



Accelerating Aviation's Transformation Into Clean Energy

EcoFlight™ EF-5C
Deigned-For-Freight
Air Logistics Freighter

Earth Friendly Flight™

Understanding Airport Hydrogen Supply Based On Mainline Hydrogen Aircraft Operations

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Understanding Hydrogen In Real-World Use Cases

- Hydrogen will be a large part of mainline aviation's clean energy future
- NOVAdev studied fueling with hydrogen for current-day passenger and cargo routes, then traded best hydrogen system options considering:
 - Hydrogen consumption and range
 - Storage and conversion methods
 - Cargo, range and payload impacts
- Hydrogen turbo-electric power best aligns with mainline CONOPS (concept of operations)
 - Turbines bridge industry transition from low-carbon SAF to zero-carbon hydrogen

EcoFlight™ EF-3K
Airliner



EcoFlight™ EF-5C
Freighter



EcoFlight™ Integrated System Architecture



- ✓ TRUSTED TECHNOLOGIES
- ✓ DESIGNED FOR CERTIFICATION
- ✓ ZERO-CO₂ HYDROGEN OR SAF

- 1 Independent Power & Propulsion Systems**
- 2 Integrated Multi-Turbine Electric Generator Network**
- 3 Distributed Open Rotor Electric Propulsion**
- 4 Blown Wing Aero With Mixed Movable Surfaces**
- 5 NASA Solid-State Flux Capacitor H2 Storage Tech**
- 6 Electric Nose Wheel Powered Taxi**



- ✓ FUTURE FORWARD
- ✓ CLIMATE ALIGNED

Comparing The Mainline At Scale Counterparts

Passenger Airliners



Metrics	737-8	EF-3K
Length (ft)	129	147
Wingspan (ft)	118	118
MTOW (lbs.)	182,000	190,000
Max Passengers	186	186
IFR Range @ MTOW (nm)	2600	3200
Cruise (Mach)	0.79	0.80

Cargo Freighters



Metrics	757-200	EF-5CH
Wingspan Ft.	152	180
MTOW (lbs)	250,000	275,000
Max Cargo @ Full Fuel (lbs.)	72,000	85,000
88X125 Containers	15	16*
Cargo Doors	1	2
Range @ MTOW (nm)	2,300	3,200
Cruise (Mach)	0.80	0.80

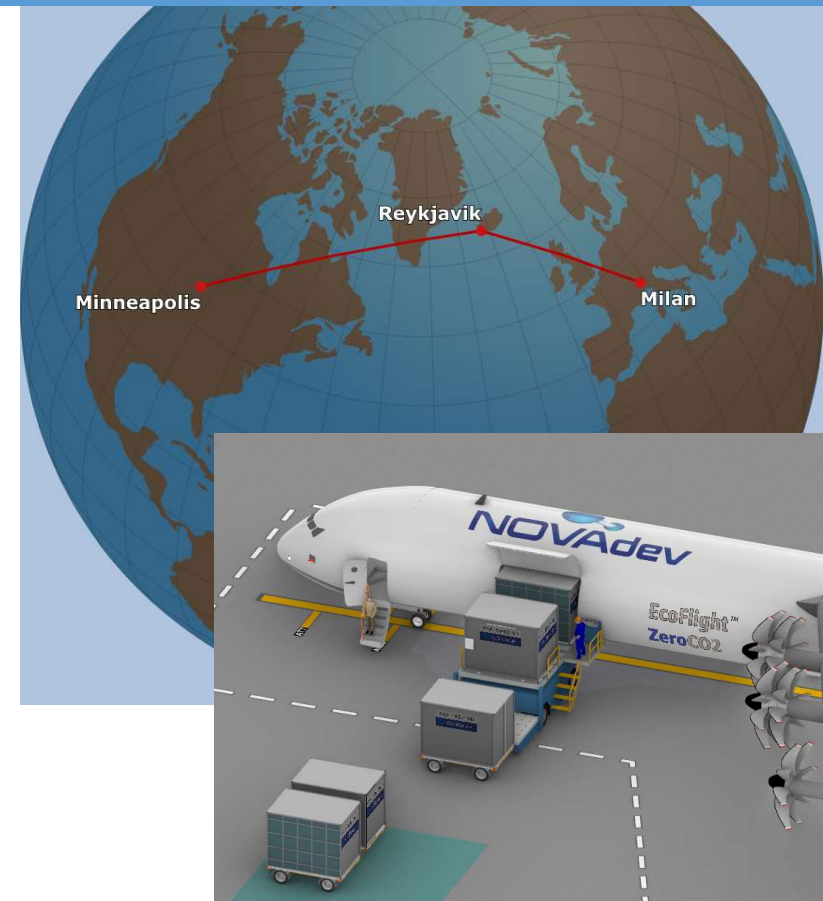
* EF-5C is point-designed for optimized 88x125x96 inch rectangular containers

