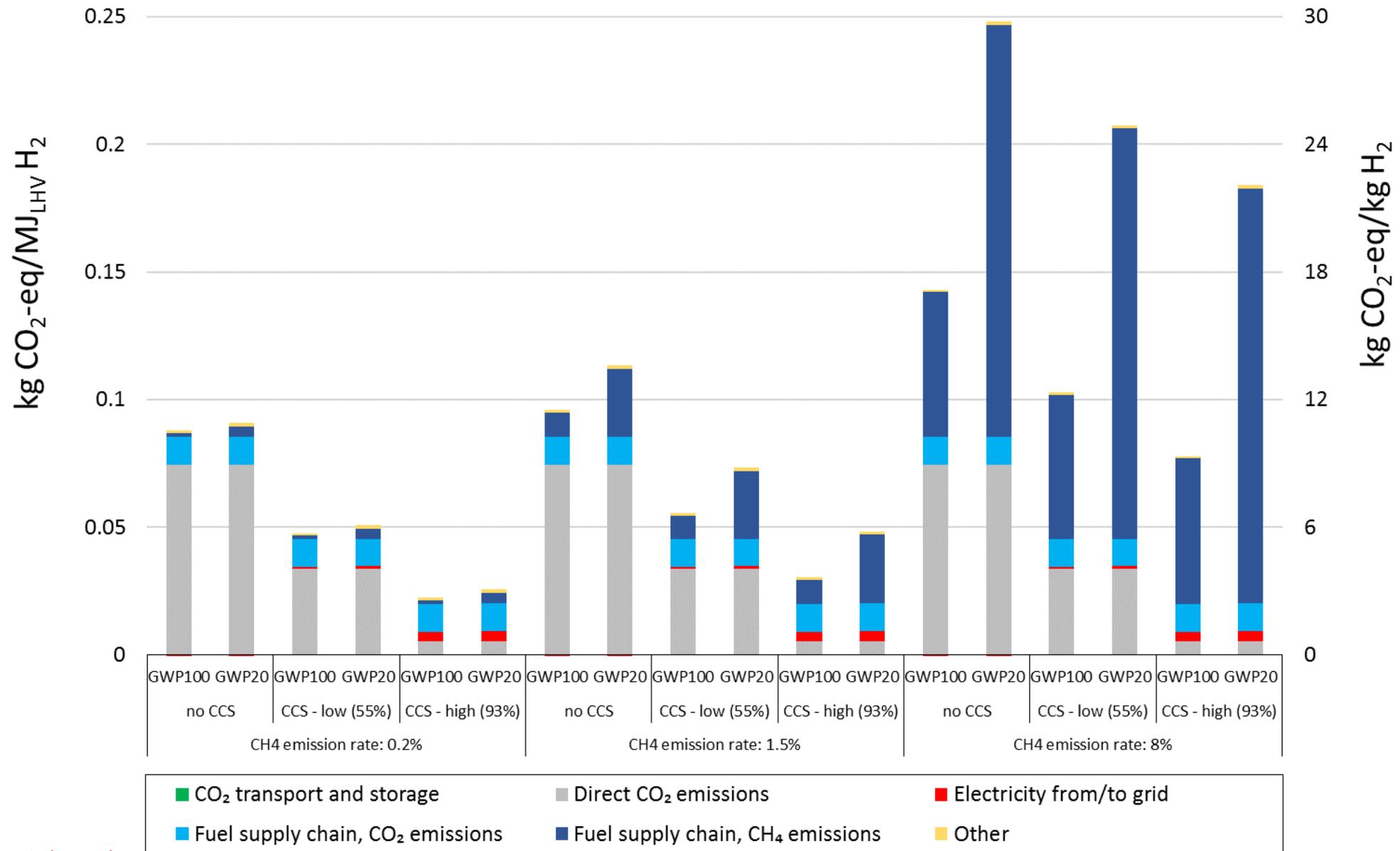
^kSustainable Process Technology, TNO, The Netherlands

