Presented by

Hans-Jürgen Heinrich

Manager Engineering

Fuel Cell Systems For Aeronautic Applications

A Clean Way from Kerosene to Energy

Hamburg, 10th of May 2007

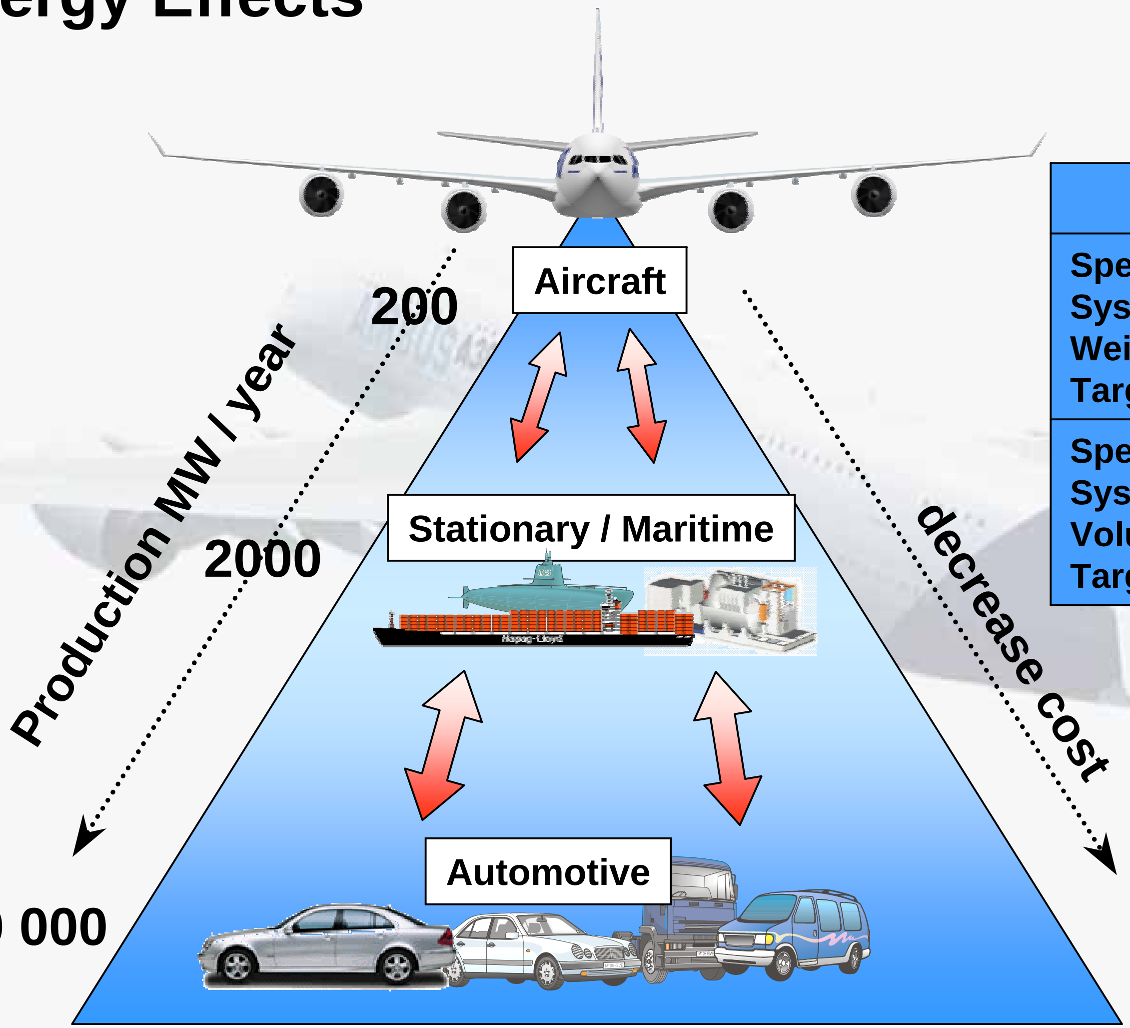
Contents

Introduction

Airbus Activities

- Airbus is one driver of industrialization and early application of fuel cell systems.
- Airbus is leading or involved in national and international projects to encourage the fuel cell technology progress.
- Airbus supports Joint Ventures of companies, authorities, universities and associations.
- Airbus supports the system supplier in design and development of airworthy qualified fuel cell systems.
- High level Aircraft requirements result in synergy effects on similar transportation applications.

Synergy Effects



	Automotive	Aircraft
Specific System Weight Targets	3 kg/kW	1 kg/kW
Specific System Volume Targets	2,5 l/kW	1,5 l/kW

Introduction

System Requirements and Environmental Conditions

- Variable outside pressures and temperatures,
  varying between –2000 ft / +43000 ft and -72°C / +56°C
- Aircraft maneuver loads
- Vibrations
- Installation area (pressurized / unpressurized)
- Transient requirements incl. starting
- Fuel supply (kerosene vs. hydrogen)
- Cooling
- Mission - profiles and safety

For each application on board of an Aircraft the most suitable fuel cell system configuration must be defined.

Contents

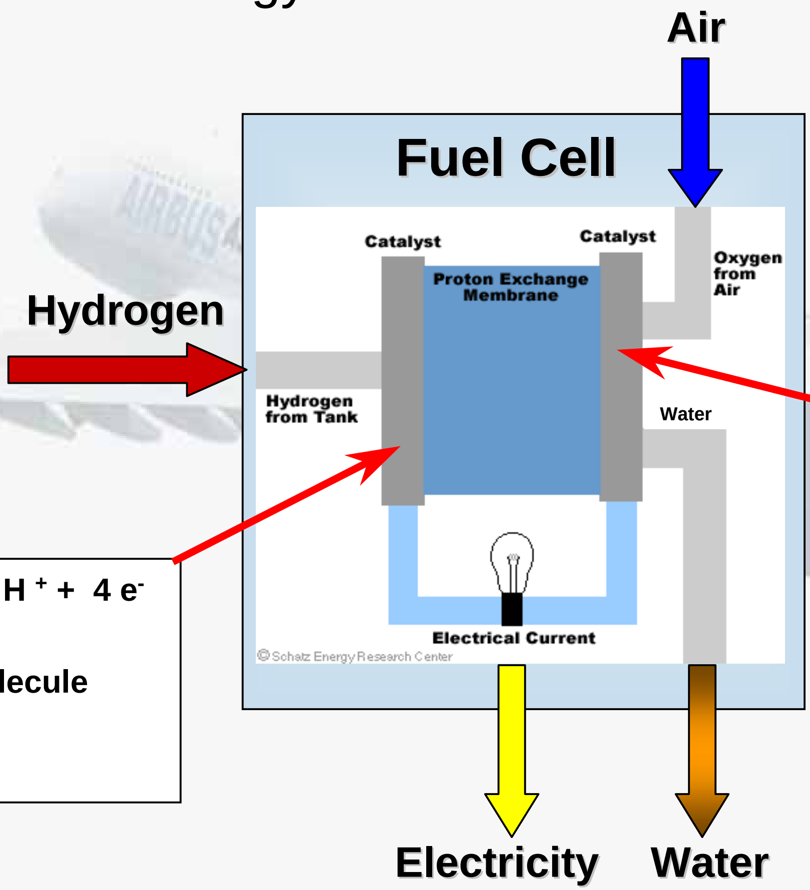
- Introduction
- **Fuel Cell System**
  - **Fuel Cell Operation**
  - **Comparison Fuel Cell vs. Heat Engine**
  - **Development and Technical Targets**
- Motivation for Fuel Cell System Application
- Fuel Cell Systems Architecture
- Airbus Fuel Cell System Strategy
- Step 1: Demonstrator
- Step 2: Fuel Cell Emergency Power System
- Step 3: Fuel Cell Power Unit
- Step 4: Fuel Cell as Primary Source
- Step 5: Alternative Fuels
- Industrialization
- Conclusion

AIRBUS

Fuel Cell System

Fuel Cell Operation

Continuously change of chemical energy (hydrogen and oxygen) **directly** to electrical energy and heat without combustion



Anode: $2\,H_2 \rightarrow 4\,H^+ + 4\,e^-$

H_2 = Hydrogen Molecule
H^+ = Proton
e^- = Electron

Cathode: $O_2 + 4\,e^- \rightarrow 2O^{2-}$
$2\,O^{2-} + 4\,H^+ \rightarrow 2\,H_2O$

