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C4T Cambridge Centre for Carbon Reduction in Chemical Technology

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Feasibility of Green Hydrogen-based Synthetic Fuel as a Carbon Utilization Option: Logistics, Pricing, and Economics

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OUTLINE

- Motivation
- Research Questions
- Methods and Scenarios
- Results
- Summary

SINGAPORE: NET ZERO BY 2050

- Reduce emissions to 60 $MtCO_2e$ by 2030
- Achieve net zero emissions by 2050
- Need for multiple decarbonization pathways
  - Net-zero pathways may take considerable time and investment to implement
  - Look into transitory low carbon pathways that function as carbon utilization or abatement options
  - Consider downstream applications for captured carbon and alternative non-fossil fuel pathways

BAU AVIATION FUEL DEMAND, SINGAPORE

	2019	Projected growth at 2050	
		4.21% [1]	5.11% [2]
Barrels (thousands per day)	183.1	557.50	703.20
CO_2 emissions (million tons per year)	27.38	83.33	105.11
Energy (terawatt hours per year)	103.55	315.28	397.68

[1] CAGR of flight movement in Changi Airport 2010-2019 from annual reports

[2] CAGR of Singapore jet fuel consumption 2010-2019

- Singapore energy and chemical sector emissions in 2017: 38.8 million tCO_2 (56% power generation, 24% refineries)
- Jet fuel consumption comparable to approximately 70% of emissions

GLOBAL AVIATION

- 2.4% of total global CO_2 emissions (2018)
- Difficult to decarbonize due to reliance on fossil fuels (i.e., crude oil-based jet fuel)
- External pressure: regulatory concerns (e.g., European Commission)

AVIATION AND ITS CARBON DILEMMA

- Main decarbonization pathway: alternative fuels
  - Sustainable aviation fuel (SAF)
    - Low feedstock availability (waste products, competing with other industries, e.g. food)
    - Inefficient yields
    - High investment costs
  - **Synthetic fuels (synfuels)**
    - Feedstock: (green) hydrogen + captured carbon
    - Similar problems to SAF: yield and cost
    - Easier to synergize with existing infrastructure (i.e., utilize captured carbon)

SYNFUEL AS A CARBON UTILIZATION METHOD

- Significantly more expensive versus conventional jet fuel
  - Premium versus kerosene from crude oil
  - Instead of cost, view as carbon utilization price
    - Price of utilizing captured carbon as an abatement for petrochemical/aviation sector
    - Synergizes the need to utilize captured carbon and lower emissions from jet fuel production/use
- Exploring synfuel production options
  - Local production with hydrogen imports
  - Overseas production via captured carbon exports

RESEARCH QUESTIONS

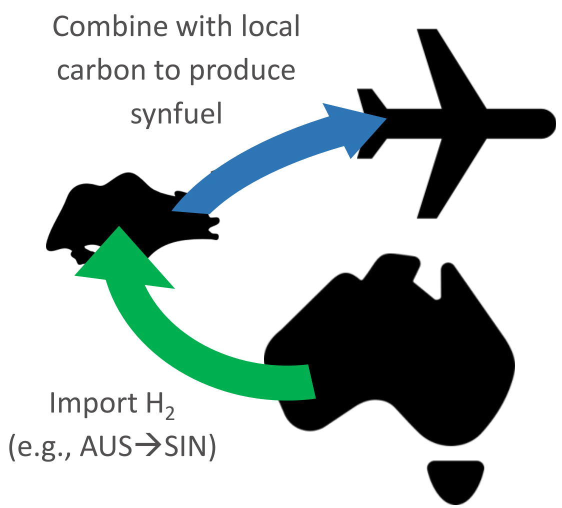
- What is the price of using captured carbon for synfuel production?
- Is local synfuel production more economically viable compared to overseas production (or vice versa)?
- How do certain cost factors affect the economic viability of synfuel production?

