HYDROGEN AIRCRAFT & AIR TRANSPORTATION ENERGY PATHWAYS

10/14/2014

STEPS Seminar

Guozhen Li

HYDROGEN AIRCRAFT

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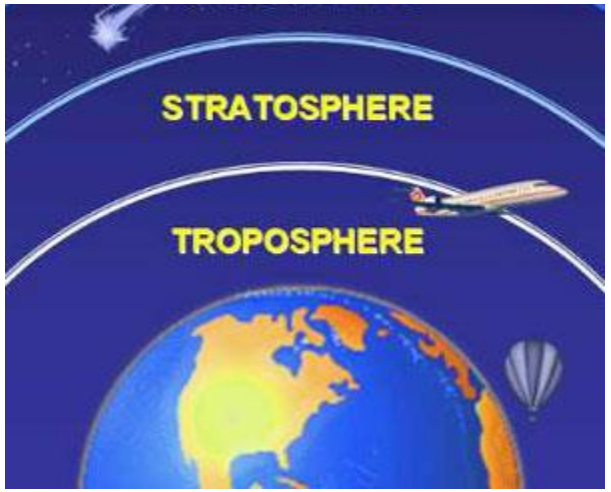
WHY HYDROGEN?

Air transportation is responsible of 5% of total anthropogenic radiative forcing (RF) effect

Air traffic is growing at a 5% annual rate; this will continue for another 20 years at least

Aircraft emit directly into the high atmosphere



WHY HYDROGEN?

Goals:

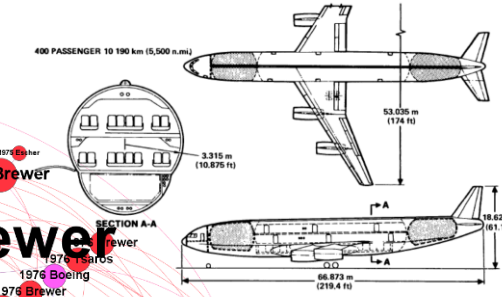
1. Relieve pressure on petroleum fuel
2. Reduce GHG/pollutant emissions

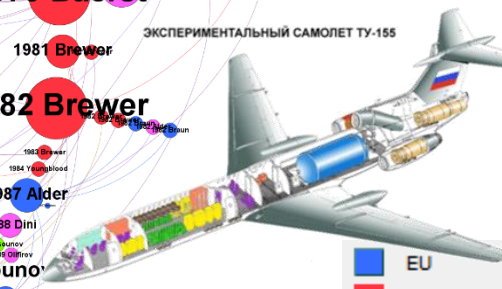
Hydrogen:

(Potentially) The ultimate solution!