Sample Mission – Hub and Spoke

Spoke – Hub – Spoke

Minneapolis – Reykjavik - Milan

- **Leg One** – Minneapolis USA to Keflavik Iceland
 - MSP to KEF
 - Upload (16) 88X125 Unit Load Devices (ULD)
 - Cargo Weight 38,100kg / 83,820 lbs.
 - Fuel for flight, reserve, and alternate airport to KEF
 - Fly route to KEF
- **Exchange Cargo in Keflavik**
 - Unload (13) ULD to Cargo Depot
 - Load (13) new ULD from Cargo Depot
 - Cargo Weight 37,450kg / 82,390 lbs.
 - Fuel for flight, reserve, and alternate airport to MXP.
 - **90 minute turn around time**
- **Leg Two** – Keflavik Iceland to Milan Italy
 - KEF to MXP
 - Fly Route to Milan Italy
 - Offload (16) ULD – Full Offload
 - Upload (16) ULD
 - Fuel for flight, reserve, and alternate airport to KEF



Range Diagram

Hydrogen Aircraft – Range Diagram

In Hydrogen aircraft as compared to SAF aircraft;

- The percentage of MTOW that is fuel is lower.
- The difference in payload weight from point A to point B is LOWER
- The curve to the right of point B is steeper due to higher empty weight

