Wasserstoff - emissionsarmes Fliegen in der Anwendung

Phillip Scheffel, 08.09.2022
APUS – Location
The headquarter of APUS Group is located 30 km east of Berlin. The offices and workshops are directly connected to the runway and taxiway of the highly developed airport EDAY. The team behind APUS has an expert reputation in the aviation industry, being a leader in electrification, aircraft design and aircraft development challenges of the future. Hydrogen research has come into focus of APUS in 2015.

APUS Group
Lilienthalstraße 2
15344 Strausberg
GERMANY

Facts – APUS Group
Founded: 2014
Experience (Key Staff): 30 Years
Approvals/Certificates: EASA 21J / 21G / ISO 9100
Staff: 35+
Infrastructure: 350 sqm Offices, 1,300 sqm Work-Shop, 1,500 sqm Test-Area
APUS Mission

What does APUS want to do?

We will offer the first certified zero emission (hydrogen electric) commercial aircraft

- 9 – 19 seats
- Cargo up to 1.7 t
- 2 x 350 kW Hydrogen Power
- 160 KTAS cruise-speed, range of 500 NM
- Replacing conventional RAM-aircraft by zero emission aircraft
- Providing lower cost (cost/passenger/mile) by using hydrogen*
- Using patented structurally integrated hydrogen storage system TUBESTRUCT™

*) direct operational costs (DoC) costs would be lower than today's conventional a/c, when the price of hydrogen becomes lower than 6.25 EUR/kg
Departing from almost every town in Europe

There is always an airport within a maximum radius of 50 km. Well over 80% of the population lives less than 20 kilometers from the nearest airport.

The largest share of all global passenger flights are flights with a flight duration of less than 2 hours (300 NM) and fewer than 10 passengers on board.

From 2035 on a few countries allow only zero emission regional flights (Denmark, Norway, New Zealand, …) Only APUS i-5 can provide competitive performance with zero emissions so far.
Energy Density – TUBESTRUCT™

With APUS patented energy storage systems APUS offers best energy density worldwide.

With METALIQ™-energy storage system the safest hydrogen storage system worldwide.

<table>
<thead>
<tr>
<th>Energy Carrier</th>
<th>Power Density [kWh / kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jet-A1</td>
<td>11,9</td>
</tr>
<tr>
<td>Petrol</td>
<td>11,5</td>
</tr>
<tr>
<td>Natural gas liquid</td>
<td>13,9</td>
</tr>
<tr>
<td>Natural gas 200 bar</td>
<td>13,9</td>
</tr>
<tr>
<td>Li-Fe-Po Battery</td>
<td>0,22</td>
</tr>
<tr>
<td>Li-Ion Battery</td>
<td>0,15</td>
</tr>
<tr>
<td>Hydrogen Metalhydрид</td>
<td>0,4</td>
</tr>
<tr>
<td>Liquid Hydrogen 2 bar</td>
<td>2</td>
</tr>
<tr>
<td>Hydrogen 700 bar</td>
<td>1,8</td>
</tr>
<tr>
<td>Hydrogen 350 bar</td>
<td>1,6</td>
</tr>
<tr>
<td>Hydrogen 350 bar</td>
<td>33,3</td>
</tr>
<tr>
<td>Hydrogen 700 bar</td>
<td>33,3</td>
</tr>
<tr>
<td>Hydrogen 2 bar</td>
<td>33,3</td>
</tr>
</tbody>
</table>

Energy carrier vs. including storage system
## Operational Costs

<table>
<thead>
<tr>
<th>Model</th>
<th>Unit</th>
<th>i-2</th>
<th>E-Panthera</th>
<th>Ampaire</th>
<th>ZeroAvia</th>
<th>SR22 (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTOW</td>
<td>kg</td>
<td>2200</td>
<td>1315</td>
<td>1900</td>
<td>2310</td>
<td>2200</td>
</tr>
<tr>
<td>dry payload</td>
<td>kg</td>
<td>400</td>
<td>100</td>
<td>200</td>
<td>300</td>
<td>400</td>
</tr>
<tr>
<td>pax</td>
<td></td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Power Unit</td>
<td></td>
<td>400.000€</td>
<td>200.000 €</td>
<td>400.000€</td>
<td>400.000€</td>
<td>100.000 €</td>
</tr>
<tr>
<td>TBO (time between overhaul)</td>
<td>h</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
<td>2000</td>
</tr>
<tr>
<td>energy consumption</td>
<td>kW/h</td>
<td>165</td>
<td>130</td>
<td>165</td>
<td>165</td>
<td>480</td>
</tr>
<tr>
<td>price per kWh</td>
<td>EUR/kWh</td>
<td>0,21</td>
<td>0,21</td>
<td>0,21</td>
<td>0,21</td>
<td>0,16</td>
</tr>
<tr>
<td>price per h</td>
<td>EUR/h</td>
<td>35,00</td>
<td>27,58</td>
<td>35,00</td>
<td>35,00</td>
<td>75,59</td>
</tr>
<tr>
<td>cruise speed</td>
<td>kts</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Energy Costs including PowerDriveCosts</td>
<td>EUR/NM</td>
<td>0,23 €</td>
<td>0,18 €</td>
<td>0,23 €</td>
<td>0,23 €</td>
<td>0,50 €</td>
</tr>
<tr>
<td>cost per pax and NM</td>
<td>EUR/NM/pax</td>
<td>0,17 €</td>
<td>0,41 €</td>
<td>0,34 €</td>
<td>0,23 €</td>
<td>0,21 €</td>
</tr>
<tr>
<td>Compared to conventional Cirrus SR22</td>
<td>EUR/NM/pax</td>
<td>81%</td>
<td>194%</td>
<td>162%</td>
<td>108%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Confidential // APUS Zero Emission Program Q3 - 2022
Efficiency Chain:
Windkraft, Elektrolyseur, Fischer-Tropsch Synthese zu SAF, Verbrennung im Dieselmotor

