# ipro • 318 $H_2$

## general information

The fuel cell, in contrast to the internal combustion engine, works on the principle of converting chemical energy into electrical energy, which can then be used to run a motor, generating mechanical energy. This is far more efficient than burning the fuel to produce thermal energy (heat), which is then converted to mechanical energy. This conversion (thermal to mechanical energy) is known to have limited efficiency, even in the ideal case.

Hydrogen gas flows into the fuel cell at the anode (negative electrode), where it separates into electrons and protons with the help of a catalyst. The protons then flow through the membrane, while the electrons are repelled and must flow out through the anode. On the other side, air or oxygen is supplied to the cathode. This oxygen reacts with the protons coming through the membrane and electrons off the cathode (positive electrode) to create water by the air stream. If the anode and cathode are connected to a load, such as a motor, an electric current will flow, powering the device.

The typical catalyst for the reaction in the fuel cell is platinum, which is extremely expensive. Platinum is already used in vehicles, but the amount of platinum needed for a fuel cell is many times greater. This has been the main hurdle for fuel cell technology. Although alternatives for platinum are being sought, none have yet been found, although some ways of reducing the amount of platinum necessary have been found somewhat effective.

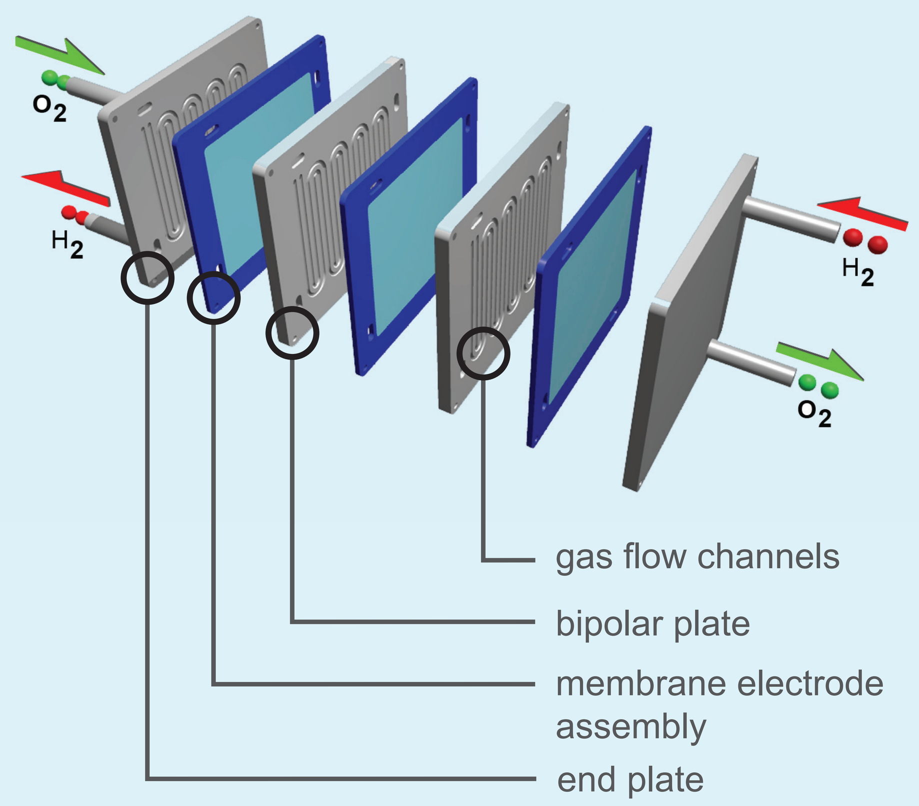
Another hurdle is the storage of hydrogen, which can be resolved by producing hydrogen from hydrocarbon fuels, particularly natural gas (methane). There are several ways, including catalytic reforming and steam reforming. The reforming process requires a series of reactions that must take place at specific temperatures; most at temperatures higher than the operation temperature of the fuel cell. The reforming process also results in impurities that must be filtered out of the gas stream before entering the fuel cell, or they will render ineffective the platinum catalyst. Ironically, one of the ways of getting rid of the contaminant carbon monoxide is to use platinum as a catalyst to preferential oxidation, which essentially burns most of the carbon monoxide and a little hydrogen in the stream.

