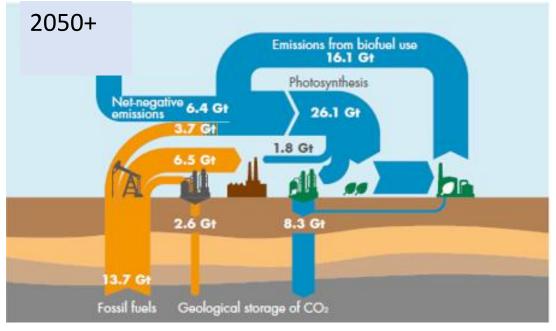
Carbon Capture & Storage: why / where?

Joe Powell (Joseph B. Powell, PhD)

NAE, Fellow AIChE, ChemePD LLC Retired Shell Chief Scientist – Chemical Engineering Former Chair: U.S. DOE Hydrogen Technical Advisory Committee

U of Houston Industry Lecturer / Stanford Energy Advisor Advisor USBCSD.org

NAE-GRP Colloquium: Opportunities and Challenges – Carbon Capture, Utilization and Sequestration

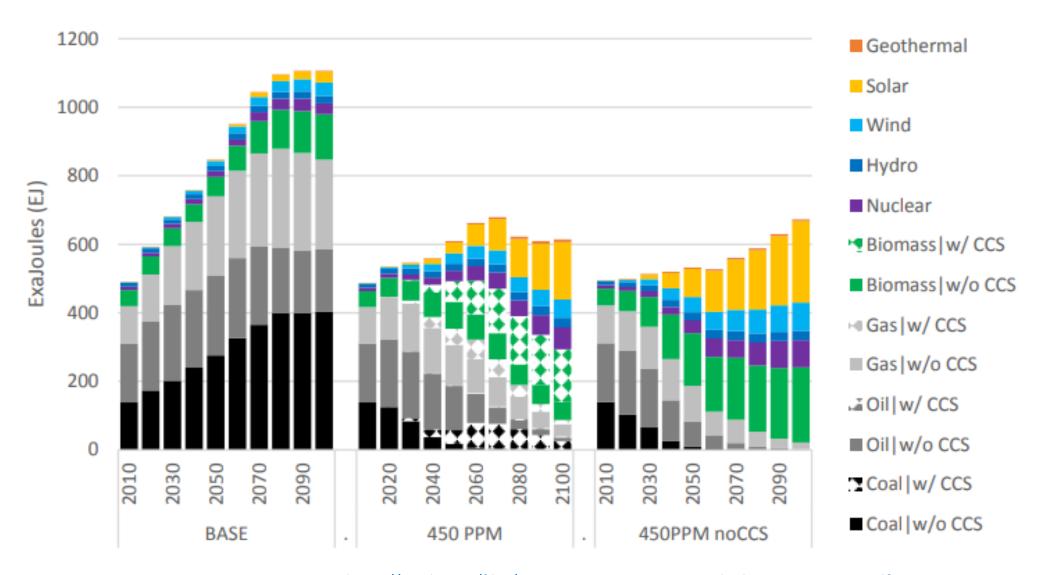


Sky scenario: www.Shell.com

Disclaimer:

Any cost information is approximate and derived from open literature and data. Do not take any observations as investment advice.

