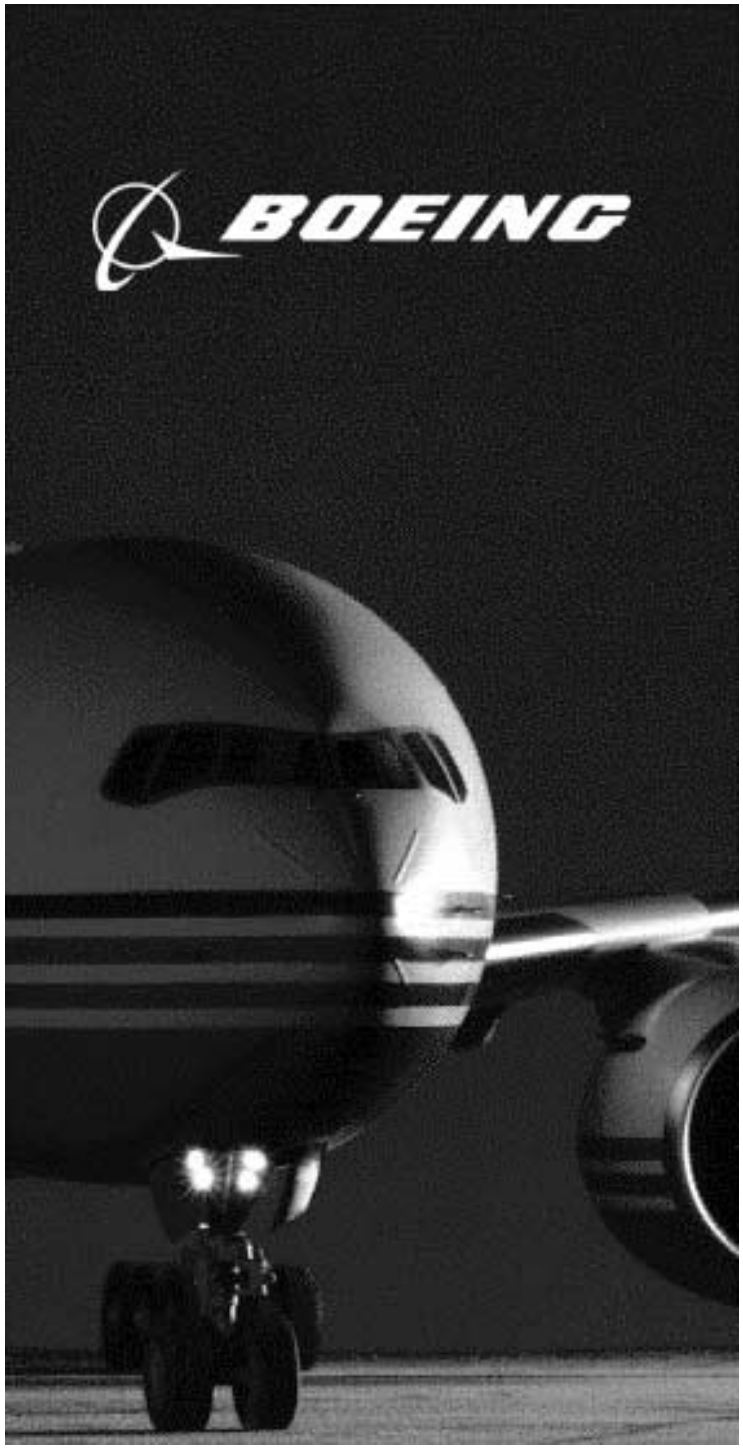

Commercial Airplanes
Hydrogen Fueled Airplanes

Presented to:

Hydrogen Production and NW Transportation

Seattle, WA

June 16, 2003

Dave Daggett
Product Development

Agenda

- Overview
- H_2 fuel and airplane design
- Supporting technologies
  - Fuel tank (weight, insulation, altitude, filling)
  - Engine (heat exchanger, combustor size, NOx)
  - Airport infrastructure
  - Environmental (contrails, ozone)
- Current hydrogen projects
- Research Opportunities
- Summary

BOEING

Overview

- **Boeing is committed to developing environmentally preferred technologies.**
- **There are many LH_2 airplane pros and cons.**
- **Production and infrastructure issues are an over-riding concern.**
- **Boeing is pursuing promising hydrogen projects.**

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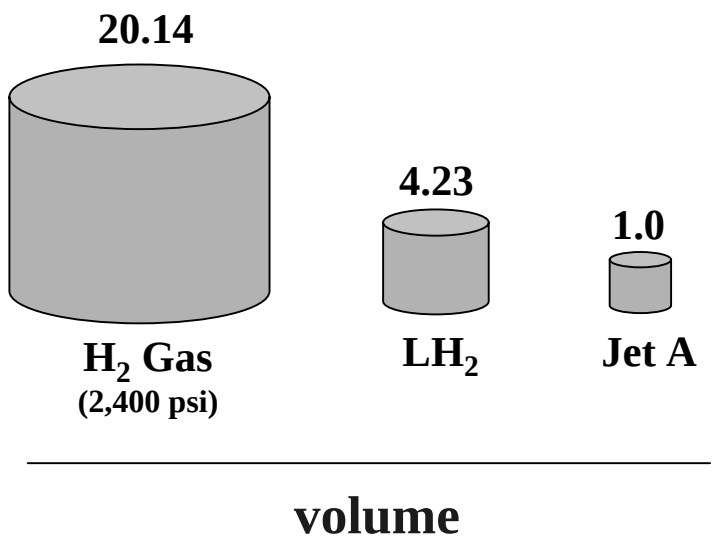
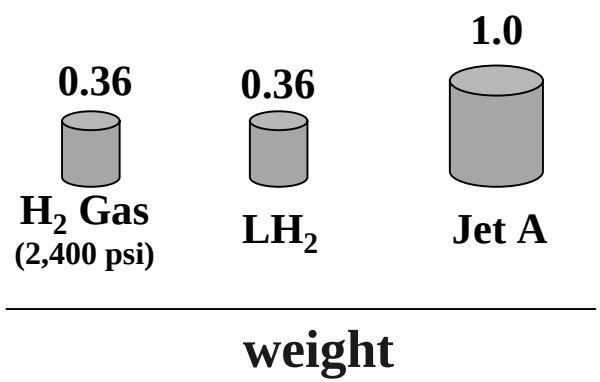
Fuel weight and volume impact airplane design