HYDROGEN AIRCRAFT

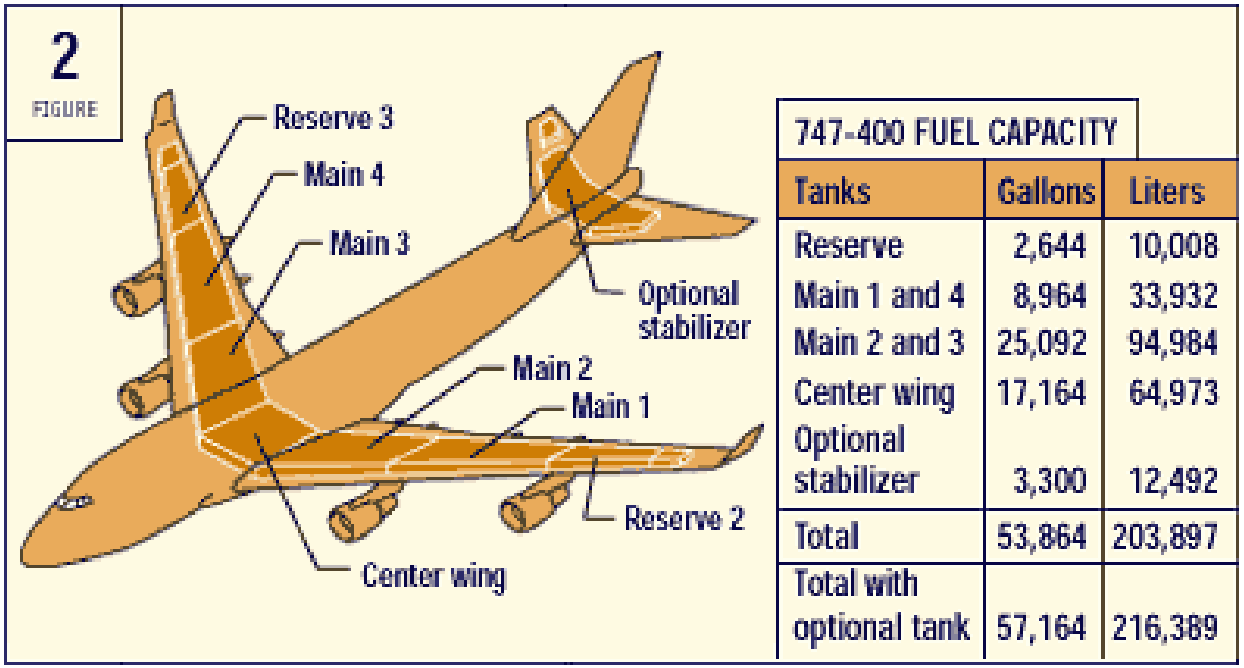
A history





HYDROGEN AIRCRAFT: CONFIGURATION

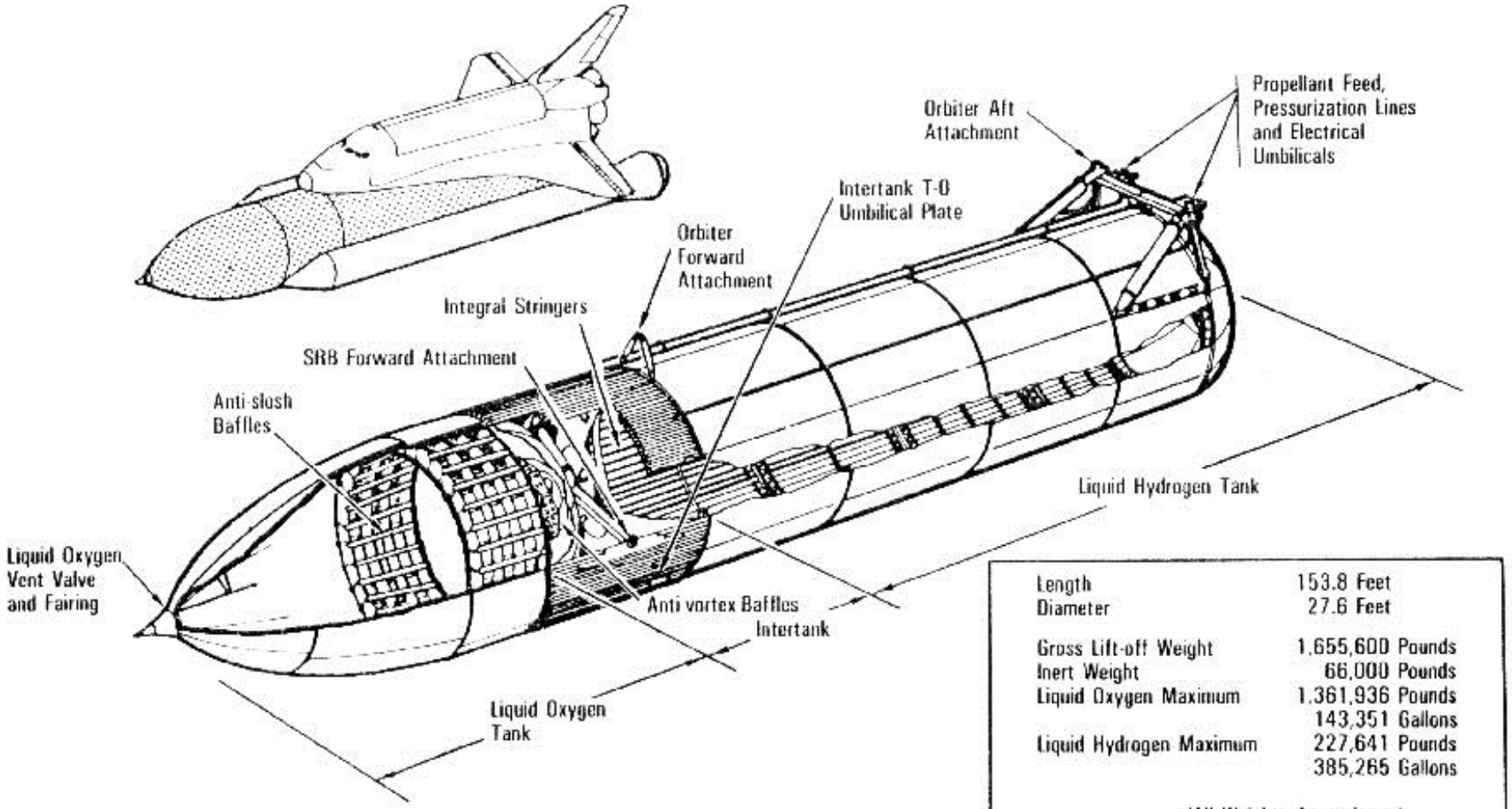
Where to store the fuel?



747-400 FUEL CAPACITY

Tanks	Gallons	Liters
Reserve	2,644	10,008
Main 1 and 4	8,964	33,932
Main 2 and 3	25,092	94,984
Center wing	17,164	64,973
Optional stabilizer	3,300	12,492
Total	53,864	203,897
Total with optional tank	57,164	216,389

HYDROGEN AIRCRAFT: CONFIGURATION



Lightweight External Tank

HYDROGEN AIRCRAFT: CONFIGURATION

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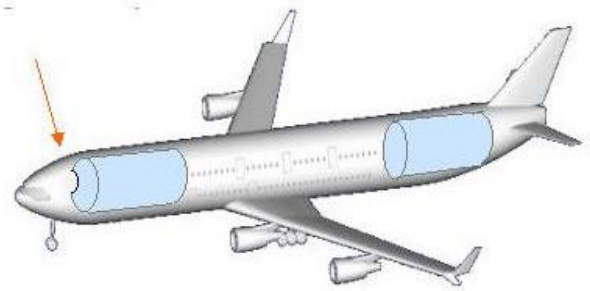


