

GreenAir and S-U-A-V

**Two European projects on
fuel cell application aboard aircraft**

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**Fuel Cell Seminar and Exposition
Orlando
October 31st – November 3rd, 2011**

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opportunities for fuel cells in aviation

□ engine independent power generation on large aircraft

- simplify energy architecture of aircraft
 - reduce fuel consumption, noise and emission
 - take advantage of collateral benefits (e.g. use heat and water from fuel cell)
- ⇒ efficiency is of superior importance



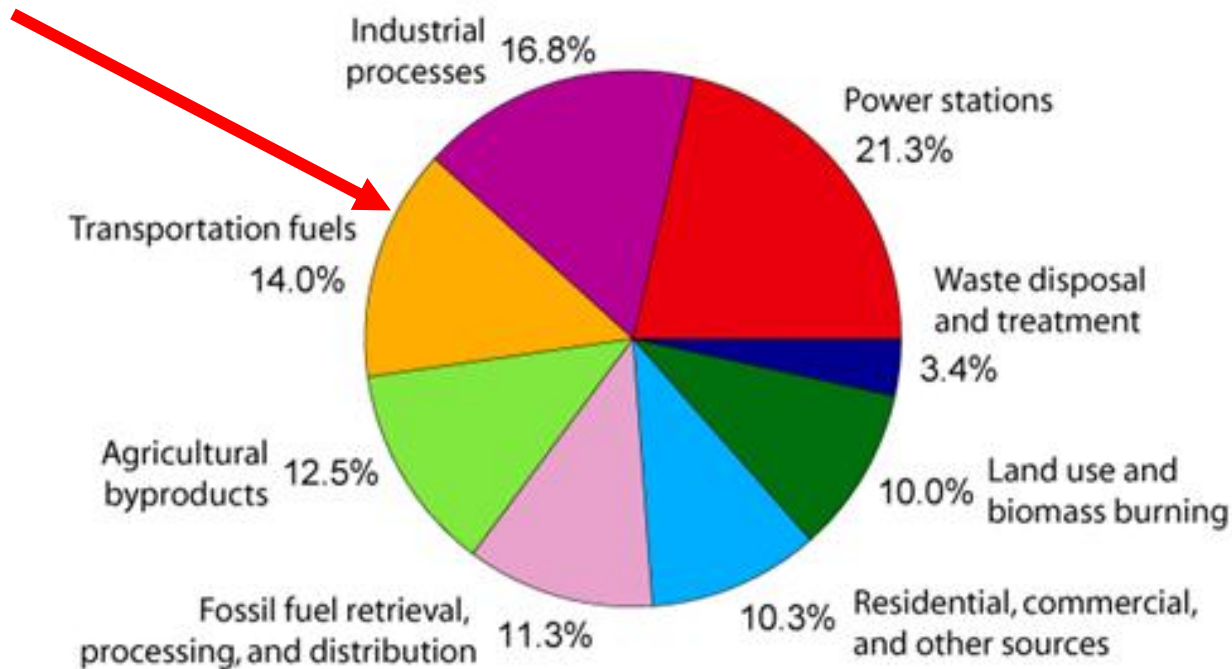
□ prime energy generation for small unmanned aerial vehicles

- increase endurance compared to battery powered vehicles
 - reduce noise and emissions
- ⇒ efficiency is not necessarily of superior importance



motivation: global greenhouse gas emissions

- ❑ transportation causes 14% GHG emission globally and significantly higher levels in industrialized countries (e.g. US: 28%, EU: 14% incl. the new member states);
~ 15% of these are due to air transport, i.e. ~ 2% of the total
- ❑ these emissions are due to combustion of fossil hydrocarbon fuel and accompanied by pollutants as e.g. NO_x, particulate matter (soot) and unburned hydrocarbons



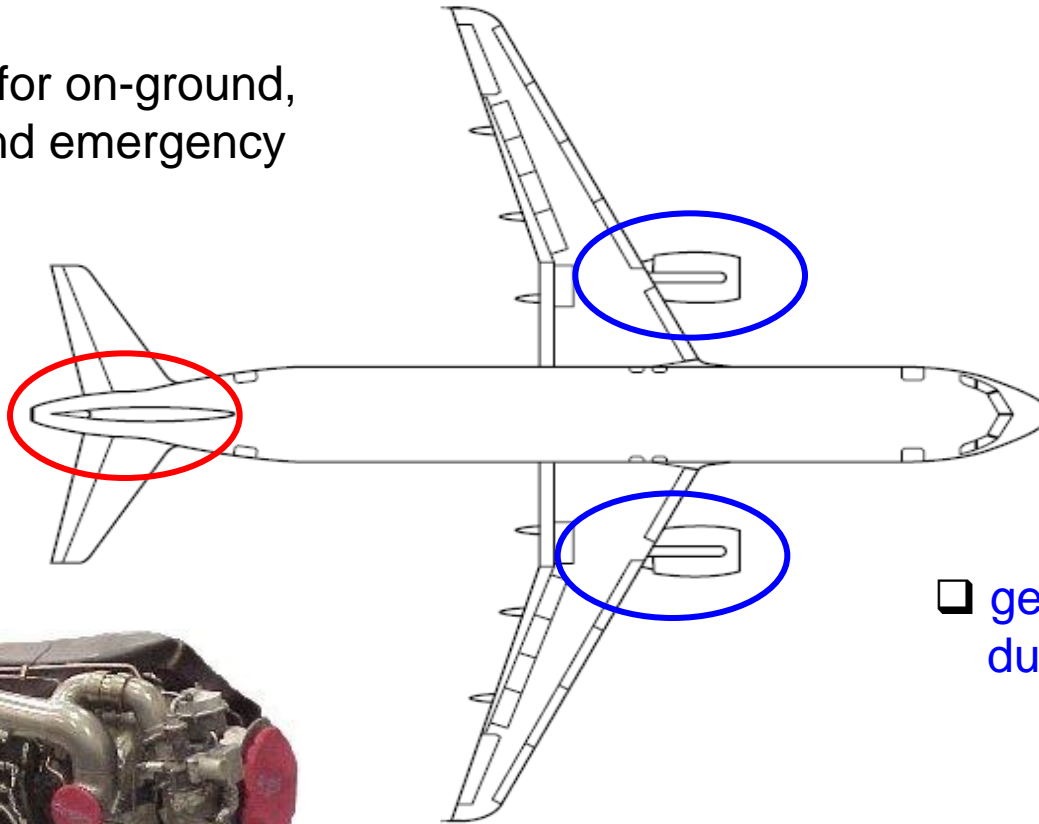
source: Emission Database for Global Atmospheric Research

motivation: politics react

- ❑ a threefold growth in passenger demand in the next 20 years is expected**
- ❑ ACARE (Advisory Council for Aeronautics Research in Europe) defined goals for “the reduction of the impact of Air Transport on environment and climate change ”**
- ❑ in particular a clear and challenging target for a 50% reduction of CO₂-emission by 2020 compared to 2000 was set**
 - 15 to 20 % due to the reduction of engine specific fuel consumption**
 - 5 to 10 % due to operational improvements**
 - 20 to 25% due to aircraft improvement ⇒ opportunity for fuel cells.**
- ❑ the American Clean Energy and Security Act was amended by the Obama Administration and explicitly addresses aircraft and aircraft engines now**