SCENARIO SETTING

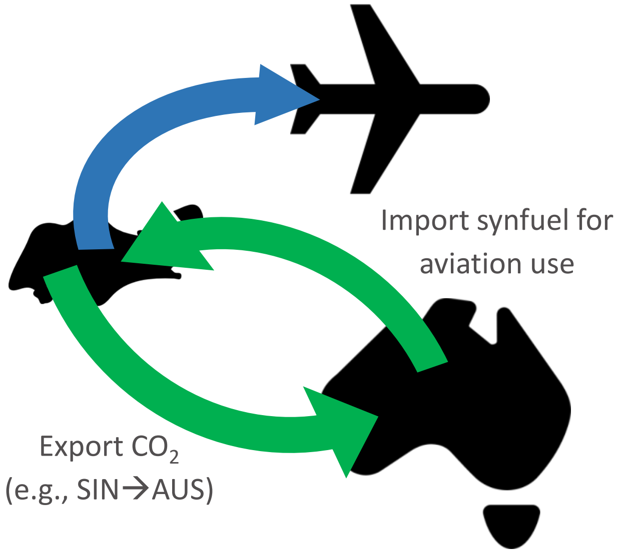
BAU SCENARIO: fossil-based jet fuel

PRODUCTION SCENARIOS

SCENARIO A: local production



SCENARIO B: offshore production



CUP AND CCUP

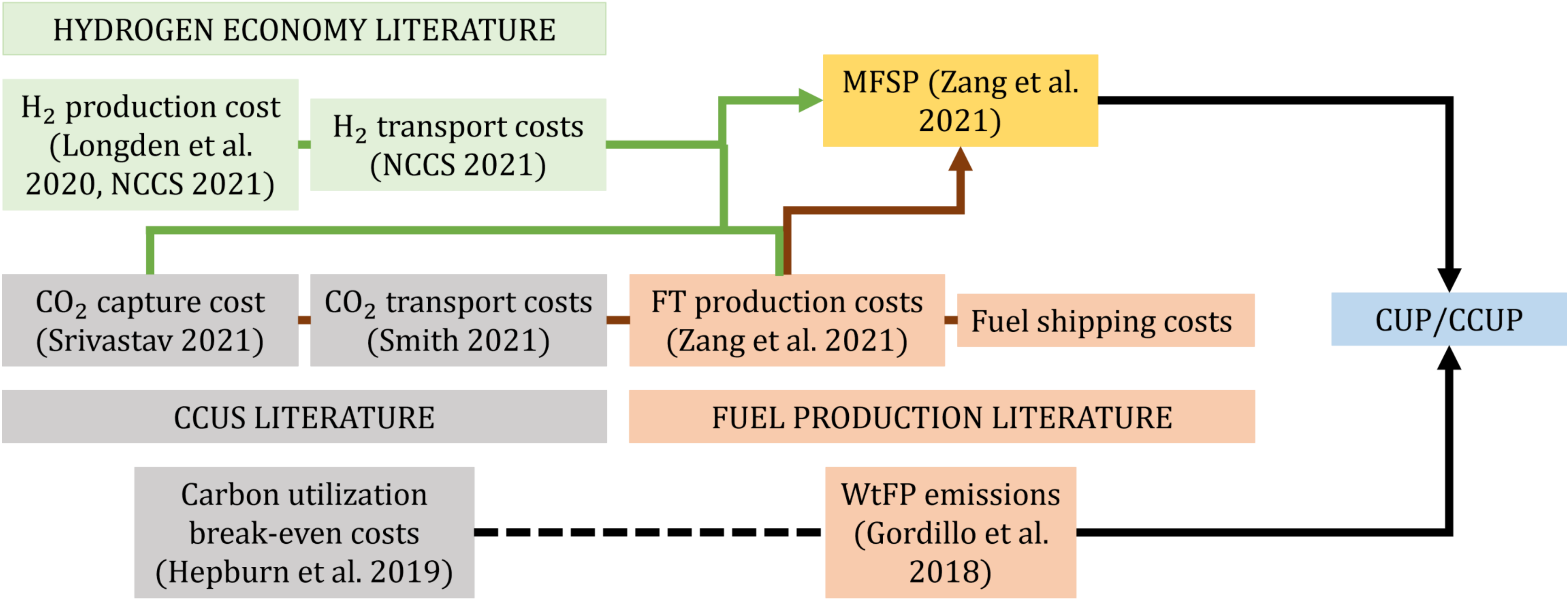
- Carbon utilization price

$$\text{CUP} = (\text{minimum fuel selling price } - \text{price of fuel from crude oil}) \times \frac{\text{total product output}}{\text{total feedstock input}}$$

- *Consequential* carbon utilization price

$$\text{CCUP} = \frac{(\text{MFSP}-\text{price of fuel from crude oil}-\text{capture cost}\times\text{WtFP } CO_2)}{\frac{\text{total feedstock input}}{\text{total product output}}+\text{WtFP } CO_2}$$

LITERATURE FOR CALCULATIONS



SCENARIO A (LOCAL SYNFUEL PRODUCTION)

Carbon capture cost in SIN
(85 USD/tCO_2 wt. ave.)

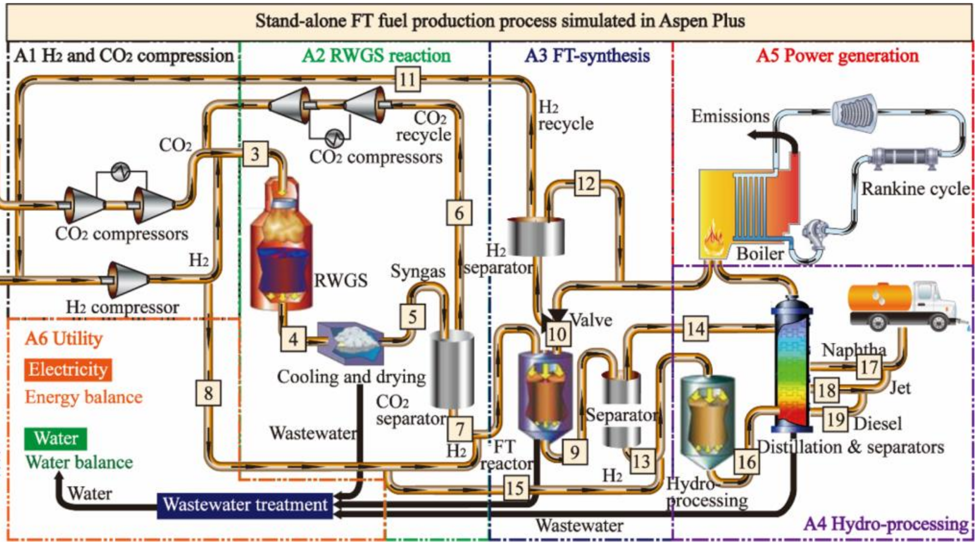
Green hydrogen from AUS
(1.04-2.87 USD/kg H_2 by 2050)