Cylindrical shape

In fuselage

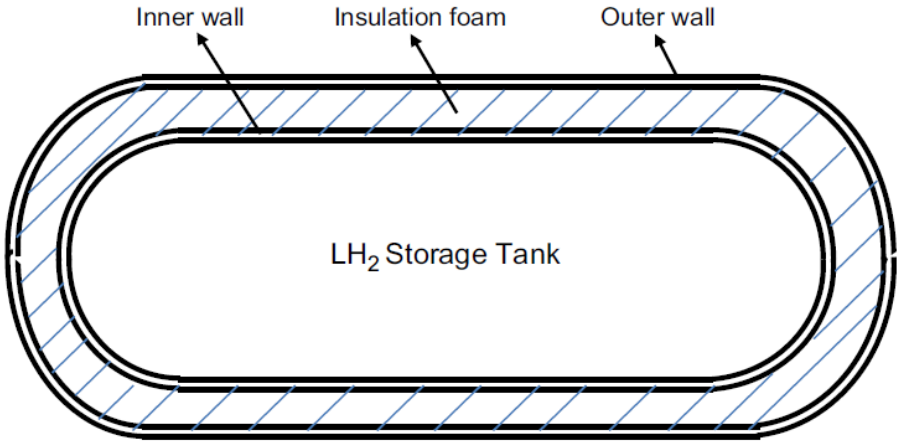
HYDROGEN AIRCRAFT: FUEL TANK

Cryogenic tank: 20K inside vs. 200~300K outside

The thank has to be insulated

Insulation technologies available:

- Multi-layer insulation
- Vacuum insulation
- Foam insulation



Foam insulation

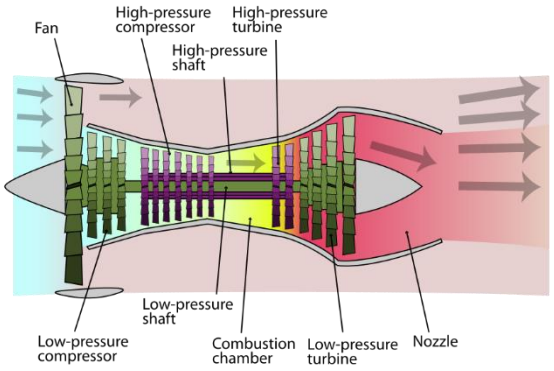
HYDROGEN AIRCRAFT: PROPULSION

How about the engine?

HYDROGEN AIRCRAFT: PROPULSION

How about the engine?

H2 has been shown to work well in modern jet engines.

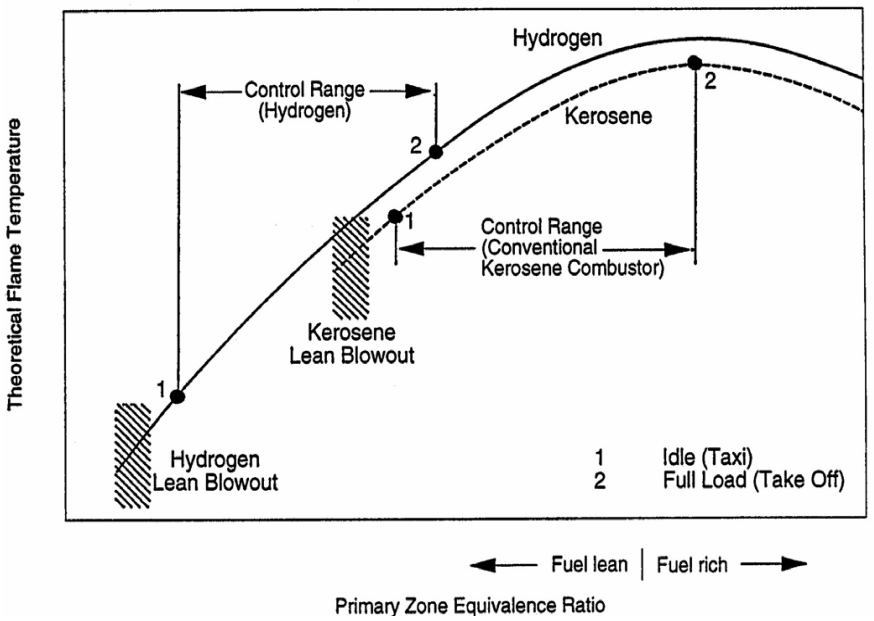


H2 offers some NOx reduction potentials:

- Lean burning
- High reaction velocity

  ↓ ↓ ↓

- Lower temperature
- Shorter time exposure to high temperature



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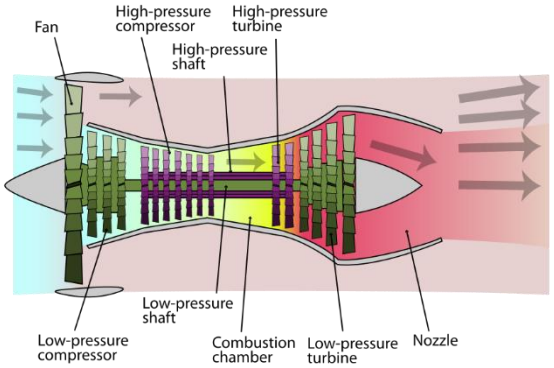