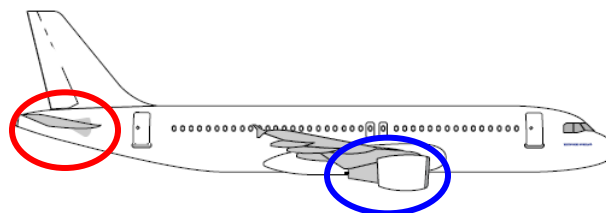
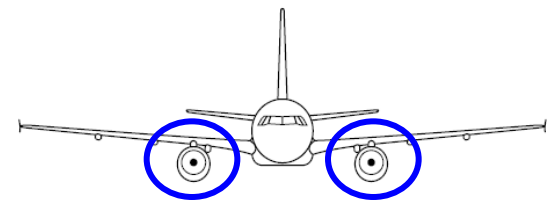
today's el. power generation on aircraft – operation and location (Airbus A320)

□ **APU** for on-ground, climb and emergency



example:
Honeywell 131-9A APU: 90 kW_{el}

□ generators at main engines during cruise

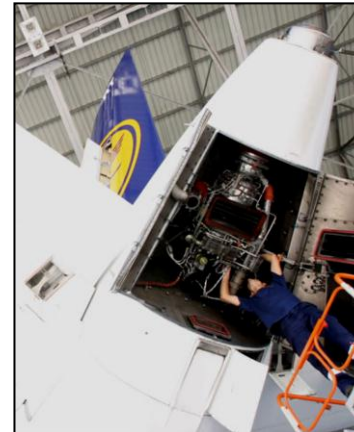


The classic APU will be replaced by a secondary power generator

Example: the A320 aircraft



A320: operaton		
fuel consumption	2.700,00	l/h
fuel consumption	24.832,69	kW
power APU	100,00	kW
eta fuel cell	50,00%	%
H2 for fuel cell	200,00	kW
H2 for fuel cell	66,67	Nm ³ /h

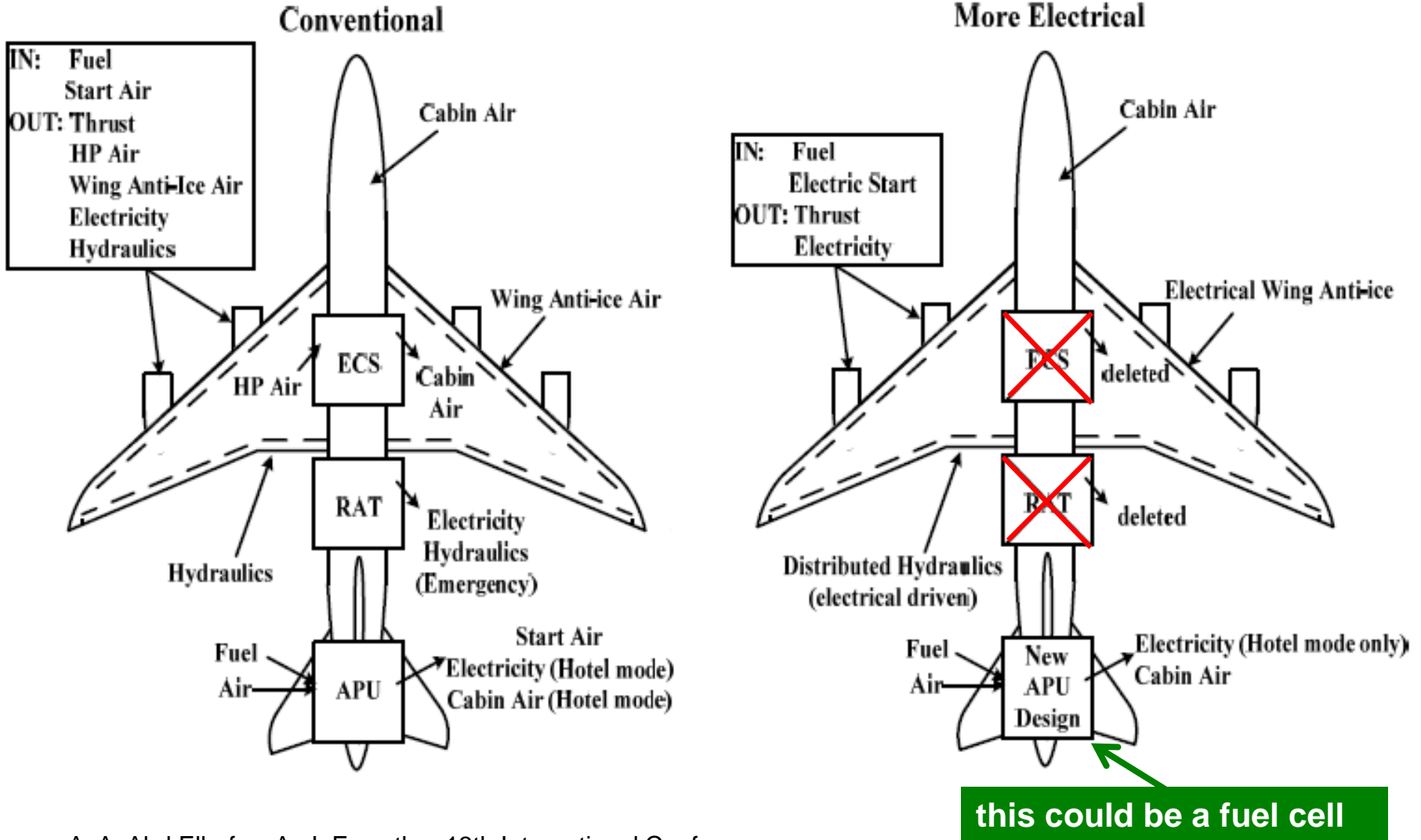


this is where fuel cells might play a role

preferably no additional fuel on board,

⇒ H₂ for the fuel cells has to be generated from Kerosene – at least for long range flights

general trend: the “More Electric Architecture”

