
AIRBUS

Presented by

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Fuel Cell Systems For Aeronautic Applications

A Clean Way from Kerosene to Energy

Hamburg, September 04 2006

Contents

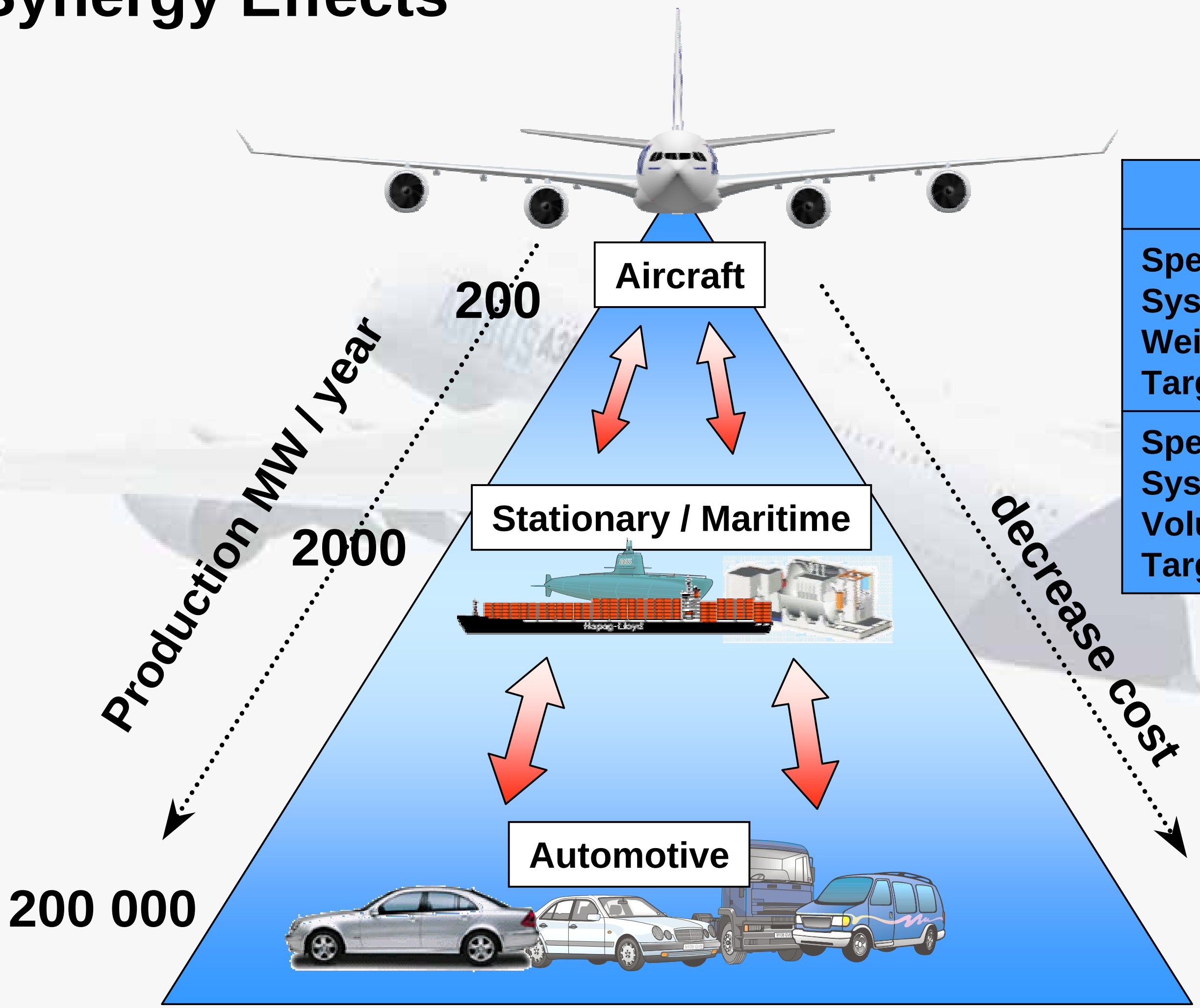
Introduction

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.

Introduction

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.

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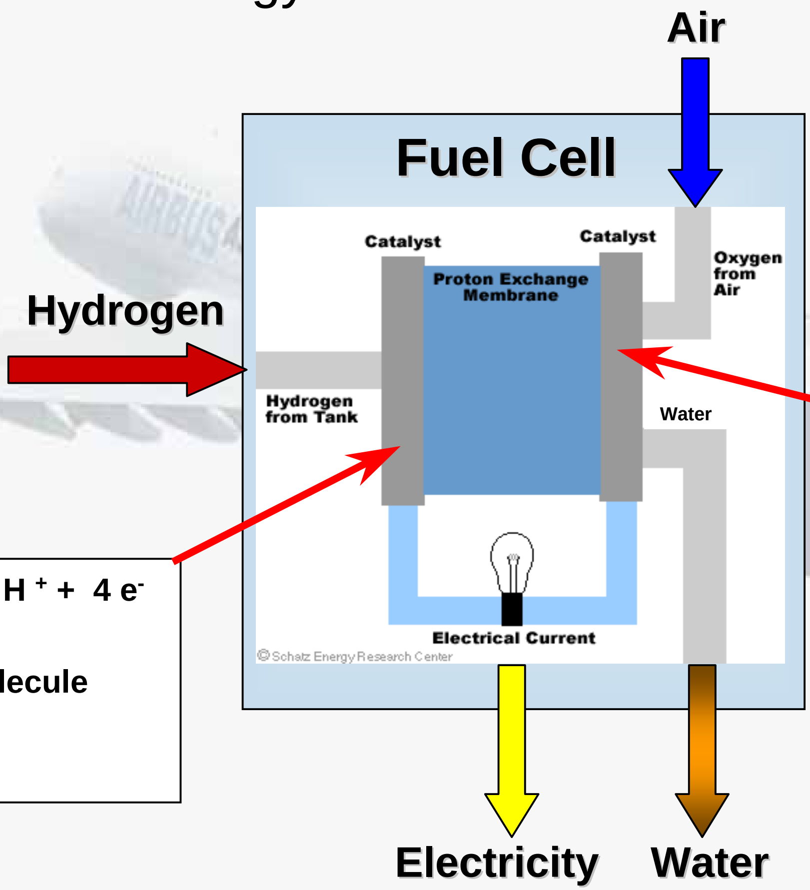
Fuel Cell System

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

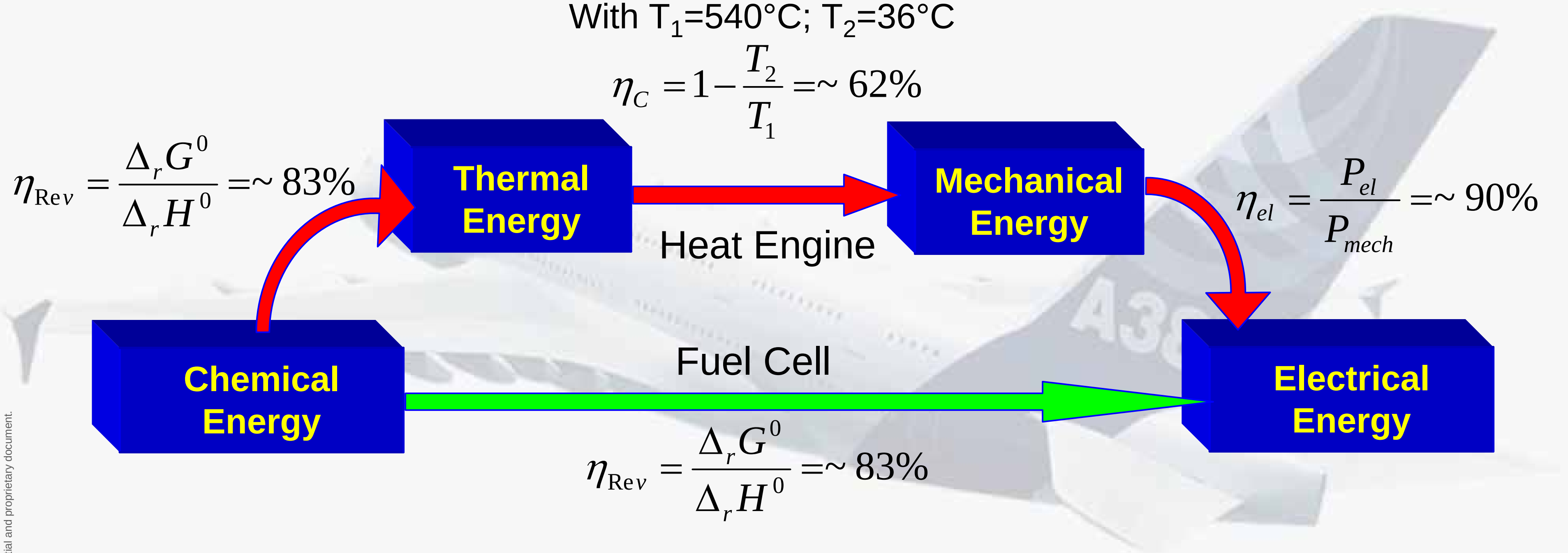
Overall Reaction: $2\ H_2 + O_2 \rightarrow 2\ H_2O$ + Electrical Energy + Heat