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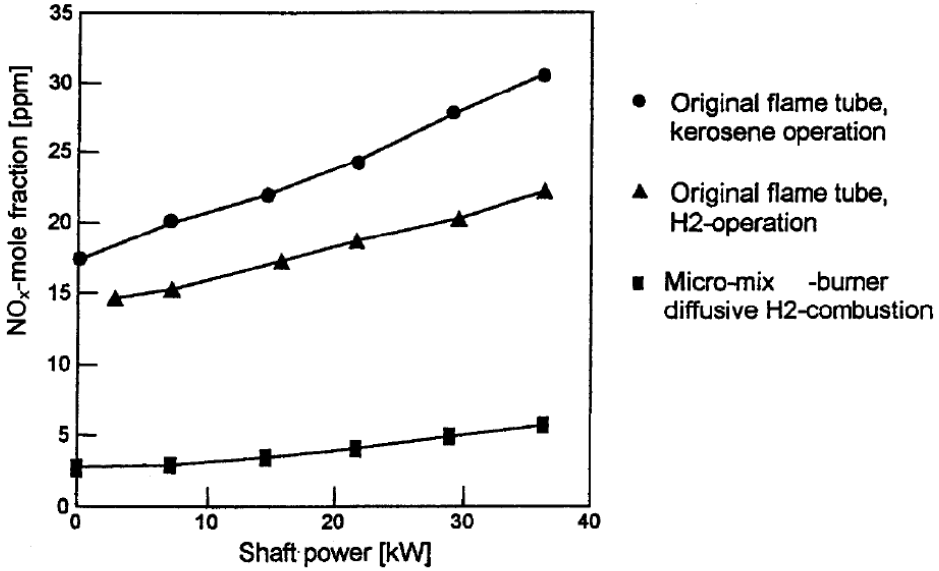


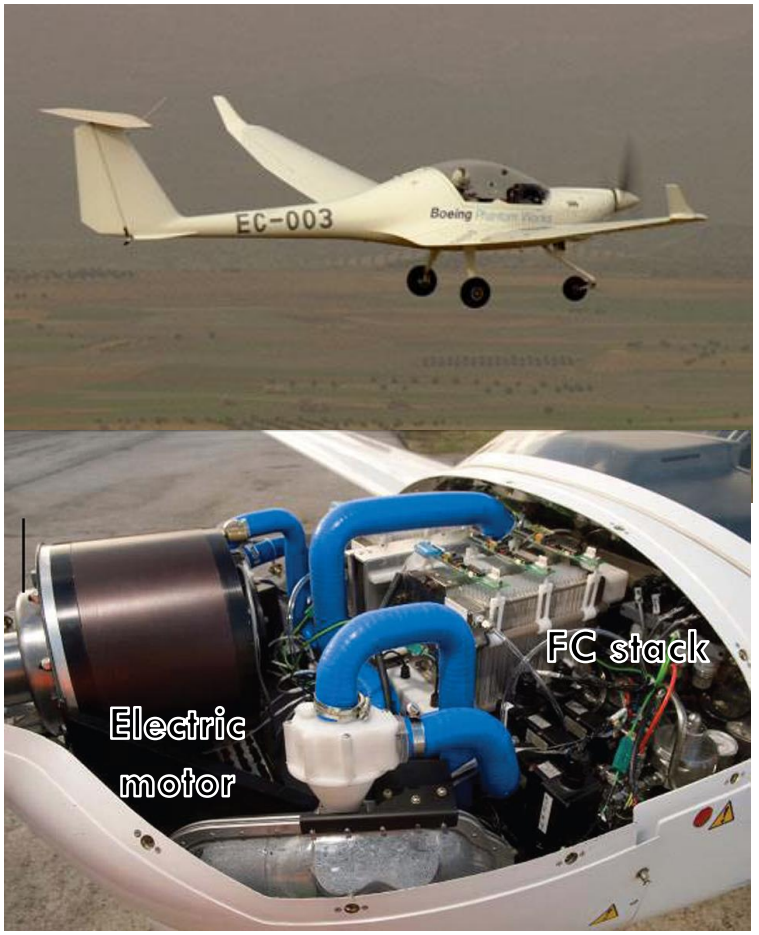
Fig. 4. Reduction of NO_x-emissions by converting a KHD T216 gas turbine to micro-mix combustion of hydrogen.

HYDROGEN AIRCRAFT: PROPULSION

How about the engine?