Range Diagram shows the relationship of Fuel weight / Payload Weight and range

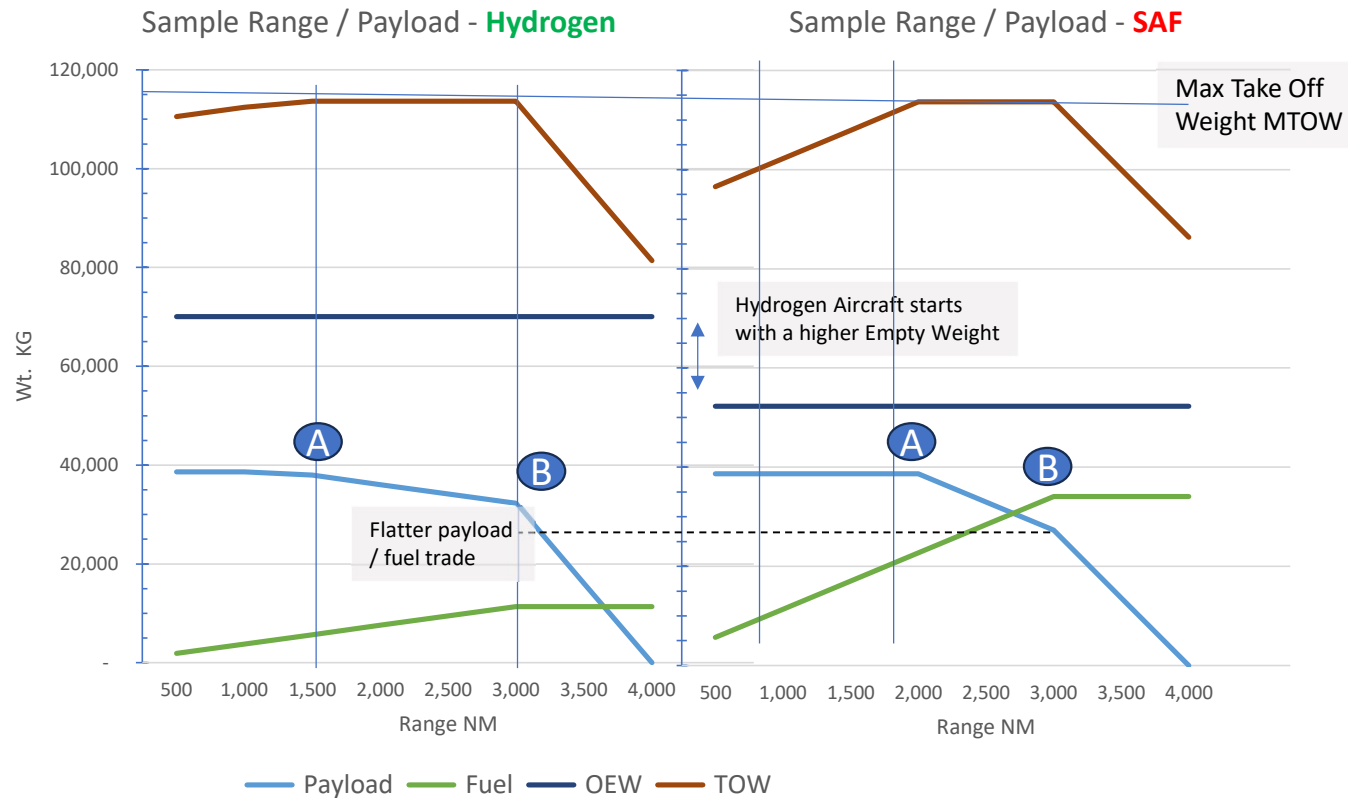
A Point A – Max Payload

B Point B – Max Fuel

Between point A and B the aircraft is at Max Take Off Weight (MTOW)

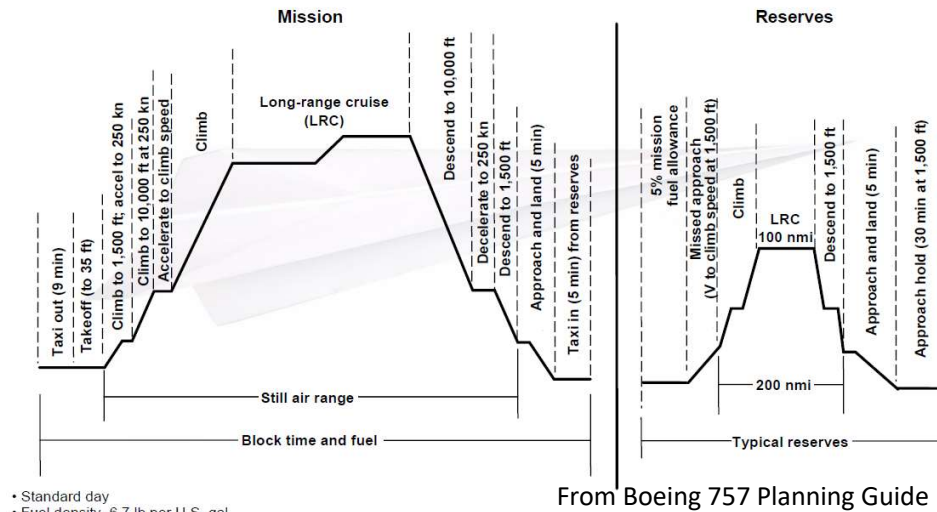
$$MTOW = OEW + \text{Payload Weight} + \text{Fuel Weight}$$