Fuel Cell System

Comparison – Fuel Cell vs. Heat Engine

With T_1=540°C; T_2=36°C

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



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

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

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

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

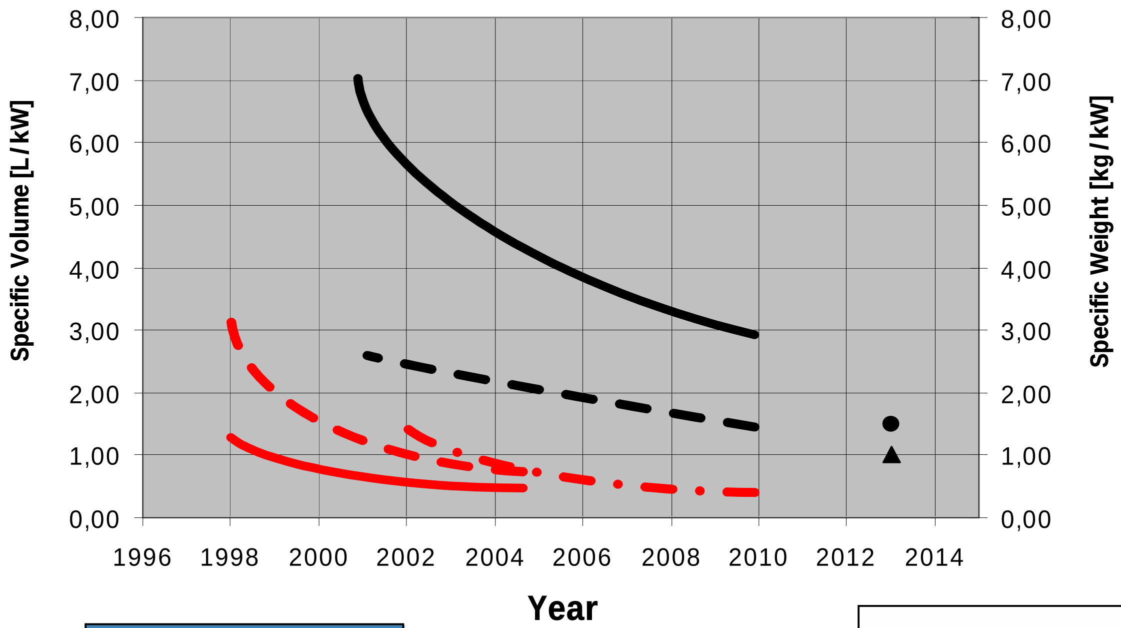
$\eta_{Heat\ Engine} = \eta_{Rev} \cdot \eta_C \cdot \eta_{el} = 0{,}83 \cdot 0{,}62 \cdot 0{,}9 = 0{,}46 = \sim 46\%$

Theoretical maximal achievable Efficiency: ~83%

Fuel Cell System

Development and Technical Targets

Development and Targets for Specific Weight and Volume of Mobile Fuel Cell Stacks and Sytems



GM St 3 – 1997 (37 kW)

Current Stack (102 kW)

Stacks:

- specific Volume GM Stack (Power increased from 37 kW – 102 kW)
- Specific Weight GM Stack (Power increased from 37 kW – 102 kW)
- Specific Volume Ballard Stack (based on net System Power 85 kW)

Systems:

- Specific Weight and Volume DOE-PNGV FC System (Power 50 kW, gasoline fuelled)
- Specific Weight and Volume DOE-PNGV FC System (Power 50 kW, H2 fuelled)
- ● Airbus Target for System Volume Density
- ▲ Airbus Target for System Weight Density

Ballard Xcellsis Hy-80 Fuel Cell Engine (68 kW)

Delphi SOFC-APU Gen.2 (2002) 5 kW System

Delphi SOFC-APU Gen.1 (2000) 5 kW System

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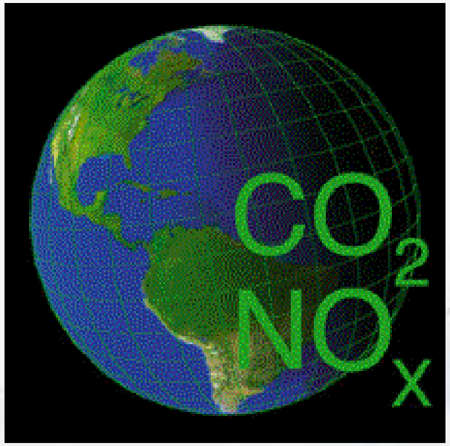
Motivation for Fuel Cell System Application

Ecological and Economical Aircraft Operation Aspects



Ecological Aspects:

- Noise reduction
- Emission reduction
- Higher fuel economy

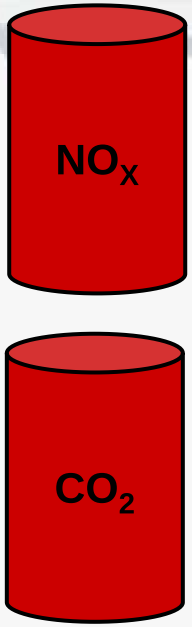
Economical Aspects:

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

Motivation for Fuel Cell System Application

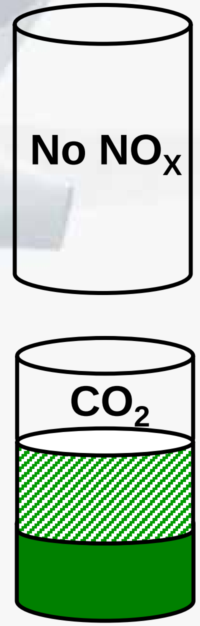
Conventional Electrical Power Generation vs. Fuel Cell System

APU | **Engine** | **No Bleed/Electric Engine** | **Fuel Cell System**



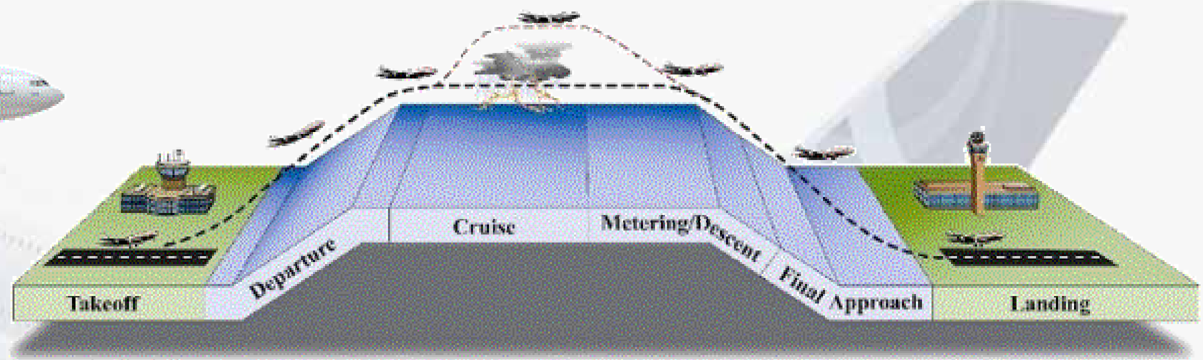
NO_X (**Nitrogen Oxides**) Emission Reduction
Total NO_X reduction
on ground and in flight

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: 3%* Aircraft Systems

  97% Propulsion

~ 3000 L per flight for Aircraft Systems operation

Motivation for Fuel Cell System Application

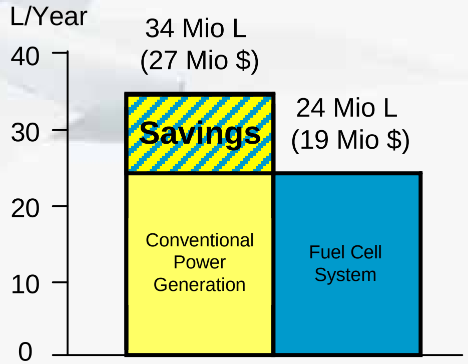
Fuel Savings

	Conventional Electrical Power Generation	Fuel Cell System
Efficiency	~40% (Maximum possible)	~60% (Target)
Fuel Use per Flight (10.000 km)	~3.000 Liter	~2.100 Liter

Kerosene Savings ~900 Liter per Flight

Annual Savings for a fleet of 30 Aircraft A330-300

- On average 377 trips per year
- Assumed Kerosene Costs for 2020: 125 $/barrel (0,79 $/L)



Fuel Savings: ~10 Mio L per Year
Money Savings: ~8 Mio $ per Year
+ Emission Fees

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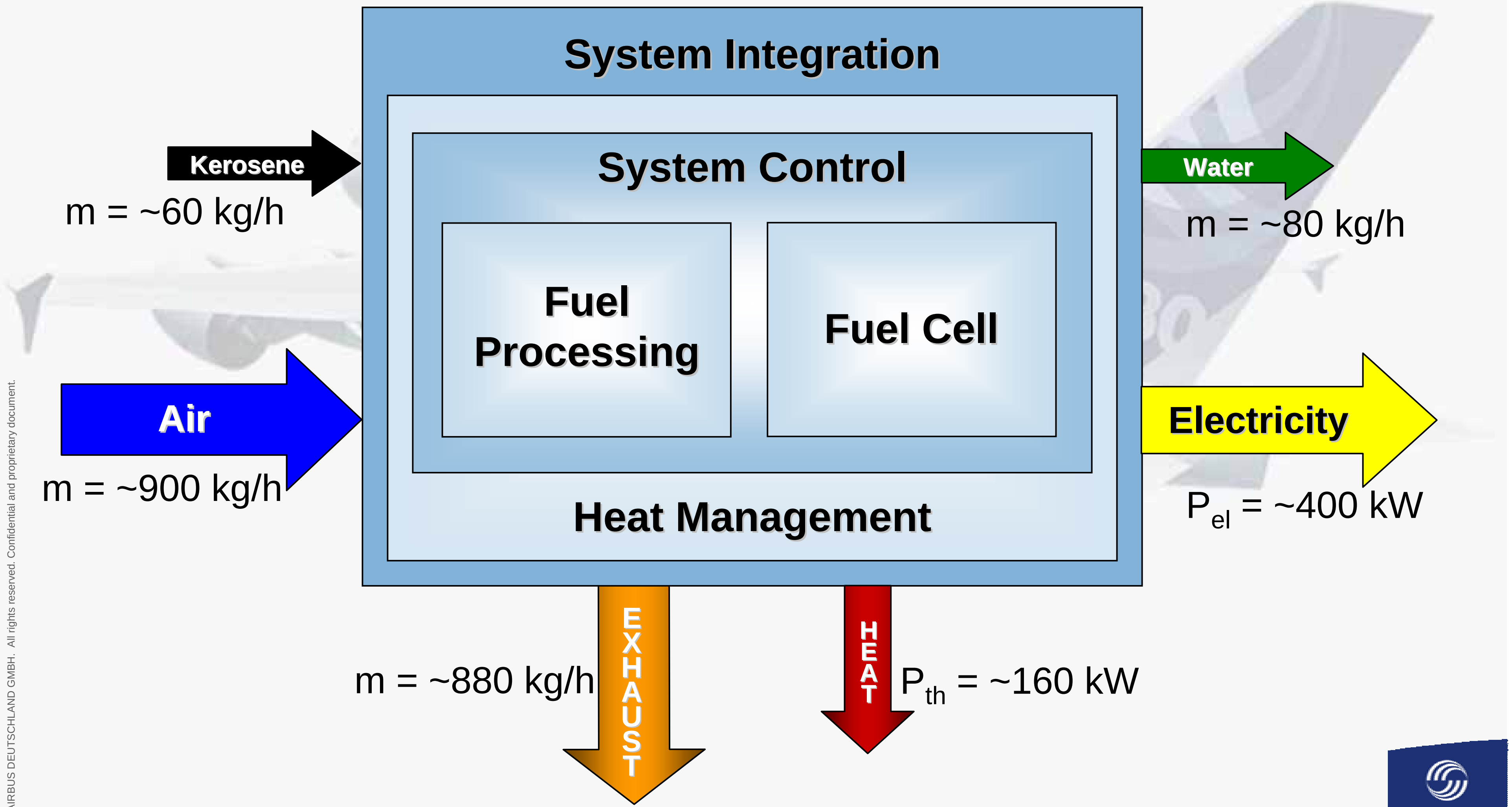
Fuel Cell Systems Architecture