## fuel cell basics

step 1: hydrogen enters the gas flow channels

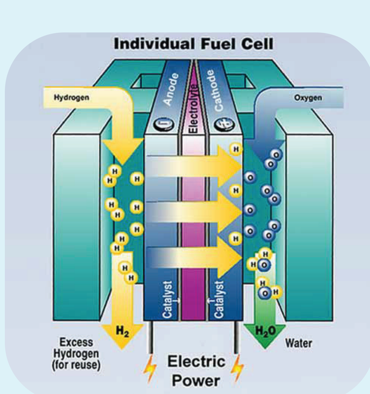
step 2: at the anode, the hydrogen molecules are broken into protons and electrons with help from the catalyst. the protons flow through the anode while electrons are repelled. this movement creates an electric current when the anode and cathode are connected to a load

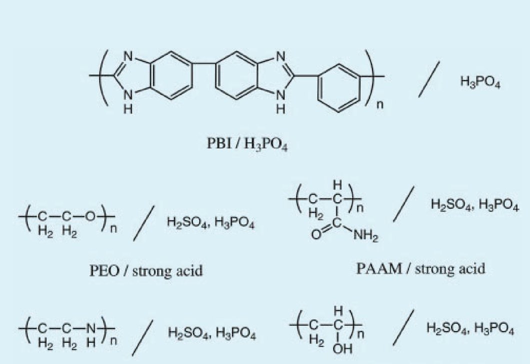
step 3: the hydrogen then mixes with oxygen flowing through a seperate gas flow channel, giving off water as the only emission




## PBI fuel cells

- has a higher operating temperature (160-180 C) allowing for faster reaction rates and less catalyst poisoning by carbon monoxide (CO)
- provides a longer fuel cell life



