Electrified future of aviation: batteries or fuel cells?

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Credit: NASA
Electrified future of aviation

... no more pollution
... no more noise
... less emissions
... more efficient use of fuel
... more power for auxiliaries

Electric aircraft market is projected to reach over $22B by 2040
Aviation electrification

Benefits

‣ Energy usage reduction (40 - 60%)
‣ Emission reduction (>90%)
‣ Noise reduction (>65%)

Energy requirements for medium range 50 passenger planes

‣ Energy density > 1 kWh/kg
‣ 4000 - 8000 kWh per hour

Batteries alone could support 2-4 seat short range planes…

but do not have enough energy density for regional aircrafts!

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160007763.pdf
Hybrid electric aircraft concepts

Airbus E-fan X
- 116 passenger series hybrid
- 400 kWh battery
- 2.5 MW electric motors

Zunum Aero
- 50 passenger series hybrid
- Range 700 miles (175 electric)

Boeing SUGAR Volt
- 154 passenger series hybrid
- 5.3 MWh battery
- 1.3 MW electric motors

Higher efficiency to offset higher cost
Aviation electrification: energy sources

Batteries
- Highest efficiency
- Energy densities above 500 Wh/kg unlikely
- Limited use for personal short range aviation

Turbines using fossil fuels + batteries
- Highest energy density but lower efficiency
- Marginal improvements in energy efficiency and emissions compared to conventional aircraft
- Need a generator and an inverter

Fuel cells using sustainable fuels + batteries
- Satisfactory energy density
- Medium energy efficiency but no inverter needed
- Suitable for small - medium size passenger planes
## Fuels for Direct Liquid FCs

<table>
<thead>
<tr>
<th>Fuel</th>
<th>B.p., deg C</th>
<th>Energy density, kWh/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel</td>
<td>340-375</td>
<td>9.2</td>
</tr>
<tr>
<td>Methanol</td>
<td>64.7</td>
<td>4.67</td>
</tr>
<tr>
<td>Dimethyl ether (DME)</td>
<td>-24</td>
<td>5.36</td>
</tr>
<tr>
<td>Ethanol</td>
<td>78.4</td>
<td>6.30</td>
</tr>
<tr>
<td>Ammonia</td>
<td>-33.3</td>
<td>4.32</td>
</tr>
<tr>
<td>Liquid hydrogen</td>
<td>-252.9</td>
<td>2.54</td>
</tr>
<tr>
<td>Compressed H₂ (700 bar)</td>
<td>gas</td>
<td>1.55</td>
</tr>
</tbody>
</table>

*Fuel cell/battery HEAV flying range*

1480 gal tank, 700 kW FC, 350 kWh battery

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* - Fuel cell efficiency 55%, battery round trip efficiency 90%, energy consumption 4.6 kWh/mile for regional aircraft

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**ATR72**

70 passengers
Comparison of electric aircraft configurations (ATR72 body)

Payload for different configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Payload, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine</td>
<td>6000</td>
</tr>
<tr>
<td>Battery*</td>
<td>4000</td>
</tr>
<tr>
<td>Fuel cell</td>
<td>5000</td>
</tr>
<tr>
<td>Turbine/battery</td>
<td>4000</td>
</tr>
<tr>
<td>Fuel cell/battery</td>
<td>5000</td>
</tr>
</tbody>
</table>

Cost of energy storage system and flying range

<table>
<thead>
<tr>
<th>Configuration</th>
<th>ESS cost, $</th>
<th>Flying range, miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>500000</td>
<td>700</td>
</tr>
<tr>
<td>Fuel cell</td>
<td>700000</td>
<td>800</td>
</tr>
<tr>
<td>Fuel cell/battery hybrid (optimized)</td>
<td>300000</td>
<td>300</td>
</tr>
</tbody>
</table>

Fuel ethanol, battery cost $150/kWh, fuel cell cost $400/kW

* - flying range 780 miles
Potential Program Requirements: Feedback Sought!

Component Requirements

• Power density comparable with hydrogen fuel cells
• Combining electrocatalysis and fuel reforming catalysis working below 550 C with no coking issues
• Non- or extremely low Pt catalysts adaptable to different liquid fuels

System Requirements

• Specific power > 3 kW/kg
• Start up time less than 15 minutes
• 5,000 thermal cycles with degradation less 5%
• Internal fuel reforming
• Fuel flexibility
• Battery/fuel cell integration
Q. Electrified future of aviation: batteries or fuel cells?

A. Hybrids (batteries + fuel cells)