System Architecture Overview

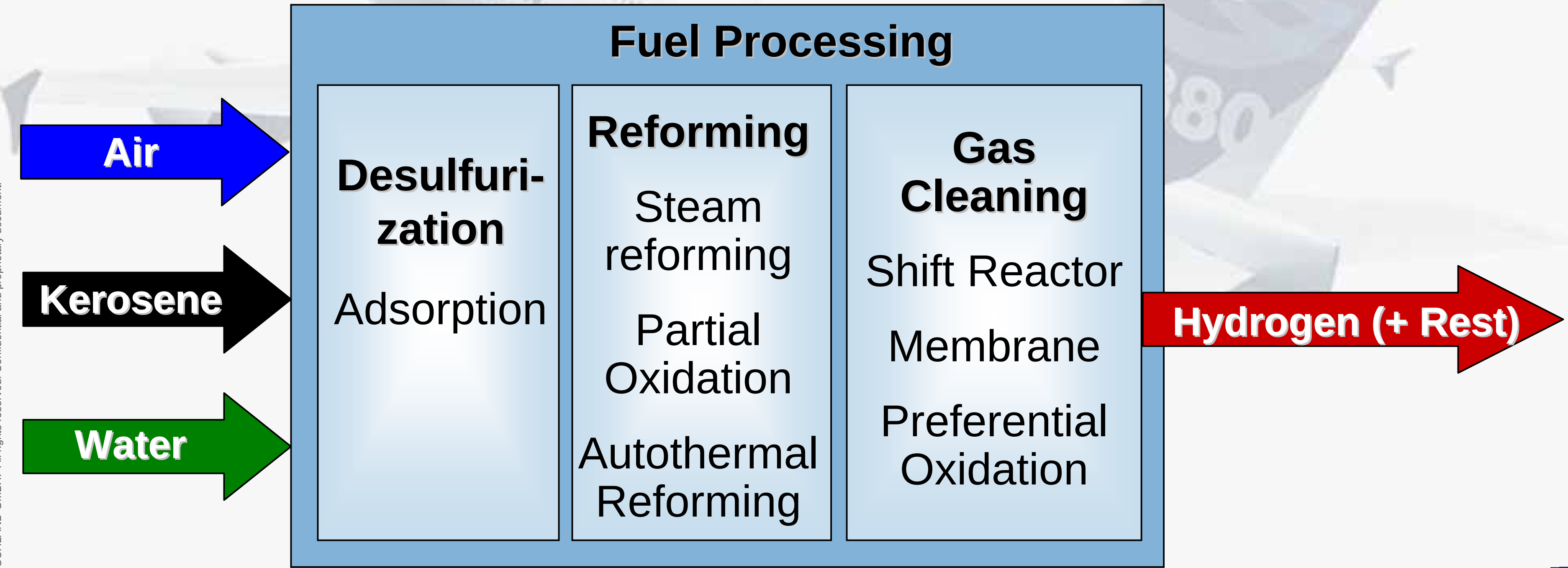


Fuel Cell Systems Architecture

Key Challenge Fuel Processing

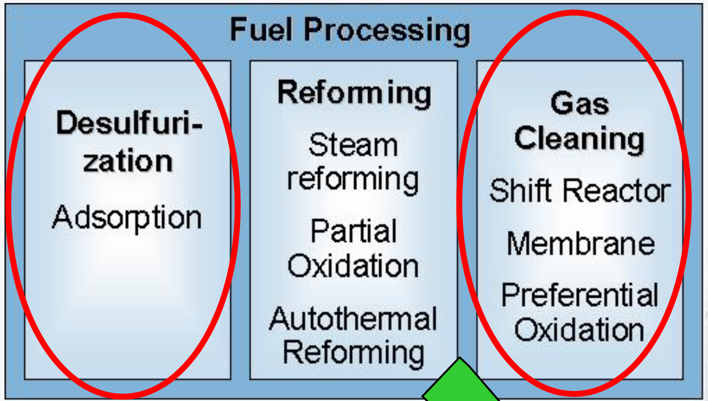
Fuel Processing is the Conversion of Kerosene into a hydrogen rich gas. Three Parts are normally necessary:

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).



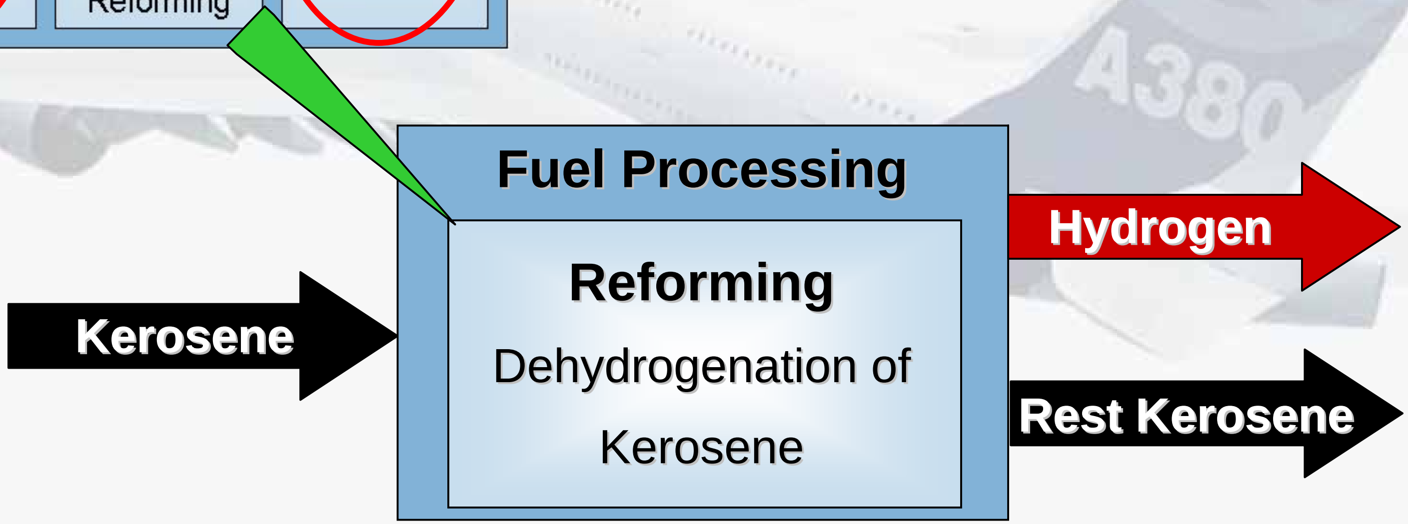
Fuel Cell Systems Architecture

Dehydrogenation



Challenge:

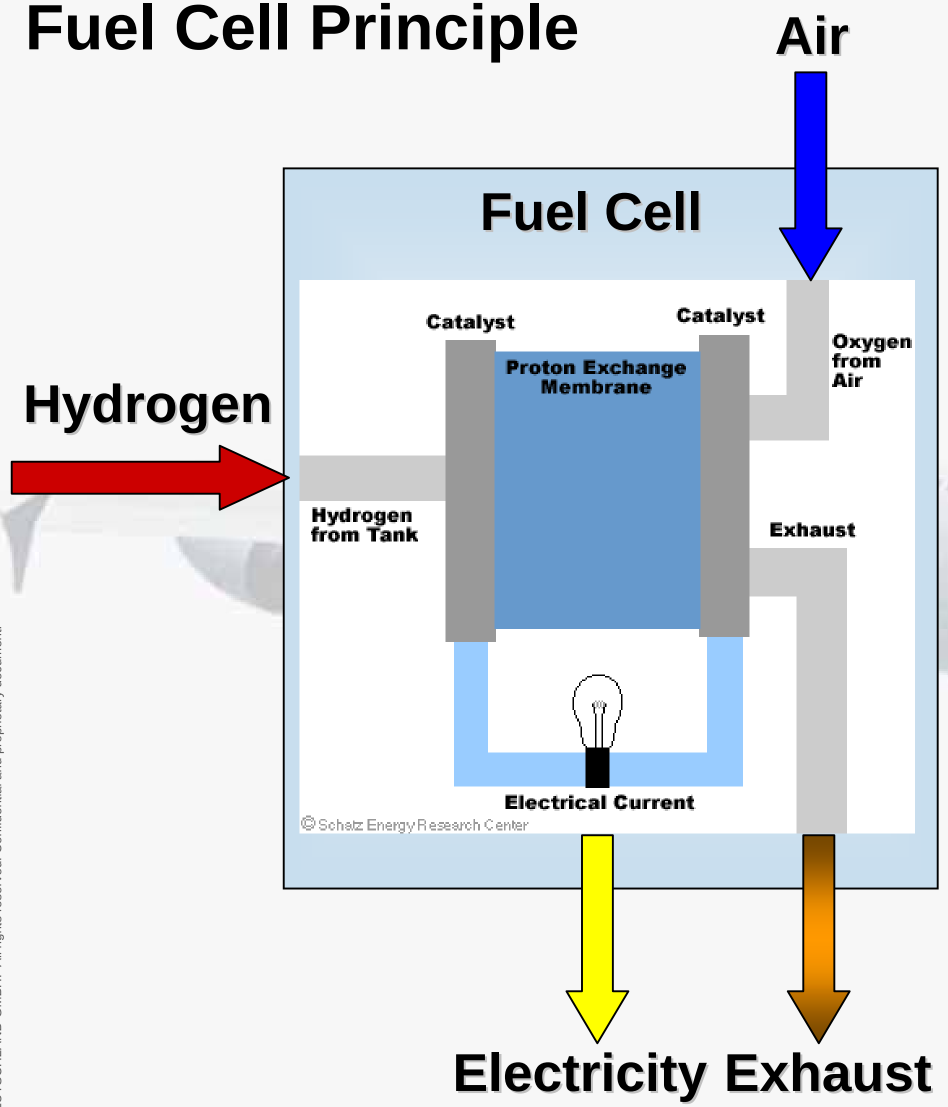
Standard Fuel Processing Methods are too complex.
⇒ A simple, lightweight and robust solution must be found!