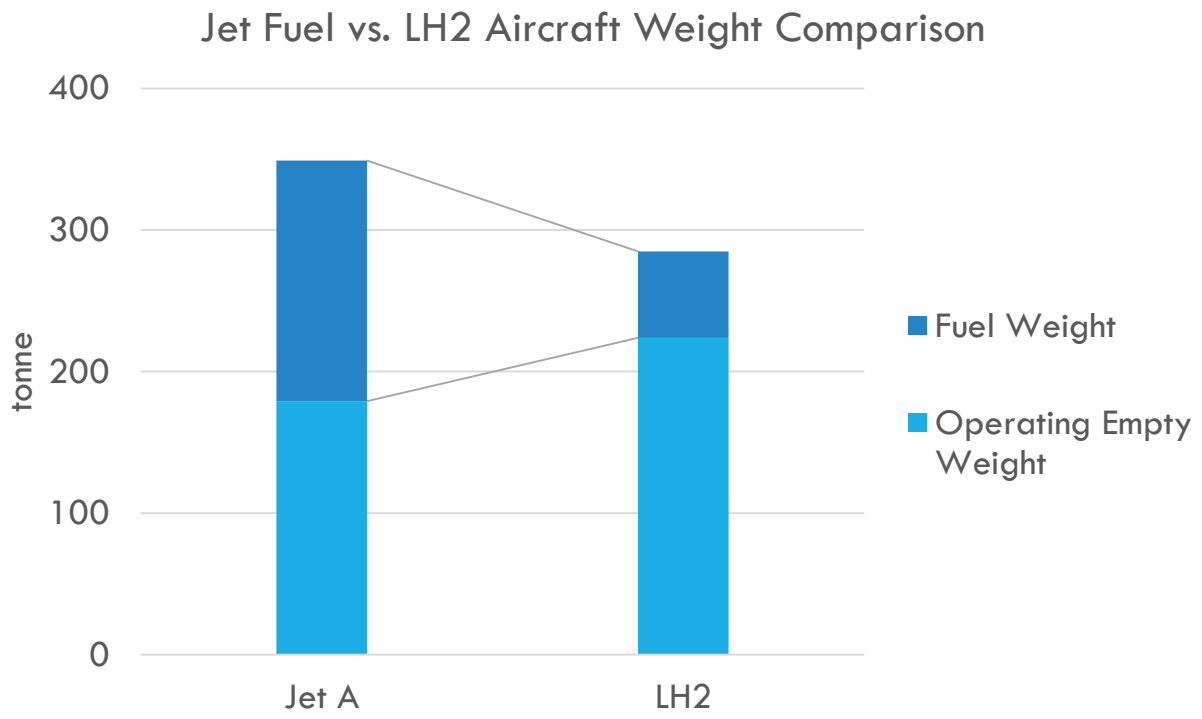
Fuel cell

First fuel cell demonstrator aircraft flew in 2008



HYDROGEN AIRCRAFT: WEIGHT

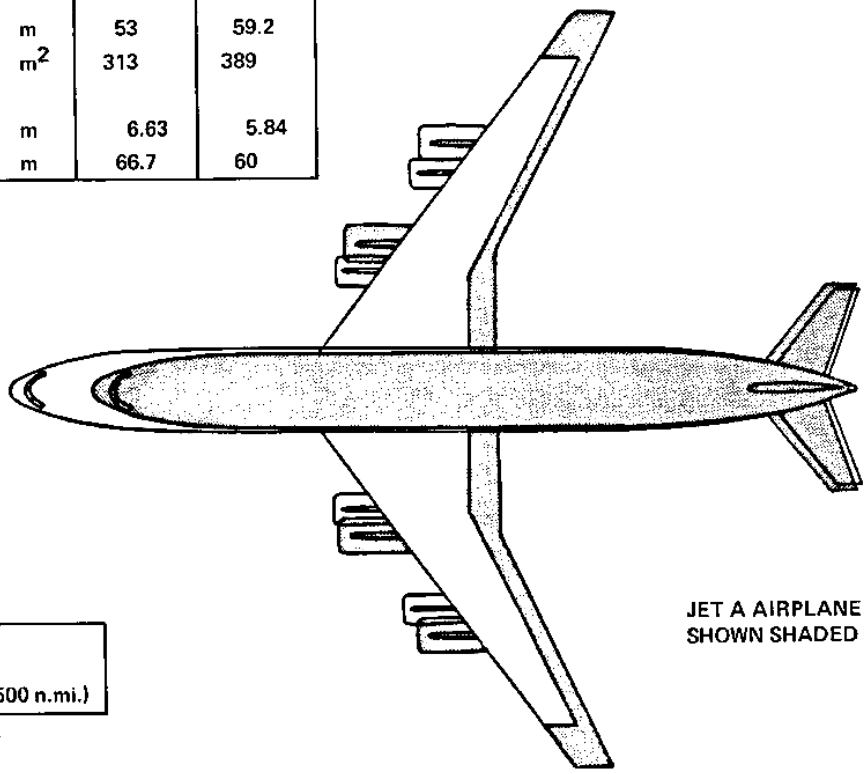
Heavier when empty, but lighter w/ fuel loaded



HYDROGEN AIRCRAFT: SIZE

Larger fuselage, Smaller wings

		LH_2	JET A
WING			
SPAN	m	53	59.2
AREA	m^2	313	389
FUSELAGE			
DIA	m	6.63	5.84
LENGTH	m	66.7	60

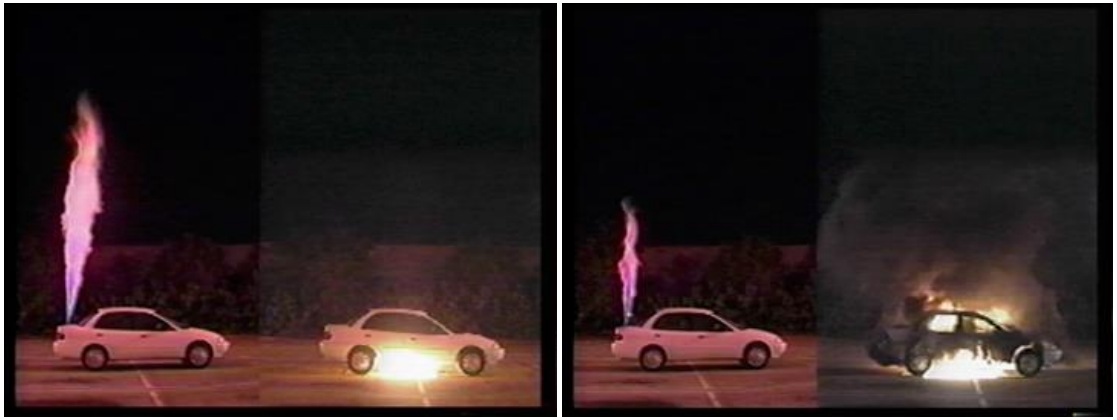


HYDROGEN AIRCRAFT: SAFETY

At least as safe as aircraft today.

