THE FUTURE OF HYDROGEN IN COMMERCIAL AVIATION: AN ECONOMIC AND EMISSIONS ANALYSIS OF JET FUEL ALTERNATIVES

Clare Callahan[1] Hannah Brown[1] Sang Hyun Ma[2] Adrielle Cailipan[2]
[1]CMU Heinz College, [2]CMU Energy Science, Technology & Policy

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MOTIVATION

- Passenger aviation is one of the highest CO_2 emitting forms of travel.
- Hydrogen (H_2) is more energy dense by weight than existing jet fuels and offers a potential fuel-based solution for aviation to continue use of combustion based flight.
- Hydrogen production processes vary in cost and CO_2 intensity and need to be critically examined.

RESEARCH QUESTION

How much can the average passenger save on emissions for a flight from NYC to London using a hydrogen-powered concept plane (Airbus ZEROe) rather than a conventional A-1 jet fueled-plane?

STUDY DESIGN

- Selected one of busiest international flights, New York City (JFK) → Heathrow (LHR, London).
- Annually, this 3,470 mile trip[3] is taken over 14,000 times[6], on average.
- Boeing 787-9, a newer and more fuel efficient plant, is one of most frequent planes to make the trip.
- Airbus concept ZEROe Turbofan plane fueled by hydrogen combustion was used as comparison.
- Capital/ R&D costs of ZEROe were not included in this analysis.

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Types of hydrogen, characterized by production pathway:

- **Green** - Electrolysis powered by renewables (for this study, electrolysis powered by wind).
- **Blue** - Steam methane reformation from natural gas with 90% carbon capture and sequestration (SMR with 90% CCS).
- **Grey** - Steam methane reformation from natural gas without carbon capture and sequestration (SMR without CCS).

PLANE SPECIFICATIONS

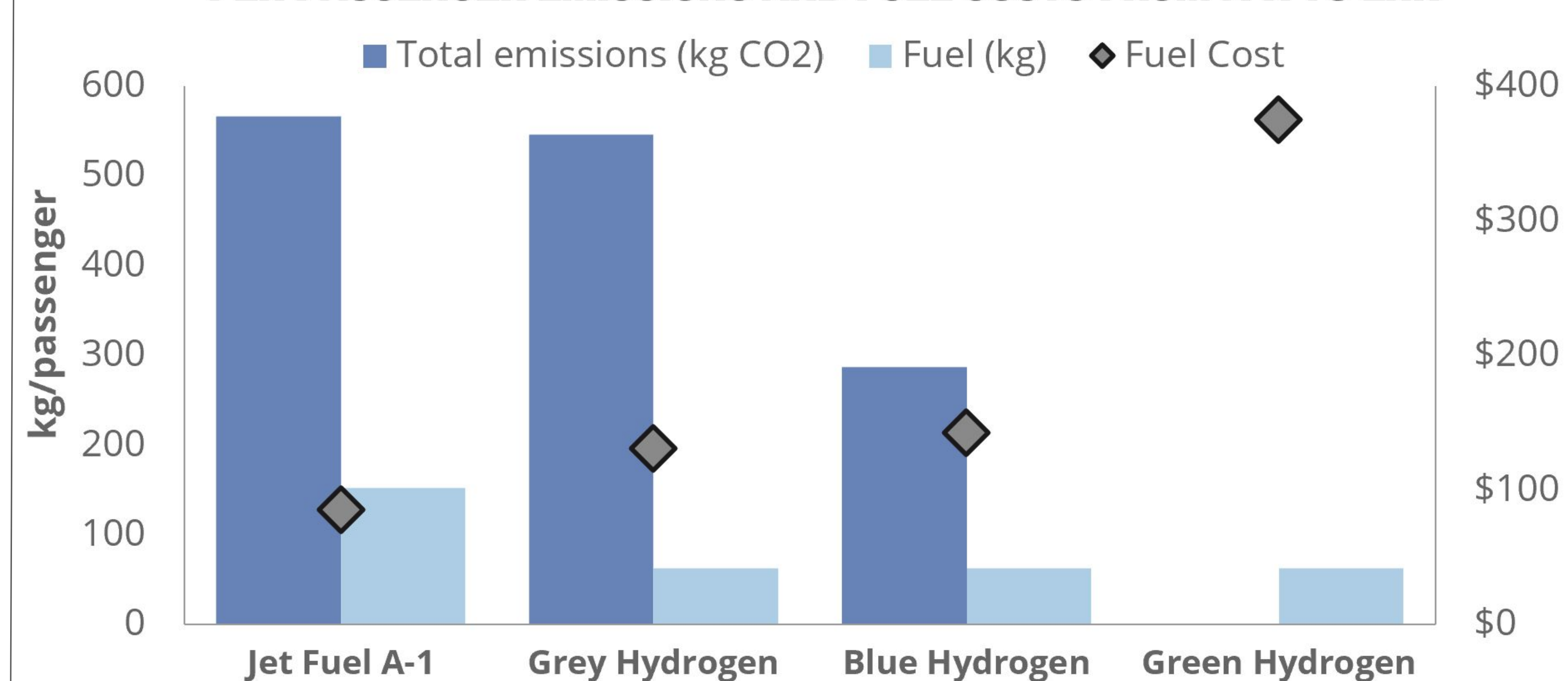
PLANE SPECIFICATIONS	Boeing 787-9[2]	Airbus ZEROe
Number of passengers	216	200
Fuel Type	A-1 jet fuel	liquid hydrogen
Fuel Energy Intensity (MJ/kg)	43.28	120
Fuel Consumption	5,600 kg/hr	TBD
Average Speed	593 mph	Avg. 600 mph