Dehydrogenation could be one possible solution

Fuel Cell Systems Architecture

Fuel Cell Principle



A **Fuel Cell** is an electrochemical device that continuously changes the electrical energy of hydrogen and oxygen from air **directly** to electrical energy and heat without combustion.

The overall chemical reaction:
$2\,H_2 + O_2 \rightarrow 2\,H_2O$

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

- PEMFC (Protone Exchange Membrane Fuel Cell)
- SOFC (Solide Oxide Fuel Cell)

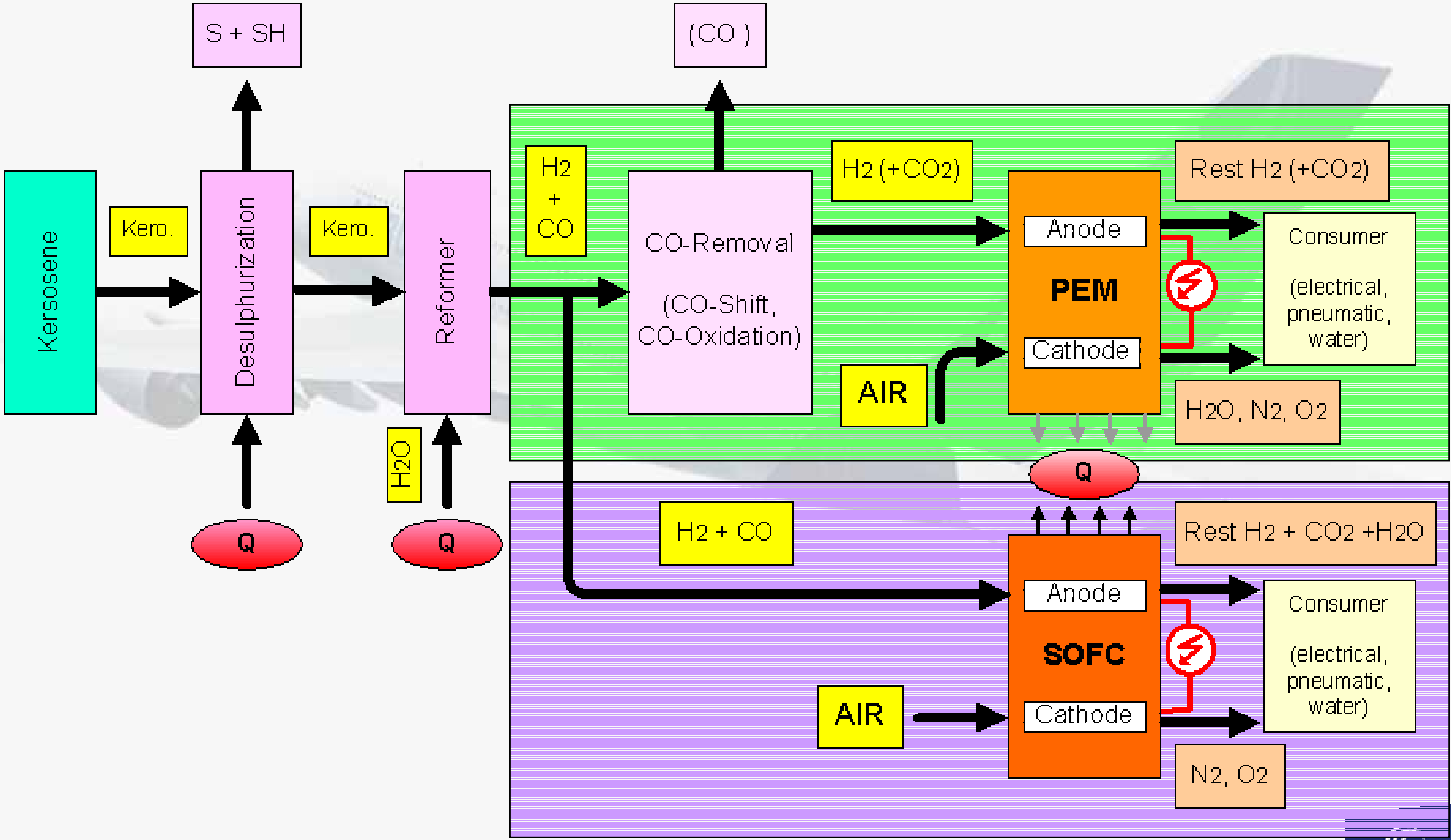
Fuel Cell Systems Architecture

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

Fuel Cell Systems Architecture

Comparison PEMFC – SOCF System



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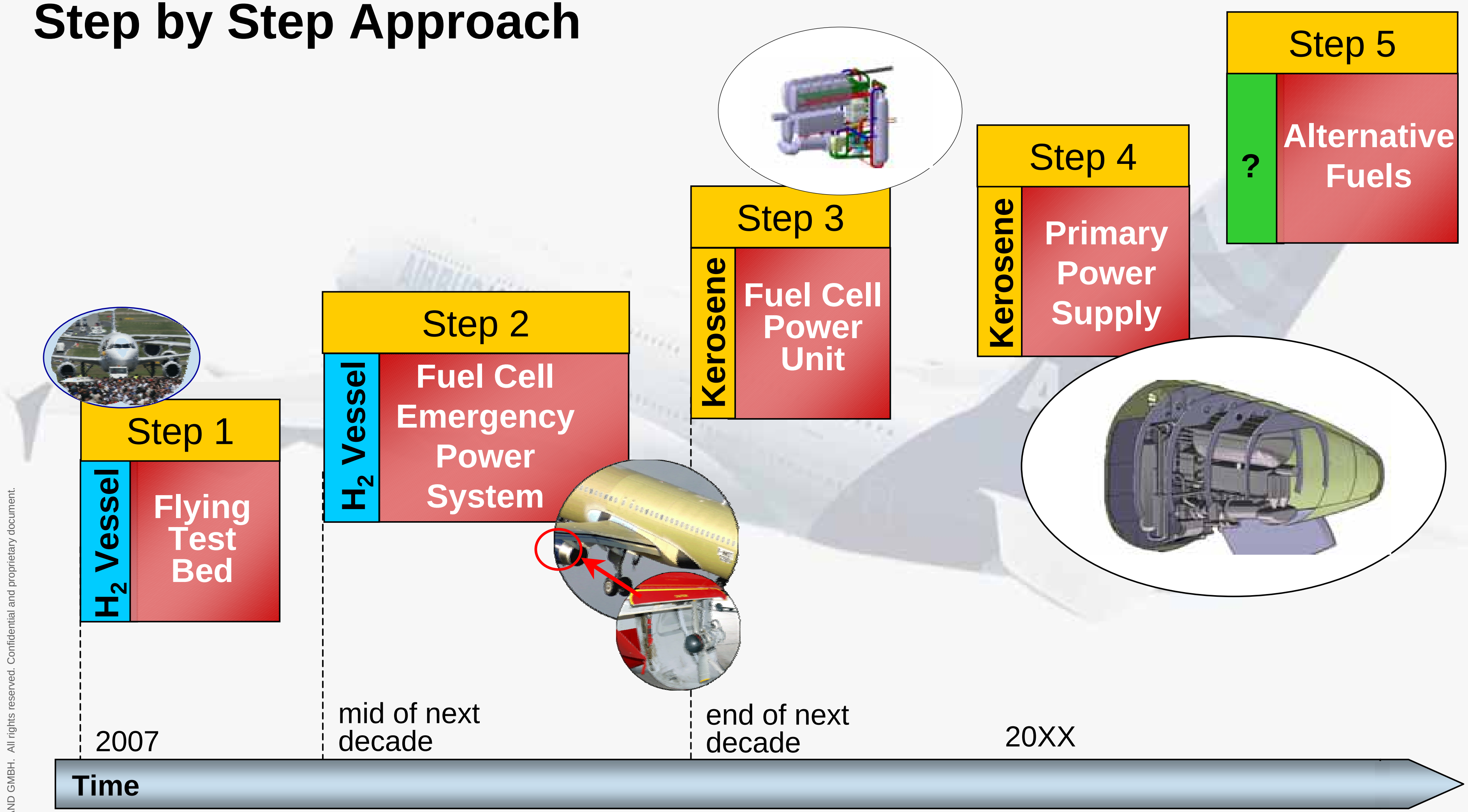
Airbus Fuel Cell System Strategy