Compressed H_2
(low volumetric density)

Liquefied H_2
(2.15 USD/kgH_2 by 2050)

LOHC
(1.67 USD/kgH_2 by 2050)

Ammonia
(1.93 USD/kg H_2 by 2050)



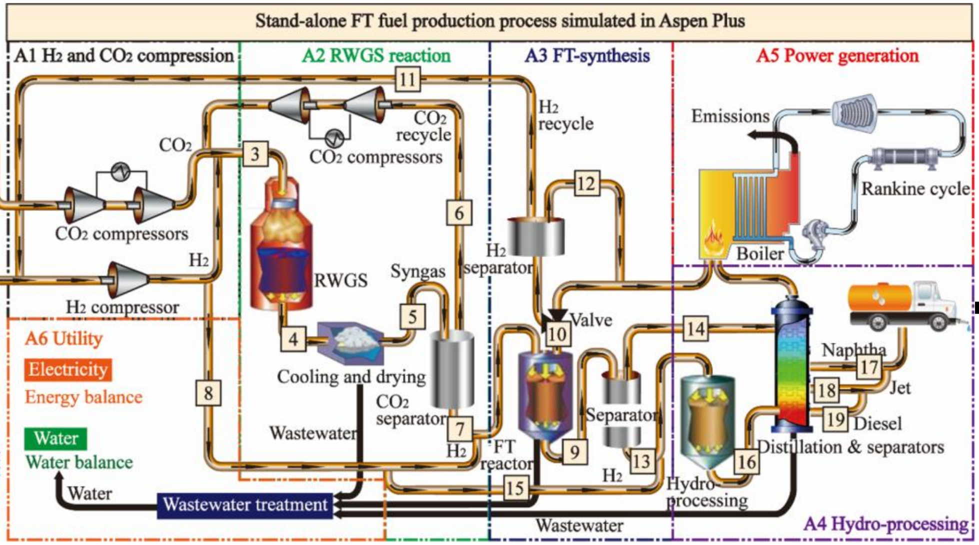
Zang et al (2021)
Minimum fuel selling price (at 2 USD/kgH_2 production cost, 35 USD/tCO_2 capture cost, no transpo costs): 5.4 USD/gal > 3.1 USD/gal (projected diesel price, 2050)

SCENARIO B (OVERSEAS SYNFUEL PRODUCTION)

Carbon capture cost in SIN
(85 USD/tCO_2 wt. ave.)

Carbon transport cost
(35-64 USD/tCO_2)

Green hydrogen from AUS
(1.04-2.87 USD/kg H_2 by 2050)