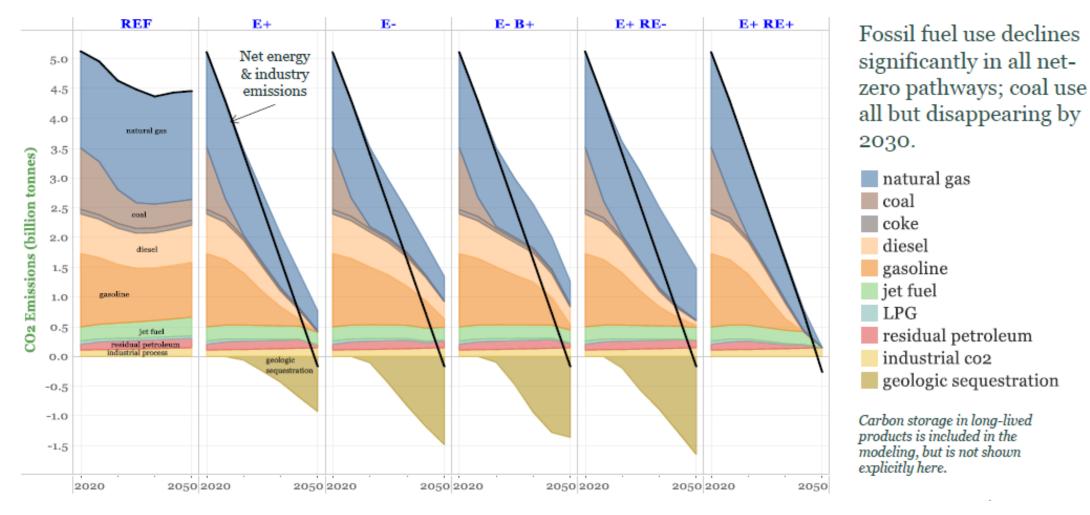
IEA: The case for CCS / cost of energy transition



Net Zero America (2021): CCS in all scenarios

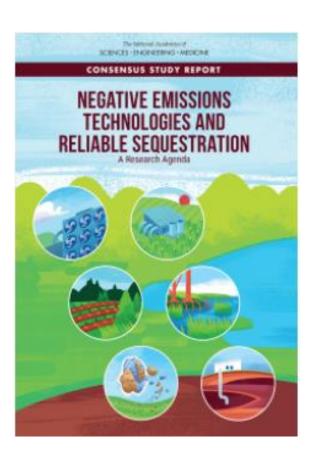
Energy and industrial CO₂ emissions are net negative by 2050 to deliver net-zero emissions for the full economy

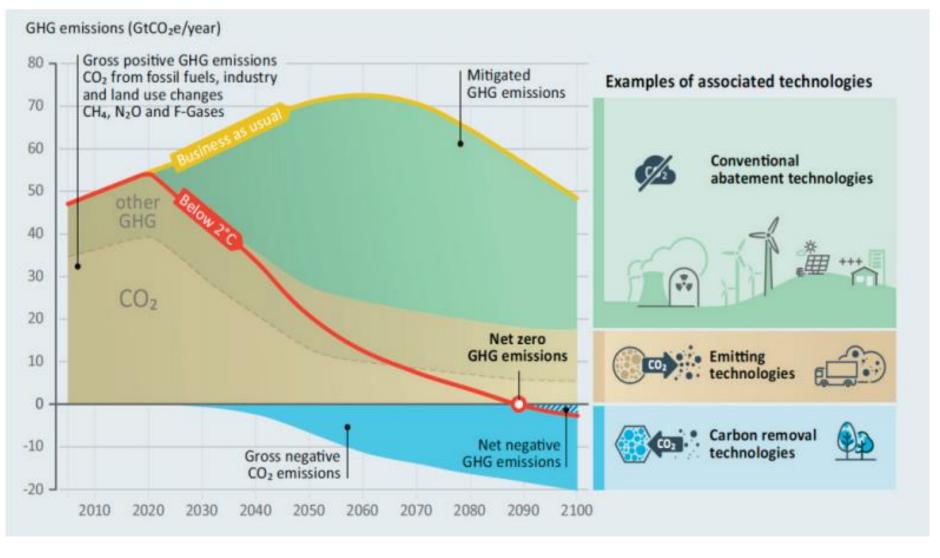




E. Larson, C. Greig, J. Jenkins, E. Mayfield, A. Pascale, C. Zhang, J. Drossman, R. Williams, S. Pacala, R. Socolow, EJ Baik, R. Birdsey, R. Duke, R. Jones, B. Haley, E. Leslie, K. Paustian, and A. Swan, Net-Zero America: Potential Pathways, Infrastructure, and Impacts, interim report, Princeton University, Princeton, NJ, December 15, 2020. https://netzeroamerica.princeton.edu