O_2 = Oxygen Molecule
O^{2-} = Oxygen Ion
H_2O = Water

Overall Reaction: $2\,H_2 + O_2 \rightarrow 2\,H_2O$ + Electrical Energy + Heat

Fuel Cell System

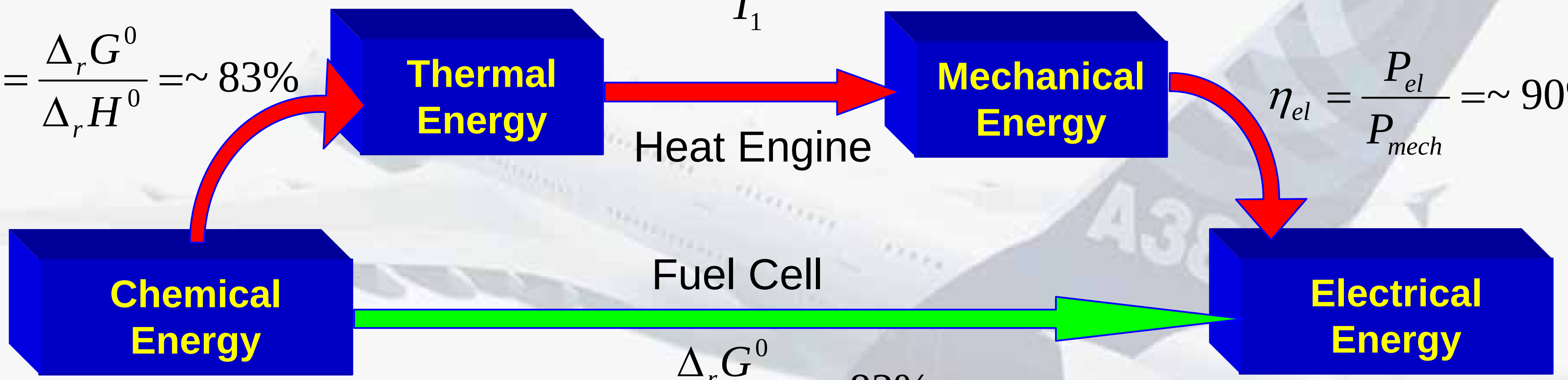
Comparison – Fuel Cell vs. Heat Engine

With T_1=540°C; T_2=36°C

$$\eta_C = 1 - \frac{T_2}{T_1} =\sim 62\%$$

$$\eta_{Rev} = \frac{\Delta_r G^0}{\Delta_r H^0} =\sim 83\%$$

$$\eta_{el} = \frac{P_{el}}{P_{mech}} =\sim 90\%$$



$$\eta_{Rev} = \frac{\Delta_r G^0}{\Delta_r H^0} =\sim 83\%$$

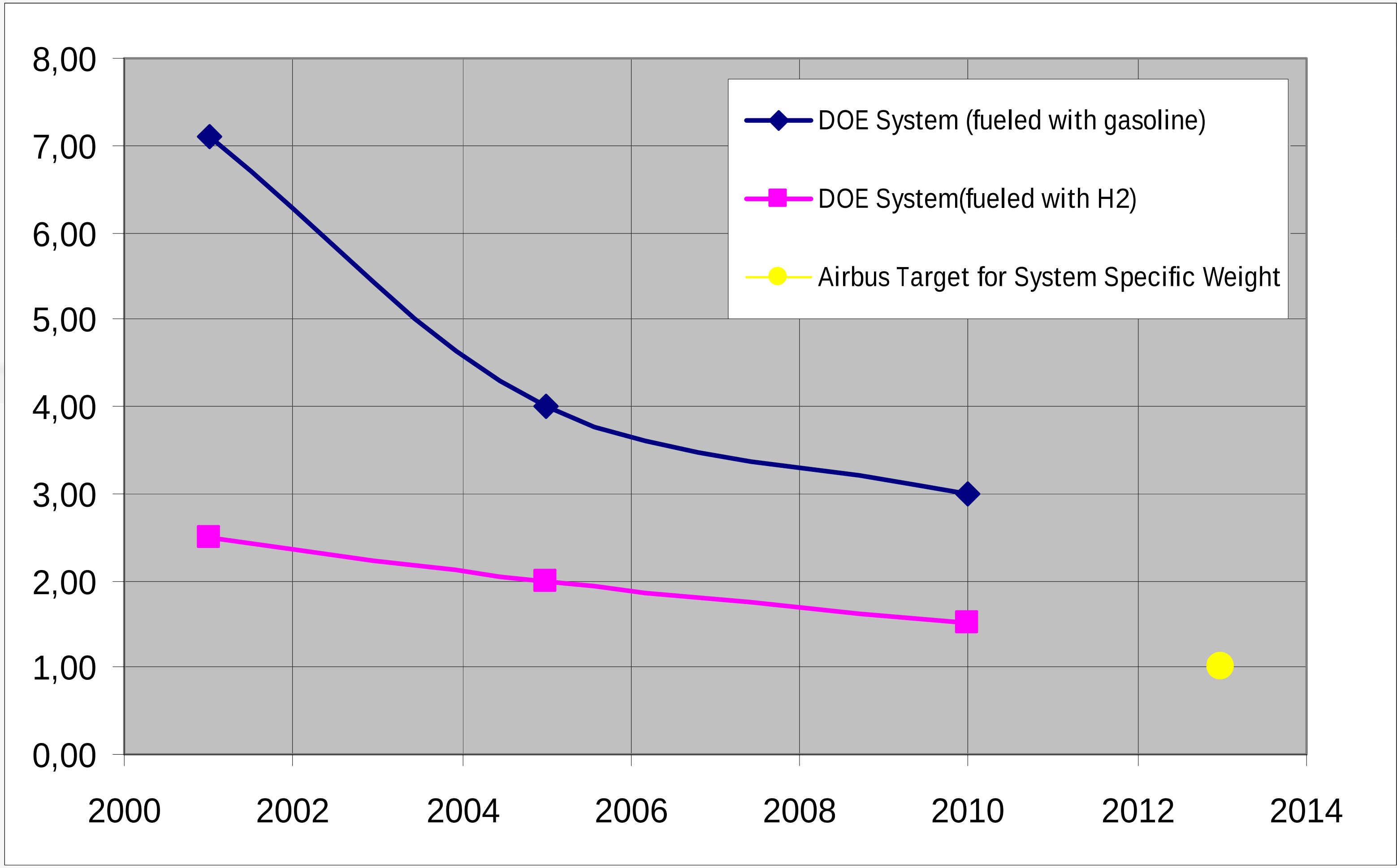
$\eta_{Fuel\ Cell} = \eta_{Rev} = (-237{,}13\ kJ \cdot mol^{-1})/(-285{,}8\ kJ \cdot mol^{-1}) = 0{,}8297 = \sim 83\%$

$\eta_{Heat\ Engine} = \eta_{Rev} \cdot \eta_C \cdot \eta_{el} = 0{,}83 \cdot 0{,}62 \cdot 0{,}9 = 0{,}46 = \sim 46\%$

Theoretical maximal achievable Efficiency: ~83%

Fuel Cell System

Development and Technical Targets

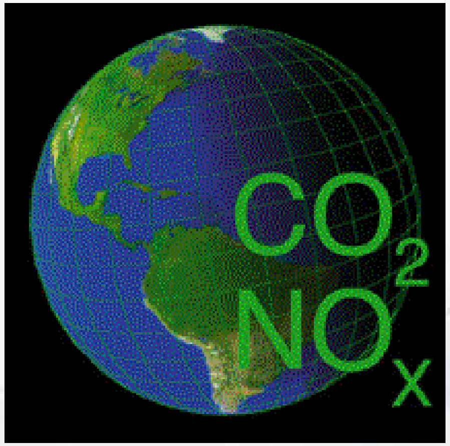


AIRBUS

Contents

Motivation for Fuel Cell System Application

Ecological and Economical Aircraft Operation Aspects



Ecological Aspects:

- Noise reduction
- Emission reduction
- Higher fuel economy

Economical Aspects:

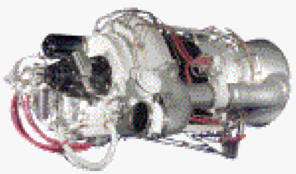
- Weight Reduction
- Low Maintenance
- Mission Improvements
- Elimination of RAT and APU
- Battery Reduction
- Potential for on-board water generation

AIRBUS

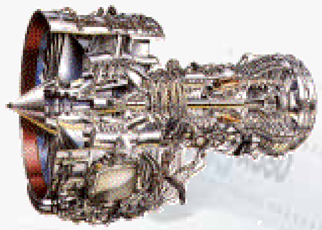
Motivation for Fuel Cell System Application

Conventional Electrical Power Generation vs. Fuel Cell System

APU

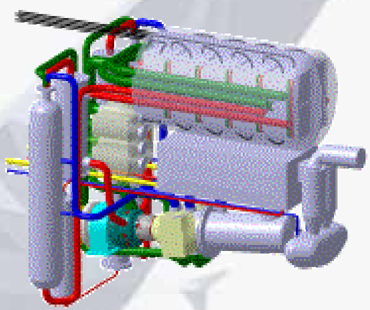


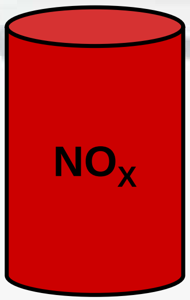
Engine



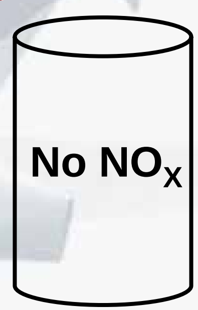
No Bleed/Electric Engine

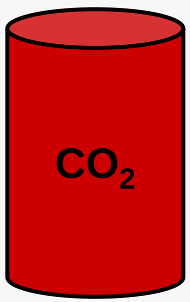
Fuel Cell System



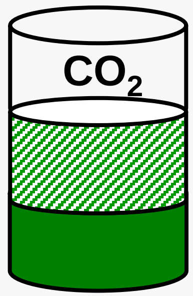


NO_X (**Nitrogen Oxides**) Emission Reduction
Total NO_X reduction
on ground and in flight