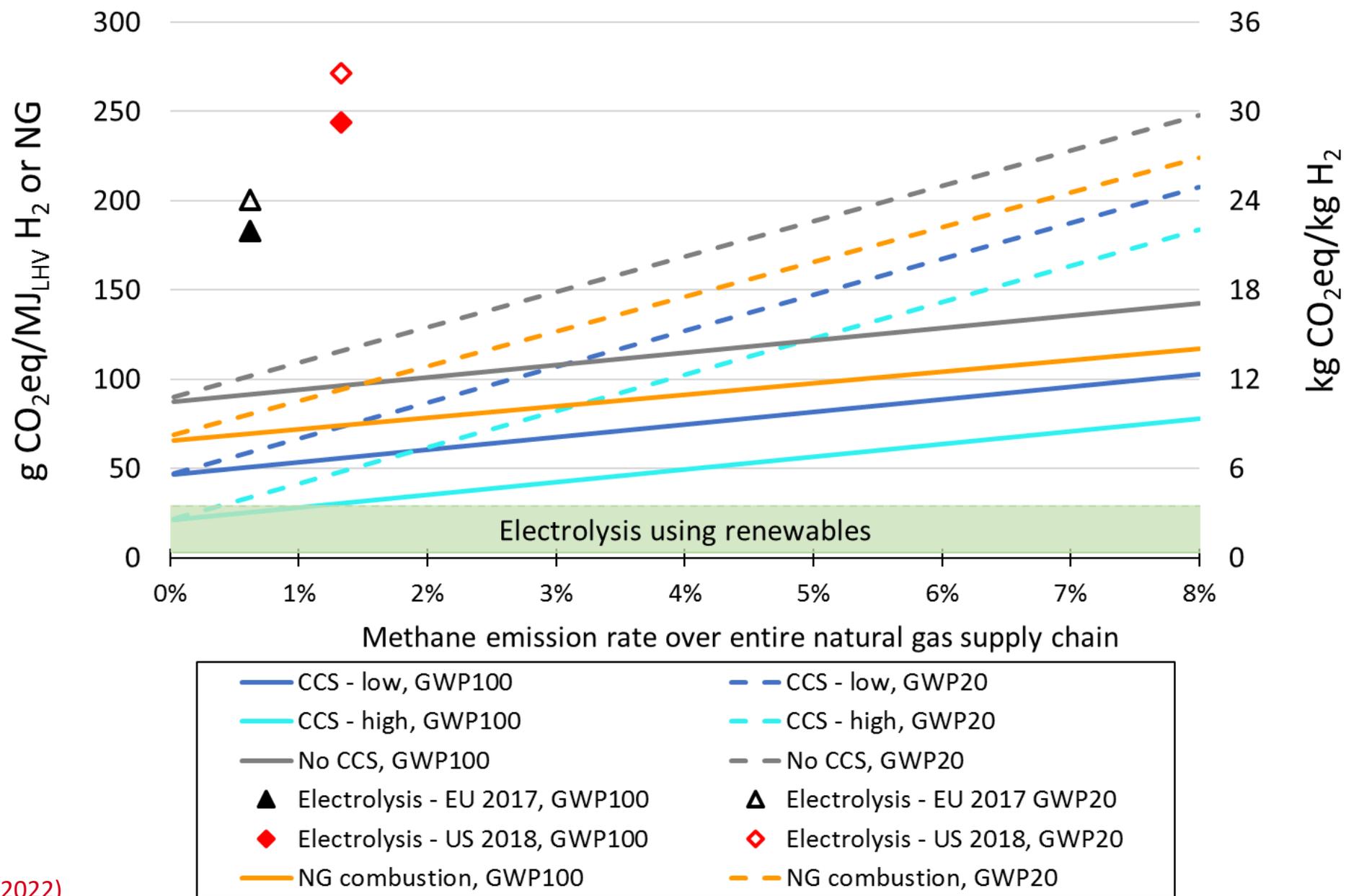
^lSchool of Engineering & Physical Sciences, Institute of Mechanical Process & Energy Engineering, Heriot-Watt University, UK. E-mail: M.Van_der_Spek@hw.ac.uk



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 kgCO₂e/kWh
- Electrolyzer comparisons at 55kWh/kg H₂ (including compression to 200 bar)
- CO₂ separation using methyl diethanolamine (MDEA)
- Two CO₂ capture cases:
 - **CCS-low:** SMR with “partial capture” (90% CO₂ removal from syngas, 55% overall capture of CO₂ at the plant)
 - **CCS-high:** ATR with two shift reactors (98% CO₂ removal from syngas, 93% from overall plant)