Step by Step Approach



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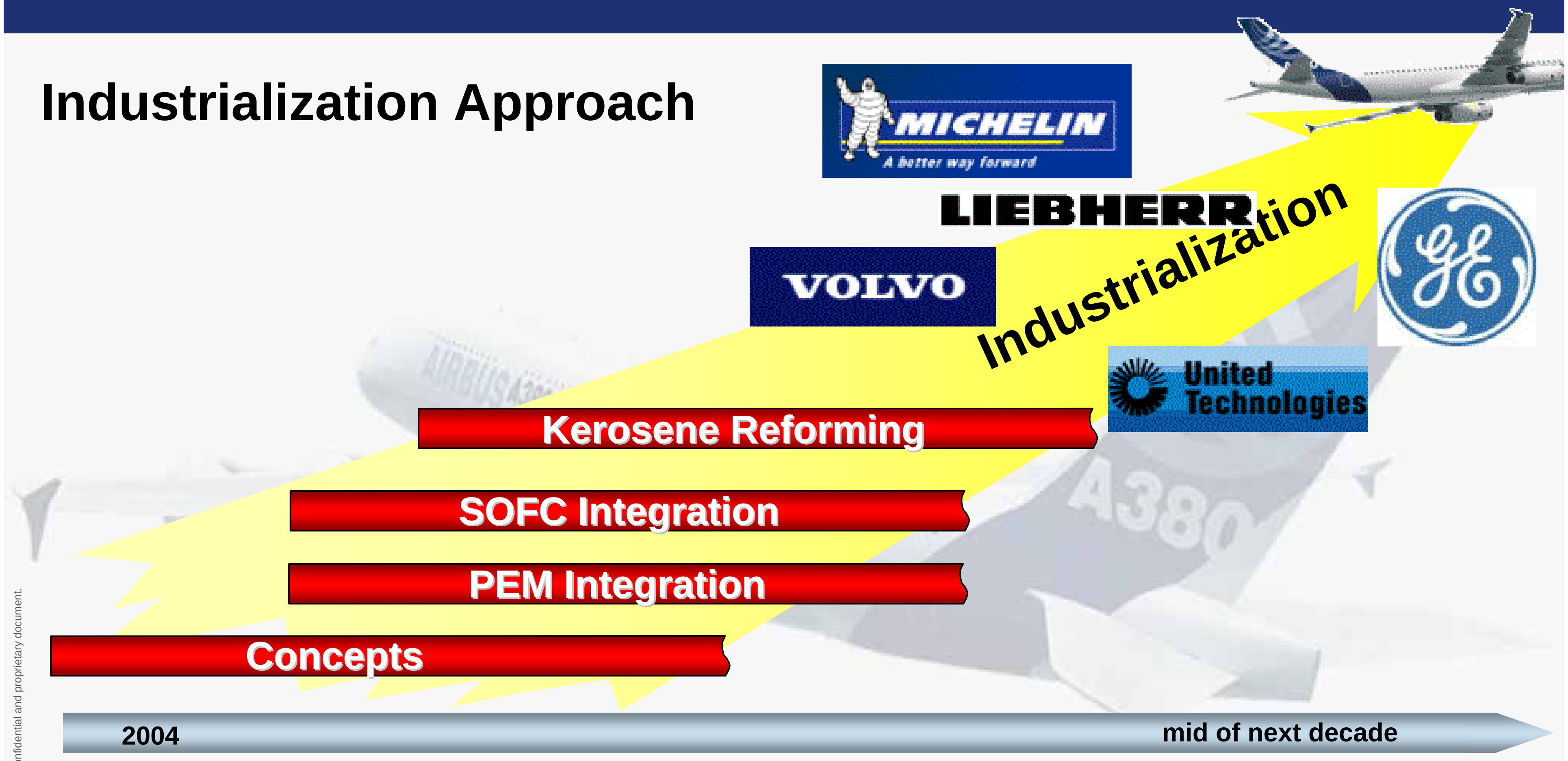
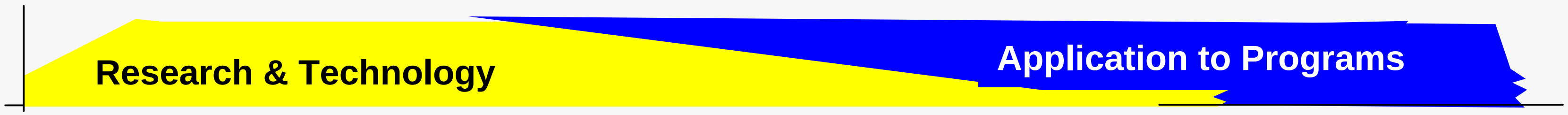
Airbus Fuel Cell System Strategy

Industrialization Approach



Overall Airbus Fuel Cell Activities



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Ongoing Projects and Activities

Overview on Fuel Cell related research projects in Airbus

Project	Content	Target
POA Power Optimized Aircraft	- Power optimization strategies - Kerosene fuelled SOFC system	- SOFC functionality Demonstrator (1 kW)
APAWAGS Advanced Power And Water Generation System	- Kerosene fuelled FC system - Water Generation - PEM and SOFC technology	- SOFC and PEMFC System ground demonstrator for power and water generation (5 kW)
CELINA Fuel Cell In A New Configured Aircraft	- Kerosene fuelled FC system - Aircraft application investigation - Preliminary safety assessment	- Dynamic system simulation - Extensive testing of PEMFC stack
FuCAp/FCEPS Fuel Cell Application (Demonstrator) Fuel Cell Emergency Power System	- FC emergency power system - H_2/O_2-Technology	- Flying test bed demonstrator 20 kW (2007) - Integrated system flight tests
MOET More Open Electric Technology	- Electrical generation and distribution on Aircraft level - Kerosene fuelled SOFC system	- Architecture assessment - SOFC system simulation
A/C SOFC Aircraft Solid Oxide Fuel Cell	-Kerosene fuelled SOFC system	- 400 kW SOFC System - Testing and benchmarking
KING Kerosene Reforming	- Fuel Processor development - Desulfurization by adsorption - Autothermal Reformer - Dehydrogenation of kerosene	- Dehydrogenation lab demonstrator (2006) - 50-100 kW Fuel Processor (2009) - 400 kW Fuel Processor

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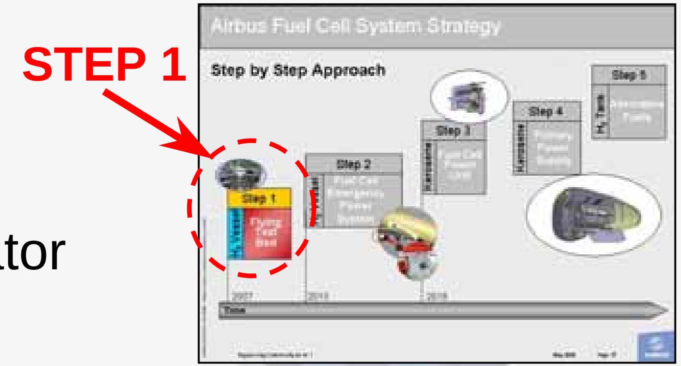
Step 1: Demonstrator

Overview



Target (2007)

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

Motivation

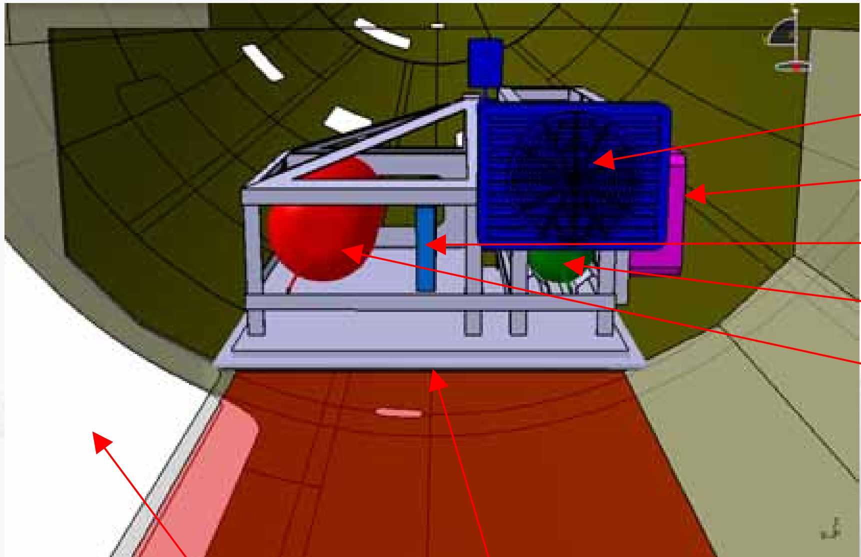
- First Safe Fuel Cell System operation on board
- Flight Test Data Collection, dynamic, heat, loads etc.