CCS – negative emissions

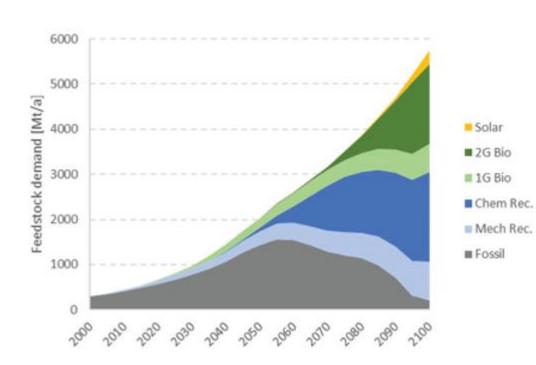


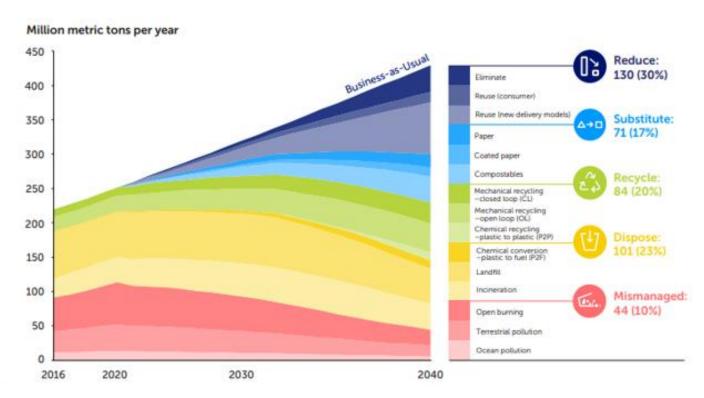


National Academies of Sciences, Engineering, and Medicine. 2019. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*. Washington, DC: The National Academies Press.https://doi.org/10.17226/25259.

Circularity scenarios: future CCS from waste recycle

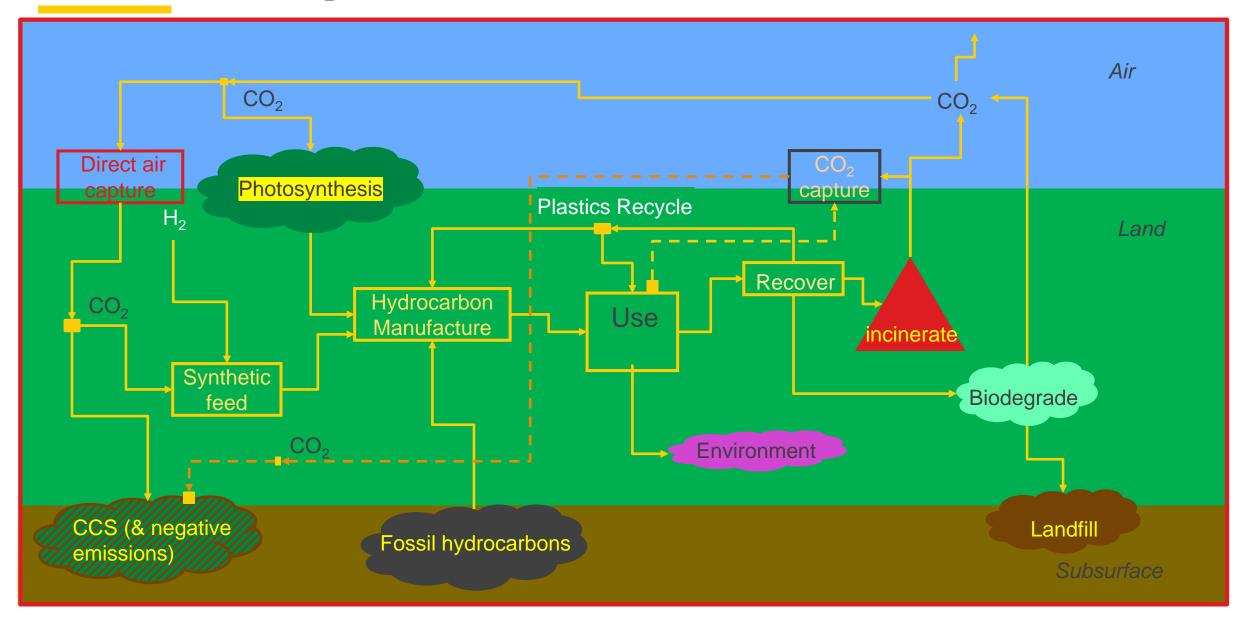
J.-P. Lange, Towards circular carbochemicals – the metamorphosis of petrochemicals, *Energy Environ. Sci.*, 2021, **14**, 4358–4376