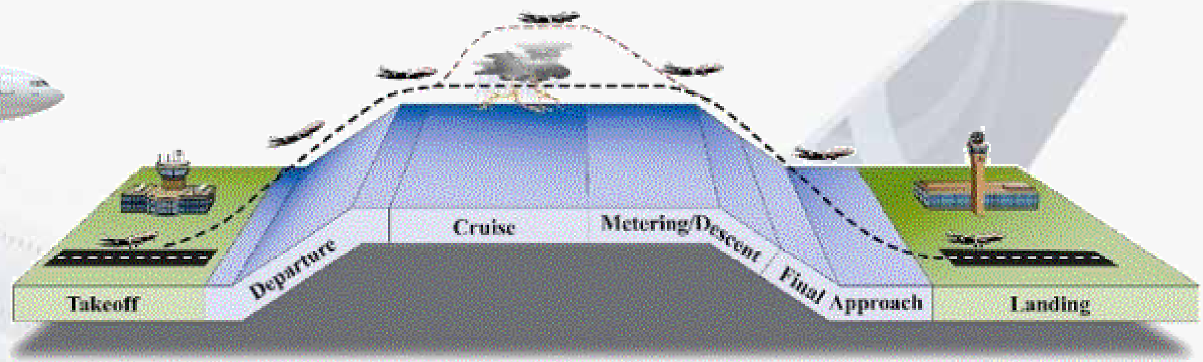


CO_2 (**Carbon Dioxide**) Emission Reduction
20% – 60% CO_2 reduction
in flight and on ground



Motivation for Fuel Cell System Application

Aircraft Mission



Example: A330-300:

- ~100 000 L per flight of ~10 000 km (Average Fuel Consumption)
- Fuel Use: up to 5 %* Aircraft Systems
  95 - 97% Propulsion

up to 5000 L per flight for Aircraft Systems operation

Motivation for Fuel Cell System Application

Fuel Savings

	Conventional Electrical Power Generation	Fuel Cell System
Efficiency	~40% (Maximum possible today)	~60% (Target)
Fuel Use per Flight (10.000 km)	~5.000 Liter	~3.500 Liter

Kerosene Savings up to 1.500 Liter per Flight

Annual Savings for a fleet of 30 Aircraft A330-300

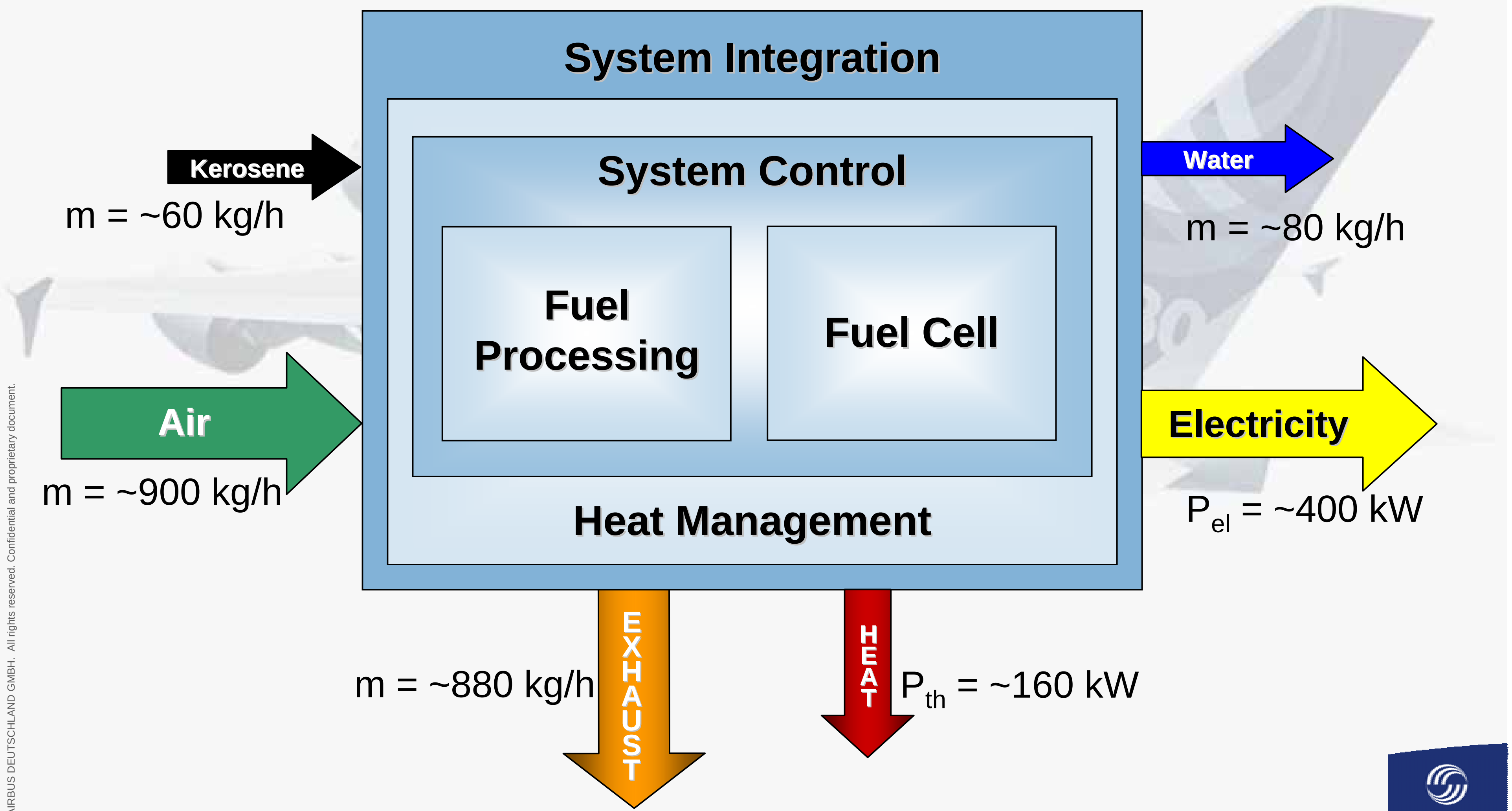
- On average ~ 380 trips per year
- Assumed Kerosene Costs for 2020: 125 \$/barrel (0,79 \$/L)

Fuel Savings: ~16 Mio L per Year
Money Savings: ~13 Mio \$ per Year
+ Emission Fees

Contents

Fuel Cell Systems Architecture

System Architecture Overview

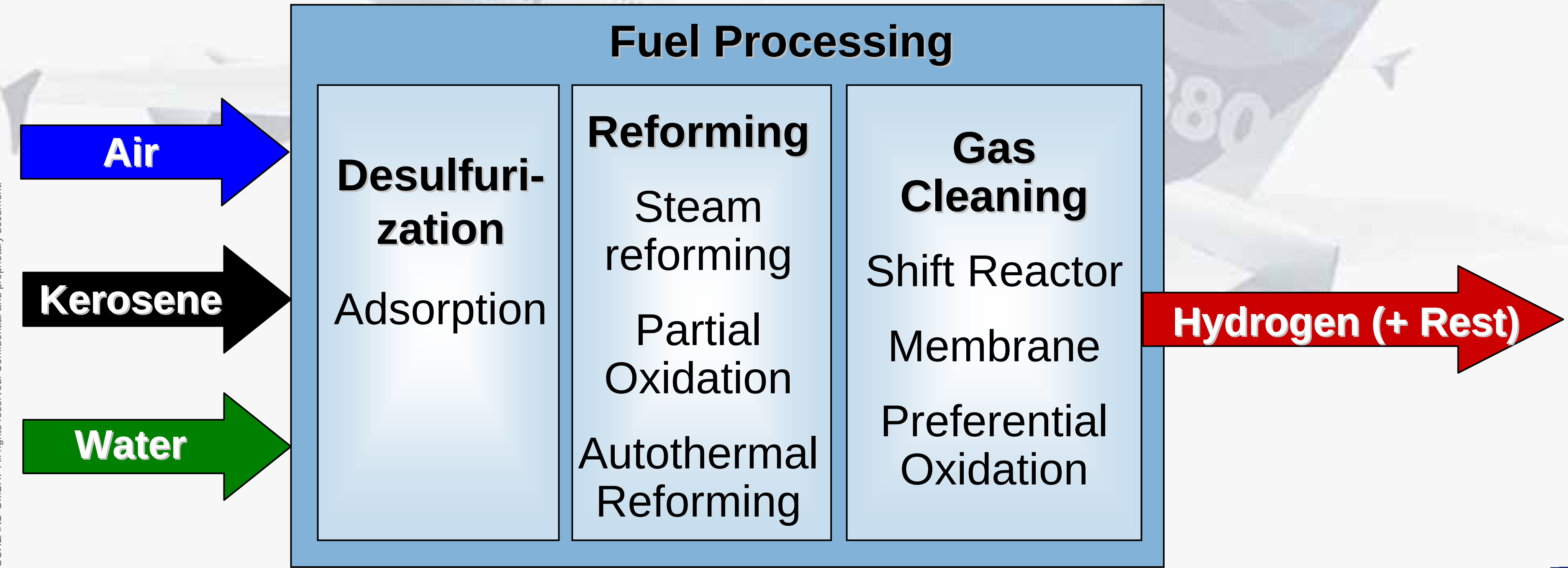


Fuel Cell Systems Architecture

Key Challenge Fuel Processing

Fuel Processing is the Conversion of Kerosene into a hydrogen rich gas. Three Parts are normally necessary:

Desulfurization: Removal of sulfur from kerosene.
Reforming: Conversion of kerosene into a hydrogen rich gas (Reformat).
Gas Cleaning: Cleaning of the reformat (depending on fuel cell).