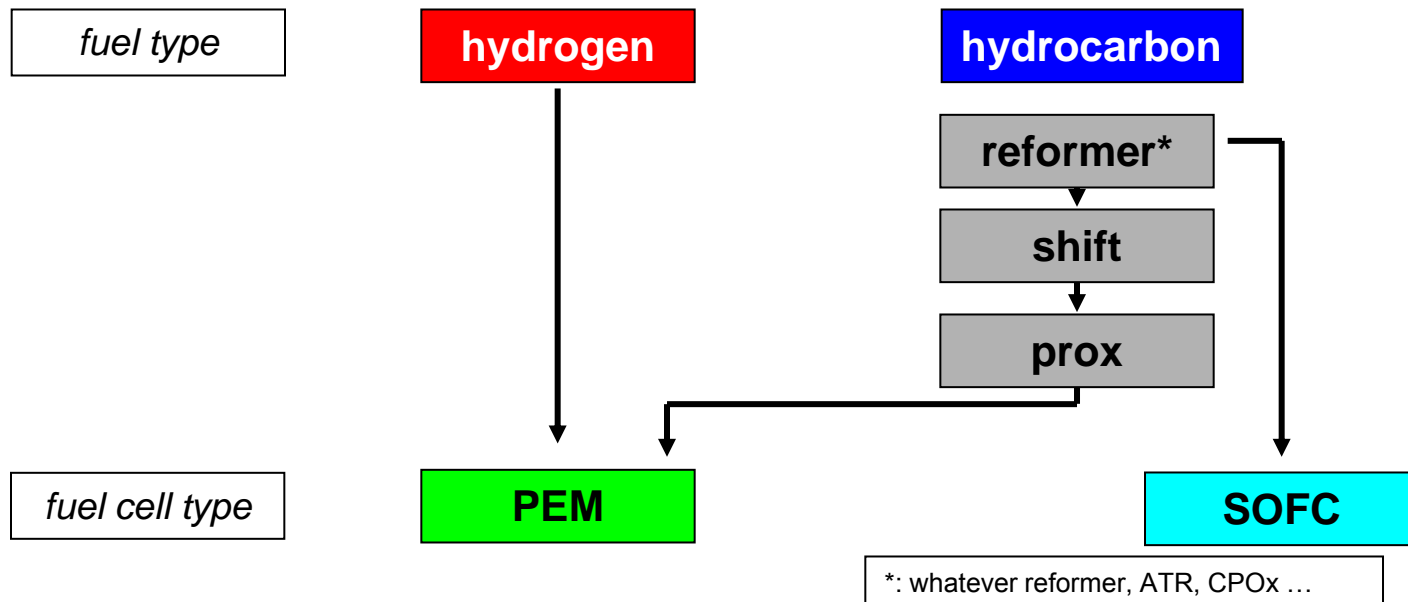


source: A. A. Abd Elhafez, A. J. Forsyth - 13th International Conference on AEROSPACE SCIENCES & AVIATION TECHNOLOGY

the application determines the fuel – the fuel determines the type of fuel cell

- ❑ hydrogen may have its niche on short haul aircraft - storage is a key issue
- ❑ for long range flights hydrogen has to be produced from the hydrocarbon jet fuel

- ❑ it is not a question of PEM or SOFC
- ❑ hydrogen fuel leads directly to PEM
- ❑ hydrocarbon fuel leads to SOFC or PEM via differently deep fuel processing



EU FP7-funded project GreenAir*

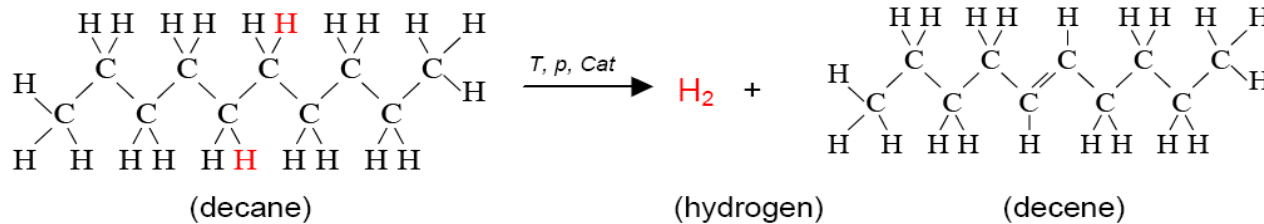


- ❑ H₂-storage on-board is limited ⇒ for larger amounts or long haul flights hydrogen has to be generated from kerosene
- ❑ development of unconventional reformer technologies for generation of H₂/reformate from jet fuel
 - partial dehydrogenation and microwave plasma assisted reforming
 - additionally fractionation of kerosene
- ❑ 3 years R&D project
- ❑ 13 partners from all over Europe
- ❑ funding by the European Commission under contract #233862 is gratefully acknowledged

*: **G**eneration of hydrogen by kerosene **r**eforming via **e**fficient and low **e**mission **n**ew **a**lternative, **i**nnovative, **r**efined technologies for aircraft application

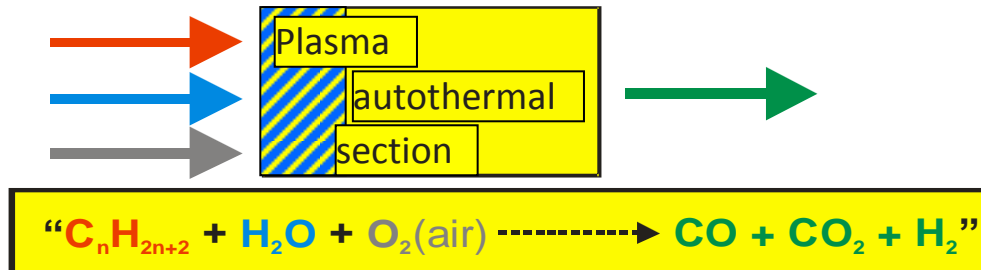
GreenAir: two (+1) unconventional reformer technologies

□ catalytic partial dehydrogenation (PDh)



subsequent gas purification

□ Plasma assisted reforming (PAR)