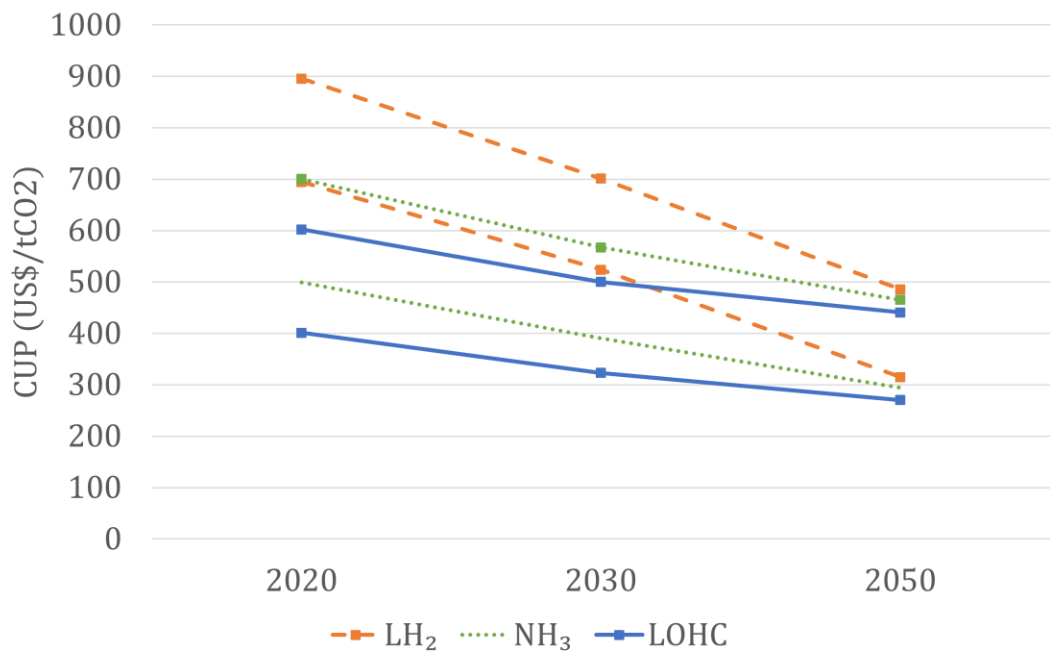


Synfuel shipping (AUS – SIN)
(4.69-9.67 USD/barrel)

SUMMARY OF RESULTS

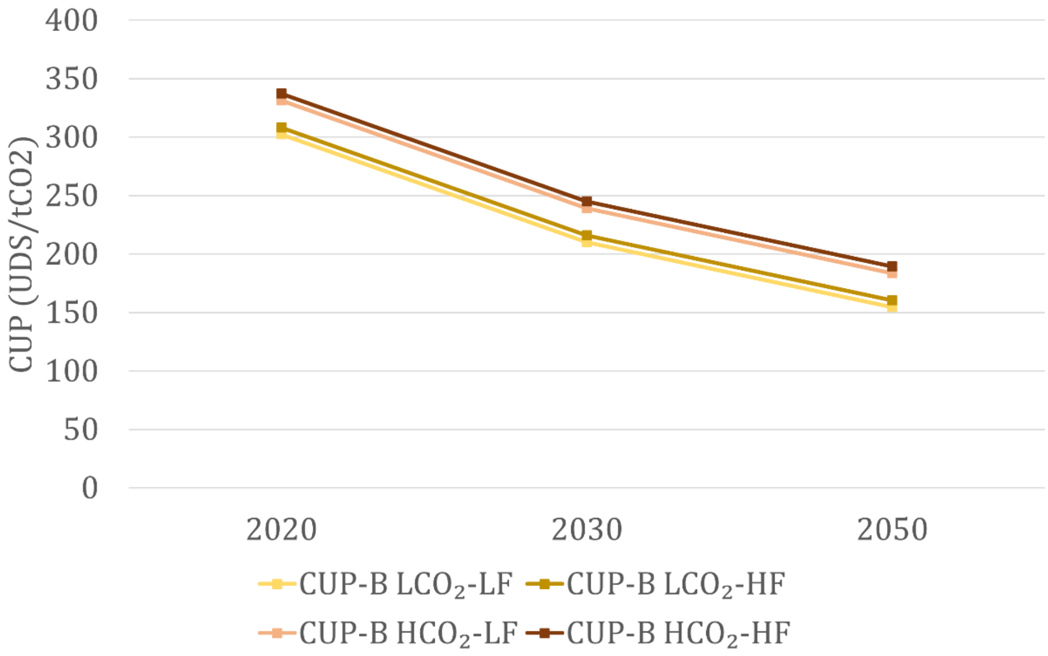
- Local production cost > overseas production cost
  - H_2 shipping costs > (captured) CO_2 and synfuel shipping costs
  - Lowest CCUP estimate at **142 USD/tCO_2** (overseas production with low CO_2 and synfuel shipping costs)
    - Lowering CO_2 capture costs further can yield CCUP below 100 USD/tCO_2
    - Singapore's advanced refining capacity can make local production competitive via economies of scale
    - Emission taxes can further lower gap between local/overseas CCUP