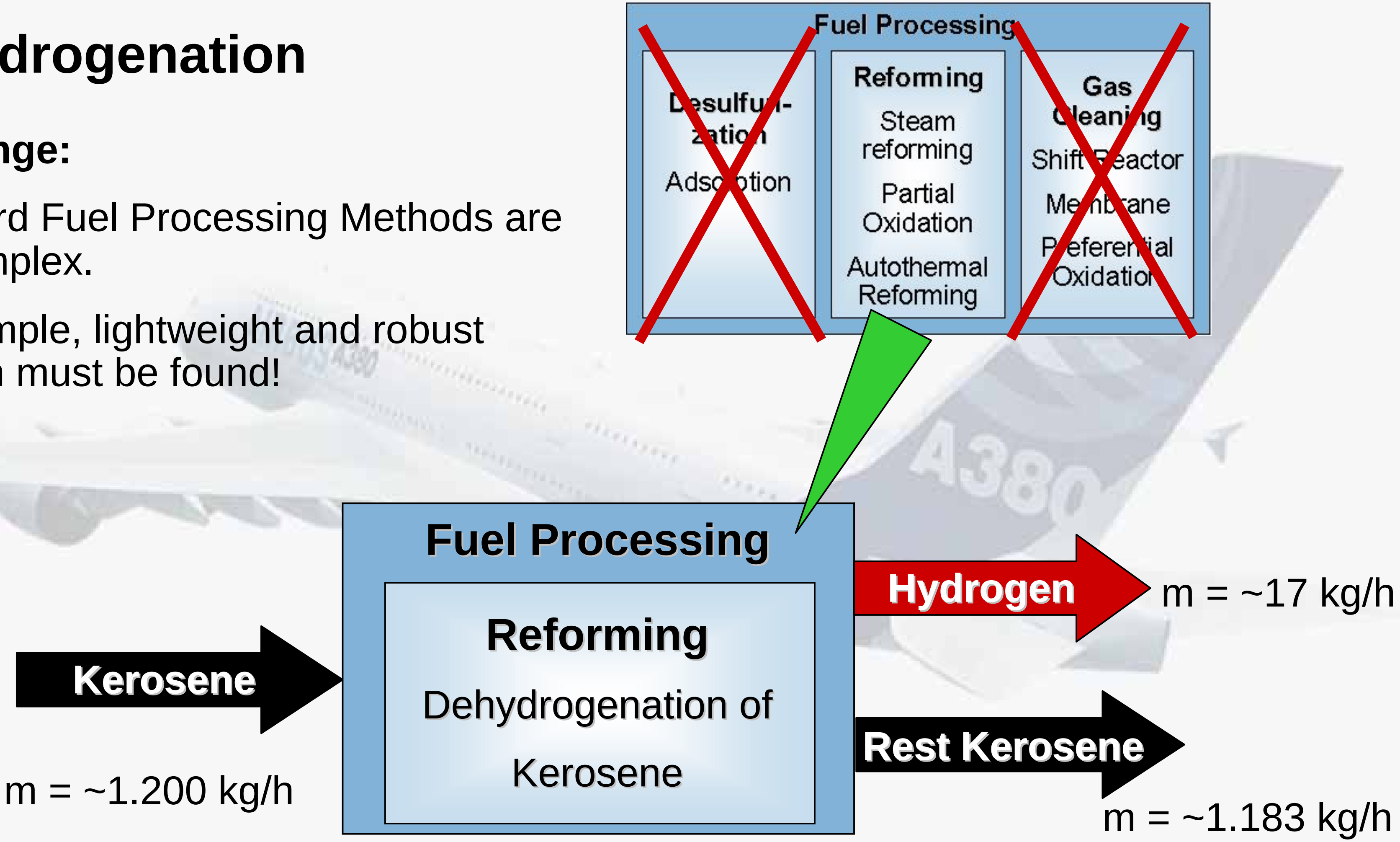
Fuel Cell Systems Architecture

Dehydrogenation

Challenge:

Standard Fuel Processing Methods are too complex.

⇒ A simple, lightweight and robust solution must be found!



Dehydrogenation could be one possible solution

Fuel Cell Systems Architecture

Different types of fuel cells with different working conditions are available:

Comparison PEMFC – SOFC

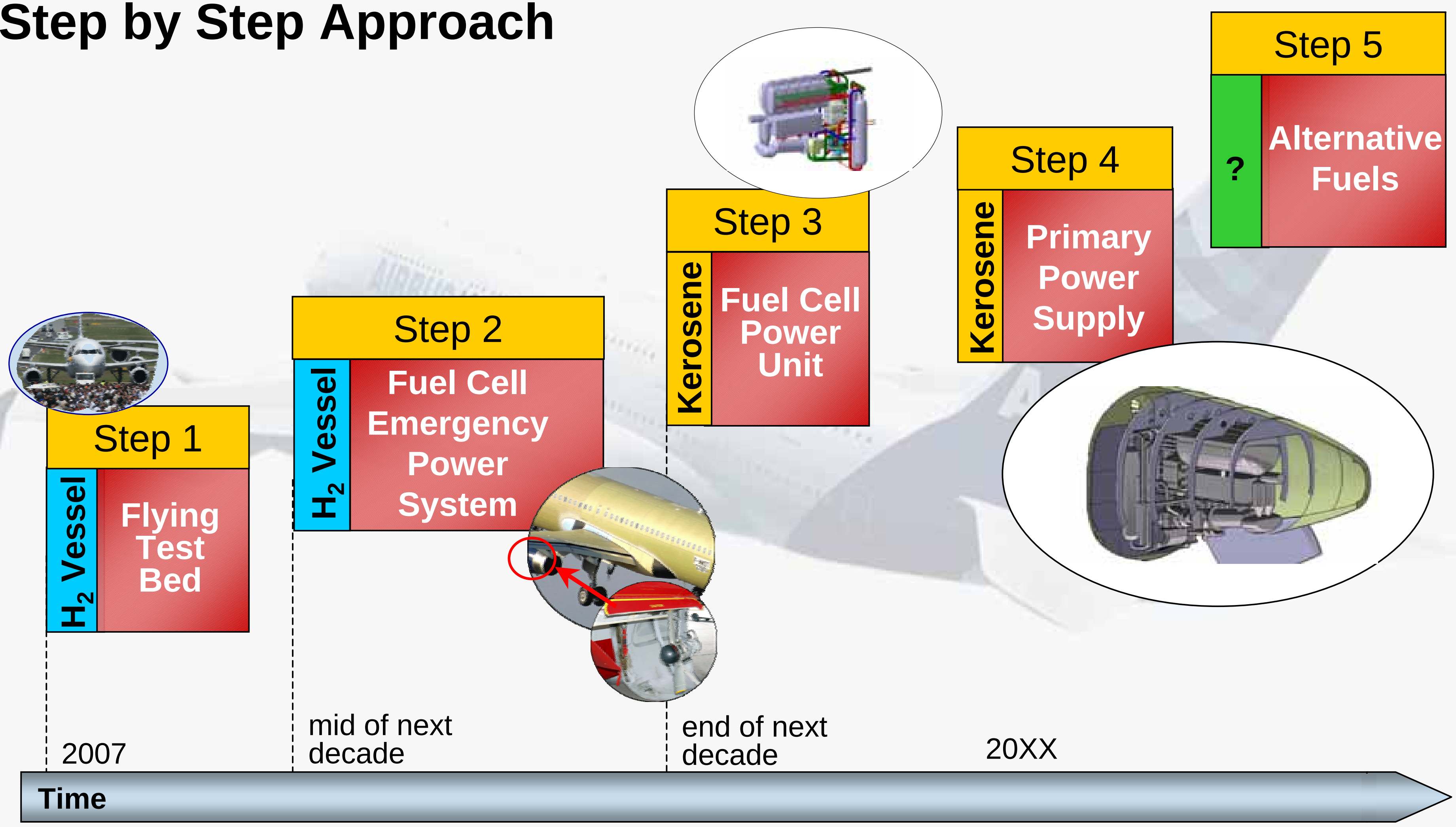
	Proton Exchange Membrane Fuel Cell (PEMFC) Fuel Cell with polymer (sulfonic acid polymer → Nafion) as electrolyte.	**Solid Oxide Fuel Cell (SOFC)** Fuel Cell with ceramic (Y_2O_3-stabilized ZrO_2 → Yttria-stabilized zirconia) as electrolyte.
Advantages	- **High development status (>100 kW_{el})** - Many thermal cycles possible - Water generation at cathode side	- High working temperature (~800°C) - Simple Cooling System - Insensitive against Gas Impurities - Simple Fuel Processing - **Highest efficiencies** - No humidification needed
Challenges	- Low working temperature (~80°C) - Complex cooling system - Sensitive against CO - Complex Fuel Processing - Humidification needed	- Only few thermal cycles possible - Low development status for mobile application (20 kW_{el}) - Water generation at anode side