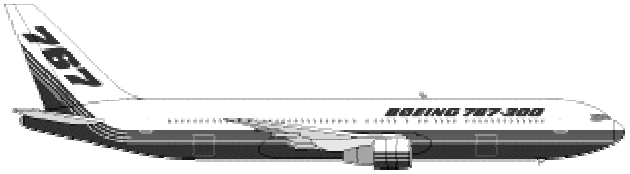


Equivalent Energy

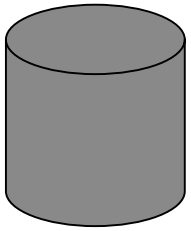
Compared to hydrogen, jet fuel is easily stored on present airplanes

BOEING

Larger fuel tank is required for hydrogen



24,000 Gallons
3,200 FT^3



Jet Fuel

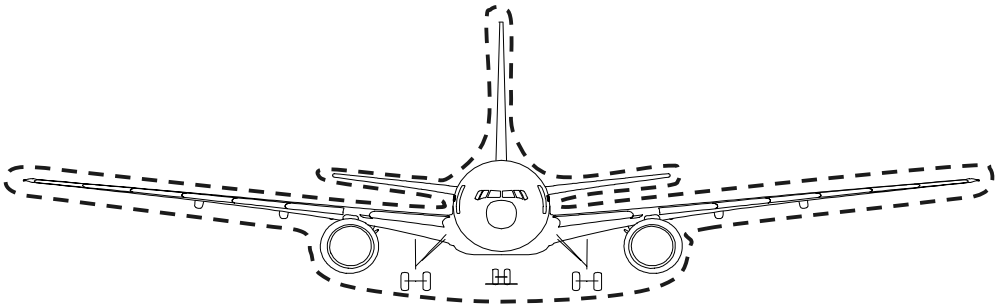
=

13,500 FT^3

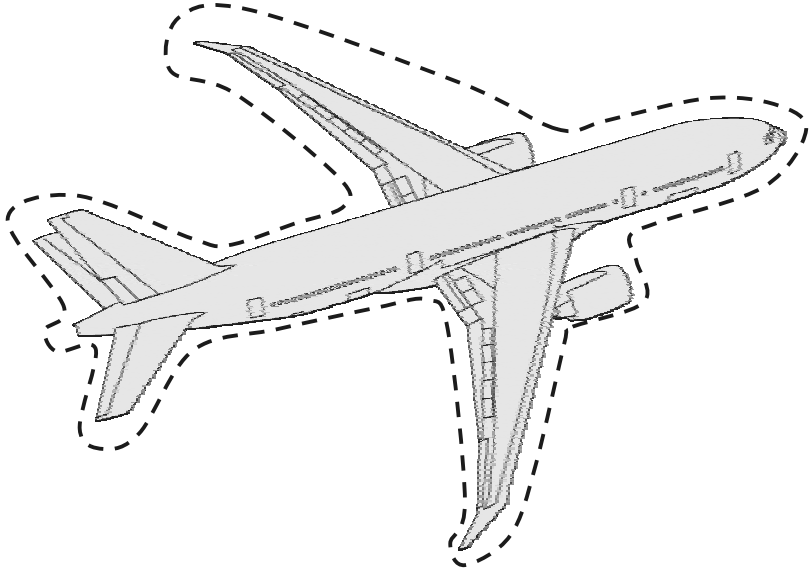
4.23 times larger area

LH_2 Fuel

An efficient airplane design should have both small frontal and surface areas

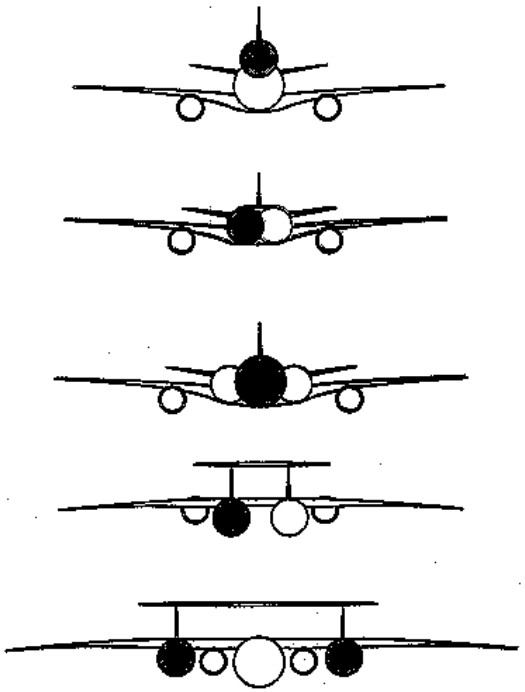


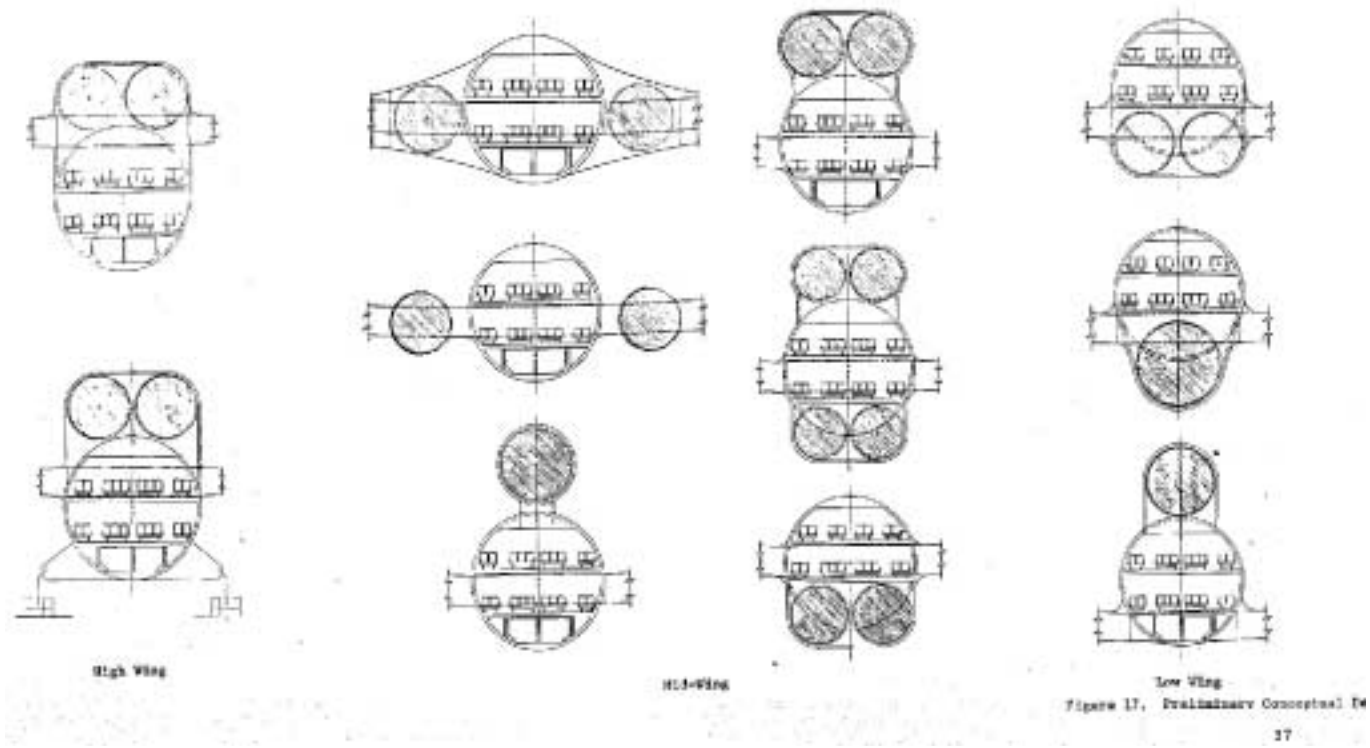
Frontal Area



Surface Area

Integrating a large cylindrical LH_2 fuel tank on an airplane is a challenge





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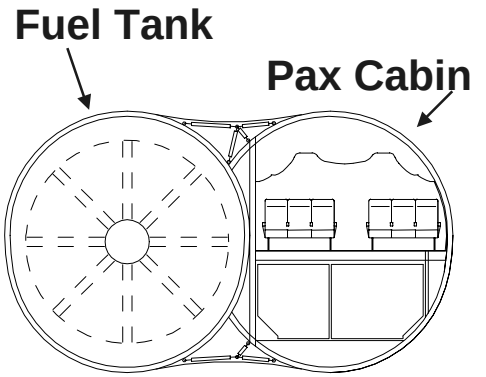
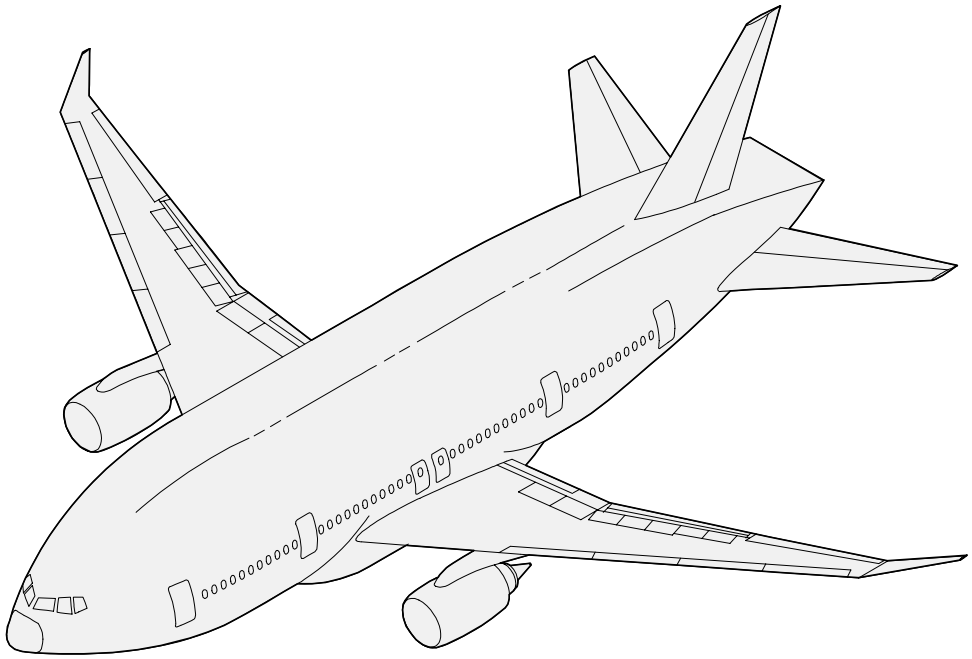
Large side LH_2 fuel tank is an option
(about the same size as the fuselage)