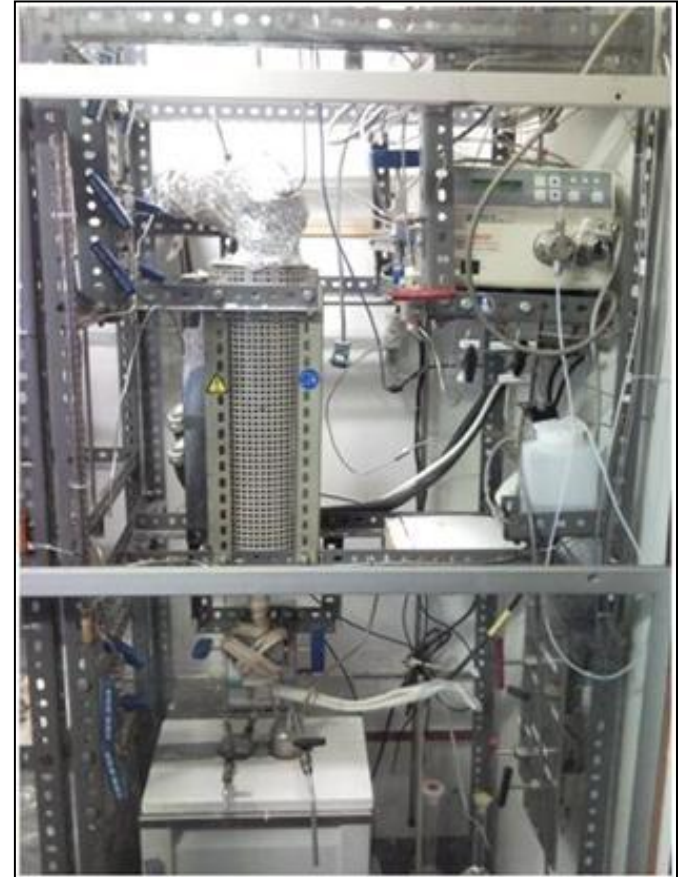
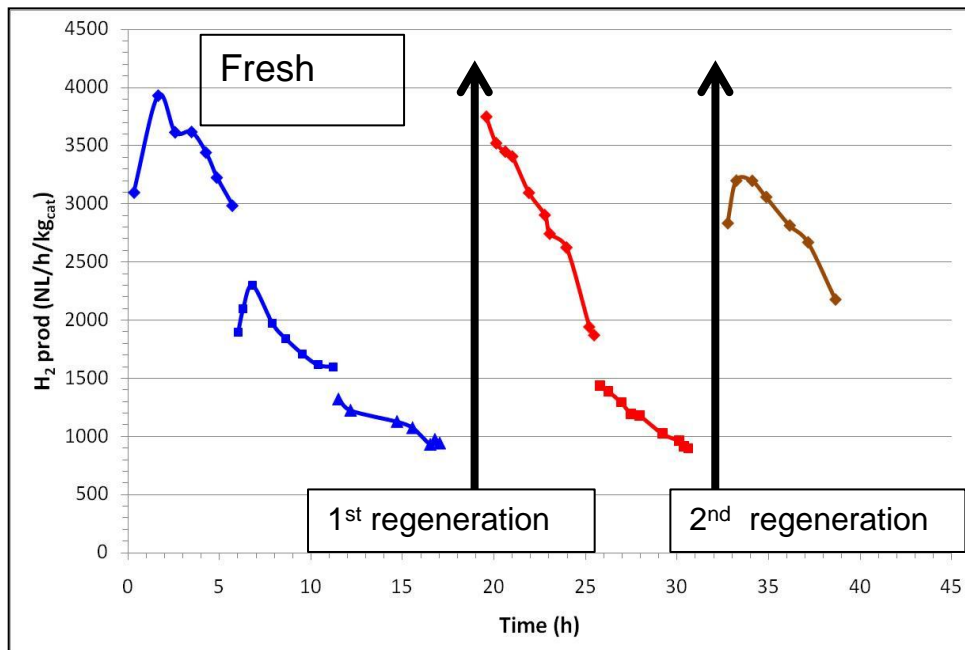
subsequent shift reaction: $\text{CO} + \text{H}_2\text{O} \text{-----} \rightarrow \text{CO}_2 + \text{H}_2$

□ fractionation

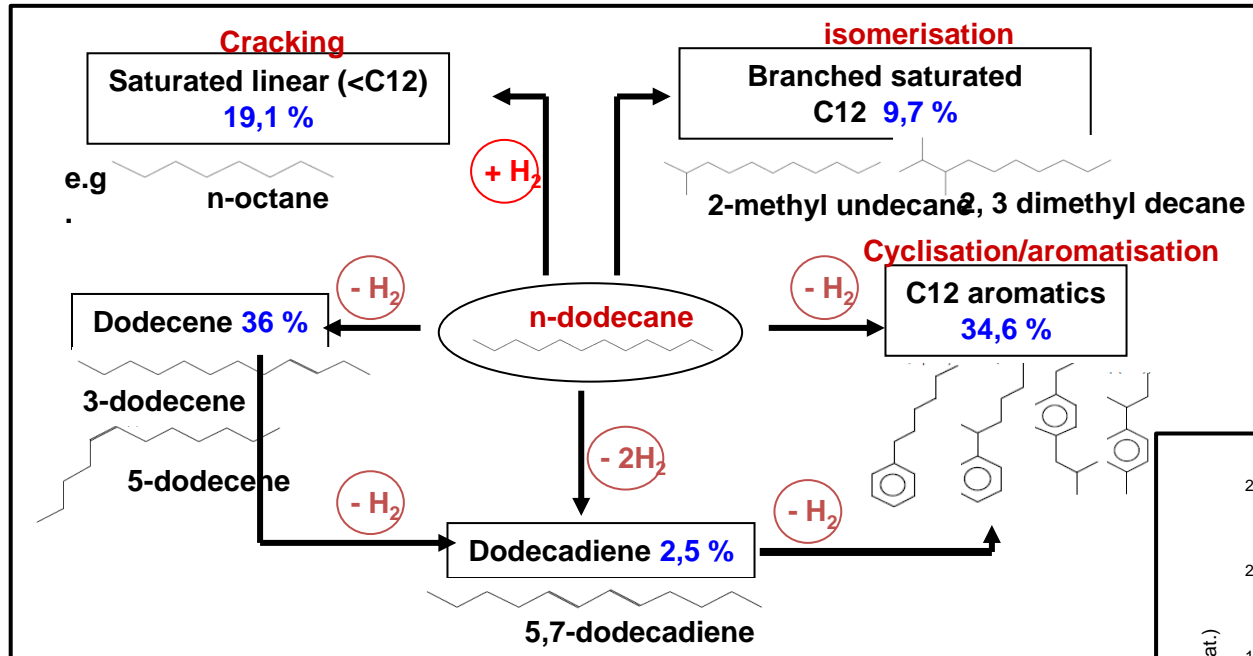
PDh: example of a catalysis tests and test rig (University of Bologna, Italy)

catalyst tests of e.g.

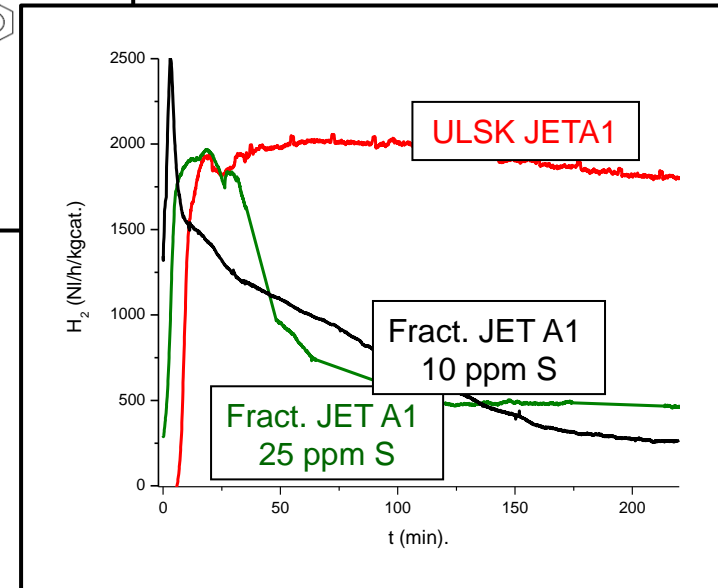
- hydrogen yield
- regeneration
- sulfur tolerance
- temperature dependence
- pressure dependence



PDh: examples of catalyst investigations (CNRS Montpellier, France)