Contents

AIRBUS

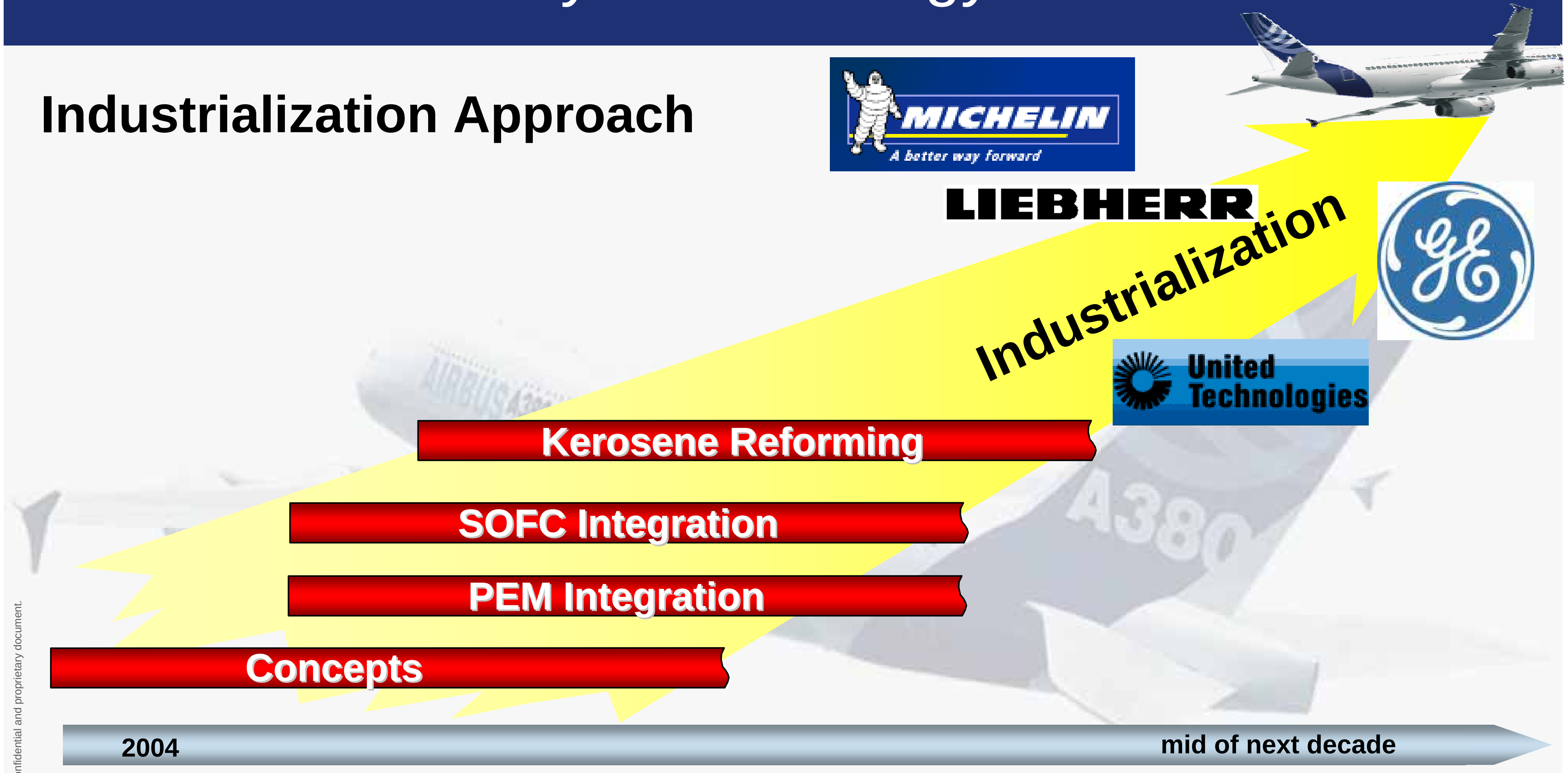
Airbus Fuel Cell System Strategy

Step by Step Approach

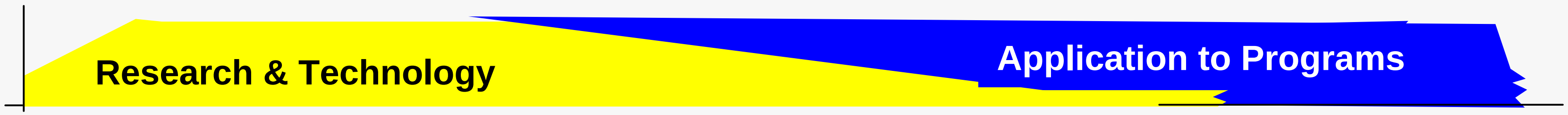


Airbus Fuel Cell System Strategy

Industrialization Approach



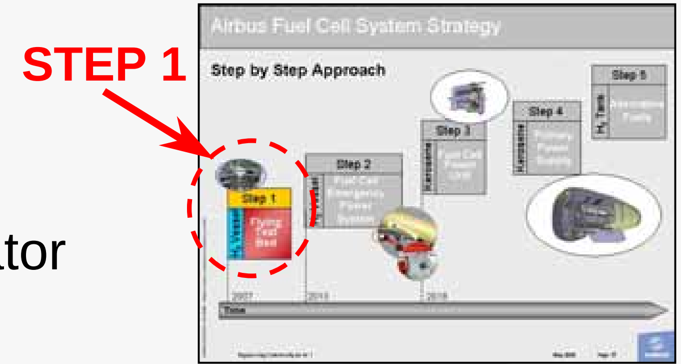
Overall Airbus Fuel Cell Activities



Contents

Step 1: Demonstrator

Overview



Target (2007)

- Build Up of a Fuel Cell System Demonstrator
- Flight Test of the Fuel Cell System

Motivation

- First Safe Fuel Cell System operation on board
- Flight Test Data Collection, dynamic, heat, loads etc.