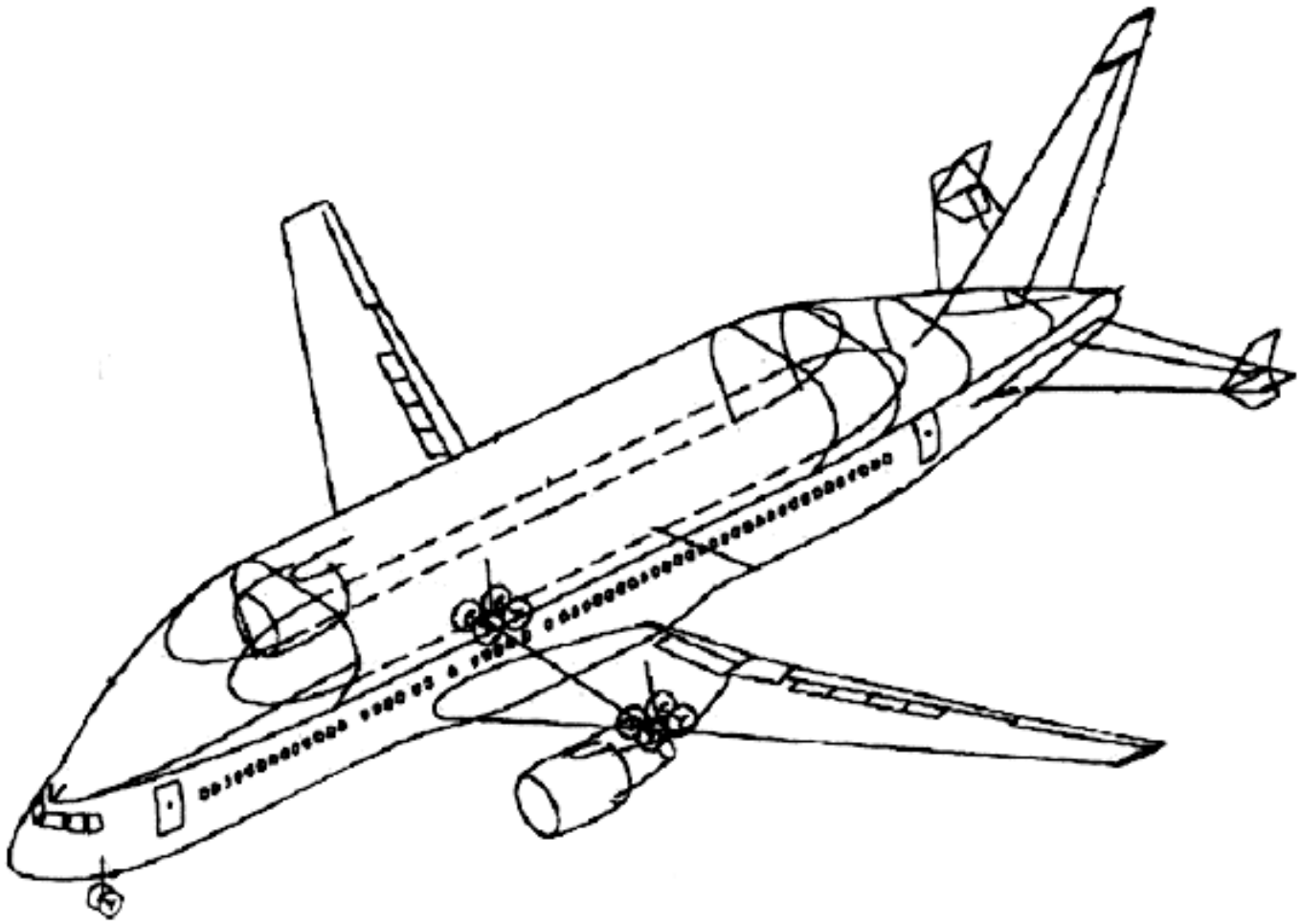


Airplane Cross Section



Liquid
Hydrogen (LH_2)
Airplane

Mounting LH_2 fuel tanks on top preserves passenger cabin space