$$OEW = \text{Operating Empty Weight}$$



Mission - Fuel Planning

Typical mission rules



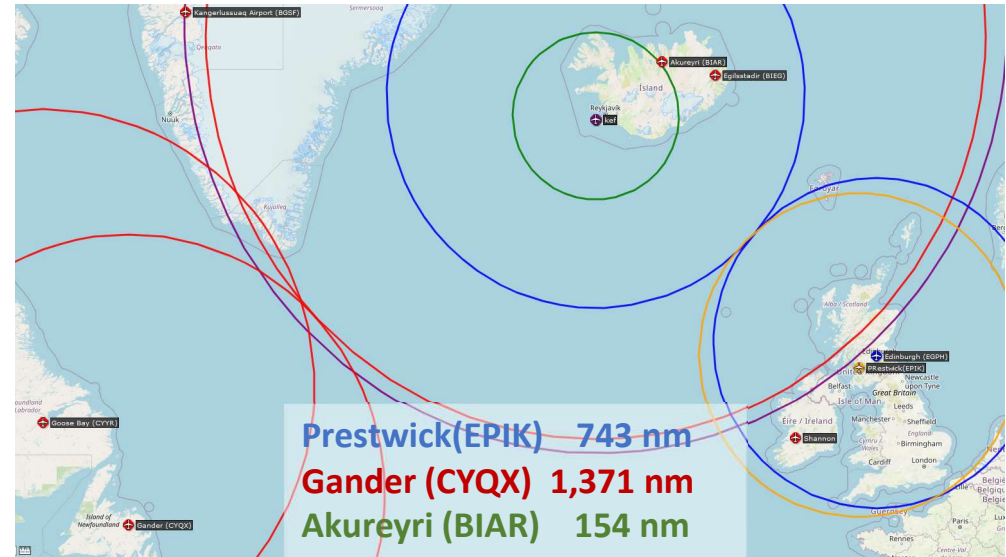
- Standard day
- Fuel density, 6.7 lb per U.S. gal
- Nominal performance

Flight Planning

- Aircraft Performance
- Aircraft Weight
- Winds
- Flight Level

Reserves

- FAA / EASA IFR Reserve
- Alternate Airport



The configuration of any aircraft needs to accommodate fuel for the reserves in addition to fuel for the mission.