SCENARIO A



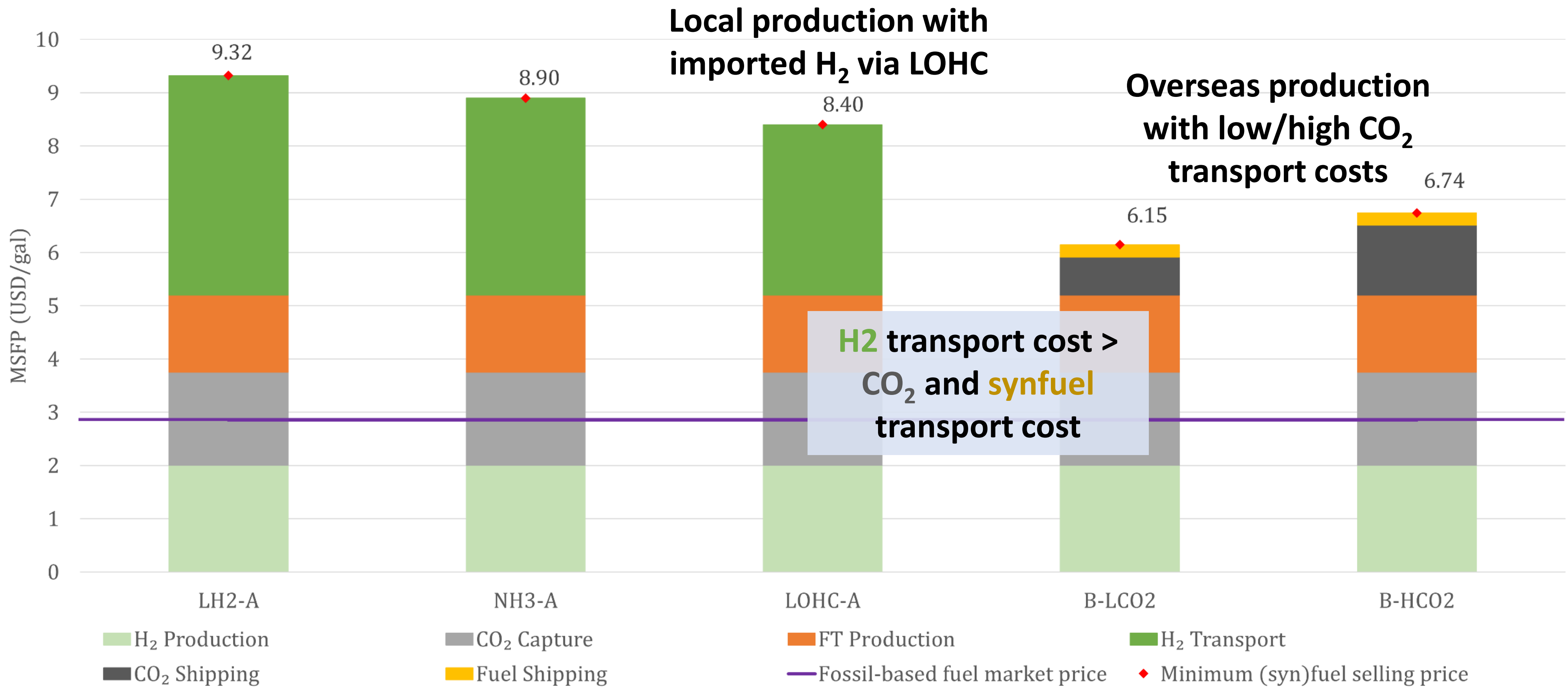
- LOHC projected to be cheapest H_2 transport medium (based on KBR study)

SCENARIO B

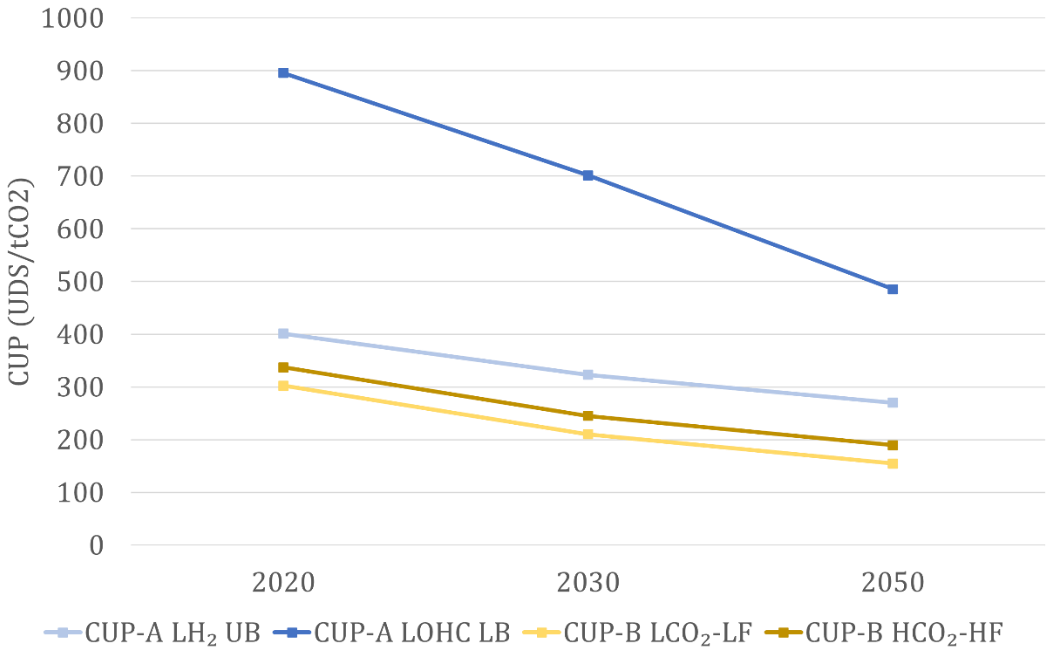


- CO_2 transport cost more significant factor compared to fuel shipping cost

COMPARING PRODUCTION SCENARIOS



COMPARING PRODUCTION SCENARIOS



- Smallest CUP for Scenario A > Largest CUP for Scenario B
- Overseas production is cheaper compared to local production

CCUP vs CUP

- CCUP reduces CUP by 16-30%
- Lowest CCUP: Scenario B with low CO_2 transport and fuel shipping costs (**142 USD/tCO_2**)