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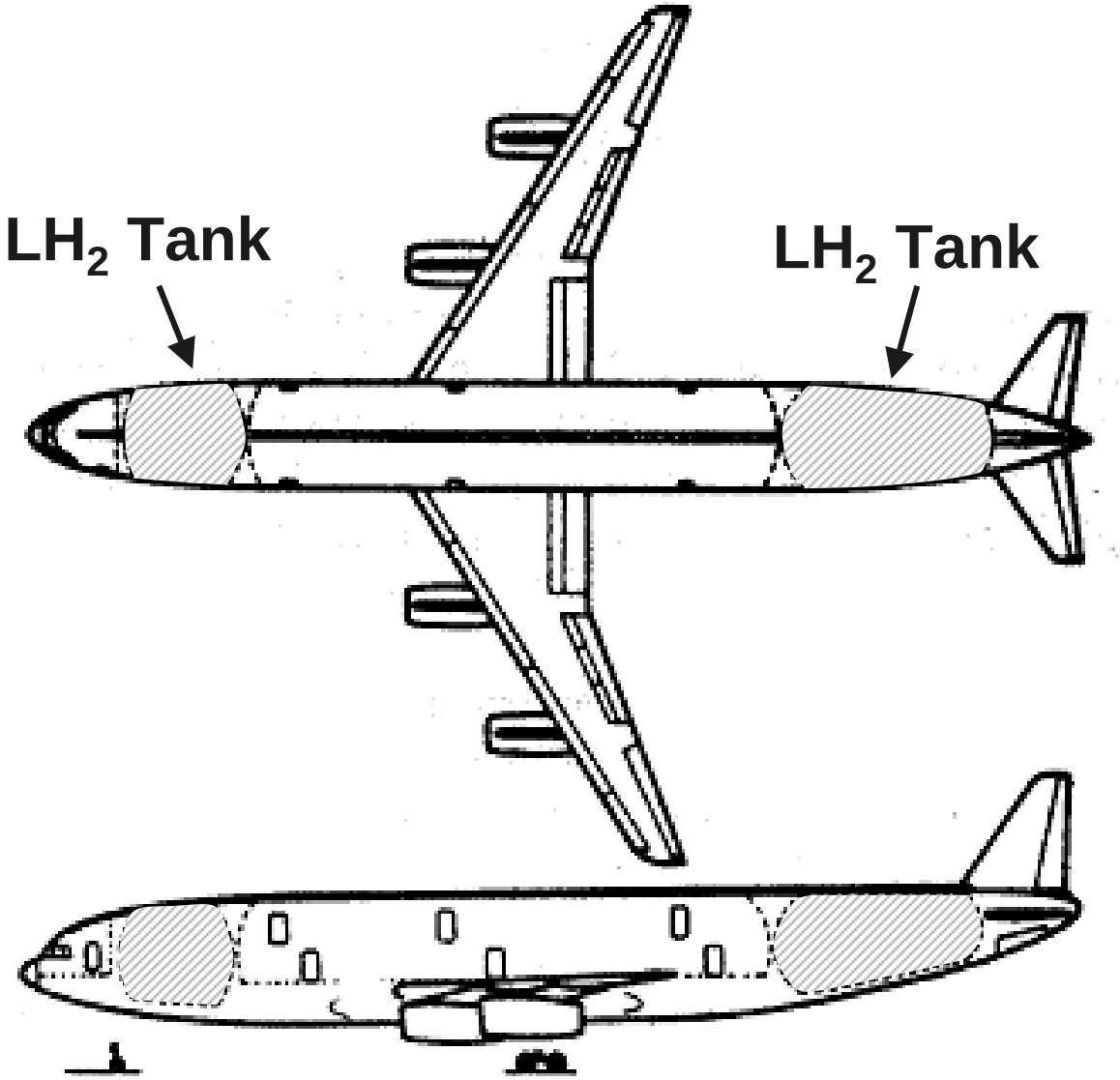
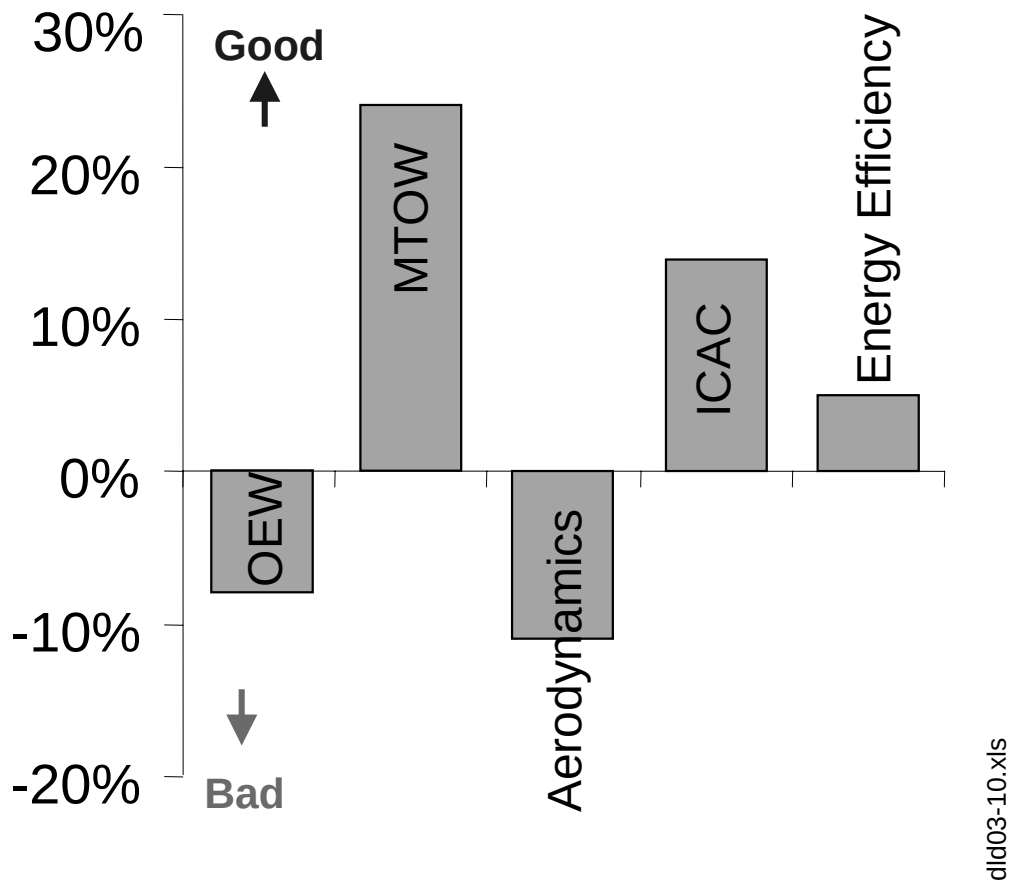
Alternate configuration is to have forward and aft LH_2 tanks