Safer than jet fuel in some aspects:

- Hydrogen burns rapidly
- Hydrogen fire rises up instead of drip down
- Hydrogen fire produces less smoke and noxious products



Hydrogen Gasoline Hydrogen Gasoline

HYDROGEN AIRCRAFT: EMISSIONS

CO2, CO, HC, Soot… → 0

NOx can potentially be reduced by 80%

H2O emission: ↗ 2.5x

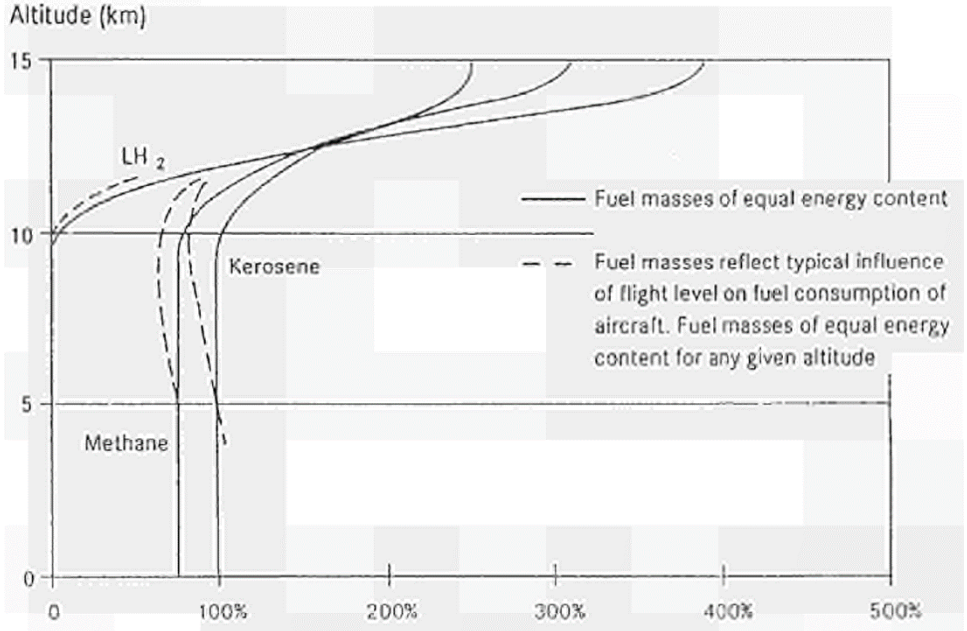


Fig. 10.14 Greenhouse effect of various fuels.

HYDROGEN AIRCRAFT

The aircraft is not the problem.

Real challenge is: the fuel supply system

HYDROGEN FUEL COST

How big is the demand?

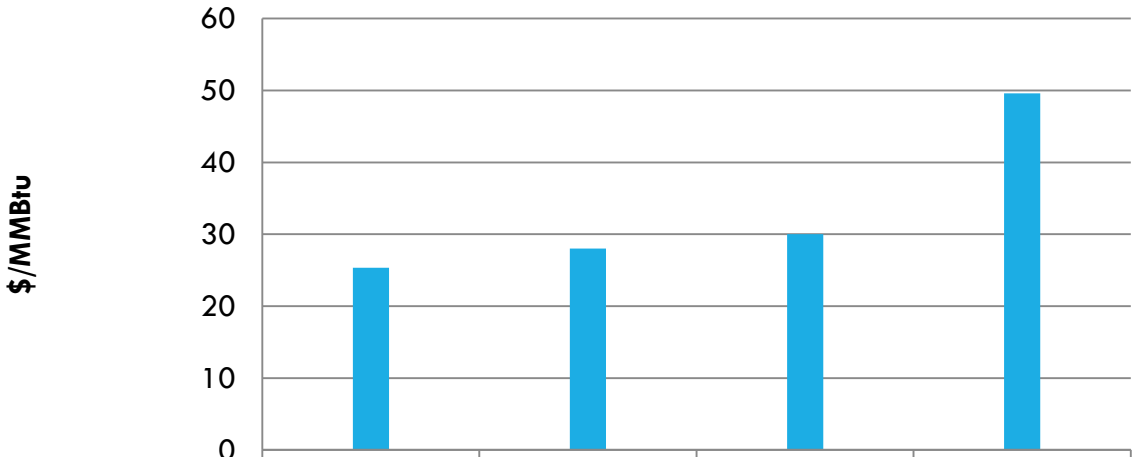
- In 2012, SFO sold 896M gallons jet fuel
  → 2.45M gallons jet fuel /day
  → 2555 tonnes LH2 /day
  (assume 5% annual growth for 20 years, and 2% annual growth for 20 years: ~4x)