Windkraft → Elektrolyse → Synthesegas-Herstellung → Fischer-Tropsch-Synthese → Aufbereitung → Sustainable Aviation Fuel

SAF Erzeugung (Power-to-Liquid Prozess mit Fischer-Tropsch Synthese)

Elektrolyse

H₂, CO

Synthesegas-Herstellung

Fischer-Tropsch-Synthese

C₇H₈

Aufbereitung

SAF Betankung

Antriebssystem

Mechanische Leistung an Antriebswelle

Windkraft

Gesamtwirkungsgrad = 16%

Verbrennung im Dieselmotor

Wirkungsgrad = 37%

Gesamtwirkungsgrad = 16%

Wirkungsgrad Power-to-Liquid = 43%
Efficiency Chain: Windkraft, Elektrolyseur, Speicherung, Verdichtung und Kühlung beim Tanken (300bar-System), BSZ-Wirkungsgrad, E-Motor

H₂ Erzeugung und Speicherung
Wirkungsgrad PEM-Elektrolyse-Anlage = 56%

Elektrischer Strom

Antriebssystem
Wirkungsgrad = 54%

Brennstoffzellensystem
Wirkungsgrad PEM-Brennstoffzellensystem = 60%

Mechanische Leistung an Antriebswelle
Gesamtwirkungsgrad = 29%

Gleichrichtung → Elektrolyse → Gastrocknung → Verdichtung (1 -> 200 bar)

H₂ Betankung (300 bar)
Wirkungsgrad: 96%

Verdichtung (200 -> 500 bar)
Vorkühlung (-33...-40°C)
Dispenser

Wirkungsgrad PEM-Brennstoffzellensystem = 60%

Elektromotor → Elektronik & Systeme → Elektrischer Strom

H₂ → Umgekehrte Elektrolyse → H₂O → Luft

Wirkungsgrad = 95%

Wirkungsgrad = 95%

Windkraft
Qualitative comparison of the variants with regard to the development effort
An urgent need for immediate emission reduction in aviation.

920 million
Metric Tons of CO₂
In commercial aviation worldwide per year

50% of the pollution by regional and short haul flights.
Without new technologies Expected to increase 3x by 2050.

-75%
The required reduction of the aviation industry's CO₂ emission by 2050
EU Green Deal proposed by The EU Commission

Powertrains and Use Case Application

Green energy consumption per passenger and mile

- Battery Electric
- Hydrogen
- Sustainable Aviation Fuel (SAF)
More individual travelling, less crowded airports and ZERO EMISSION!

• Save time at boarding and arrival.
• Be closer to your final destination.
• Travel more individually.
• Avoid Emissions!
Autonomous self-production on airstrips

Together with renewable energy producers APUS develops the necessary hydrogen ground infrastructure to provide enough energy on each destination.
H2-Airports of the future – in Brandenburg already reality

Not so different from today, but with much more PV

- liquid hydrogen on all national airports
- 300bar gaseous hydrogen on most general aviation airports
- On small airstrips only bottles with 400bar necessary
- No drainage necessary
Hydrogen Fuel-Tank and Powertrain
Impressions from the workshop “APUS i-5”
Partner network
Benefit from APUS as a renowned aviation expert for your future-oriented entry into the multi-billion market of sustainable aviation.

Together with Rolls Royce, one of the most established powertrain supplier in aviation, APUS is developing complex high voltage systems, integration concepts and certified products on highest safety and industrialization level.

Fraunhofer is the leading research institute for high voltage converters. Together with APUS Fraunhofer develops a completely new DC/DC converter for aviation with lowest gravimetric power density.

Powercell SE produces industrialized fuel cells for automotive industry. Together with APUS Powercell SE will shape the aviation sector for aviation fuel-cells.

HEGGEMANN is an established supplier of certified aviation metal parts since almost 60 years. With HEGGEMANN, APUS targets the market for all hydrogen supply components.

Federal Republic of Germany invests currently 238 mn € in the technology, 39 mn € already approved for 2022.