Typical LH_2 Airplane performance

- **Heavier empty weight (OEW)**
- **Lighter takeoff weight (MTOW)**
- **Increased drag**
- **Higher initial cruise altitude capability (ICAC) and climb**
- **Slightly better energy efficiency**



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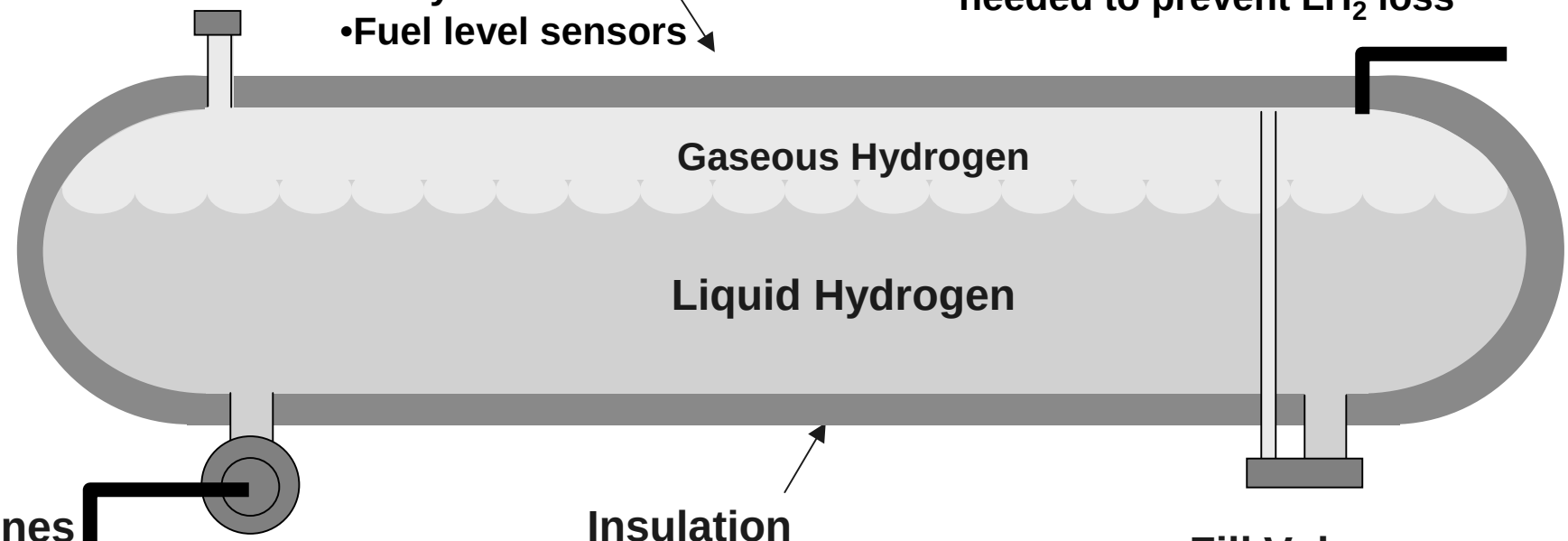
Fuel tank design will be a challenge

Tank
- Composite?
- Non-permeable
- Thermal & pressure cycling
- 20+ year life
- Fuel level sensors

Pressure Regulation
- Outside pressure fluctuations over flight envelope
- Constant internal pressure needed to prevent LH_2 loss

Vent and Relief
- Venting flammable gas



Fuel Lines
- Large dia.
- Route outside cabin

Pump
- Long lived pump
- No cavitation

Insulation
- Limit boil-off when parked
- Prevent air liquifaction
- No frost accumulation
- Withstand shock/stresses
- Thermal cracks

Fill Valve
- Time to fill warm tank
- Special fill equip. and training
- No air present

- Public Perception – acceptance of fuel tank overhead?