→ 10K tonnes LH2 /day in 2050s

HYDROGEN FUEL COST

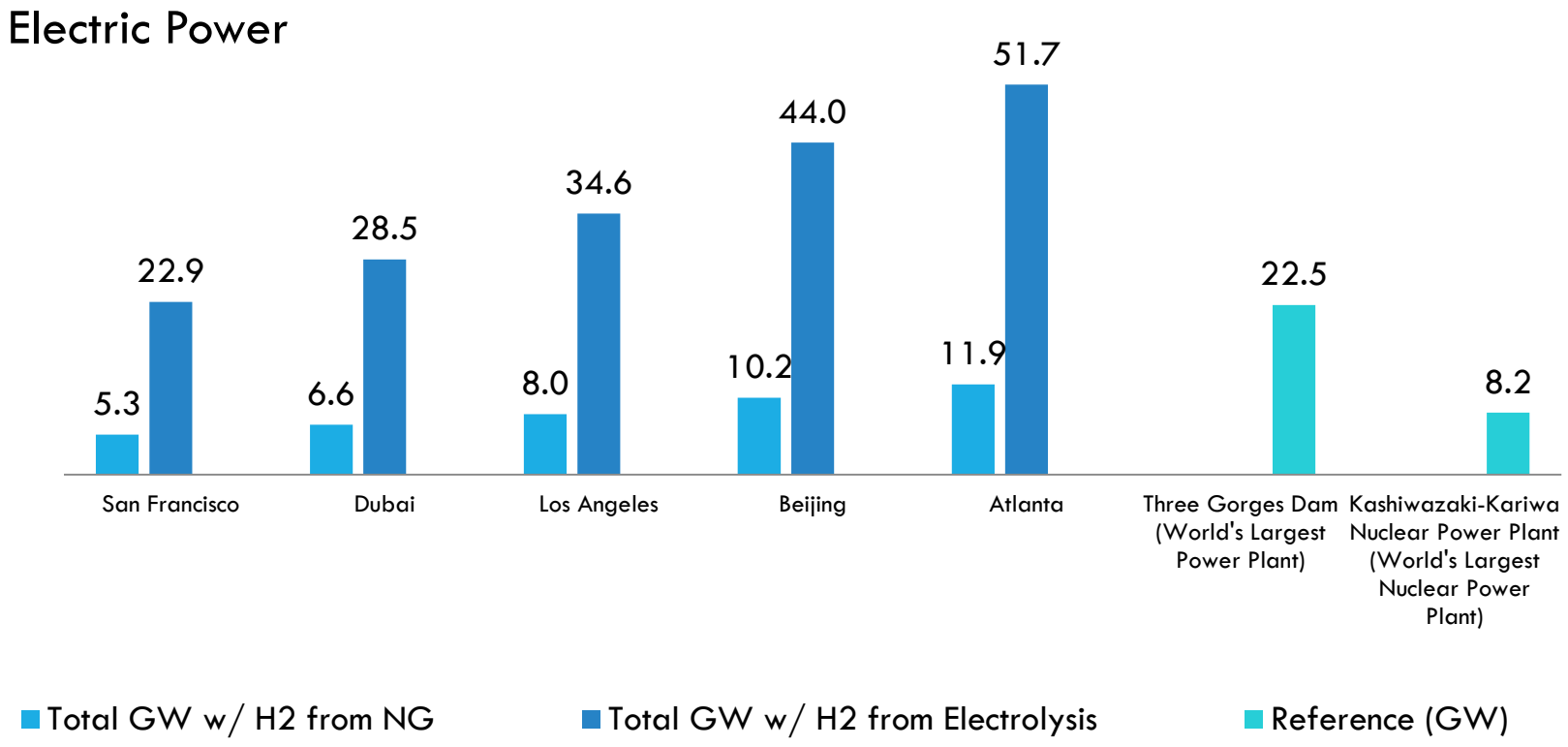
Good news

- LH2 price ~$2.9/kg (produced from NG), or ~$4.8/kg (from electrolysis)
- These prices are competitive with jet fuel



	Jet fuel 2012	Jet fuel 2040	LH2 from NG	LH2 from electrolysis
$/MMBtu	25.3	28.0	30.0	49.6
% Jet fuel 2012	100%	110%	118%	196%
% Jet fuel 2040	91%	100%	107%	177%