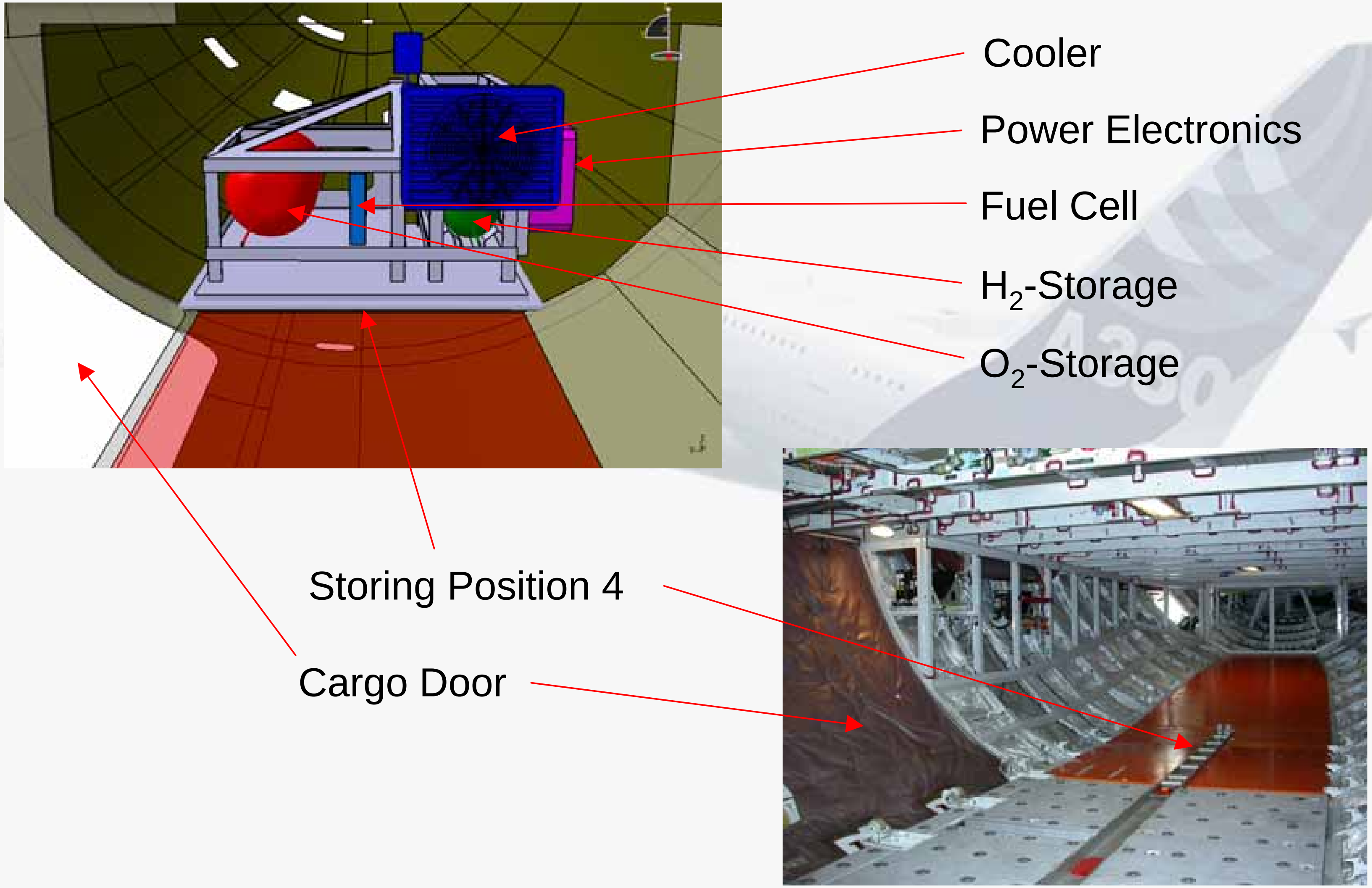
System Specification

- Power: 20 kW_{el}
- Fuel Cell: PEMFC
- Fuel: Pressurized Hydrogen and Oxygen

AIRBUS

Step 1: Demonstrator

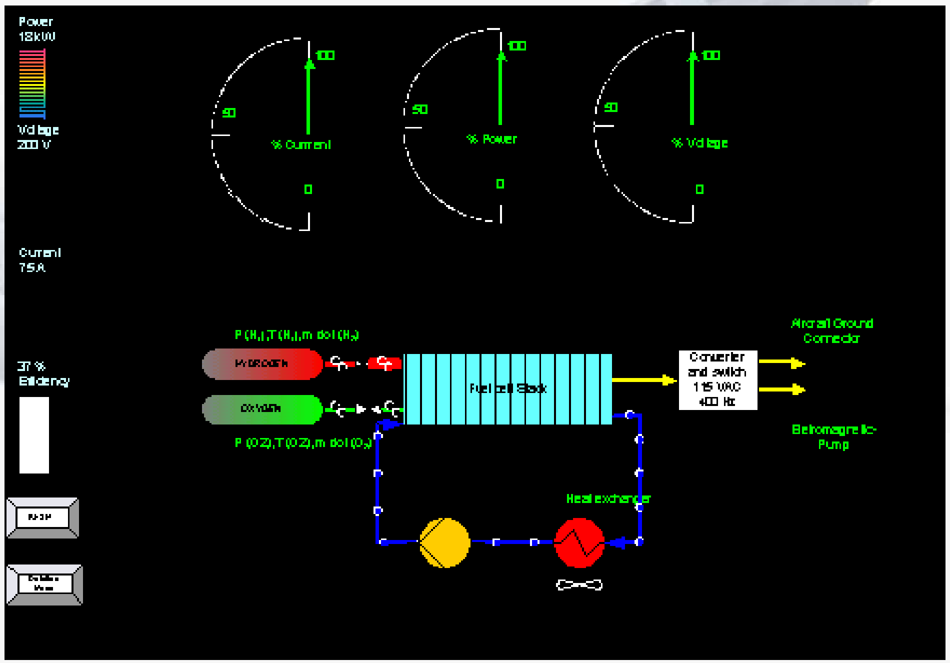
Installation Area



Step 1: Demonstrator

Test Data Collection

Flight Test Engineering Station

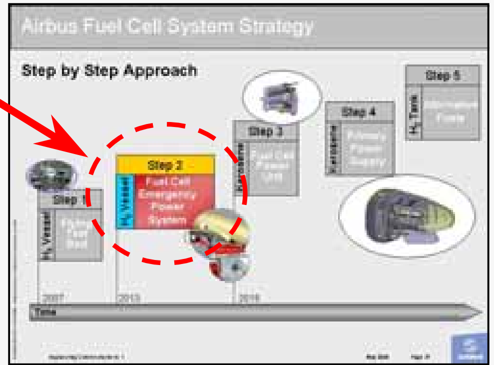


Contents

Step 2: Fuel Cell Emergency Power System

Overview

STEP 2

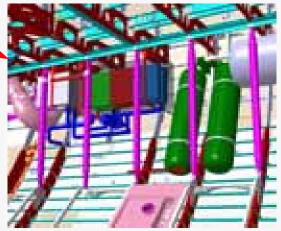


Target (mid of next decade)

- Substitution of the Ram Air Turbine (RAT) by Fuel Cell Emergency Power System (FCEPS)

RAT

FCEPS



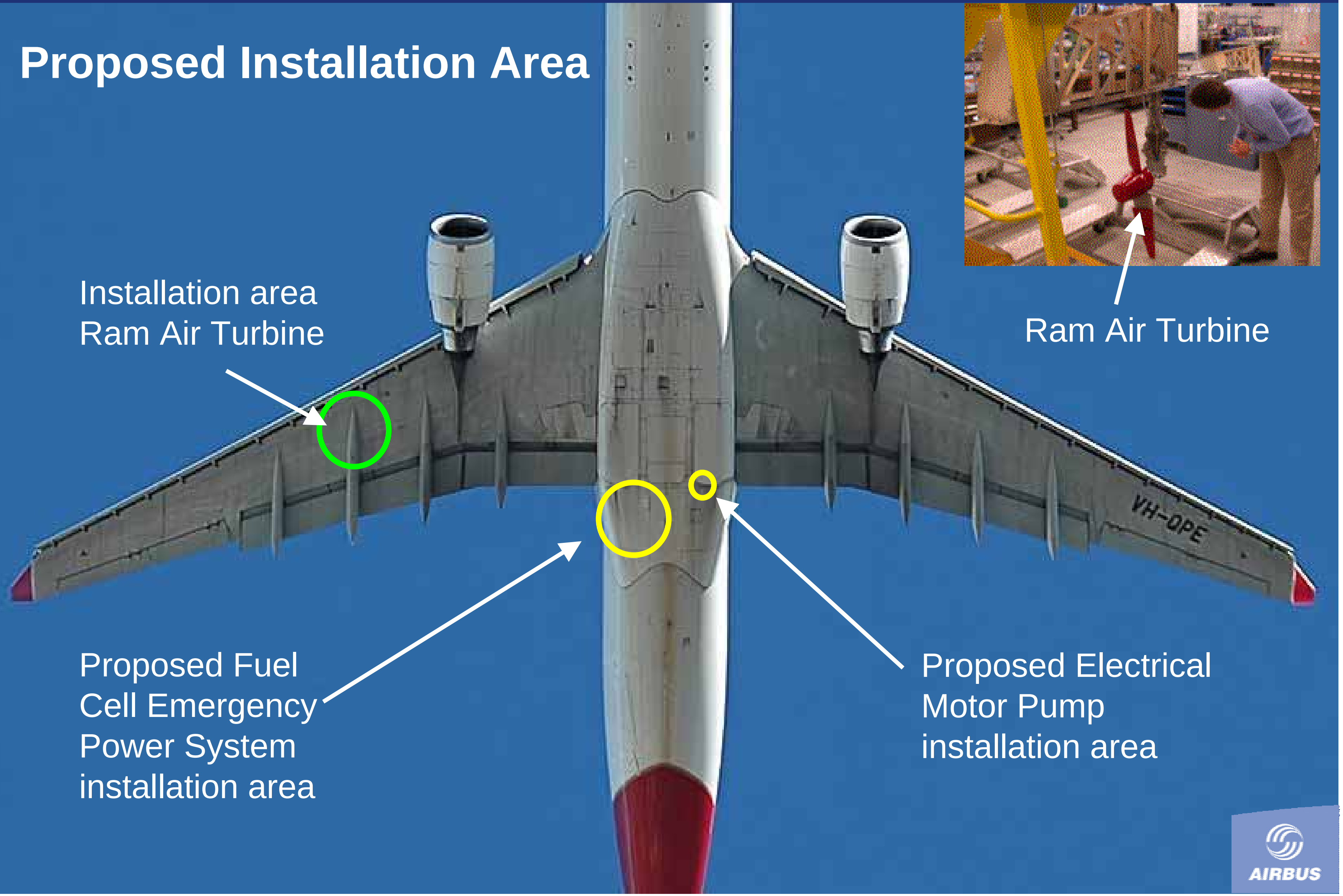
Advantages

- Support of the All Electric Aircraft Concept
- Weight Reduction
- Short System Starting Time
- Low Maintenance Costs
- Health Monitoring possible

