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Sustainable Mobility: Perspective and Strategies towards Fuel Cell Hybrid Electric Vehicles

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Sustainable Mobility

It is one of the main political strategy of European Union (UE) devised to reach a greenhouse gas level compatible with European target: 20% less than actual value of CO_2 into 2020.

PRINCIPAL OBJECTIVES

- to support innovation and integration in the mobility system
- to make the transport systems eco-friendly
- to decrease the transport decongestion using intermodal transport and logistic network
- to provide incentives for competiveness in transport system

PRINCIPAL ACTIONS FOR TRANSPORT MANAGEMENT OPTIMIZATION

- To increase the **public urban transport** (using minibus, reserved lane and limited traffic zone)
- Tariff regulation systems: urban toll for admission to particular streets and zones, park pricing
- **Park and ride** (facilities for private car and public transport exchange)
- **Urban mobility plans** (such as transfer from home to work and vice versa)
- **Car sharing** and **car pooling services**
- To introduce the company and area **mobility manager** figure
- **Information technology systems** (ITS) for the traffic flow management (routing to urban parking , road sign, GPS service)
- To provide incentives for development of **pedestrian crossing** and **cycle tracks** for implementation of **bike sharing** service

FC and Transport Applications in the CNR ITAE projects

Fuel cells are not the solution of the transport problems, but we think that if fuel cells are used in integrated systems with other innovative technologies, could contribute to create alternative propulsion systems.

The projects in which CNR ITAE is involved are addressed to different markets:

EARLY MARKETS

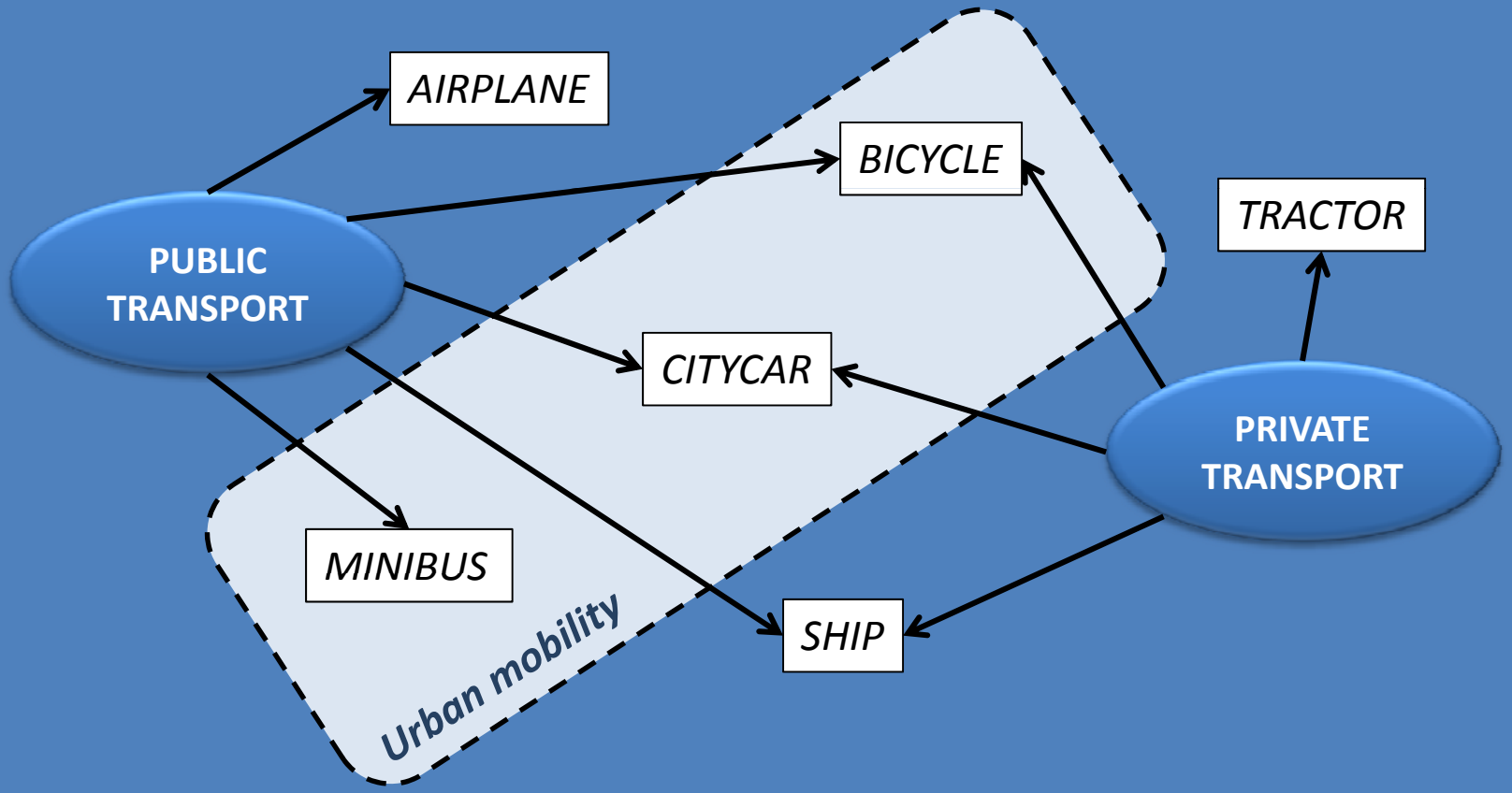
- The aim is the nearly marketing of the products
- Powertrain is composed by integrated technologies (electric motor, batteries, fuel cells, superacps, etc.)
- Fuel cells have a small size because they are used like on board batteries recharge ("range extender")
- The technical aim is to increase the range of traditional electric vehicles (in terms of km or hours)
- The lower fuel cell power means a reduction in terms of stack size then a less cost of it as well as hydrogen storage amount (and cost)
- Low cost for fleet investment and management