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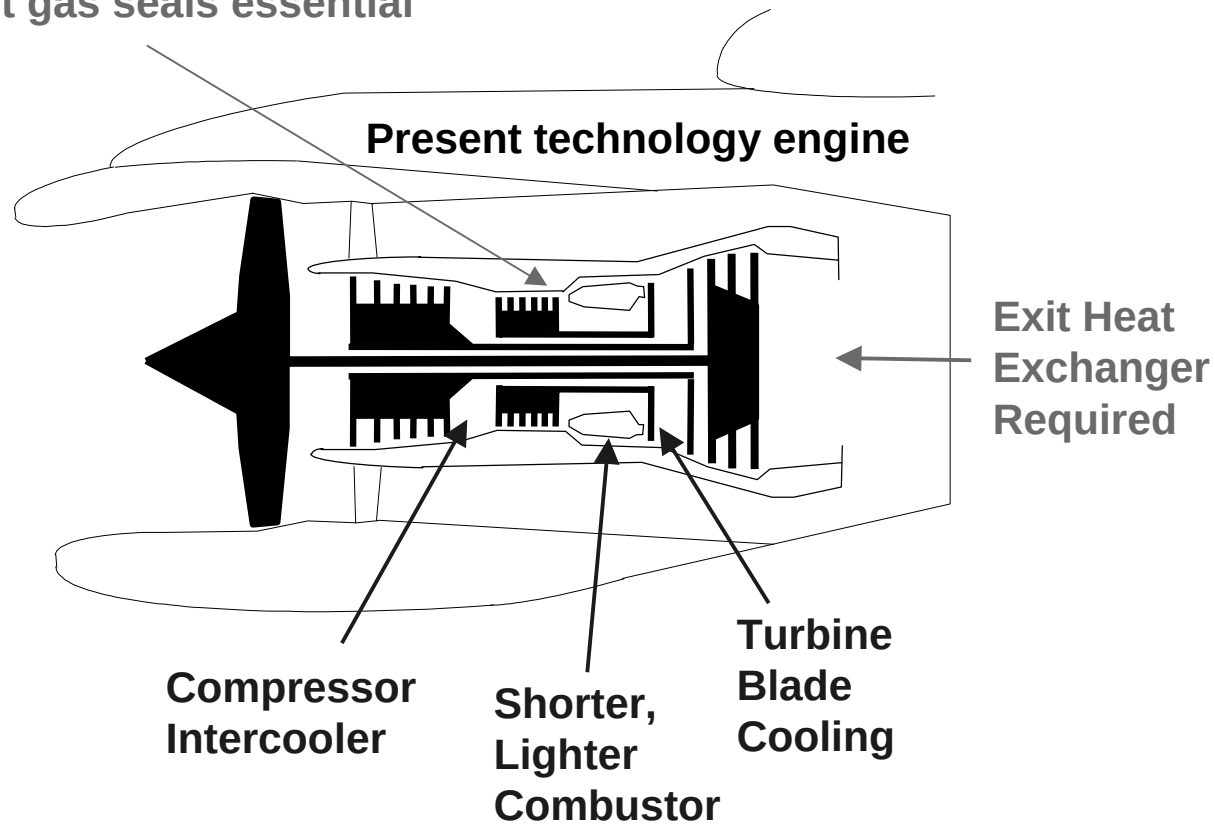
Specially designed LH_2 fueled engines may have improved performance

- H_2-tight gas seals essential



- *5-10% improvement in specific fuel consumption*
- *Improved life and reduced maintenance possible*
- *Lower NOx emissions*

Hydrogen can be safe*

LH_2 tanks are less susceptible to damage

- Smaller frontal area for impact
- Protected by more structure
- Designed for higher pressure

Fuel properties

- No detonation
- Flame front travels upwards
- Brief fire duration
  (15 sec for 400 pax airplane)
- Low flame radiation
- H_2 doesn't pool