AIRBUS

Step 2: Fuel Cell Emergency Power System

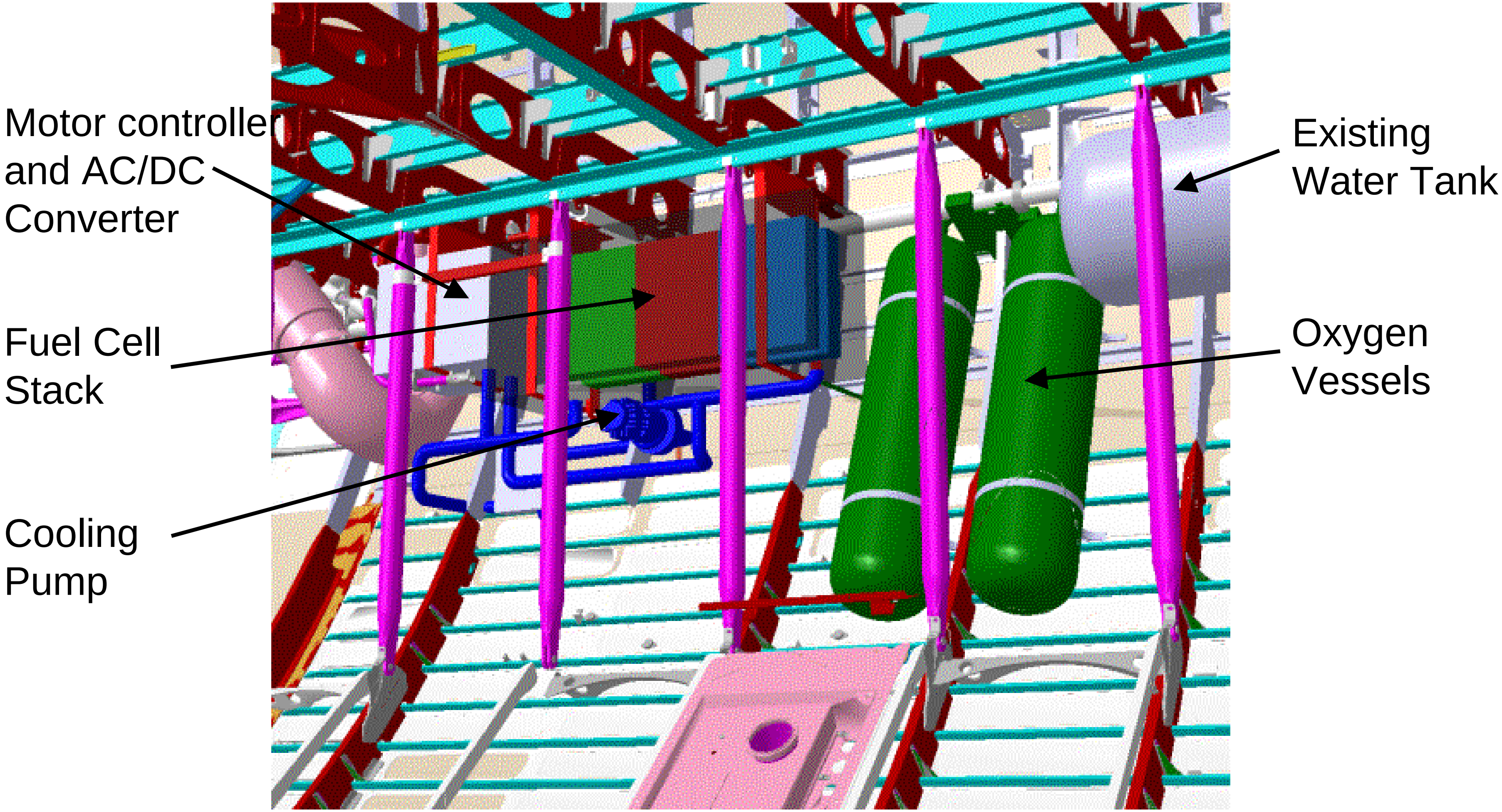
Proposed Installation Area



AIRBUS

Step 2: Fuel Cell Emergency Power System

Installation Concept

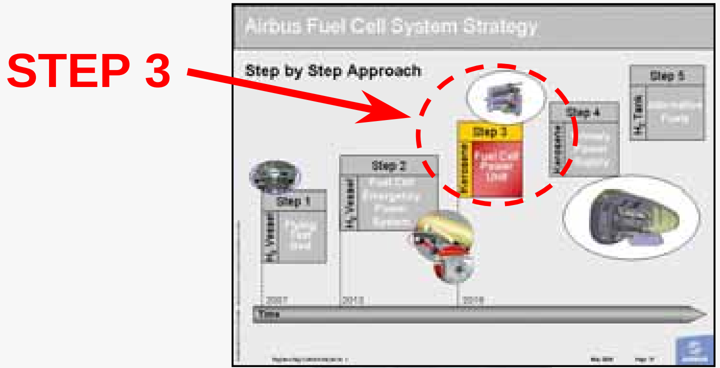


View from aft cargo compartment into Aircraft lining

Contents

Step 3: Fuel Cell Power Unit

Overview



Target (end of next decade)

- Power Generation by Fuel Cell System

Advantages

- Support of the All Electric Aircraft Concept
- Weight Reduction
- Mission Improvements
- Elimination of RAT and APU and battery reduction
- Potential for on-board water generation
- Emission Reduction

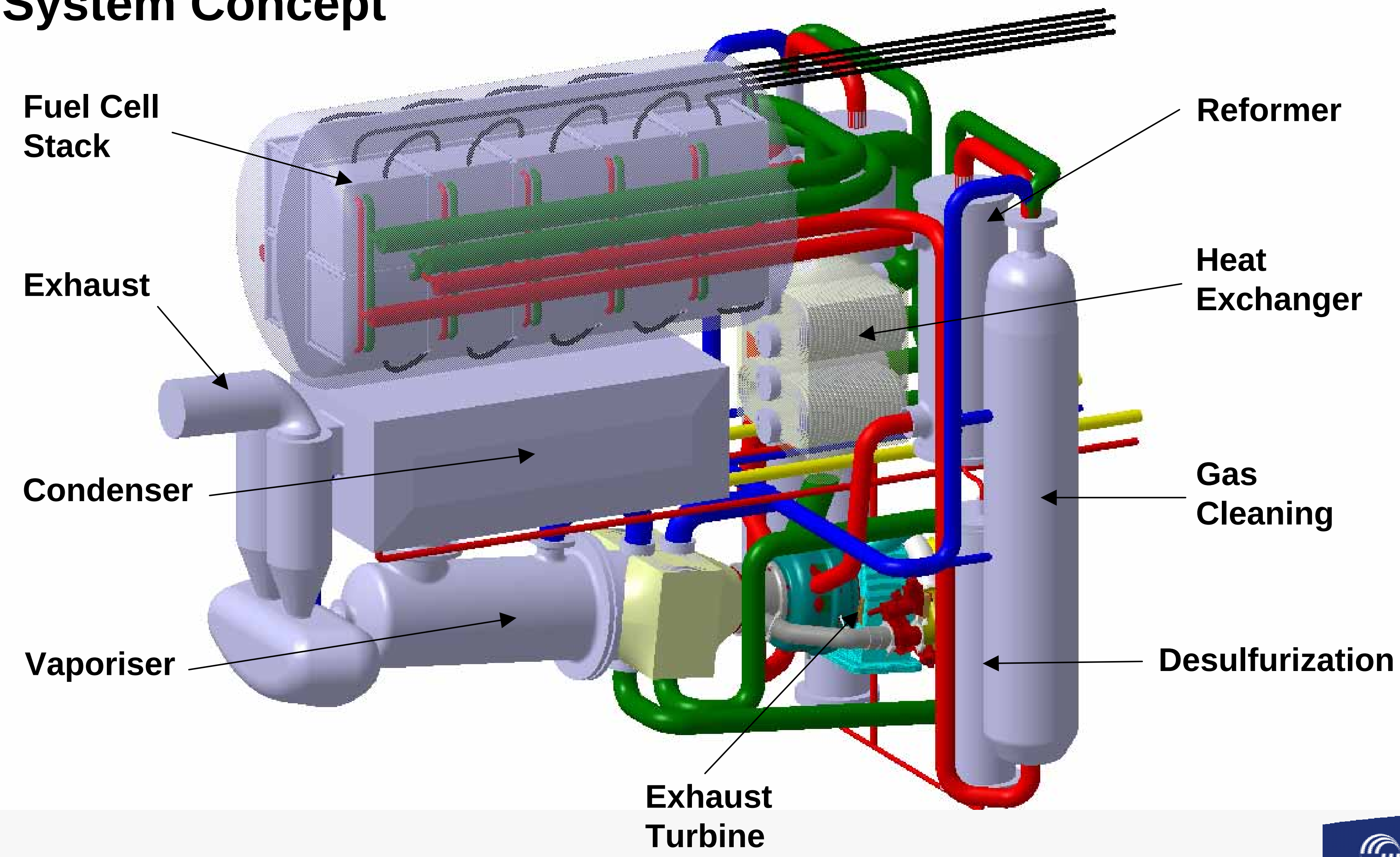
System Specification

- Power Output: 400 kW_{el} (possible configuration: 4*100 kW-System)
- Fuel: Kerosene
- Specific Weight: 1 kg/kW
- Specific Volume: 1,5 L/kW