Pew 2020: https://www.pewtrusts.org/-/media/assets/2020/07/breakingtheplasticwave_report.pdf

Circular Economy



Infrastructure Utilization: Ports and stacked

sector uses Import mainly from South Europe, North Africa and the Middle East. **PROJECTS** TIMETABLE **HYDROGEN** Backbone
The backbone connects production and import
(tankers) with clients in the part area. Public Blue hydrogen Hvision for blue hydrogen production. Natural **Backbone and Maasvlakte ECONOMY IN** conversion park operational gas and refinery gas are converted into hydrogen The released CO2 is stored in depleted gas fields 2023 **ROTTERDAM STARTS** under the North Sea (Porthos). **Conversion park** WITH BACKBONE 2GW conversion park (industrial estate) for the production of green hydrogen with electrolysis. Transport
A consortium is being developed with the aim of Shell goes operational with 150-250 MW electrolyser on operating 500 trucks on hydrogen. Under the name 81tgNE, 17 porties are collaborating on a climate-neutral transport corridor between Raterdam and Genco based on hydrogen. conversion park (investment decision 2021) Upscaling of electrolysers Shell is planning a 150-250 MW electrolyser for 2023 the conversion park. Nouryon, BP and the Port of Rotterdam Authority have teamed up in H2-Fifty on the development of a 250 MW electrolyser. H2-Fiby's 250 MW Eventually, hydrogen can also be used to heat greenhouses and buildings, particularly where heat networks or heat pumps are not a solution. electrolyser goes operational (investment decision 2023) Offshore wind energy is linked to the 2025 production of green hydrogen. In addition to the large projects shown here, many smaller ones are in preparation. Connection to national H₂ grid, Road transport: Chemelot and North large-scale imports of hydrogen compounds are needed to provide Northwest Europe with adequate supplies of sustainable energy. This requires import 500 hydrogen-powered trucks 2025 ninals and pipelines. Installation of H-vision operational Imminut decision 2022) 2026 2030 CO2 PIPELINE CONNECTION TO INDUSTRY USES H₂ FOR HEATING AND AS FEEDSTOCK TRANSPORT NORTH RHINE WESTPHALLA CABLE Hy BACKBONE TRANSPORT TO CHEMELOT

•Rotterdam Harbor:

•www.portofrotterdam.com /en/doing-business/port-ofthe-future/energytransition/hydrogen-inrotterdam