SCENARIO A

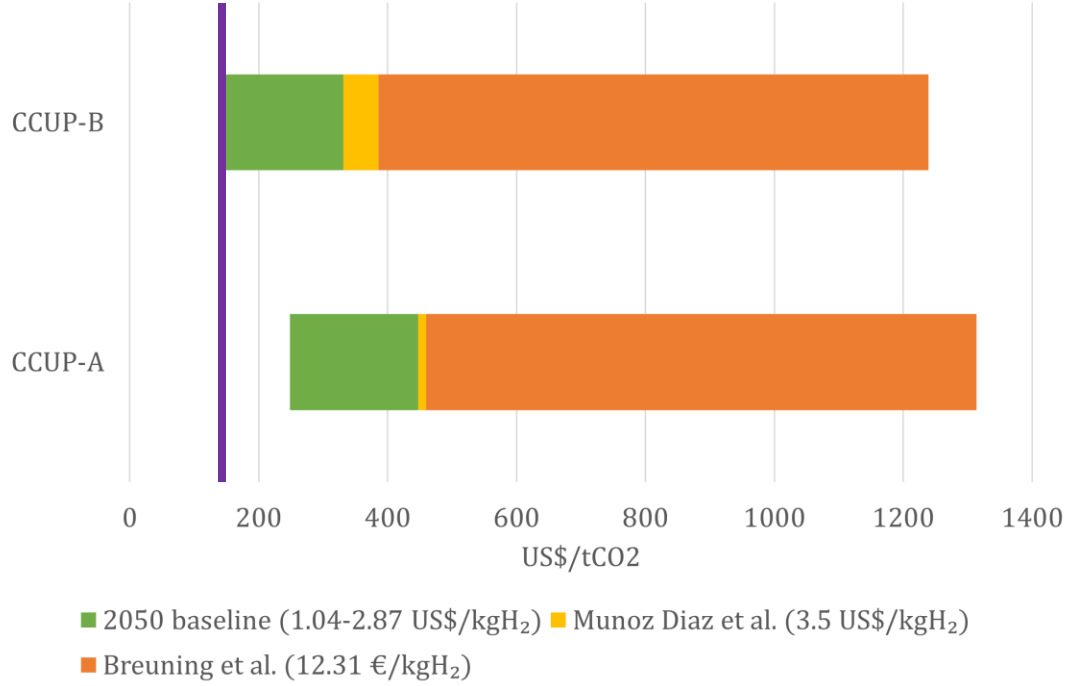
H_2 Pathway	2020	2030	2050
LH_2	640–825	482–646	290–447
NH_3	460–645	359–522	271–428
LOHC	369–555	297–461	249–406

SCENARIO B

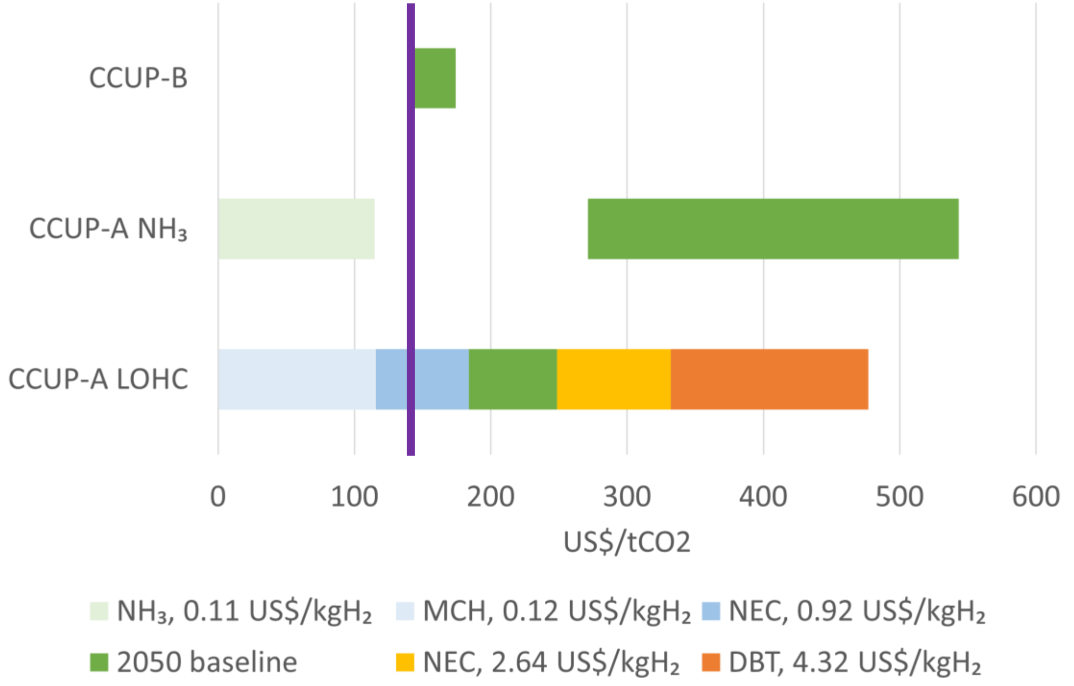
	2020	2030	2050
CO2 transport: 35 USD/Tco_2	278–284	194–199	142–148
CO2 transport: 64 USD/tCO_2	305–311	220–226	169–174