* NASA-Glenn CR-165525 & CR-165526

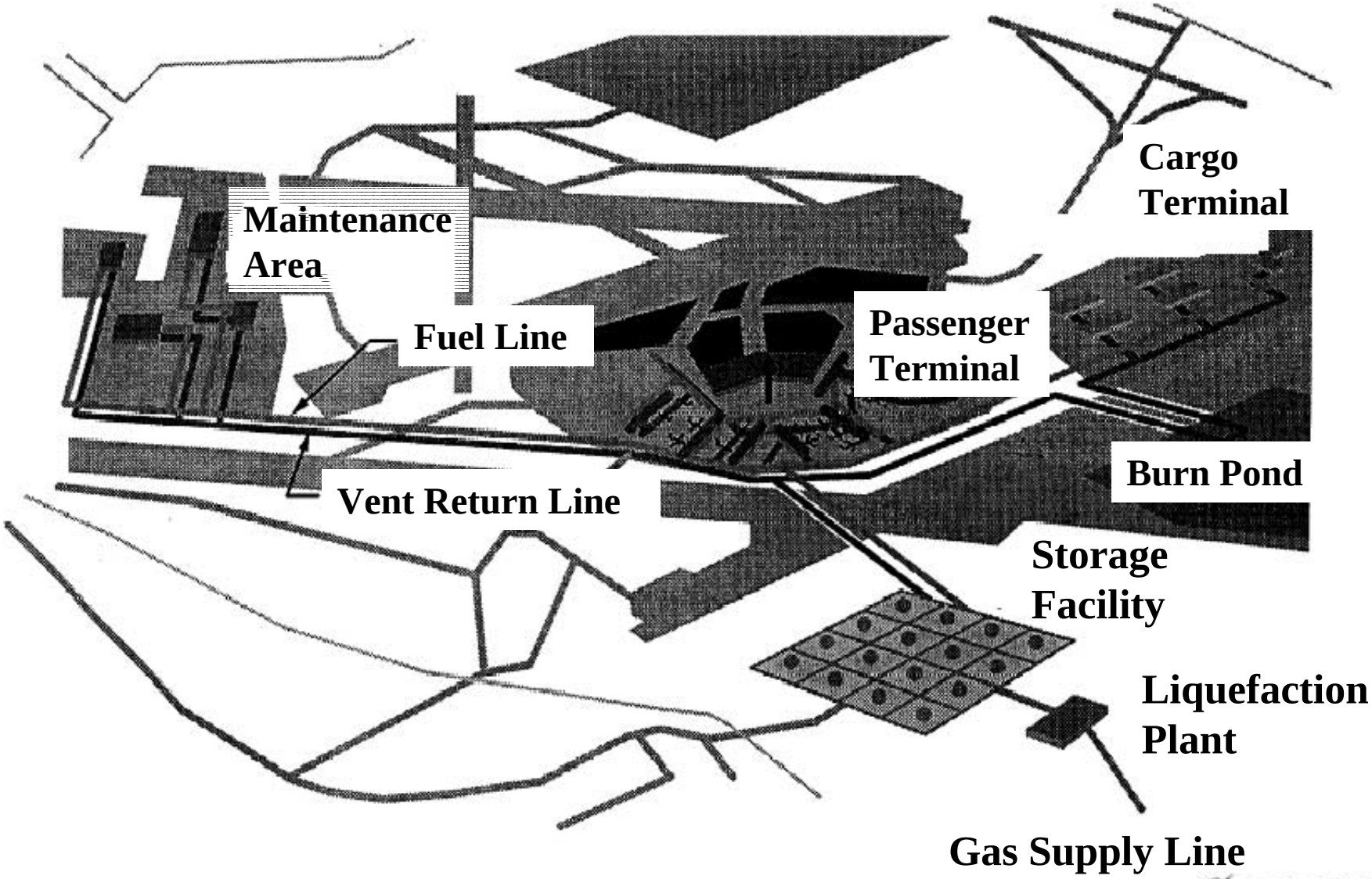
- Airplanes -

- Automobiles -

Hydrogen Car | Gasoline Car

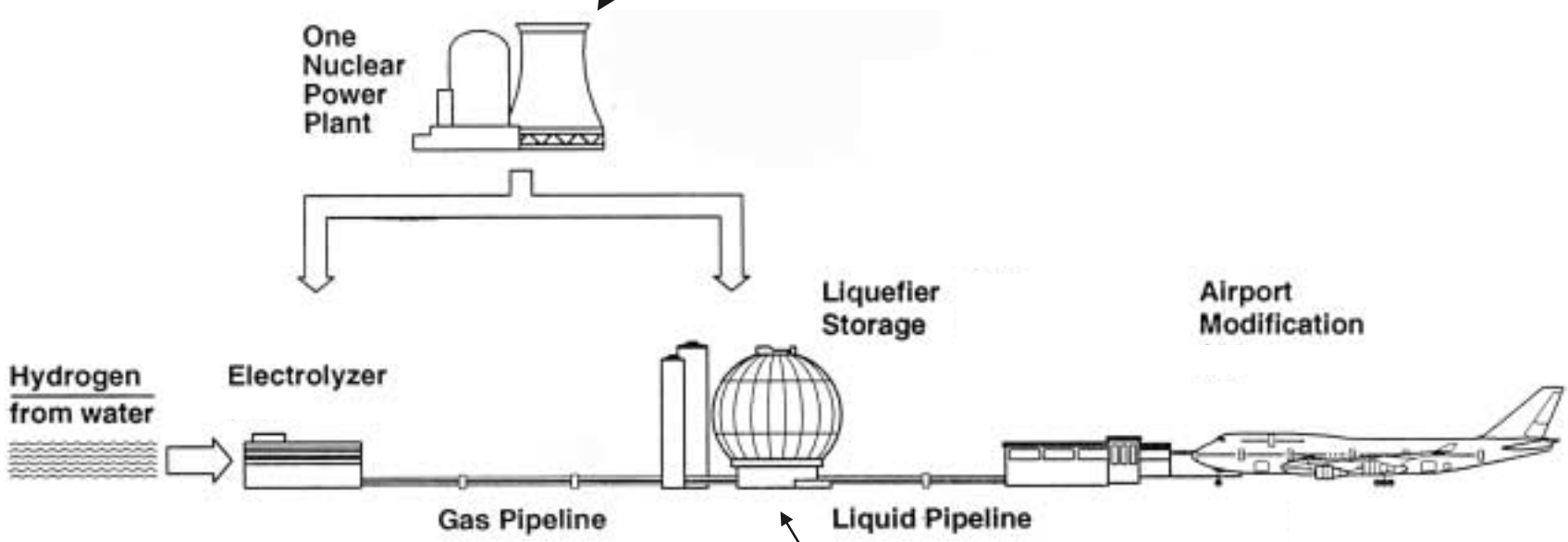
Pooling gasoline

New airport infrastructure will be required for hydrogen fuel



For zero CO_2 emissions, hydrogen fuel infrastructure cost for airports is very high

Nuclear reactors or high efficiency solar energy collector would be required to eliminate CO_2 emissions from the manufacture of hydrogen.

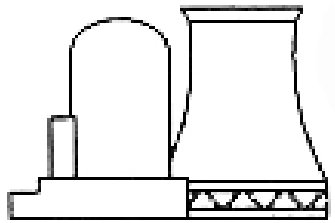


An all new airport fuel delivery system would be needed with gas recovery at every gate.

Cost of hydrogen must be cost competitive with Jet-A fuel

One gallon of Jet-A

$1.00



Nuclear
3.7-5.5¢ kWh

$2.30*

Wind
4-6¢ kWh

$2.50*

Other:
- **Coal**
- **Natural Gas**
- **Solar**
- **Bio**
- **Future ?**

$ _____

*** Equivalent energy to 1 Gallon Jet-A fuel (2.5 lb. H_2 gas)**

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Hydrogen life cycle environmental issues

Likely Environmental Gains:

- **Zero CO_2 emissions**
- **Zero HC & CO emissions**
- **No smoke**
- **Reduced NOx**
- **Zero particulates/aerosols**

Environmental Uncertainties:

- **H_2 and higher H_2O emissions**
  - **any notable atmospheric impacts?**

Implementation Challenges:

- **CO_2 emissions from Hydrogen production**
  - **Nuclear power required?**
- **Airport Storage**
  - **Significant land space required?**

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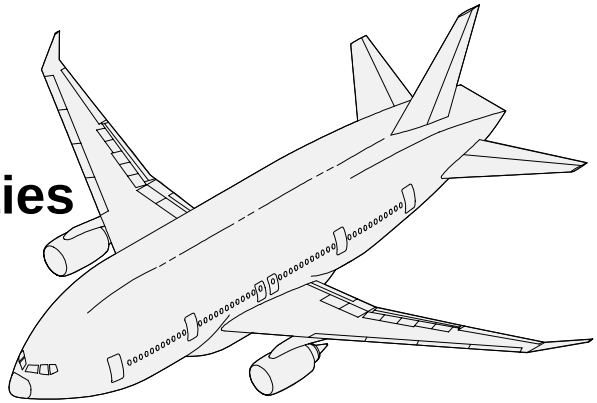
Hydrogen Airplane Summary

Advantages:

- **Reduced emissions**
- **Lower takeoff weight**
- **Higher altitude capability**
- **Engine design opportunities**
- **Better energy efficiency**
- **Oil independent fuel?**
- **H_2 fits well with PEM fuel cell systems**



Liquid Hydrogen Study Airplane

Challenges:

- **4X larger fuel tanks**
- **Higher drag**
- **Higher empty weight**
- **H_2 production issues**
- **New infrastructure**
- **Cost**
- **High technical risk**
- **Passenger acceptance**
- **High altitude effects**

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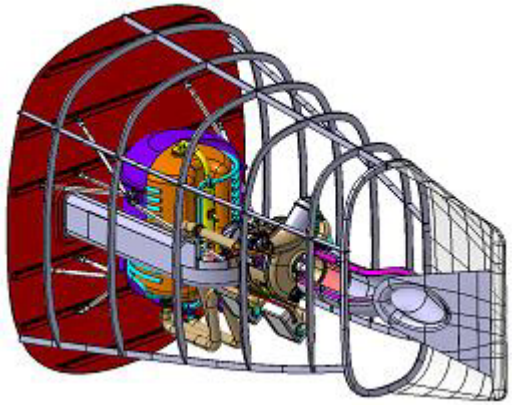
Until LH_2 fueled airplane challenges are solved, focus is on other applications

Un-manned Aerial Vehicles

Airships



Fuel Cell APU
(reformed jet fuel)