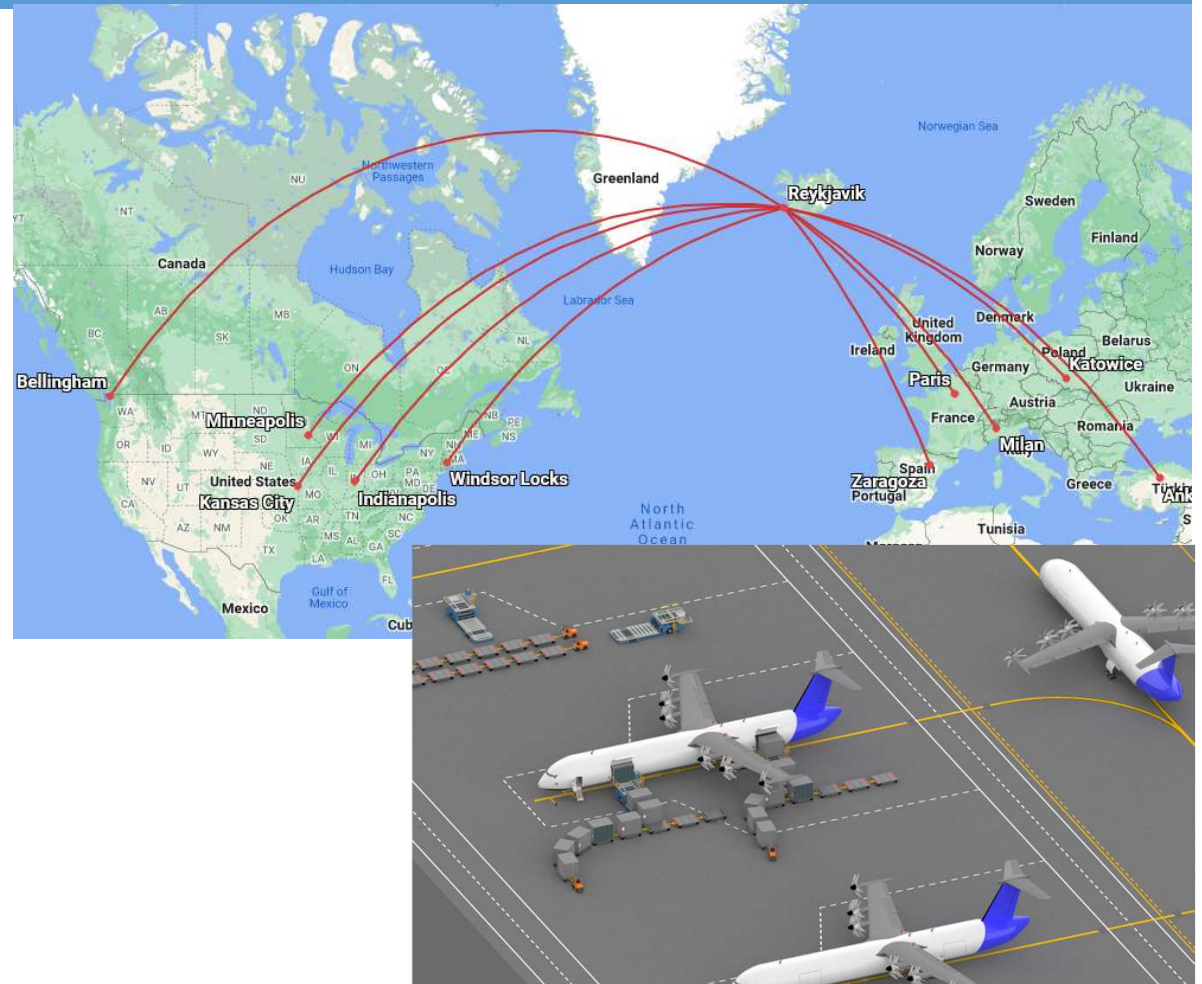
The need for reserve fuel combined with the lower density of hydrogen, increases the weight and size of hydrogen aircraft.

Hub Airport - Hydrogen

Hub Airports

Challenges:

- Large quantities of hydrogen needed
 - Small hub 10-20 million kg of hydrogen per year
 - Large Hub over 100 million kg of hydrogen per year
- Piped in or Produced on site
 - Significant power requirements
 - Offsite production still requires onsite storage
 - Redundancies for supply
 - Liquid plus gas recovery infrastructure
- Need the ability to offload fuel – Simple with Jet fuel, difficult with hydrogen
- Multiple aircraft refueling at the same time




KEF Keflavík Iceland Hub

- Refueling 10 airplanes for a single flight each day at Keflavik
 - Over 75,000 kg LH2 per day
 - **Over 23,000,000 kg LH2 per year**
- Power To Produce the Hydrogen over 1,200 Gigawatt hours per year
 - electrolyzer efficiency of 44kWh/kg H₂
 - Liquification efficiency 9kWh/kg LH₂
- Fuel needs to be created on site or piped in.

10 aircraft use over 6% of the total energy generated in Iceland

Flight from KEF to	CODE	Distance NM	Fuel Load kg H2			Power Needed MWh	
			Daily	Weekly	Yearly	Daily	Yearly
Minneapolis USA	MSP	2559	9,198	55,189	2,869,842	488	152,102
Windsor Locks USA	BDL	2161	7,437	44,619	2,320,209	394	122,971
Indianapolis USA	IND	2626	9,425	56,551	2,940,650	500	155,854
Kansas City USA	MCI	2869	10,248	61,490	3,197,459	543	169,465
Bellingham USA	BLI	3085	10,980	65,880	3,425,734	582	181,564
				-	-		
Milan, Italy	MXP	1520	5,157	30,945	1,609,137	273	85,284
Ankara, Türkiye	ESB	2393	7,951	47,706	2,480,700	421	131,477
Paris, France	CDG	1215	4,189	25,132	1,306,838	222	69,262
Zaragoza, Spain	ZAZ	1537	5,212	31,271	1,626,088	276	86,183
Katowice, Poland	KTW	1543	5,231	31,386	1,632,070	277	86,500
			Daily	Weekly	Yearly	Daily	Yearly
			75,028	450,168	23,408,728	3,976	1,240,663
			kg Liquid Hydrogen			Megawatt Hours	