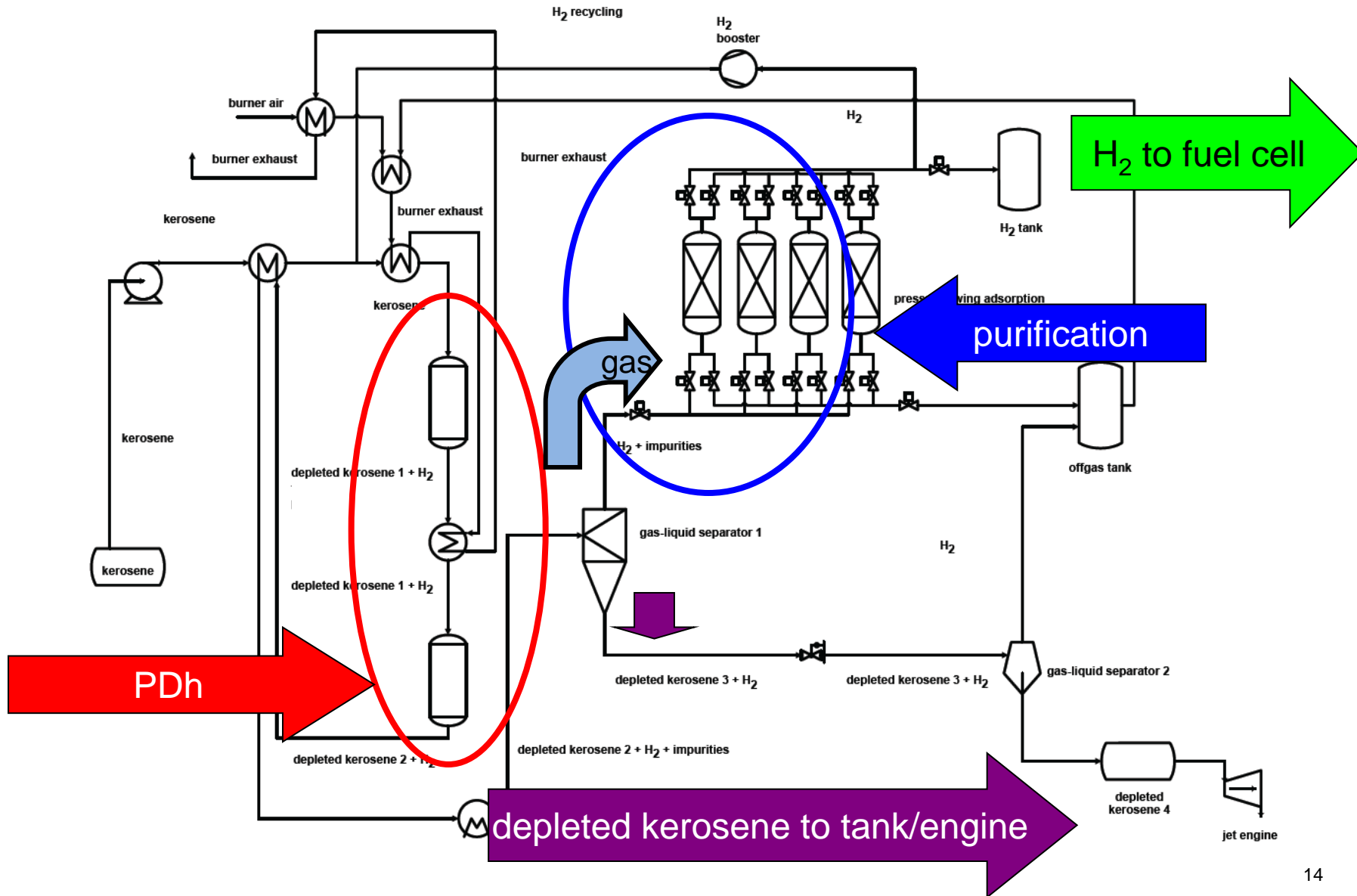


PDh reaction pathways of Dodecane



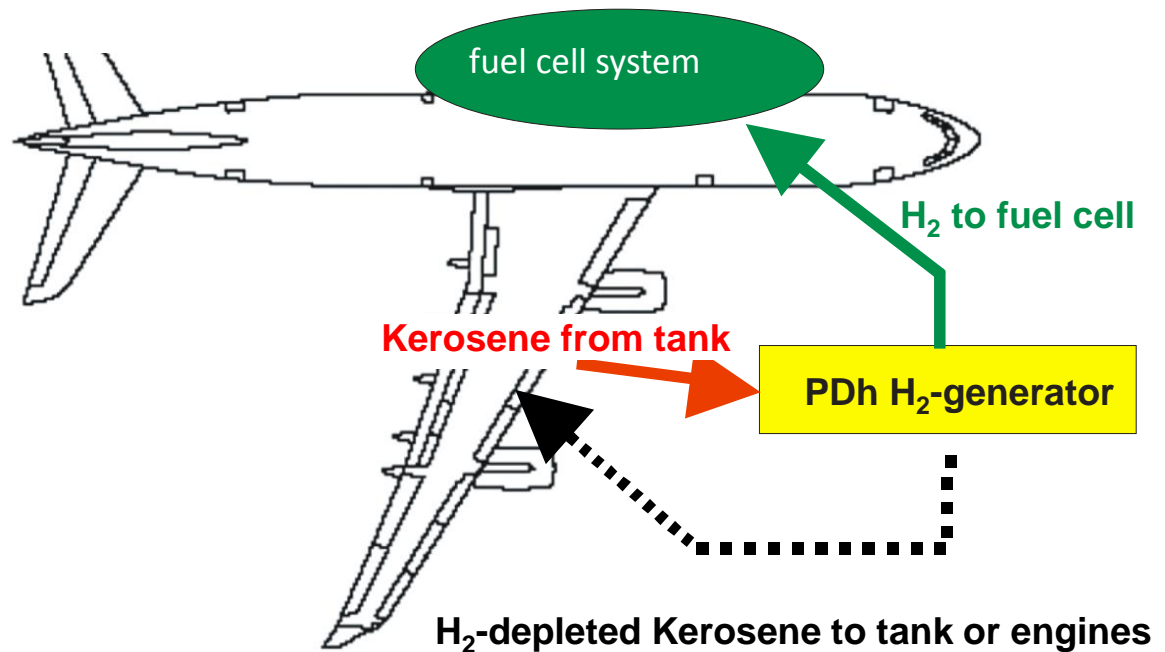
influence of sulfur content in fuel

PDh: basic system design (CESA, Spain; HyGear, Netherlands)