HYDROGEN FUEL SYSTEM IMPACTS

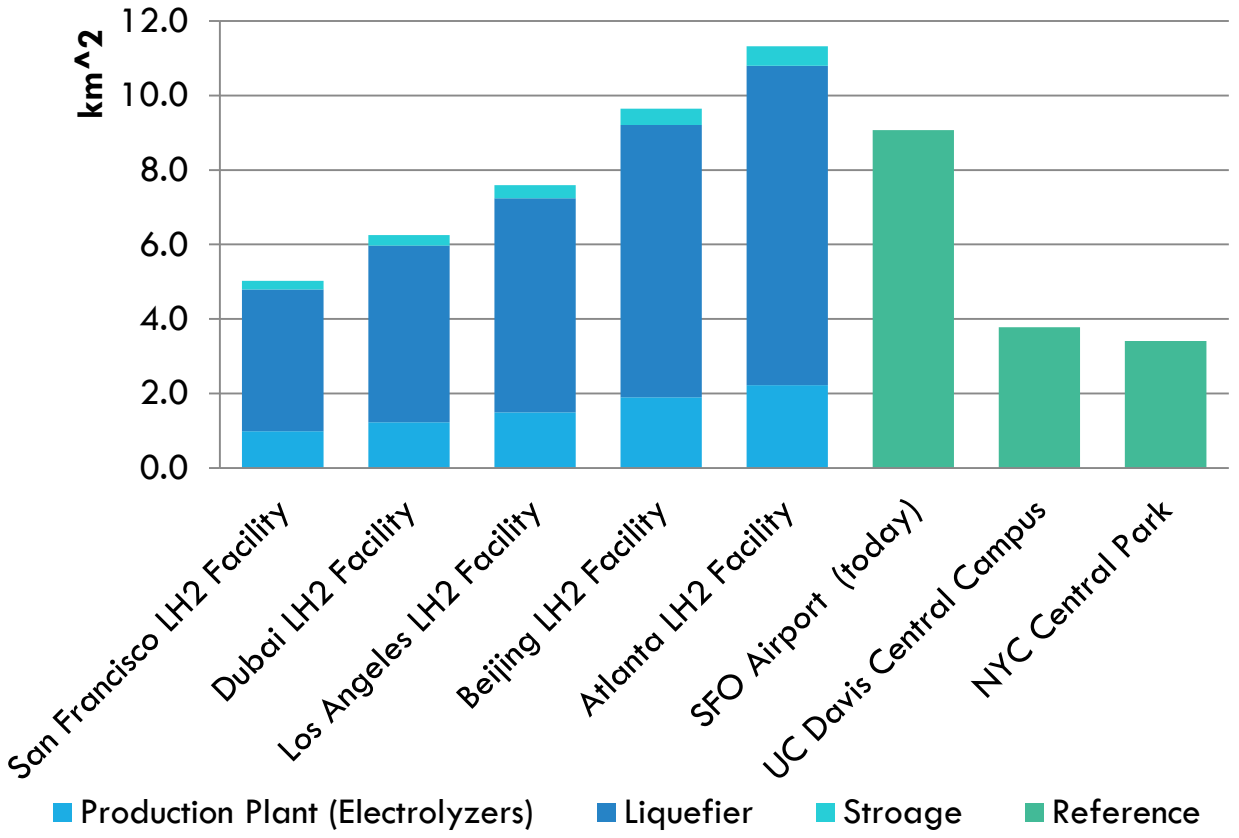


*Considering the energy consumption rate of a Boeing 747, it's a 0.14GW widget!

*1GW for 1 hour = powering an average California home for 2 months

HYDROGEN FUEL SYSTEM IMPACTS

Land



HYDROGEN FUEL SYSTEM IMPACTS

Land

AIR TRANSPORTATION ENERGY PATHWAYS

Where are we now?

☹ Aviation fuel essentially unchanged since a century ago

☹ Things change extremely slow in the air transport industry

☺ Airplanes are getting more efficient

☺ Airline operations are enhancing efficiency

☹ Air traffic is growing fast

☺ Drop-in biojet fuel is being recognized

AIR TRANSPORTATION ENERGY PATHWAYS

Where are we heading?

More efficient conventional aircraft
- On market
- Gaining popularity

Bio jet
- Early commercialization
- Receiving certification

LNG
- In design
- A few engine tests
- Likely to appear and go into tests around 2050

LH2
- Mostly conceptual
- A few engine tests

AIR TRANSPORTATION ENERGY PATHWAYS

Biojet

☺ Drop-in

- No changes to aircraft or airport facility

☹ Expensive

- ~50% more expensive than jet fuel

☹ Blend limit

- Must meet jet fuel standards

AIR TRANSPORTATION ENERGY PATHWAYS

LNG

- ☺ Inexpensive feedstock
- ☺ Greener than jet fuel
- ☹ New infrastructure needed
- ☹ Still carbon-based

AIR TRANSPORTATION ENERGY PATHWAYS

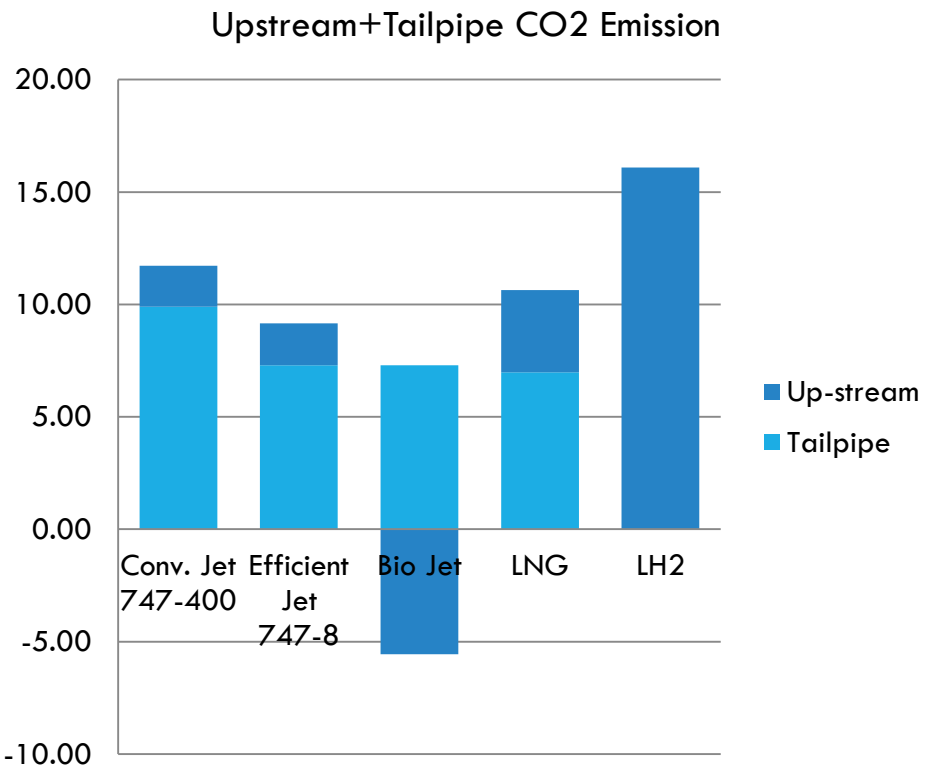
LH2

☺ No carbon

☹ Expensive

☹ New infrastructure needed

(?_?) Can H2 be produced "greenly"



THANK YOU

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