ENERGY PROFILE  IRENA
Iceland International Renewable Energy Agency

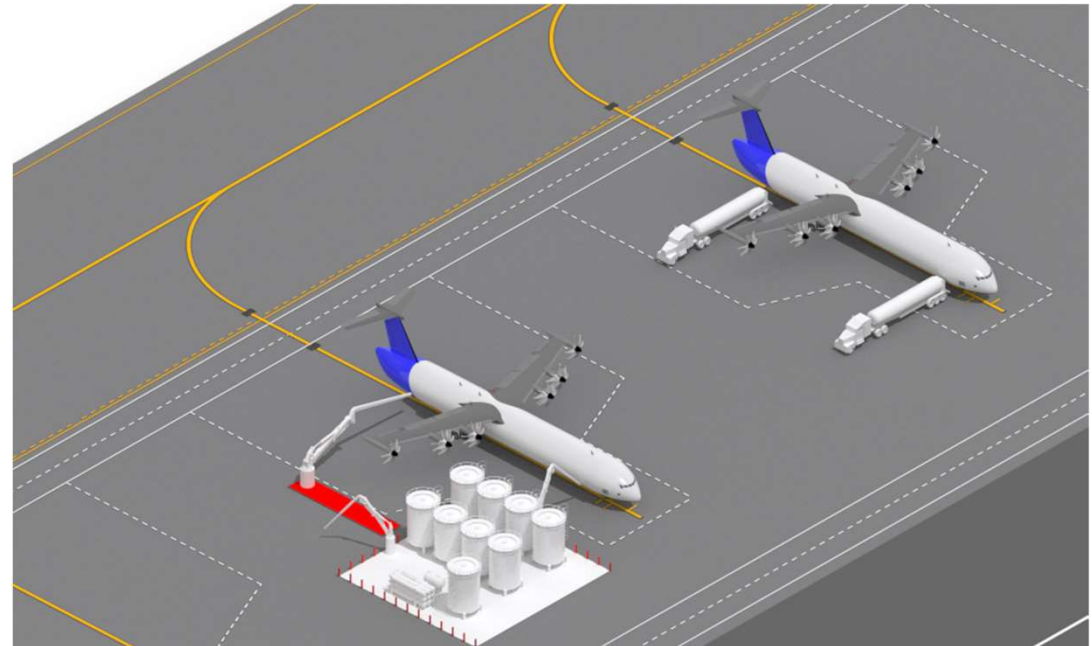
Generation in 2020	GWh	%
Non-renewable	3	0
Renewable	19 130	100
Hydro and marine	13 157	69
Solar	5	0
Wind	7	0
Bioenergy	0	0
Geothermal	5 961	31
Total	19 133	100

Spoke Airport - Hydrogen

Spoke Airports

Challenges:

- Even 'small spokes' need large volumes of hydrogen
- Supporting a single aircraft may need over 1 million kg LH₂ per year
- Small usage but will require dedicated ramp / apron / 'at the fence' space
- Trucked in
 - Standard LH₂ tankers hold less than a full load for an aircraft
 - On site storage still needed to ensure aircraft operations - Redundancies for supply
 - Liquid plus gas recovery infrastructure – Gas recover at truck adds complexity
- Produced on Site
 - Difficult to do in small quantities cost effectively
 - Possible to collocate with other users, difficult to 'share the volume'
- Certified / Trained refueling technician costly to keep full time – may limit operations
 - Pilots typically don't refuel