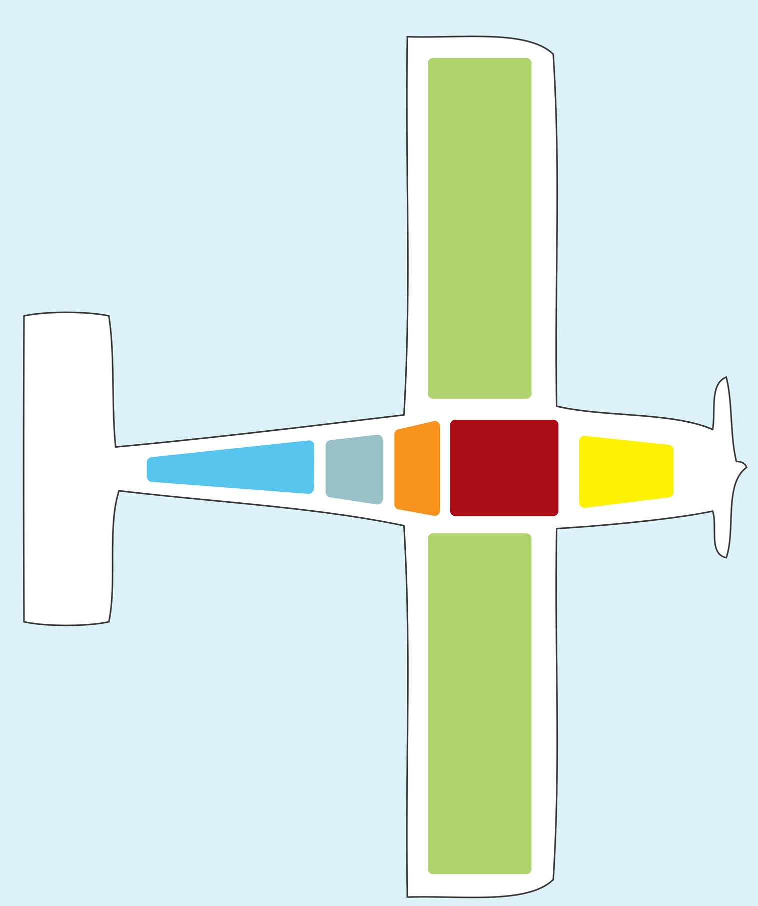



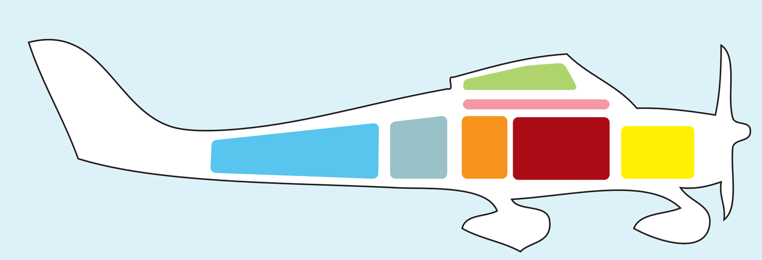

chemical structures of acid base complex membranes

## aircraft design

### cesna skycatcher

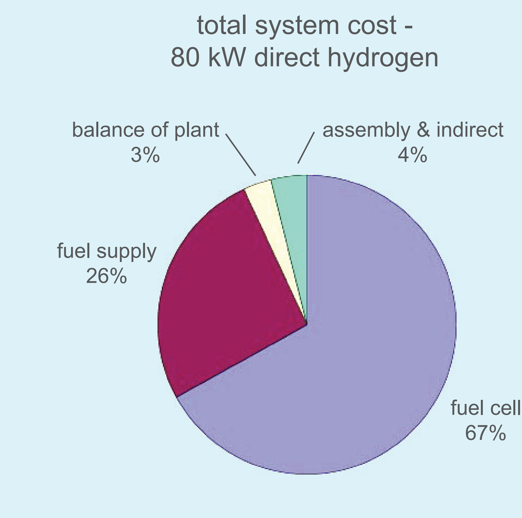
- medium size gives enough space to fit the fuel cell and all components into previous passenger space
- the fuel cell replaces the cockpit
- electronics and supporting systems fit into the storage areas
- fuel and engine spaces are used for their original purpose

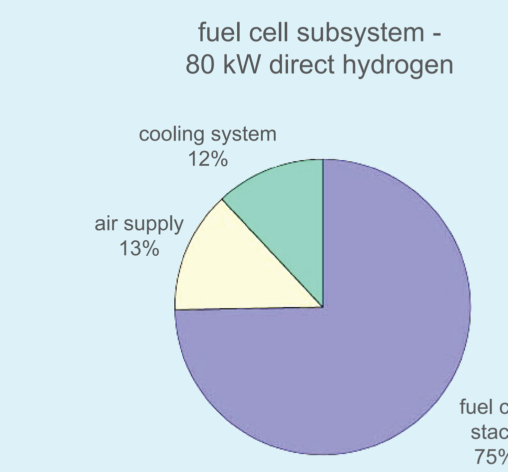


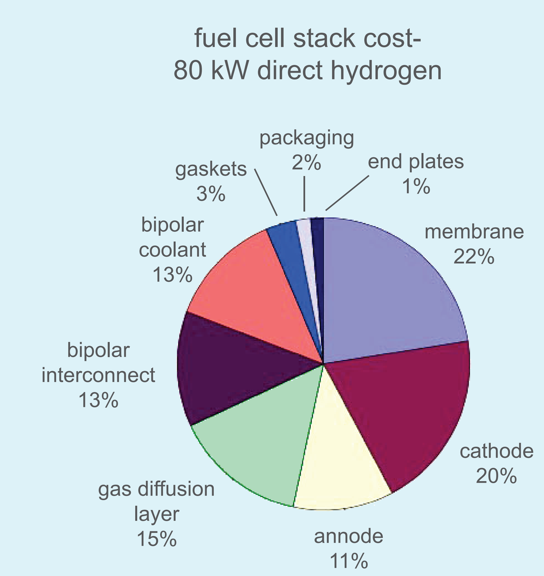


Fuel | Insulation | Control electronics | Power electronics | Methonol reformer | PBI fuel cell | Engine

## cost analysis




## our process

Unmanned aircraft vehicles (UAVs) and unmanned submersible vehicles were compared, with the conclusion that UAVs were the most likely candidate for a fuel cell-powered vehicle due to current functioning designs. Commercial automobiles were ruled out because a fuel cell engine and associated reforming processes are too heavy and not space efficient. Unmanned submersible vehicles were dismissed because storage of hydrogen and oxygen would be too difficult under the high pressures encountered in the deep sea. Unmanned aircraft vehicles were decided upon as the best option because of space available in aircrafts versus submersibles.

Several UAV designs were considered, with the limitation of a maximum weight of 500 lbs. First we looked at models on the market developed by large corporations such as Boeing, Northrop Grumman, AeroVironment and General Atomics. Each was determined to be too small for the required amount of power. Next, we investigated model airplanes, which are advantageous because their power and size requirements are easily accessible. However, replacing the battery with a fuel cell system was deemed unlikely due to size limitations.

Finally, it was decided the most feasible choice was converting a two-man airplane into a UAV.

## calculations

| | | | |
|---|---|---|---|
| **Cockpit Dimensions** | 119 | 112 | 176 cm |
| **Current Density** | 0.4 A/cm^2 | | |
| **Cell Voltage** | 0.6 V/MEA | | |
| **Bipolar Plate Thickness** | 0.1 cm | | |
| **Total MEA Thickness** | 0.4 cm | | |
| **Reduction in MEA Area** | 1 cm | | |
| **Flight Time** | 4 hours | | |
| **Temperature of Cell** | 160 °C | | |
| **Electricity Needed for Hydrolysis of 1 kg of H2** | 55 kWh | | |
| **Fuel Cell Efficiency** | 50 % | | |
| **Hydrogen Density** | 27 L/kg | at 10,000 psi | |