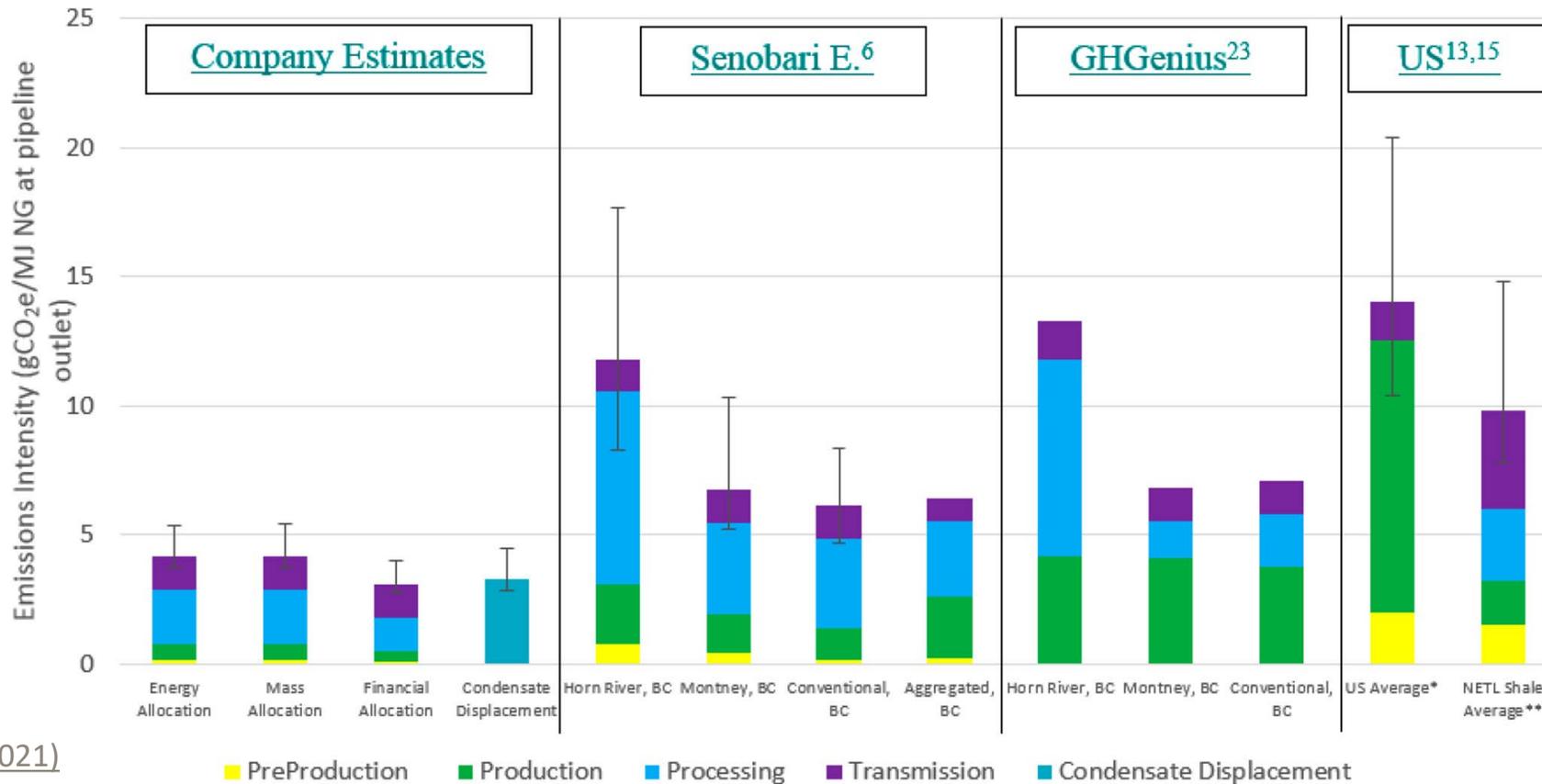




What does this mean for hydrogen and Alberta?

1. High overall CO₂ 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

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

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!?

Acknowledgements

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



Questions?

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