Two approaches to Spoke Airports

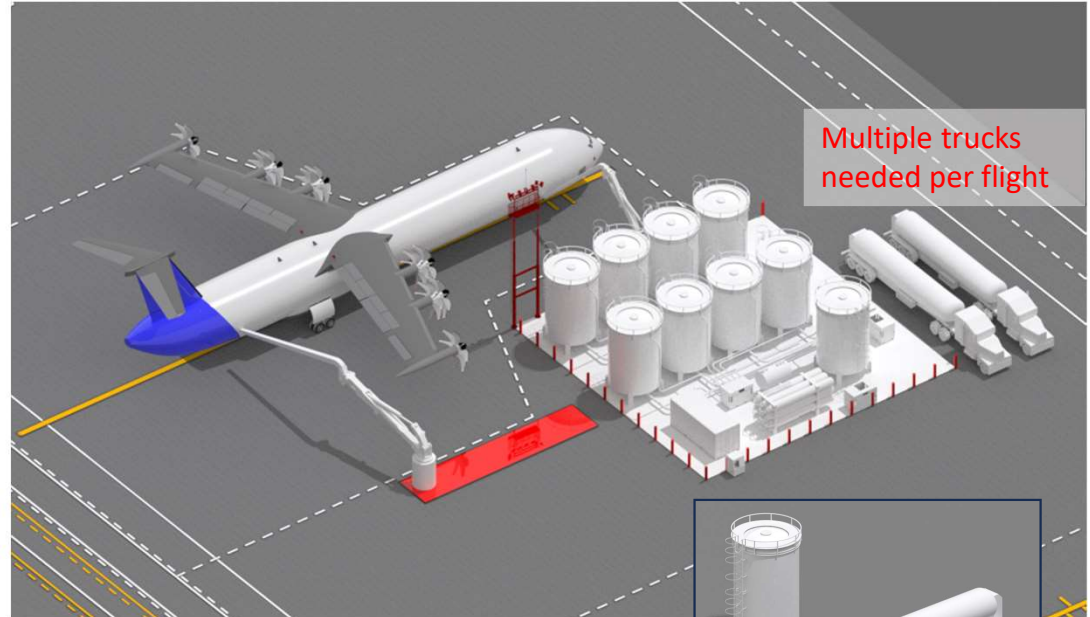
- Pull up Refueling
- Truck Refueling

Minneapolis and Milan Spokes

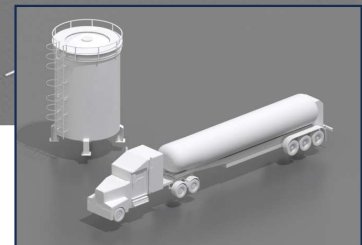


'Spoke' Refueling Station

- On Site Storage – (8) 60k Liter Liquid Recovery Tank – (1) 60K liter Truck Off Loading Stations (2) Recovery H2 Gas
- Compressor
- 350 bar storage tanks (Offload or Dispense)



Multiple trucks needed per flight



3,800 kg / truck
Each 60m³ tank holds one truck of LH2

Flights from Spokes to KEF		Fuel Kg LH2			Truck Deliveries		
Flight from		Distance NM	Daily	Weekly	Yearly	Weekly	Yearly
Minneapolis	MSP	2,559	9,198	55,189	2,869,842	15	755
Milan	MXP	1,520	5,557	33,344	1,733,889	9	456

*3,800 kg useable per truck

Cost of Jet Fuel

Green Hydrogen is an electricity problem

From an energy standpoint, 1 gallon of Jet-A is approximately equal to 1 kg of H₂