SENSITIVITY ANALYSIS: HYDROGEN COSTS

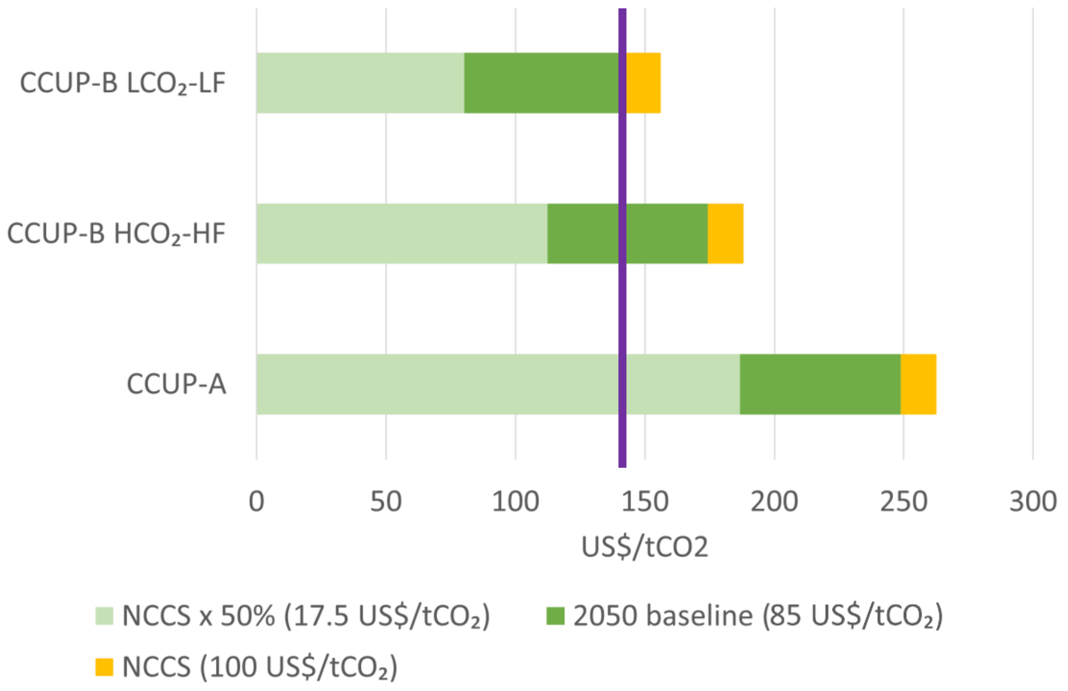
- CCUP can fluctuate significantly depending on H_2 production costs