PEM Demonstrator Airplane

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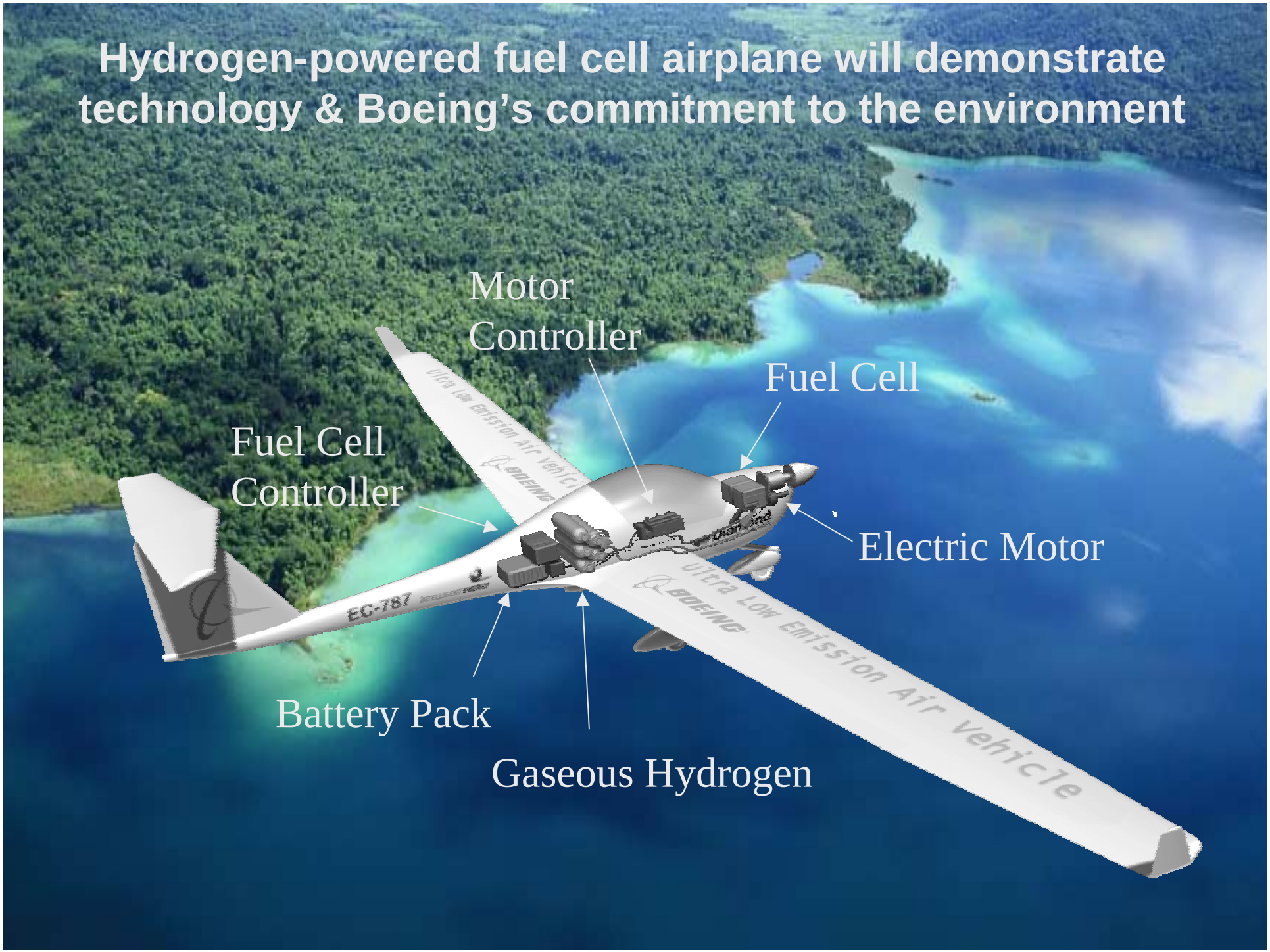
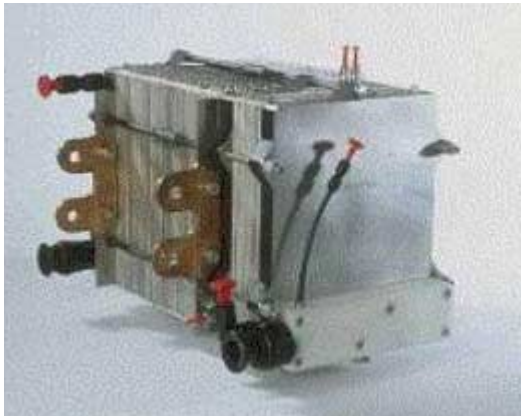
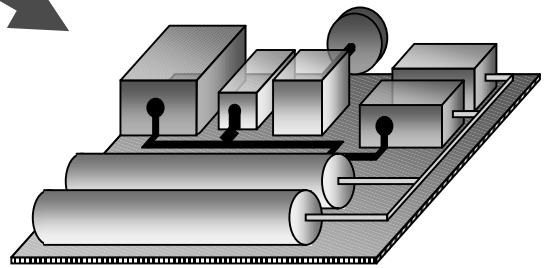
Hydrogen-powered fuel cell airplane will demonstrate technology & Boeing's commitment to the environment



Demonstrator airplane will ease transition of fuel cells into commercial airplanes

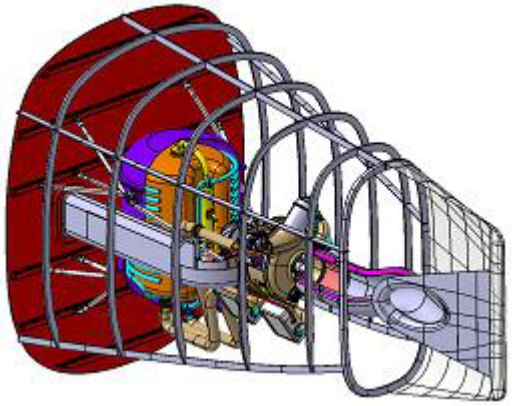


Lab PEM Unit



Bench Test

20 kW Flight Test



130 – 600 kW Production SOFC Units

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Animation of a 2015 solid oxide fuel cell APU (reformed Jet-A)

Boeing Commercial Airplanes creates sustainable profitable growth with environmentally preferred products, processes, and services.

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Hydrogen research opportunities

(from an aviation perspective)

- **Hydrogen production in an environmentally friendly, cost effective manner.**
- **Infrastructure required to get the hydrogen to the airplane**
- **LH_2 storage in a small, light-weight, long-lived system.**
- **Total system environmental impact assessment.**

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Thank you!