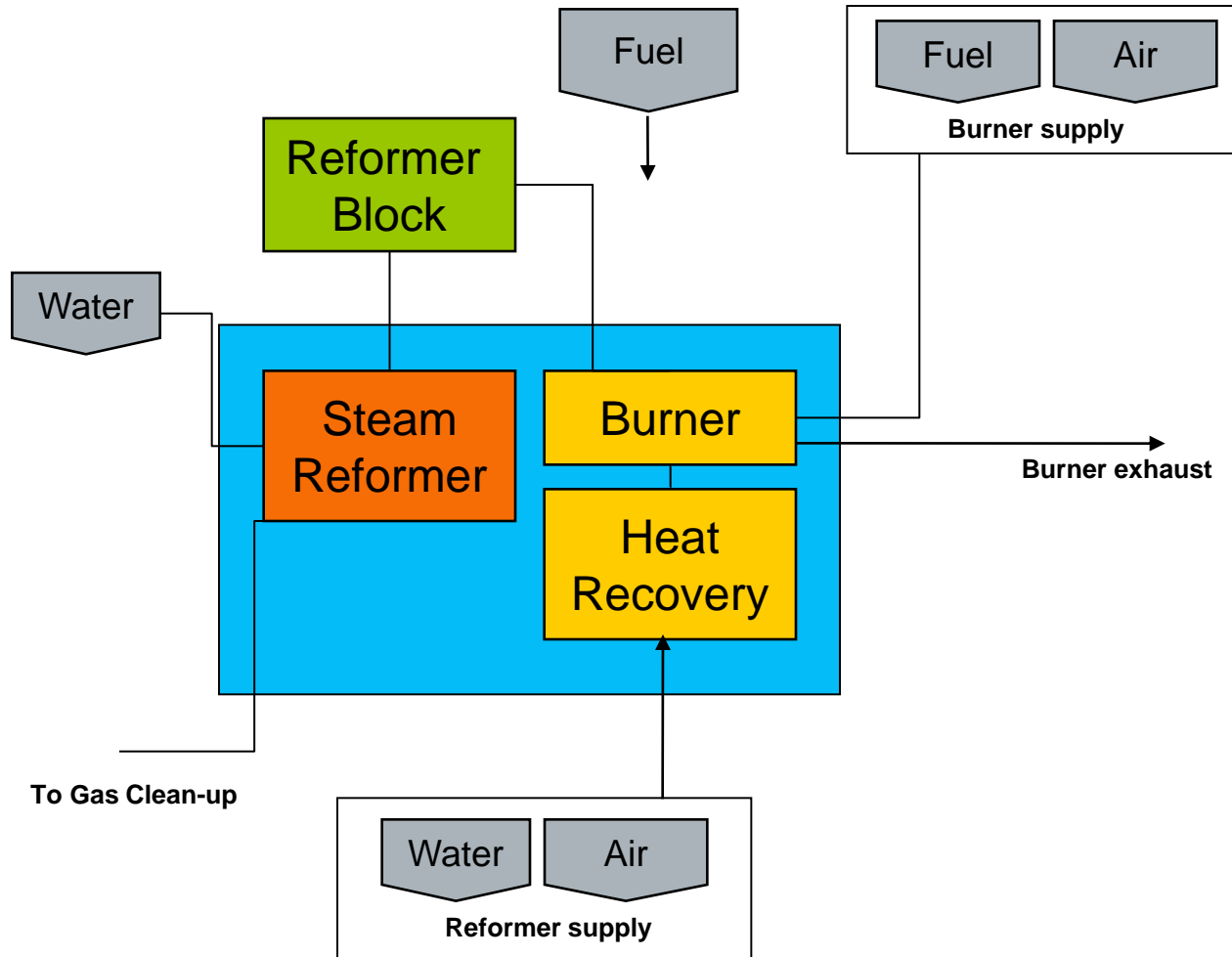


PDh: main challenges

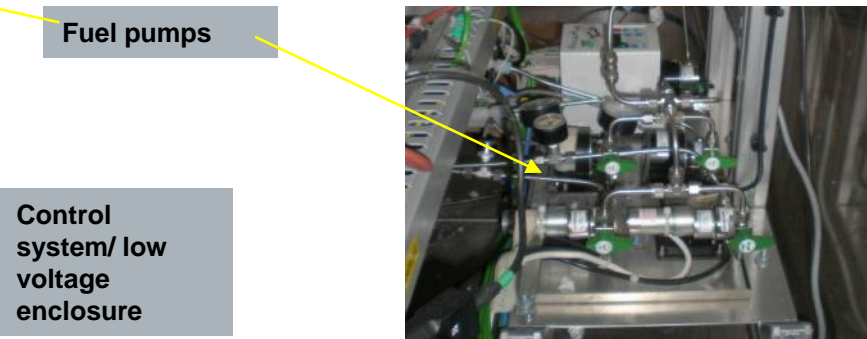
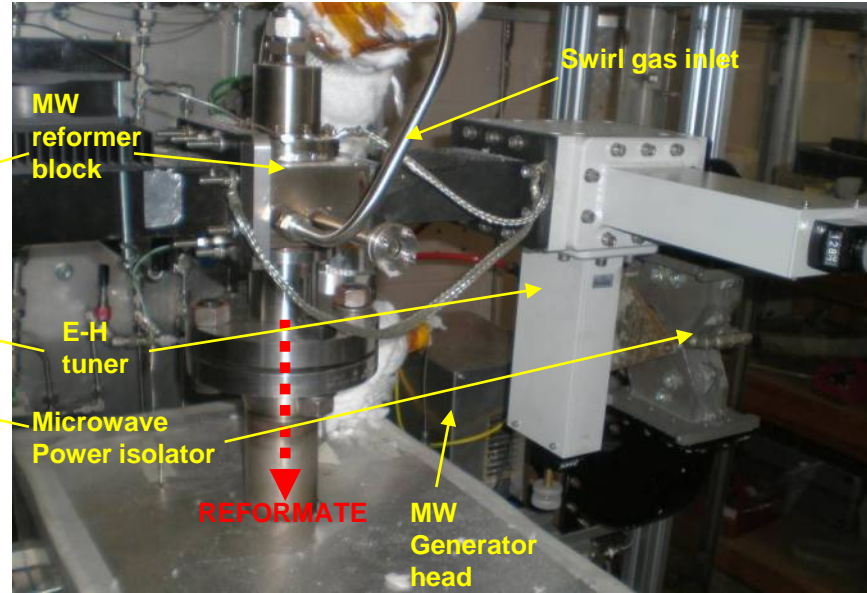
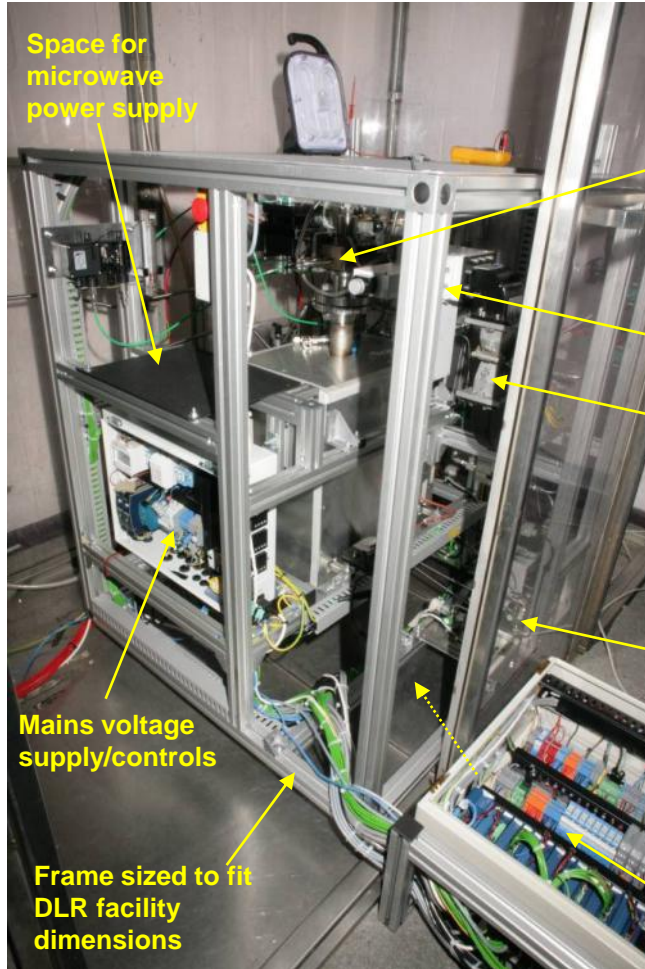
- catalyst performance and lifetime (degradation)
- process parameters
- Sulfur-compatibility
- coke formation
- gas cleaning
- systems design and integration