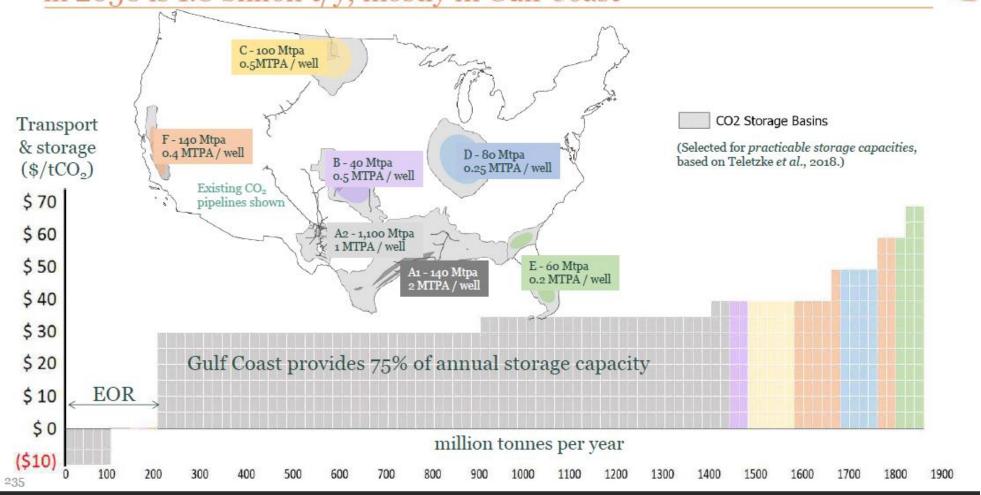
Gasunie & EBN



https://www.porthosco2.nl/en/

Net Zero America (2021): CCS in all scenarios

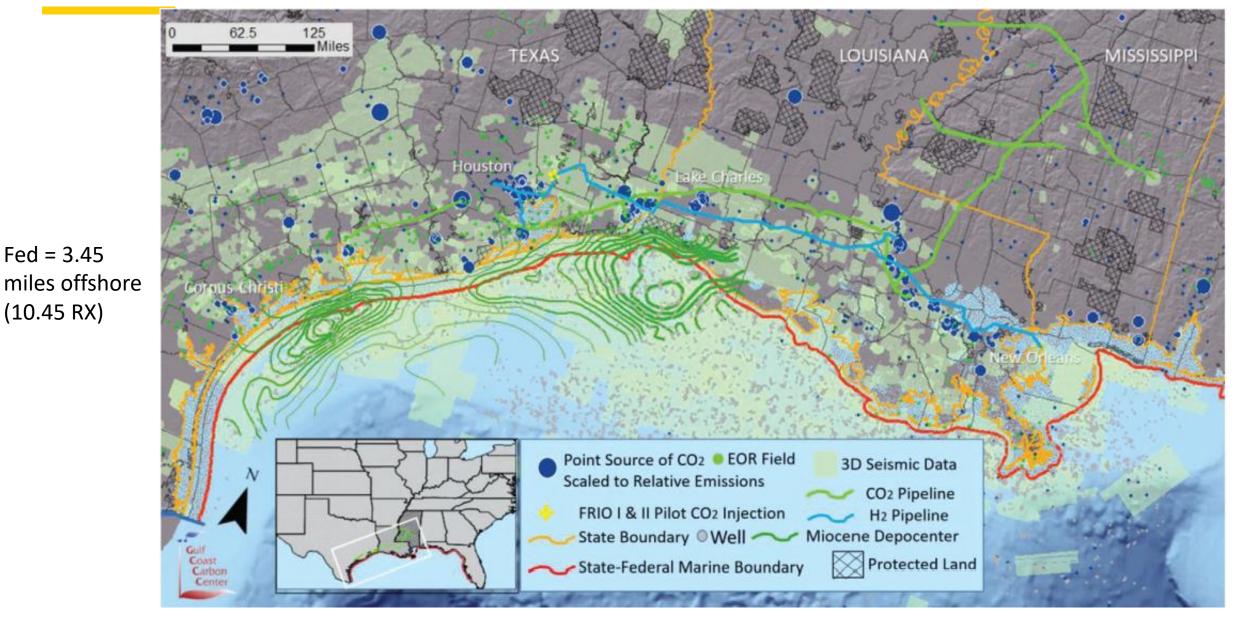
Notional CO₂ storage capacity appraised, permitted and developed in 2050 is 1.8 billion t/y, mostly in Gulf Coast



E. Larson, C. Greig, J. Jenkins, E. Mayfield, A. Pascale, C. Zhang, J. Drossman, R. Williams, S. Pacala, R. Socolow, EJ Baik, R. Birdsey, R. Duke, R. Jones, B. Haley, E. Leslie, K. Paustian, and A. Swan, Net-Zero America: Potential Pathways, Infrastructure, and Impacts, interim report, Princeton University, Princeton, NJ, December 15, 2020. https://netzeroamerica.princeton.edu