**Stacking**

| | # of MEAs | MEA Area (cm^2) | Voltage (V) | Current (A) | Power (kW) |
|---|---|---|---|---|---|
| | 2530 | 247 | 1518 | 98.8 | 150.00 |
| *Motor Requirements* | | | *750* | *135* | *101.25* |

**Farraday's Law Calculations - Amount of Hydrogen**

| Q (C ) | F (C/mol) | M (kg/mol) | z | m (kg) | Total Mass (kg) |
|---|---|---|---|---|---|
| 1422720 | 96485 | 0.00201588 | 2 | 0.01486258 | 37.61 |

**Power Calculations - Amount of Hydrogen**

| kWh | m (kg) |
|---|---|
| 600 | 21.82 |

**Flow Rate**

*Hydrogen*

| Moles | Mdot(kg/s) | Vdot (m^3/s) | Mdot (kg/h) | Vdot (m^3/h) |
|---|---|---|---|---|
| 19921.82 | 0.002788889 | 0.000094 | 10.04 | 0.3384 |

*Oxygen* Volumes Found Using HYSYS

| Moles | Mass (kg) | Volume (m^3) | Mdot (kg/h) | Vdot (m^3/h) |
|---|---|---|---|---|
| 9960.91 | 319.32 | 628.80 | 0.022 | 0.044 |
| | | | 79.83 | 157.20 |

*Air* Calculated Using HYSYS 21 % O2 by Volume

| Moles | Mass (kg) | Volume (m^3) | Mdot (kg/h) | Vdot (m^3/h) |
|---|---|---|---|---|
| 0.00 | 0.00 | 2994.29 | 0.00 | 0.00 |
| | | | 342.60 | 748.30 |

**Catalyst**

| | Mass for 1 MEA (kg) | Mass for All (kg) | $ | Catalyst Loading |
|---|---|---|---|---|
| *Platinum - Anode* | 0.0000988 | 0.25 | 9950.00 | 0.4 mg/cm^2 |
| *Carbon Fiber - Anode* | 0.0000988 | 0.25 | 0.75 | |
| *Platinum - Cathode* | 0.0001482 | 0.38 | 14925.00 | 0.6 mg/cm^2 |
| *Carbon Fiber - Cathode* | 0.0001482 | 0.38 | 1.13 | |

**PBI**

| | Mass for 1 MEA (kg) | Mass for All (kg) | $ | PBI Loading |
|---|---|---|---|---|
| *Anode* | 0.00008892 | 0.23 | 68.18 | 0.36 mg/cm^2 |
| *Cathode* | 0.0001482 | 0.38 | 113.64 | 0.6 mg/cm^2 |

Assuming 10% of Nafion Cost

| | |
|---|---|
| PBI Cost | 0 |
| PBI Density | 1.98 |
| PBI Cost/Mass | 0.00 |

**Metal Bipolar Plates** Density 8.00 g/cm^3 Price

| | Volume (cm^3) | Mass of 1 Plate (kg) | Mass for All (kg) | $ | |
|---|---|---|---|---|---|
| | 16.47 | 0.13 | 222.31 | 750 | $5/kW |
| Stainless Steel Core - Nitrided | Au plated Al | | | | $35/kW |

**Fan**

| Flow Rate (ft^3/min) | Weight (g) | $ |
|---|---|---|
| 0.5 (less than this) | 60 | 15 |

**Fuel Cell Heat**

| | | | |
|---|---|---|---|
| Efficiency | 0.49 | | |
| Total Energy | 1212202 | kJ/h | |
| Heat Energy | 620884 | kJ/h | |
| Heat Transfer Coefficient | 14 | W/m^2 K | For steam to air |
| Log Mean Temperature | 338.58 | K | |
| Needed Heat Transfer Area | 464902616 | m^2 | |
| | 465 | km^2 | |

**Total Mass**

| Component | Mass (kg) | Total Mass (kg) |
|---|---|---|
| Hydrogen | 40.16 | 271.48 |
| Catalyst/Support | 8.35 | |
| PBI | 0.60 | |
| Bipolar Plates | 222.31 | |
| Fan | 0.06 | |

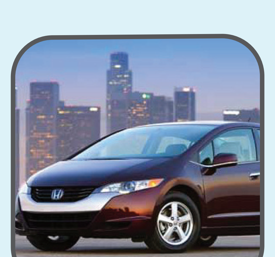
**Total Cost**

| | Total Cost ($) |
|---|---|
| Hydrogen | 765 |
| Catalyst/Support | 0.00 |
| PBI | 0.00 |
| Bipolar Plates | 750.00 |
| Fan | 15.00 |

Motor
d = 14.7 in
l = 35.63 in

## timeline

talisman | firebee | i-gnat UAV | puma UAV | skylark UAV | t34 mentor | cessna skycatcher



hydrogen cars — submirsibles — aircraft

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