Plasma Assisted Reforming (PAR): block diagram for reformer system (QinetiQ)

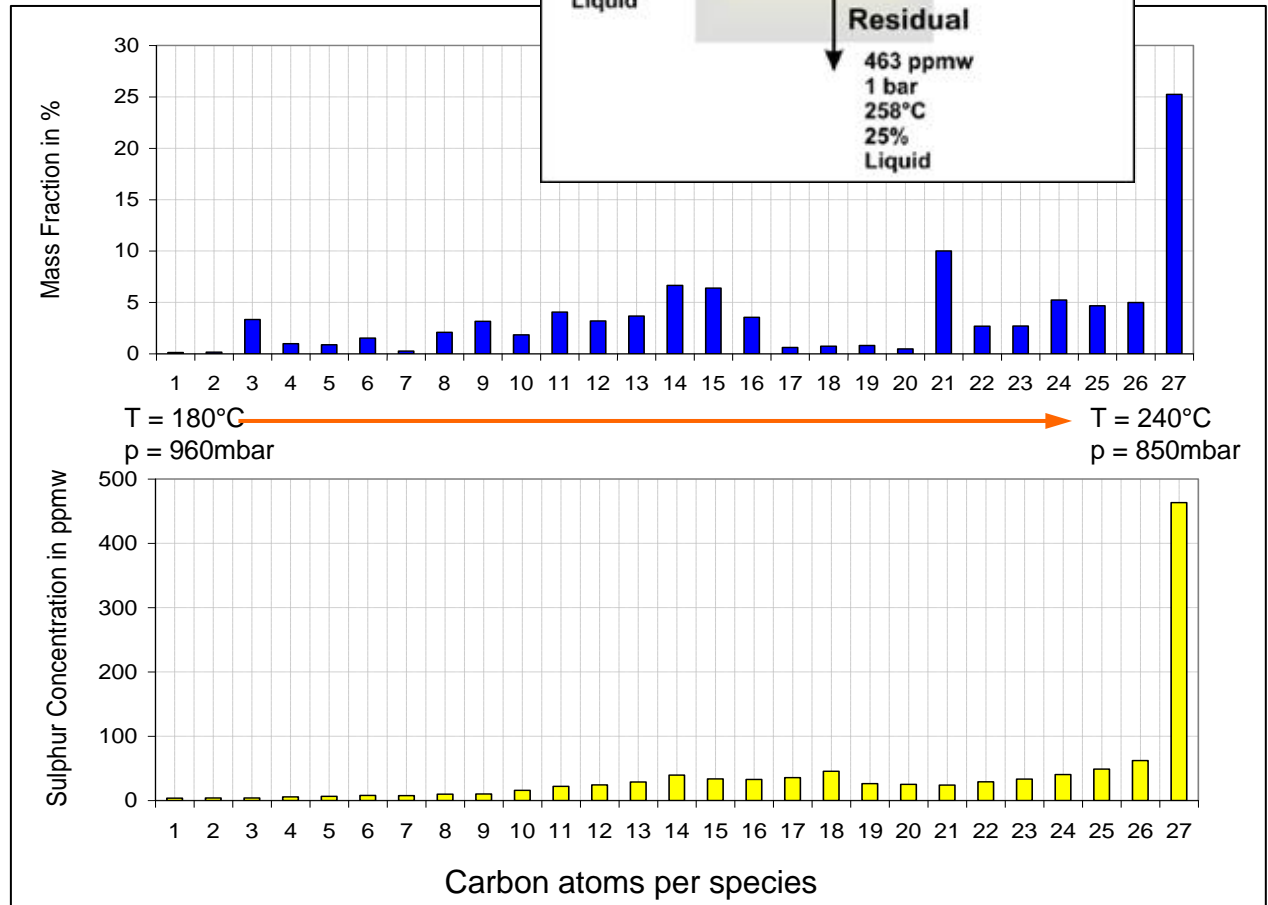
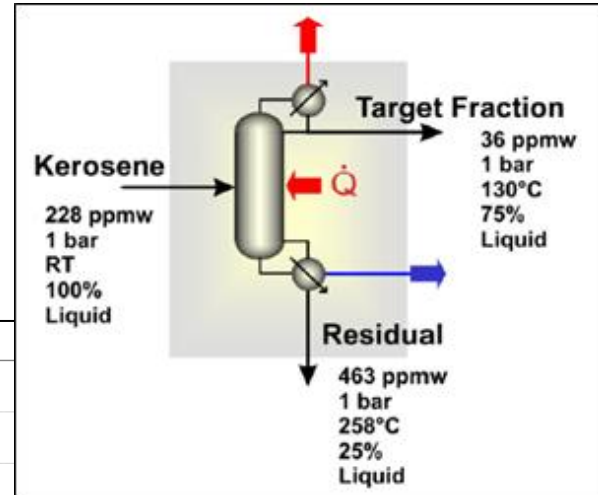


PAR: reformer system hardware (QinetiQ)



fractionation of kerosene (DLR)

- extraction of fractions with lower sulphur content
- reduction of carbon forming species
- reduction of volume to be treated in PDh