System Specification

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

Step 1: Demonstrator

Installation Area



Cooler

Power Electronics

Fuel Cell

H_2-Storage

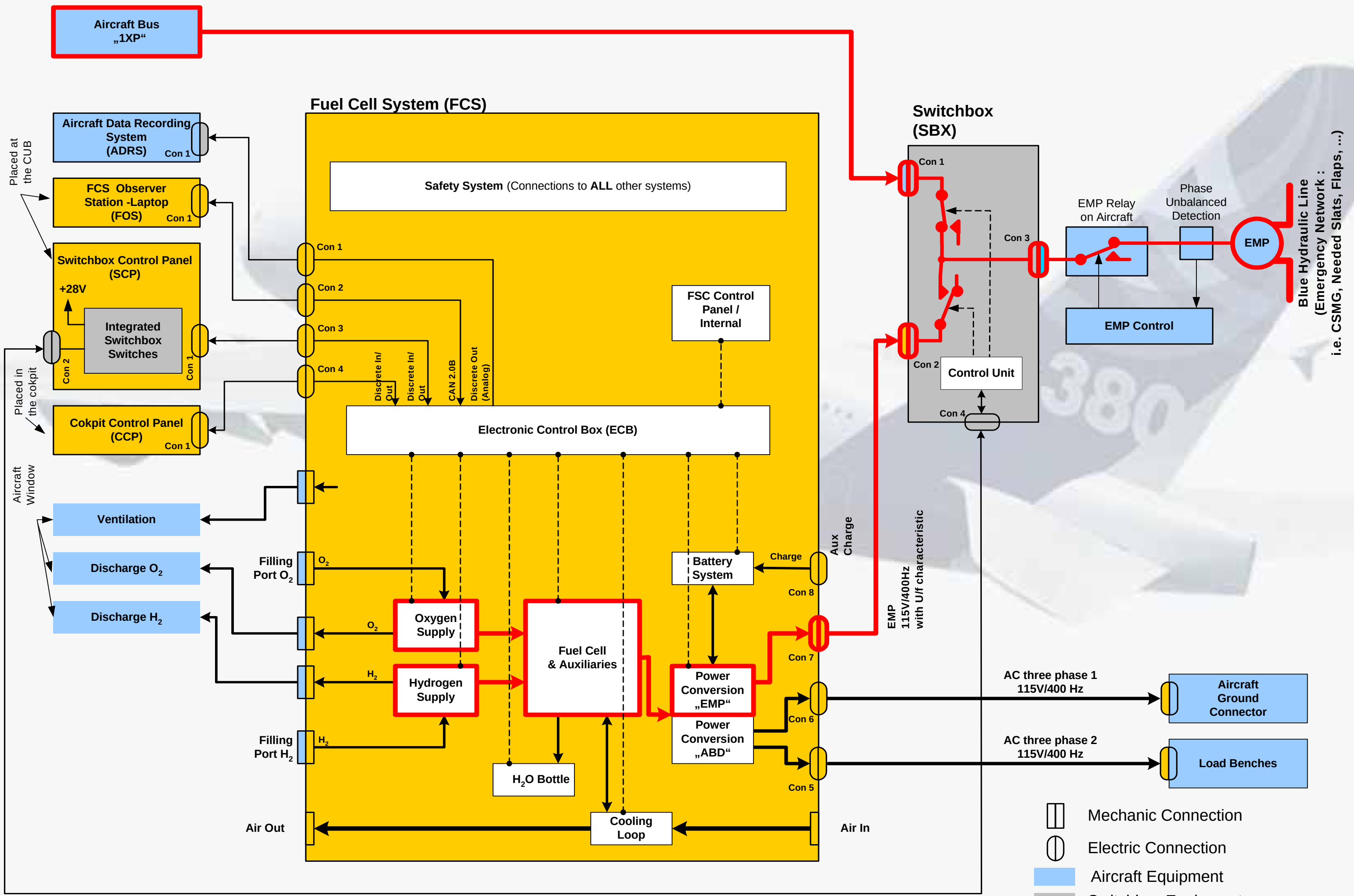
O_2-Storage

Storing Position 4

Cargo Door

Step 1: Demonstrator

System Architecture

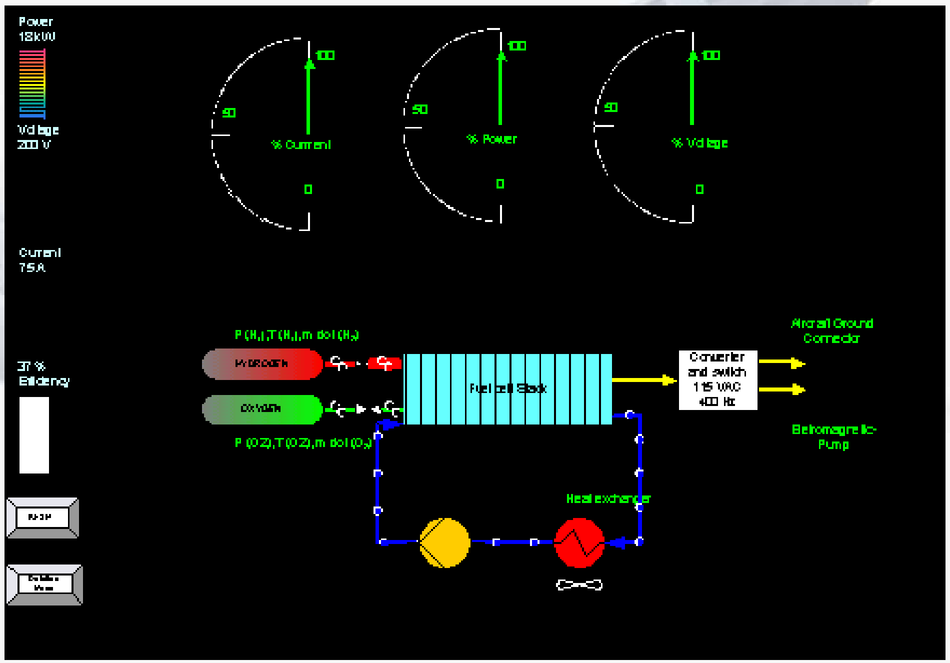


Author : Heiko Marz - EYVEC

Step 1: Demonstrator

Test Data Collection

Flight Test Engineering Station



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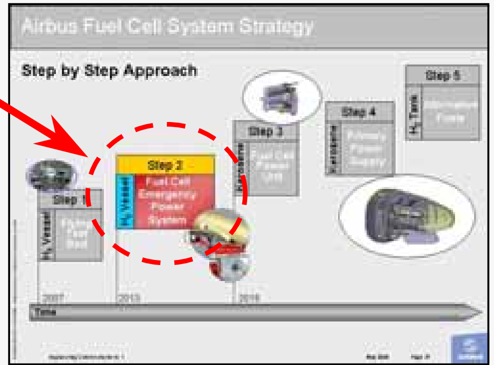
Step 2: Fuel Cell Emergency Power System

Overview

STEP 2

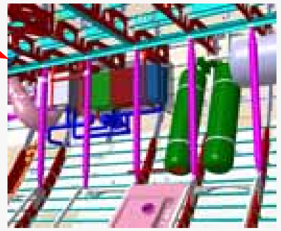


Target (mid of next decade)

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

RAT

FCEPS

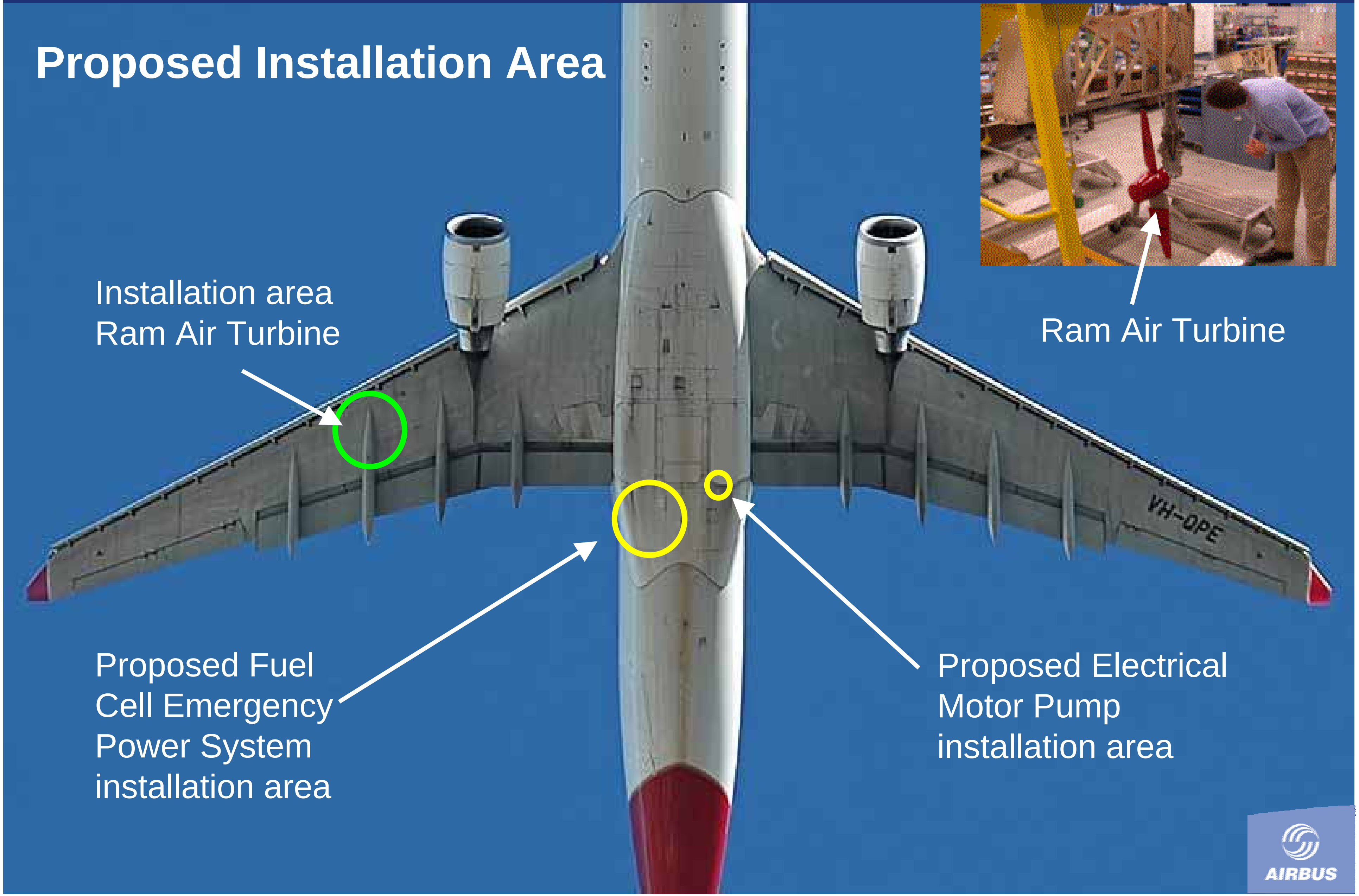


Advantages

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

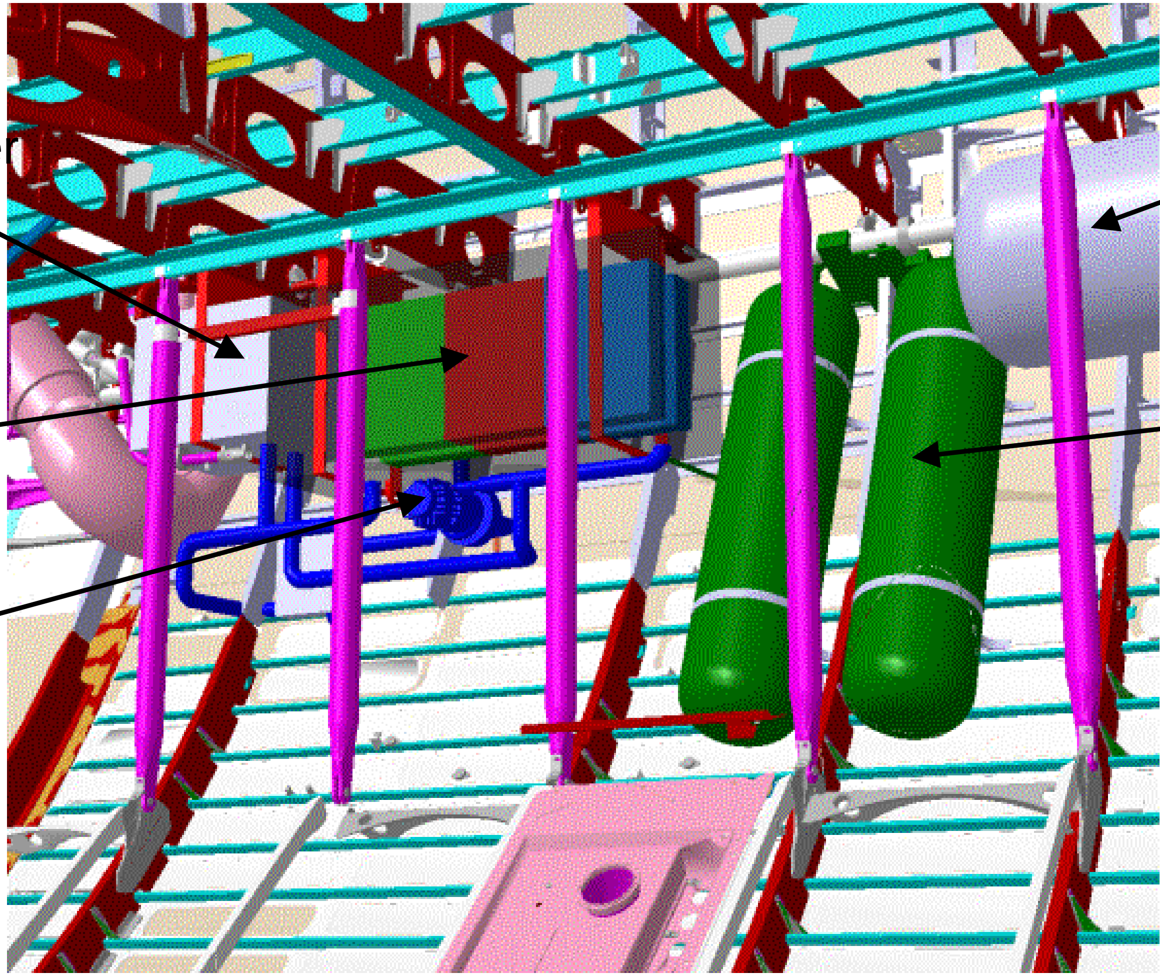
Step 2: Fuel Cell Emergency Power System