AIRBUS

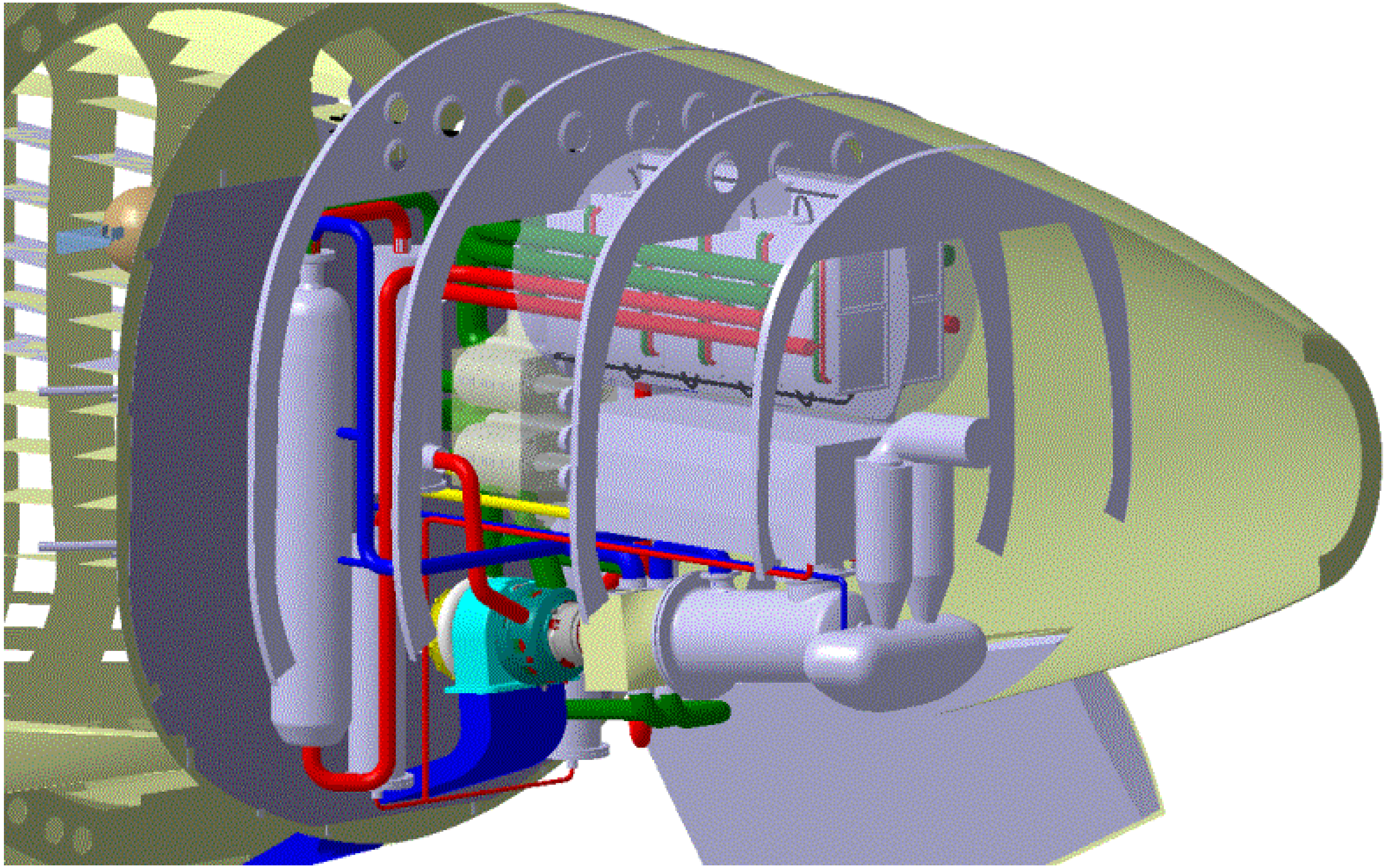
Step 3: Fuel Cell Power Unit

System Concept



Step 3: Fuel Cell Power Unit

Tail Cone Integration Concept

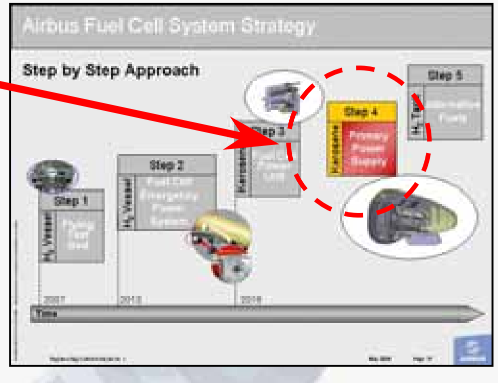


Contents

Step 4: Fuel Cell as Primary Power Source

Overview

STEP 4



Target (20XX)

- Primary Power Generation by Fuel Cell System

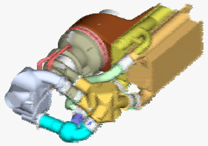
System Specification

- Power Output: 1000 kW_{el}
- Fuel: Kerosene

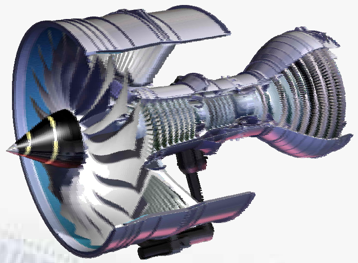
High Mature, Reliable and Safe Fuel Cell System!

Step 4: Fuel Cell as Primary Power Source

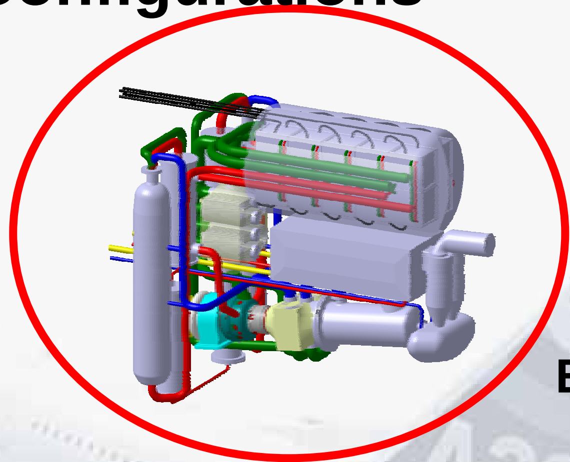
Advanced Aircraft System Configurations



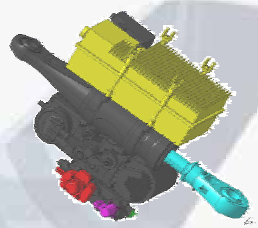
Electrical Powered Air Conditioning



Advanced Main Engines



Fuel Cell System



Electrical Actuators

Emerging technologies:

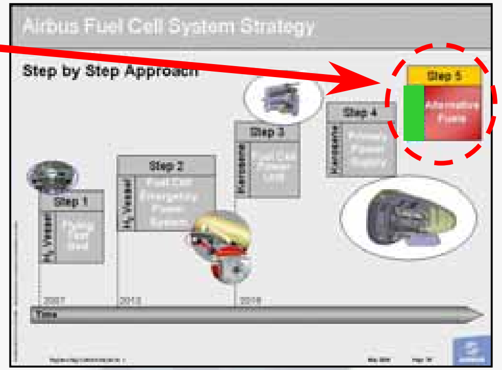
- Optimized electrical and mechanical systems
- Power supply by fuel cell systems
- Advanced cabin system concepts
- New Aircraft system architectures

Contents

Step 5: Alternative Fuels

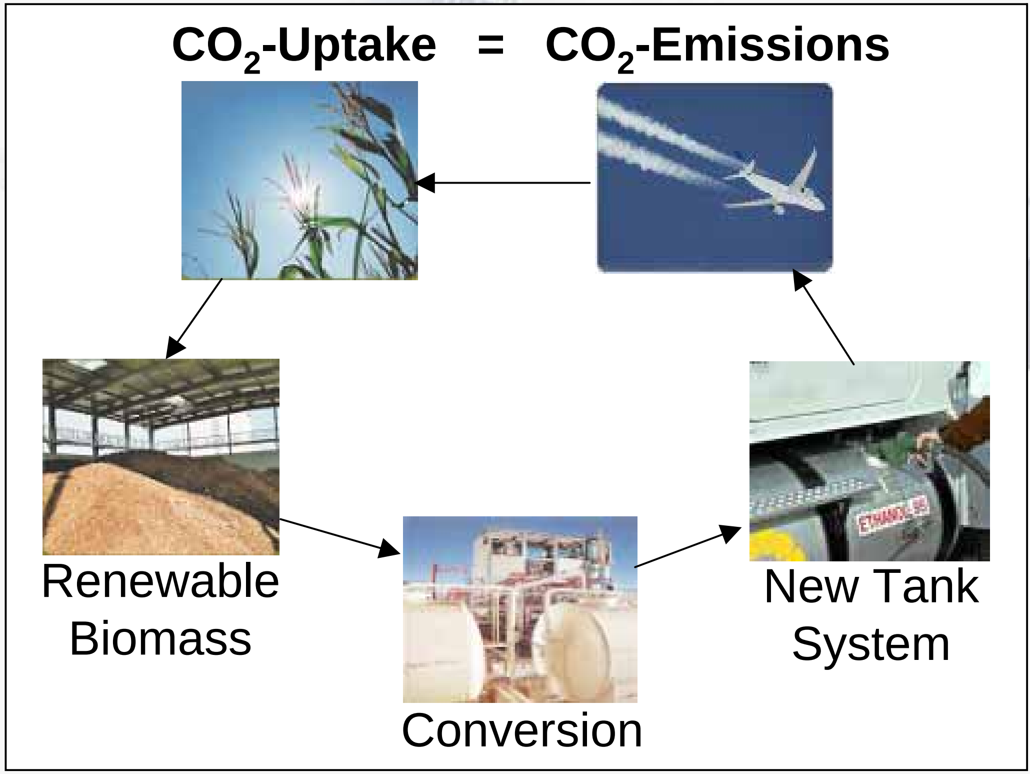
Overview

STEP 5



Target (20XX)

Power Generation by Fuel Cell System with Alternative Fuels



Alternative Fuels:

- Desulfurized Kerosene
- Hydrogen
- Ethanol/Methanol
- Biofuels

New Aircraft Generation

- Hydrogen Fuelled Aircraft
- New Tank System
- Fuel Cell System without Fuel Processing

Contents

AIRBUS

Industrialization

Partners:

AIRBUS

BMWA BUNDESMINISTERIUM für WIRTSCHAFT und ARBEIT

Universities and Institutes:

Forschungszentrum Jülich in der Helmholtz-Gemeinschaft

UNIVERSITY OF PATRAS

"Jožef Stefan" Institute

Universität Hannover I:F:I

JRC

Universität Stuttgart

Hochschule für Angewandte Wissenschaften Hamburg Hamburg University of Applied Sciences

LEEI

DLR

utbm université de technologie Belfort-Montbéliard

ECN

TUHH Technische Universität Hamburg-Harburg

l2ES

Companies:

DASSAULT AVIATION

AIR LIQUIDE

AOA apparatebau gauting

THALES

EADS

AKG

alp's advanced low pollution power systems

Germanischer Lloyd

DIEHL Avionik Systeme

MTU Aero Engines

Industrialisation Partners:

LIEBHERR

GE

MICHELIN A better way forward

United Technologies

Industrialization

Growing Systems Test Lab in Hamburg

Test Rig with Reformer for SOFC Application

Test Rig with Integrated PEM Fuel Cell

Test Rig for SOFC

Contents

Conclusion

- Airbus is involved/driving projects and tasks to bring forward the fuel cell industrialization with major suppliers especially in aeronautical applications

- Airbus will gain an early integration with the step by step approach
  - Soon experience with applied hardware
  - Fundamental basis for further development

- Airbus is committed to apply fuel cell systems with strong support by industrial partners and system suppliers

- Airbus is at the forefront of fuel cell technology and innovation

- Our advanced, environmental friendly and economical products will ensure an excellent competitiveness


THANK YOU FOR YOUR ATTENTION!
AIRBUS


AIRBUS

AIRBUS

AN EADS JOINT COMPANY
WITH BAE SYSTEMS