EU / FCH JU funded project S-U-A-V*



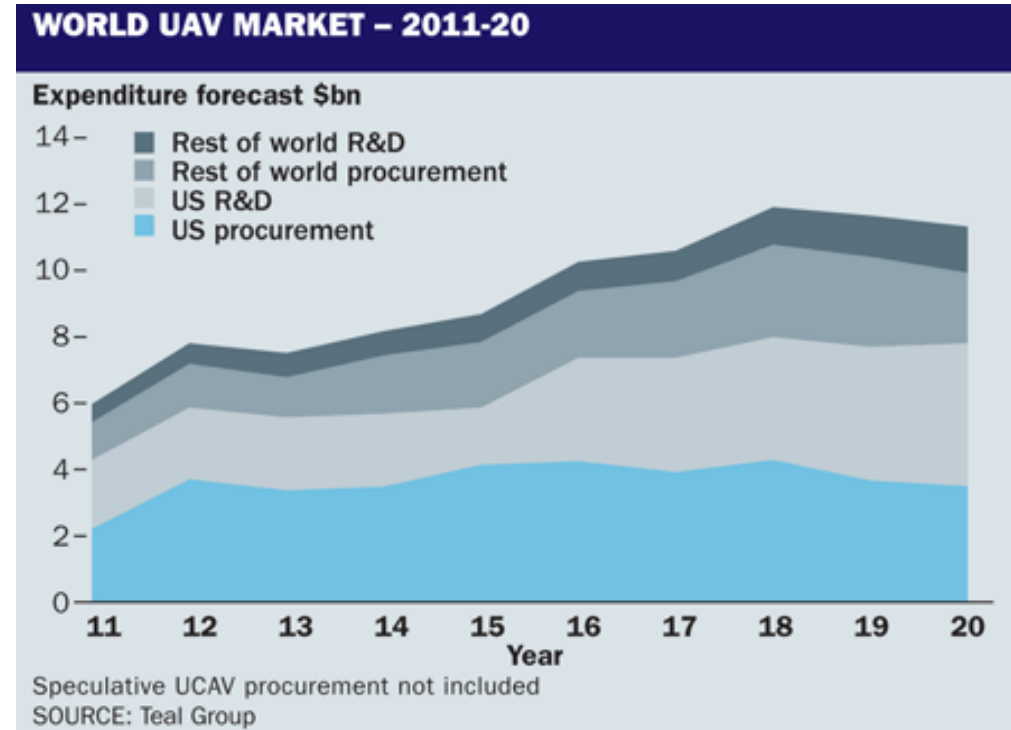
- ❑ development of a 100 W fuel cell system with sofc microtubes and propane reforming
- ❑ integration and test in/with a real mini-UAV platform
- ❑ 3 years R&D project (will start December 1st, 2011)
- ❑ 10 partners from all over Europe
- ❑ funding by the Fuel Cell and Hydrogen Joint Undertaking is gratefully acknowledged

SOFC powered **u**n**m**anned **a**erial **v**ehicle

S-U-A-V: market relevance

Teal Group's 2011 market study:

- ❑ UAV spending will almost double over the next decade from current worldwide UAV expenditures of \$5.9 billion annually to \$11.3 billion
- ❑ Civil operators such as coastguard services and border patrols will increasingly look to UAVs to meet new requirements or satisfy existing ones.
- ❑ As airspace issues are resolved, other non-military uses are certain to follow, with rich rewards for companies able to develop new UAVs or adapt existing ones to meet them.



S-U-A-V: market relevance

NASA Civil UAV Capability Assessment:

“... a wide range of applications that include UAVs taking on new missions ...”

Examples of these missions include:

- Law Enforcement & Disaster Operations
- Digital Mapping & Planning/Land Management
- Search & Rescue
- Fire Detection and Firefighting Management
- Communications and Broadcast Services
- Precision Agriculture and Fisheries
- Ground Transportation Monitoring and Control
- Satellite Augmentation Systems
- Air Traffic Control Support
- Power Transmission line Monitoring
- Environmental Research & Air Quality Management/Control
- ...



S-U-A-V objectives

- design, optimisation and construction of a 100-200W micro-SOFC stack
- integration of the stack into a hybrid power system comprising the mSOFC stack and a battery
- development and build-up of a propane fuel processor to generate reformat gas
- build-up of other equipment for the electrical, mechanical and control balance of plant (BoP).

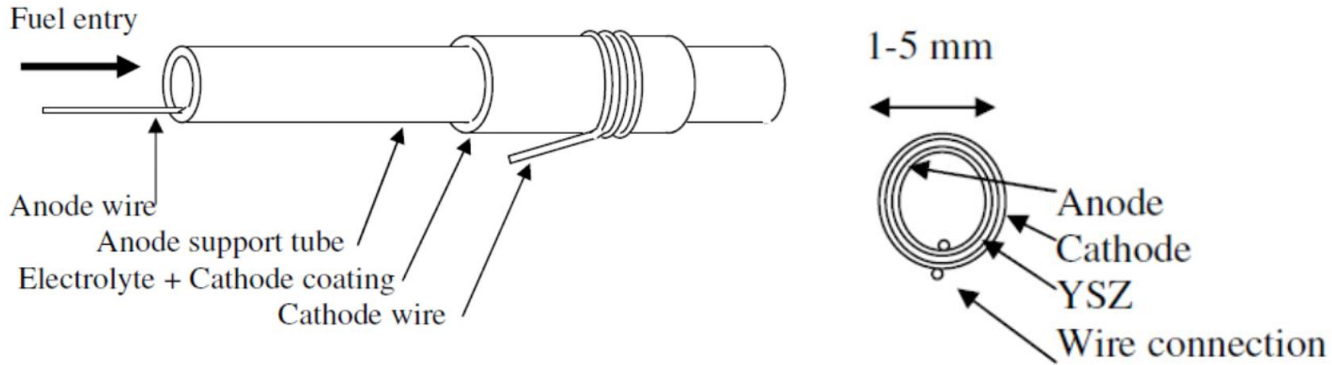
- S-U-A-V is primarily aiming at the CopterCity UAV platform from Surveycopter (France) but will consider other options (in particular fixed wing vehicles) too.



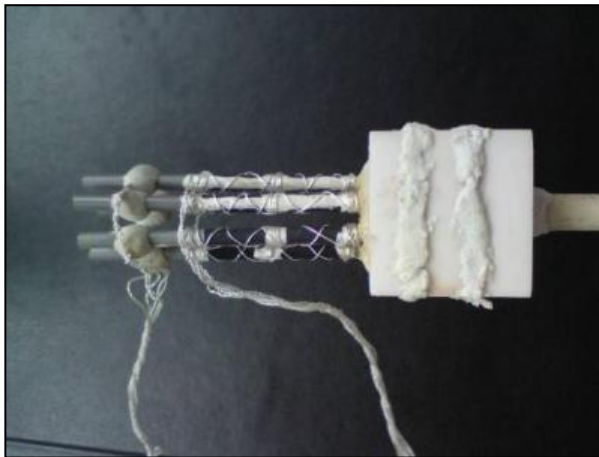
S-U-A-V objectives

- propane was chosen as the fuel due to its superior energy density compared to hydrogen, whichever storage technique is used
- SOFC was chosen since it can directly convert reformat (i.e. CO/H₂-mixtures) to electricity which significantly reduces effort and complexity of fuel processing
- the design of the mSOFC power generator will be primarily driven by the weight and volume available in the mini-UAV
- overall goal is a 3-times longer mission duration, efficiency is of less concern

S-U-A-V: micro-tubular sofc technology



principle design of m-sofc stack



100-cell m-sofc stack

closing remarks

- ❑ there were airborne fuel cells since 1981
- ❑ since the late nineties fuel cells became of interest for aeronautical application
- ❑ first demonstrations were made already by e.g. Boeing, Airbus and DLR



- ❑ for commercial use of fuel cells in air transport the fuel is a key issue, it should preferably be generated from the jet fuel on board (H_2 for PEM, reformat for SOFC)
- ❑ for unmanned vehicles mission duration is the key driver, reformed liquid fuel is needed for that because of the storage constraints of H_2

Acknowledgment

the author wants to gratefully acknowledge

- funding from the European Commission and the FCH JU
- the good and fruitful collaboration with and among the consortium partners

Thanks for listening! Questions?

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