Proposed Installation Area



Step 2: Fuel Cell Emergency Power System

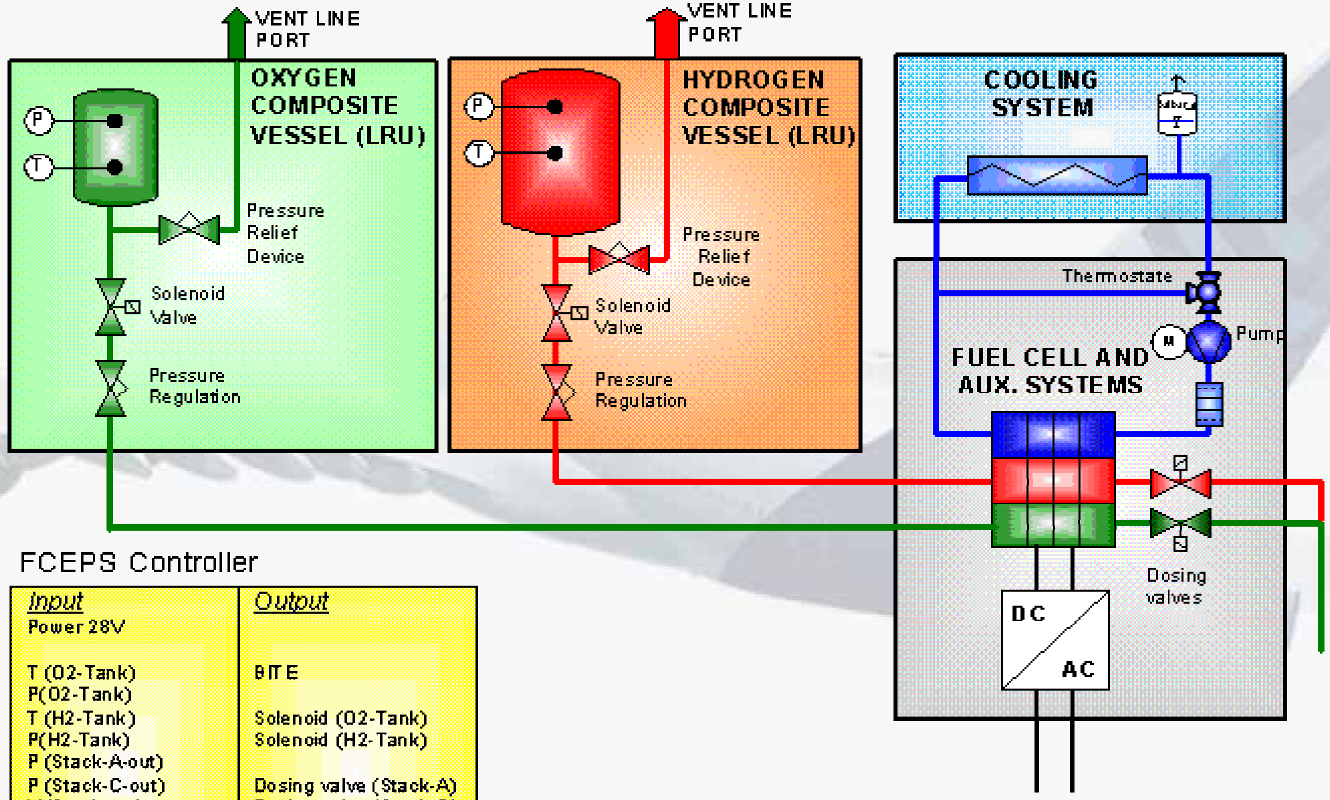
Installation Concept



View from aft cargo compartment into Aircraft lining

Step 2: Fuel Cell Emergency Power System

System Architecture



FCEPS Controller

Input	Output
Power 28V	
T (O2-Tank)	BITE
P(O2-Tank)	
T (H2-Tank)	Solenoid (O2-Tank)
P(H2-Tank)	Solenoid (H2-Tank)
P (Stack-A-out)	
P (Stack-C-out)	Dosing valve (Stack-A)
V(Stack out)	Dosing valve (Stack-C)
I(Stack out)	
T (cooling)	CPC control signal
MC Commands	MC commands
Aircraft Commands	

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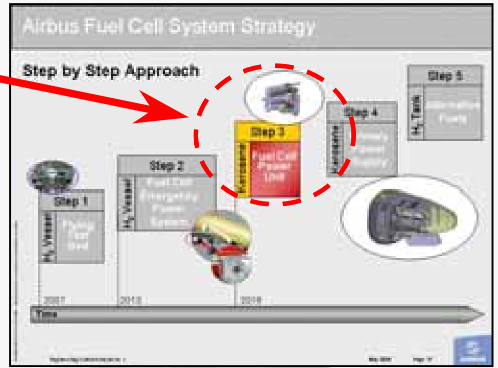
Step 3: Fuel Cell Power Unit

Overview

STEP 3



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}
- ➢ Fuel: Kerosene
- ➢ Specific Weight: 1 kg/kW
- ➢ Specific Volume: 1,5 L/kW

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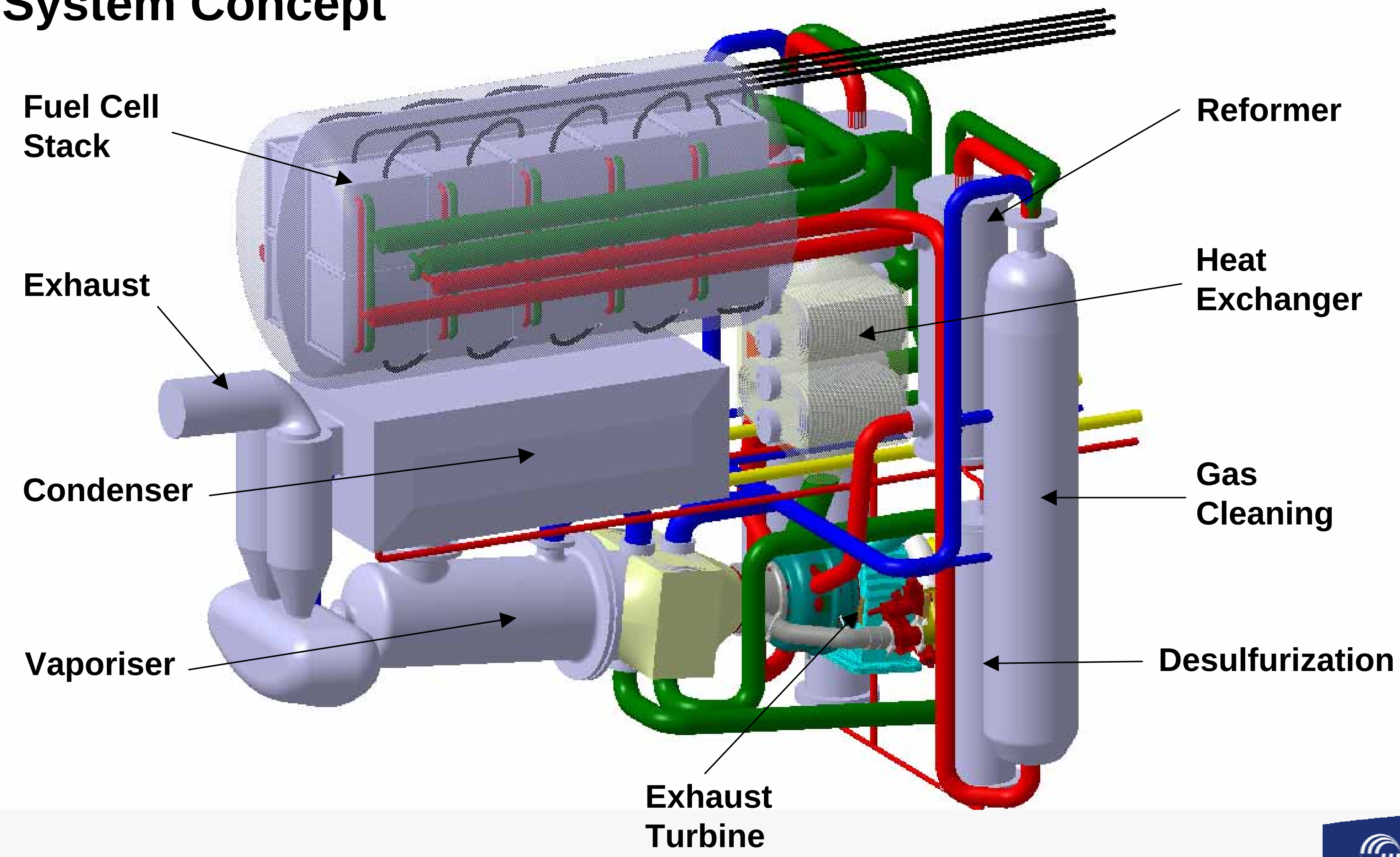
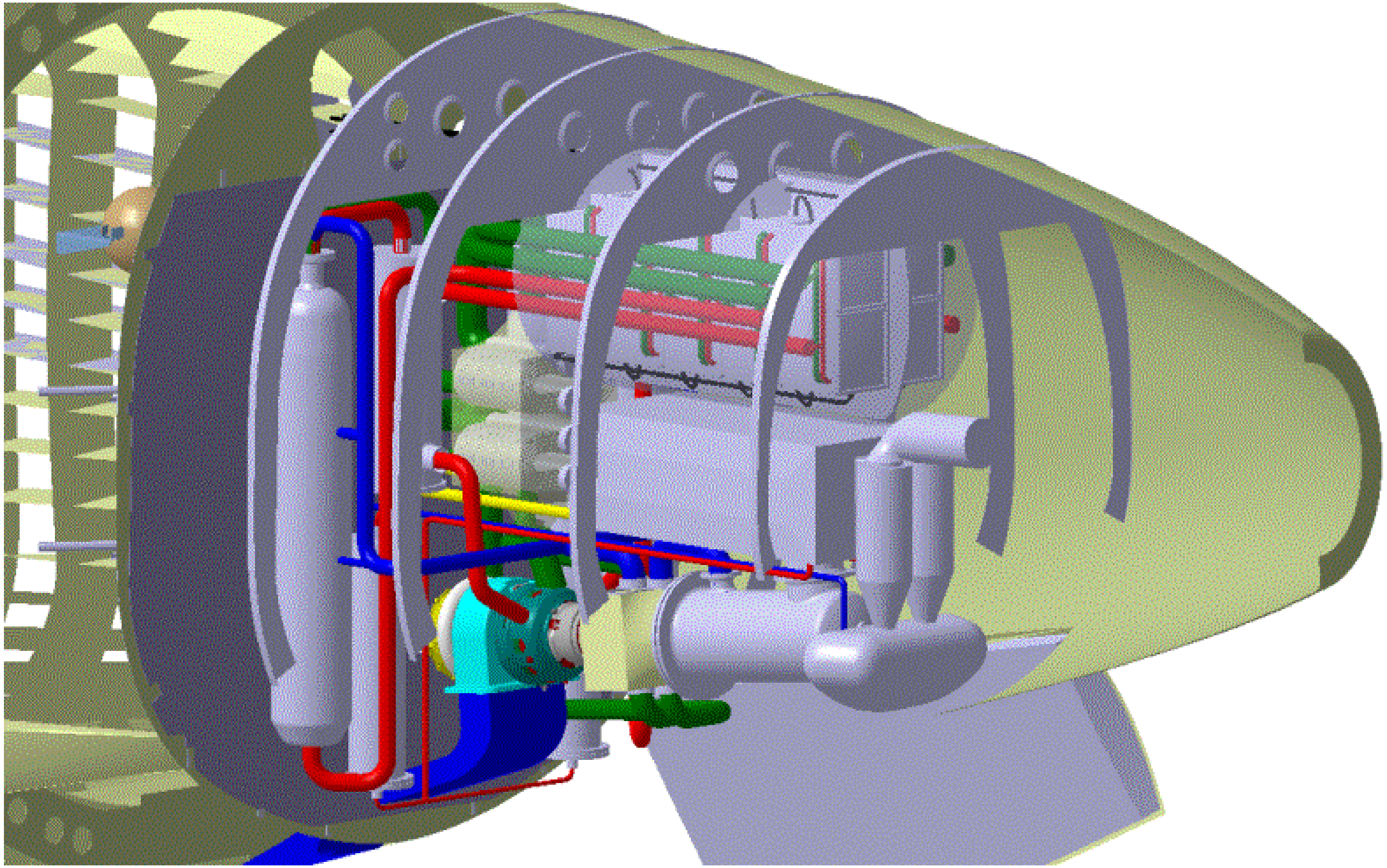
Step 3: Fuel Cell Power Unit