- Development of H_2 transport pathways will impact CCUP

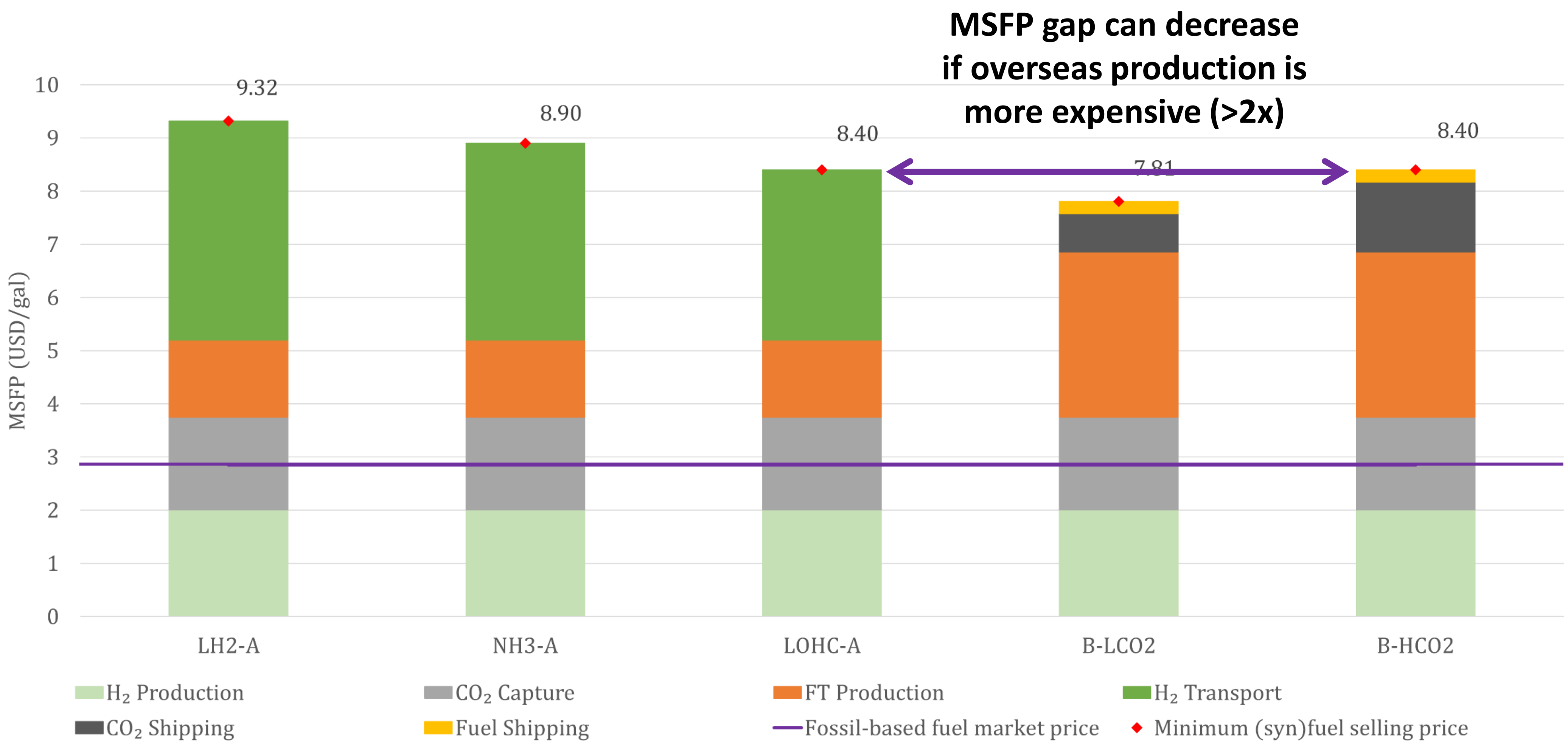


SENSITIVITY ANALYSIS: CARBON COSTS

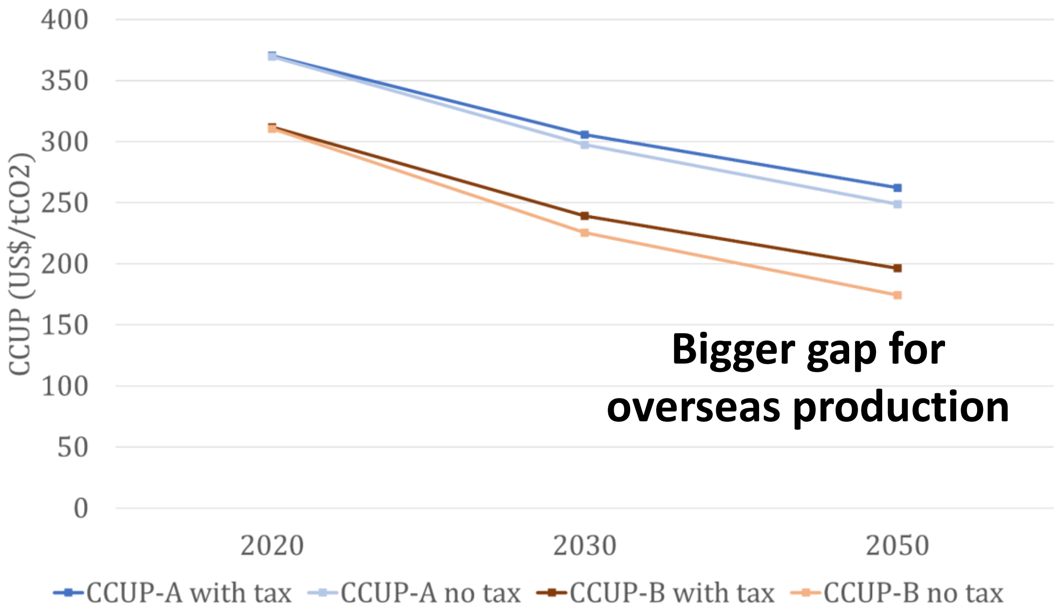


- CO_2 capture costs likely to go down, can bring CCUP below 100 USD/tCO_2

ECONOMIES OF SCALE



EMISSIONS FROM SHIPPING INPUTS/OUTPUTS



- Account for additional emissions caused by (conventional) shipping (both scenarios)
- Carbon taxes can decrease scenario gap by 11%

SUMMARY

- Singapore’s path to net zero requires the exploration of multiple pathways to decarbonization, including interim carbon abatements
- The aviation sector’s pathway to decarbonization lies in alternative fuels
- We estimate the price of utilizing captured carbon to produce synfuel (local or overseas), including a measurement (CCUP) that accounts for avoided emissions from continued fossil-based fuel production
- Overseas synfuel production is more viable than local production
- Main cost driver: hydrogen feedstock cost
- Investigate effect of different cost factors on CCUP

FUTURE WORK

- Economic analysis for decarbonization pathways
  - Enlarged models for carbon utilization (electricity imports, regional analysis)
  - Circular economy/CCU for maritime sector
  - Other downstream applications (e.g., low carbon plastics)
- Carbon pricing models for different decarbonization pathways and sectors
  - Carbon pricing for the maritime sector
  - Differentiated carbon pricing for multiple industries

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