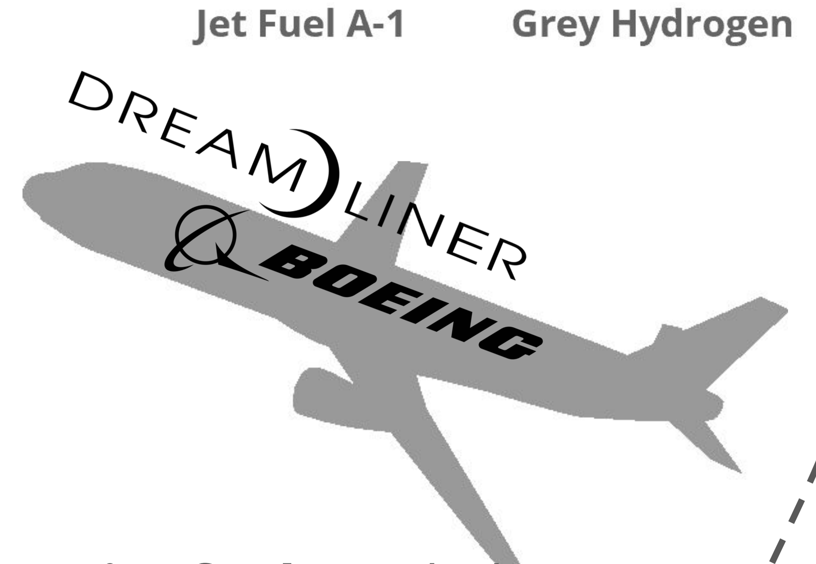
METHODOLOGY & ASSUMPTIONS

- The necessary fuel needed to get the plane from JFK to LHR was calculated based off Boeing 787-9 fuel consumption rates.
- The minimum energy needed for the flight was found; the Airbus ZEROe was assumed to operate similarly to that of the 787-9.
- The volume of liquid H_2 required for the flight was calculated to be greater than that of A-1 jet fuel; however, liquid H_2 was significantly lighter in total weight. We assume additional equipment to store and cool the liquid H_2 will not exceed the weight savings.
- The emissions for jet A-1 fuel and the three H_2 types were calculated using life cycle assessment data [13] or extrapolated. [12]
- The H_2 fuel prices are reported purely as production prices which consider production and liquefaction costs. H_2 sale data, is currently limited; however, price points identified fall within production cost ranges.[14]
- The ticket prices were extrapolated from the average plane ticket price from JFK to LHR such that fuel is equal to approximately 18% of the total ticket price.

RESULTS

PER PASSENGER EMISSIONS AND FUEL COSTS FROM JFK TO LHR





A-1 jet fuel needed to make the flight:

10,821 GALLONS (72,092 LBS)

Liquid hydrogen needed to make the flight:

47,495 GALLONS (27,688 LBS)

EMISSIONS

EMISSIONS	A-1 Jet Fuel	Grey H_2	Blue H_2	Green H_2
Flight emissions (metric tonnes CO_2)	122	109	57	0
Flight emissions per MJ (kg CO_2/ MJ)	0.085	0.076	0.04	0
Price of fuel[12] ($/kg)	$0.56	$2.08	$2.27	$5.96
Passenger emissions (kg CO_2/ passenger-mile)	0.163	0.157	0.083	0

Average plane ticket from JFK to LHR[10]: **$478**

Grey H_2 plane ticket: **$813**

Blue H_2 plane ticket: **$880**

Green H_2 plane ticket: **$2,188**

CONCLUSIONS

Today an H_2-powered flight from JFK-LHR could cost less than a business class flight for a 4-100% reduction in emissions. Grey H_2, with a 4% emissions reduction will not significantly reduce air-travel emissions; however, if the aviation industry waits for green hydrogen cost-competitiveness before H_2 integration we may not see significant reductions in emissions from air travel for more than two decades. With only a 40% reduction in cost, Blue H2 can offer a comparably priced ticket as current jet-fuels and a 47% reduction in emissions. Blue H_2 may offer a stop-gap and significantly reduce air travel emissions while the industry awaits the anticipated 60% reduction in the cost of H_2 by 2030.

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