System Concept



Step 3: Fuel Cell Power Unit

Tail Cone Integration Concept



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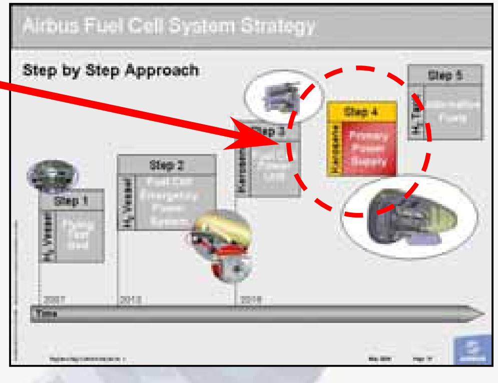
Step 4: Fuel Cell as Primary Power Source

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!

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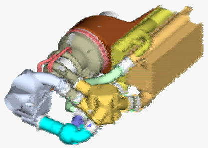
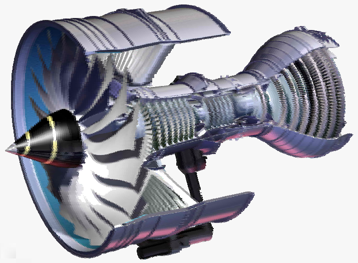
Step 4: Fuel Cell as Primary Power Source

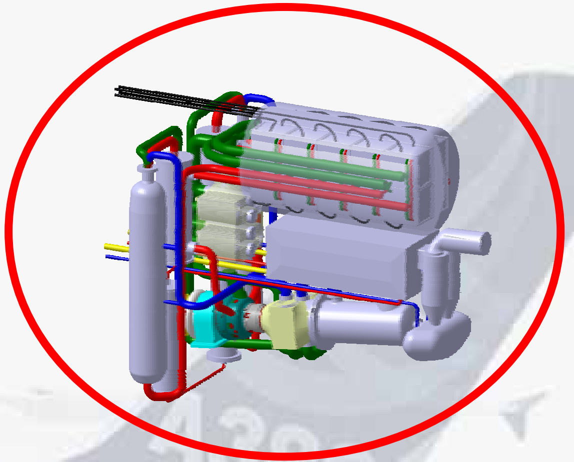
Advanced Aircraft System Configurations



Electrical Powered Air Conditioning



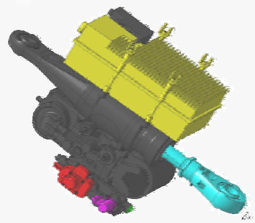
Advanced Main Engines



Fuel Cell System

Emerging technologies:

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



Electrical Actuators

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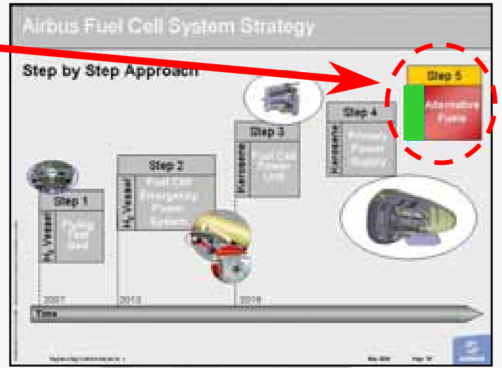
Step 5: Alternative Fuels

Overview

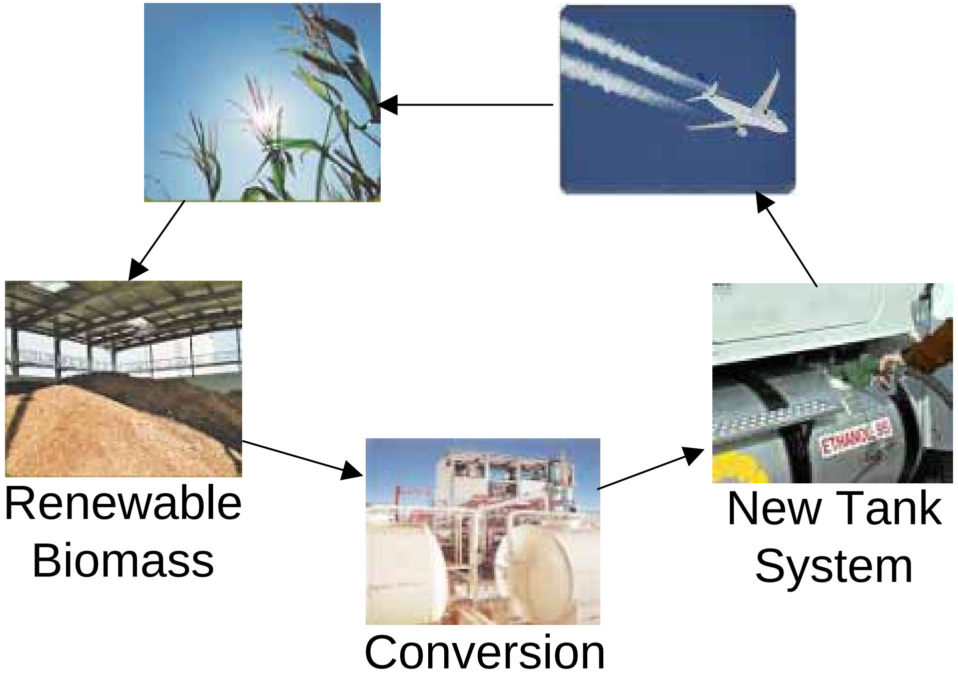
STEP 5



Target (20XX)

Power Generation by Fuel Cell System with Alternative Fuels

CO_2-Uptake = CO_2-Emissions



Alternative Fuels:

- Desulfurized Kerosene
- Hydrogen
- Ethanol/Methanol
- Biofuels
- Sunfuels

New Aircraft Generation

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

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- Step 3: Fuel Cell Power Unit
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- Step 5: Alternative Fuels
- **Industrialization**
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  - **Airbus Growing Systems Test Lab**
  - **hycity – Landesinitiative Brennstoffzellen und Wasserstofftechnologie Hamburg**
- Conclusion

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Industrialization

Partners:

AIRBUS

Invited:

BOEING

GROUPE DASSAULT

Universities and Institutes:

Forschungszentrum Jülich in der Helmholtz-Gemeinschaft

UNIVERSITY OF PATRAS

"Jožef Stefan" Institute

DLR

Universität Hannover

Universität Stuttgart

Hochschule für Angewandte Wissenschaften Hamburg / Hamburg University of Applied Sciences

utbm université de technologie Belfort-Montbéliard

TUHH Technische Universität Hamburg-Harburg

EADS

Companies:

DASSAULT AVIATION

AOA apparatebau gauting

L2ES

AIR LIQUIDE

THALES

alp's

MTU Aero Engines

EADS DEFENCE & SECURITY

JRC

AKG

ECN

DIEHL Avionik Systeme

LEEI

Germanischer Lloyd

Industrialisation Partners:

MICHELIN A better way forward

United Technologies

GE

LIEBHERR

VOLVO

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

Industrialization

Landesinitiative Brennstoffzellen und Wasserstofftechnologie Hamburg

Airbus is founding member of the Landesinitiative Brennstoffzellen und Wasserstofftechnologie Hamburg. Targets of the Initiative:

- Promotion of fuel cell and hydrogen technology in Hamburg
- Reduction of CO_2 emissions
- Integration of renewable energies
- Secure of the Life Quality in Hamburg
- Stimulation of the Economy and Science in Hamburg

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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 applicated 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


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AIRBUS

AN EADS JOINT COMPANY
WITH BAE SYSTEMS