Fed = 3.45

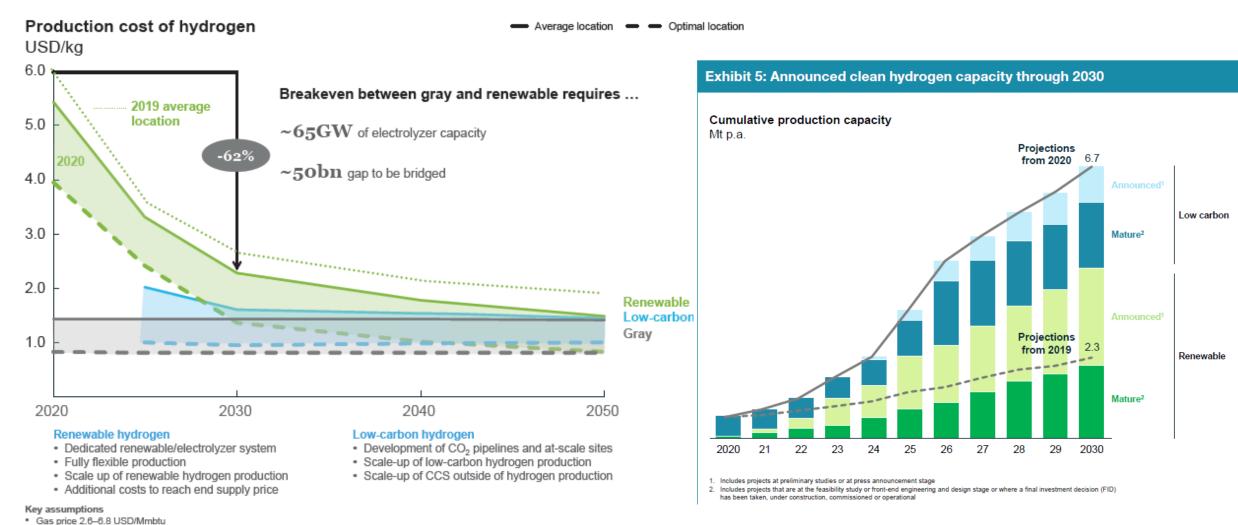
(10.45 RX)



Copyright of Shell International B.v.A. P. Bump, S. D. Hovorka and R. H. Trevino (UT-BEG), Carbon capture, utilization, and storage hub development on the Gulf Coast, Greenhouse Gas Sci Technol, 2021, 11, 619-632.

McKinsey / Hydrogen Council

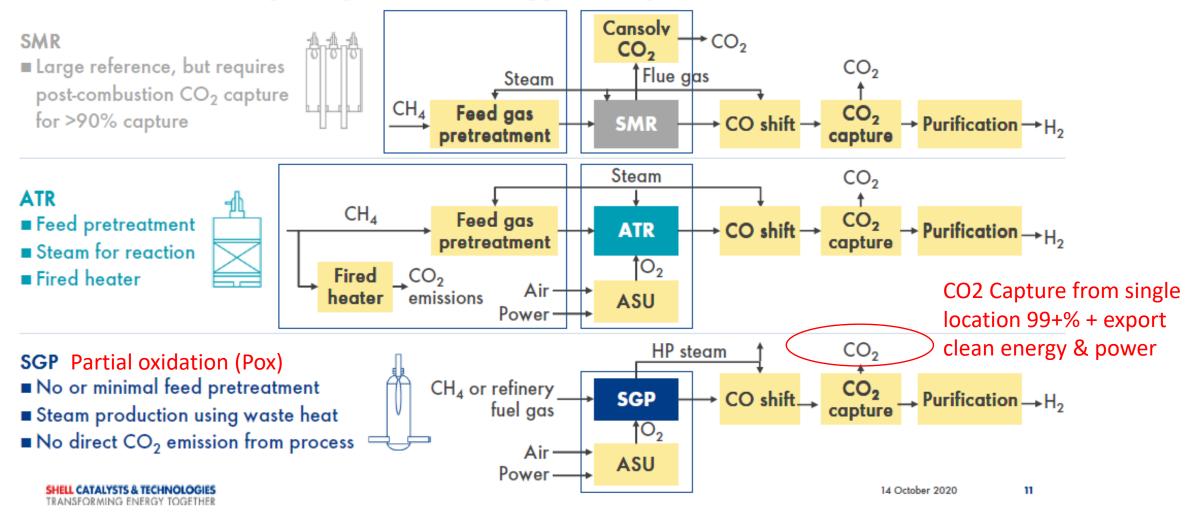
LCOE USD/MWh 25-73 (2020), 13-37 (2030) and 7-25 (2050)