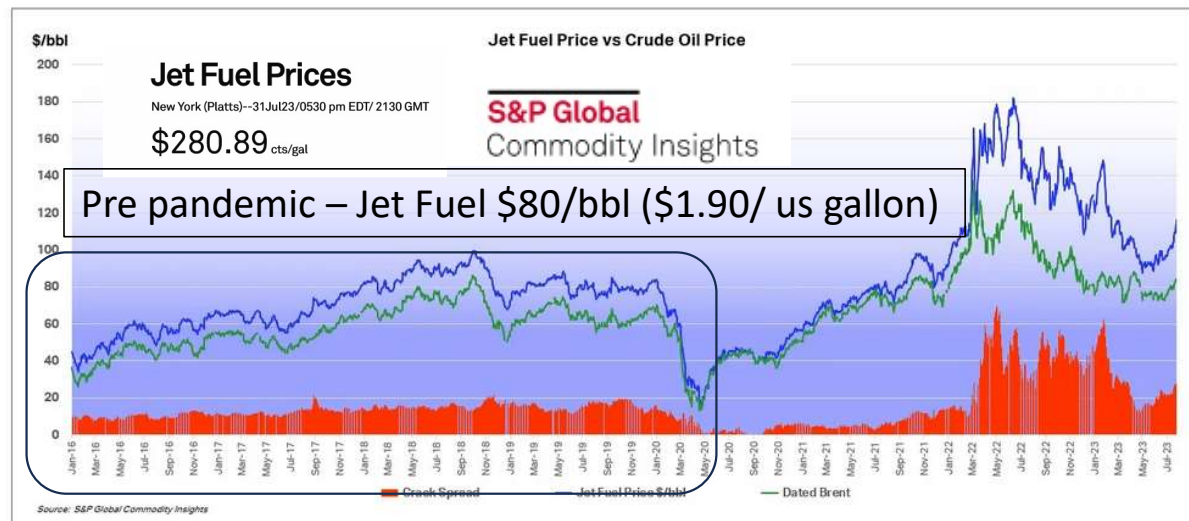
Electricity is the major (but not only) cost input to green hydrogen.

To make hydrogen

Electrolysis 44 kWh/kg H₂

Liquification 9 kWh/kg H₂

- 53 kWh/kg LH₂ total
- At \$.04/kWh JUST the electricity cost is \$2.12 per kg LH₂ - (€1.92)
- Efficient production of hydrogen needs baseload power 24/7
- Fluctuation in supply for many sources of green energy compounds the problem
- Hydrogen for aviation may be 'region Specific'



British Airways Plc

Annual Report and Accounts
Year ended 31 December 2020

Operating and financial statistics

Not forming part of the audited financial statements

Total Group continuing operations

Average fuel price (US cents/US gallon)

“Nozzle Price”

Year ended 31 December

2020	2019	2018
160.17	207.65	224.72

Cost Effective Hydrogen – Needed for Hydrogen Aviation Acceptance

Conclusions

- Aircraft are designed around missions
Hydrogen aircraft don't operate the same as SAF/ Jet Fuel aircraft
- Large aircraft + long routes = large volumes of hydrogen
..and have a large environmental effect...
- It may be easier to build the airplane than to get the fuel for it
 - Any future in hydrogen aviation will require new infrastructure... trucking in gray hydrogen will not support the needs
- We care about the environment... but at what cost?
 - For hydrogen aircraft to be adopted the fuel cost needs to be in line with Jet Fuel





About NOVAdev

NOVAdev is engaged in development of commercial aircraft and airborne systems that enable earth-friendly, zero-carbon aviation at transcontinental range and mainline scale.

The company's EcoFlight™ hydrogen-electric propulsion system and air transport designs incorporate practical and certifiable innovations for hydrogen fuel and electric propulsion.

Our vision is future generations enjoying the experience of safe, clean, comfortable air travel along with the family, cultural and geographical engagement it brings. Accordingly, we pair trusted technologies with pragmatic innovations in developing system solutions that define "next generation".

NOVAdev's team is made up of senior engineering leaders having backgrounds with the aerospace industry's most prominent aircraft and system manufacturers, and with expertise in aircraft structures and stress, aerodynamics and flight control, propulsion, hydrogen technologies, test and certification, commercial flight operations, and program management.

NOVAdev is an innovation company, applying novel solutions to aerospace engineering challenges.