Hydrogen Council / McKinsey: Hydrogen Insights A perspective on hydrogen investment, market development and cost competitiveness February 2021 https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021.pdf

Blue Hydrogen Manufacture: SMR \rightarrow ATR \rightarrow POx

Different blue hydrogen technology line-ups

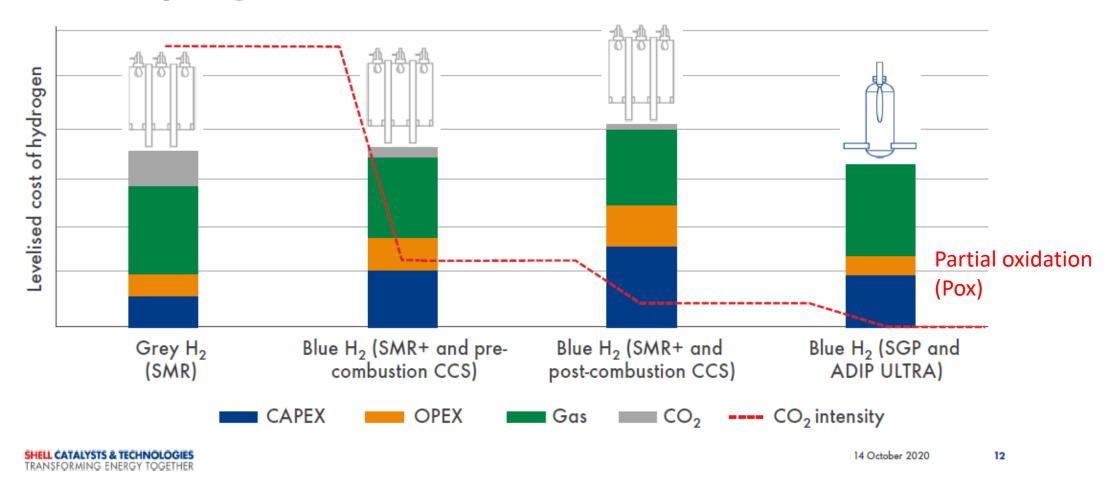


Shell Blue Hydrogen Technology, Hydrocarbon Processing Webcast Oct 2020

https://www.hydrocarbonprocessing.com/magazine/2021/june-2021/special-focus-process-optimization/increasing-blue-hydrogen-production-affordability

Hydrogen Manufacture: SMR \rightarrow ATR \rightarrow POx

SMR is the most common hydrogen technology, but is it also the best for blue hydrogen?



Shell Blue Hydrogen Technology, Hydrocarbon Processing Webcast Oct 2020

https://www.hydrocarbonprocessing.com/magazine/2021/june-2021/special-focus-process-optimization/increasing-blue-hydrogen-production-affordability

Conclusions / Q&A / Follow-up

- ■CCS= global affordability for energy transition & permanent storage (1000+ years)
- ■Utilization (CCUS) is challenged as alternative because CO₂ is often re-emitted.
- United States is uniquely advantaged for storage in depleted hydrocarbon reservoirs
- ■Offshore CO₂ storage can improve stakeholder acceptance
- Blue hydrogen (natural gas conversion + CCS) is already at DOE 1:1:1 targets and offers attractive options for decarbonization

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Thank you!