FUTURE MARKETS

- The aim is the future marketing of the products
- Powertrain configuration is the "full power fuel cell"
- Fuel cells have a big size power close the electric motor power ("total fuel cell")
- The bigger fuel cell power means an increase in terms of stack cost and hydrogen storage amount (and cost)
- These vehicles represent a new concept of transport because they are a high-tech product, provided with innovative components and equipped with hardware and chassis made with new light materials

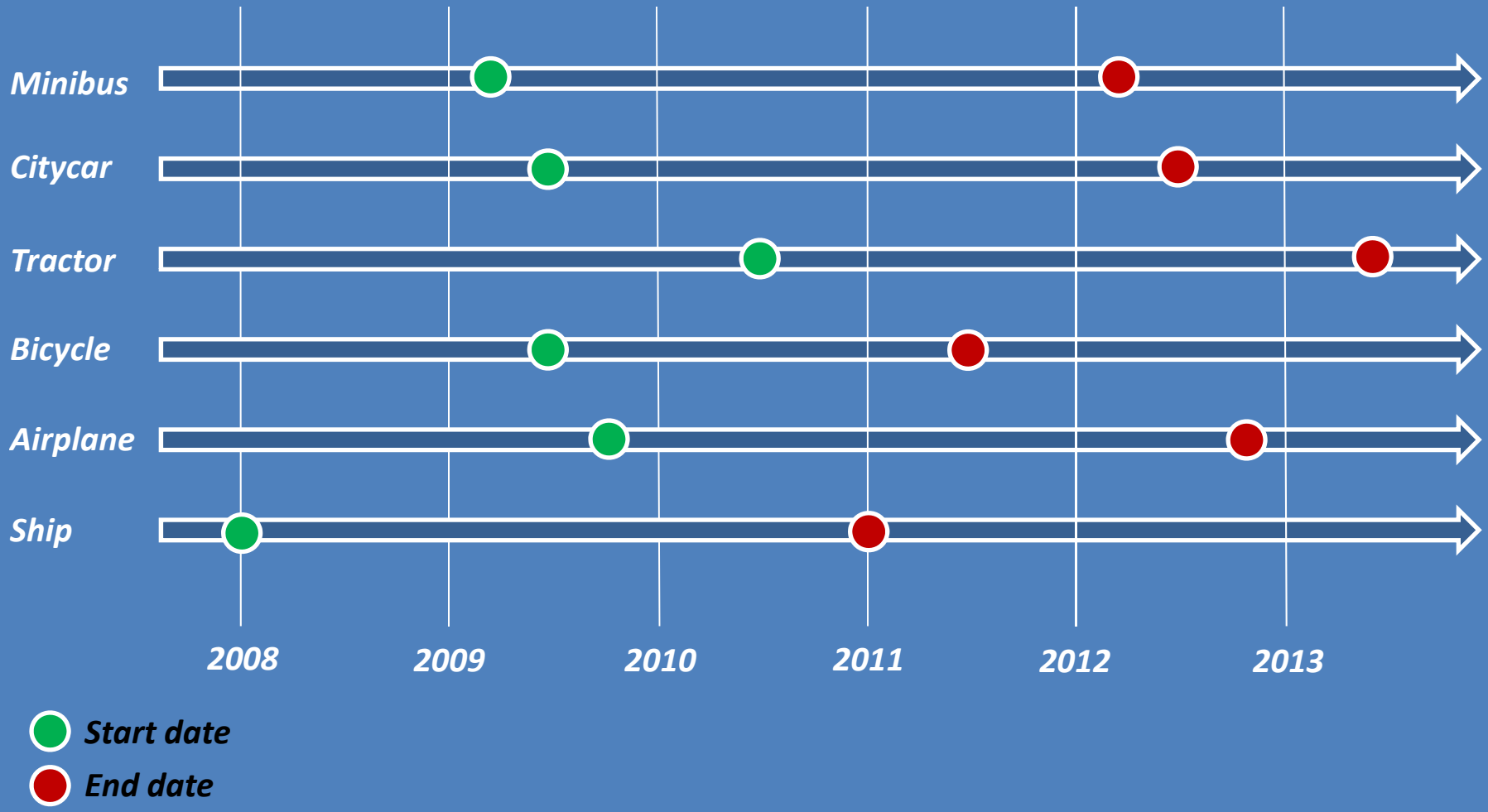
Demonstration Projects

Demonstration projects regard the development of public and private fuel cell hybrid electric vehicles (FCHEVs) and in particular minibus, citycar, bicycle, tractor, ship and airplane. Some of these are vehicles used in the urban transport (minibus, citycar and bicycle).



Demonstration Projects

TIMETABLE



THE MINIBUS PROJECT: "H-BUS"

(A three years national plan)

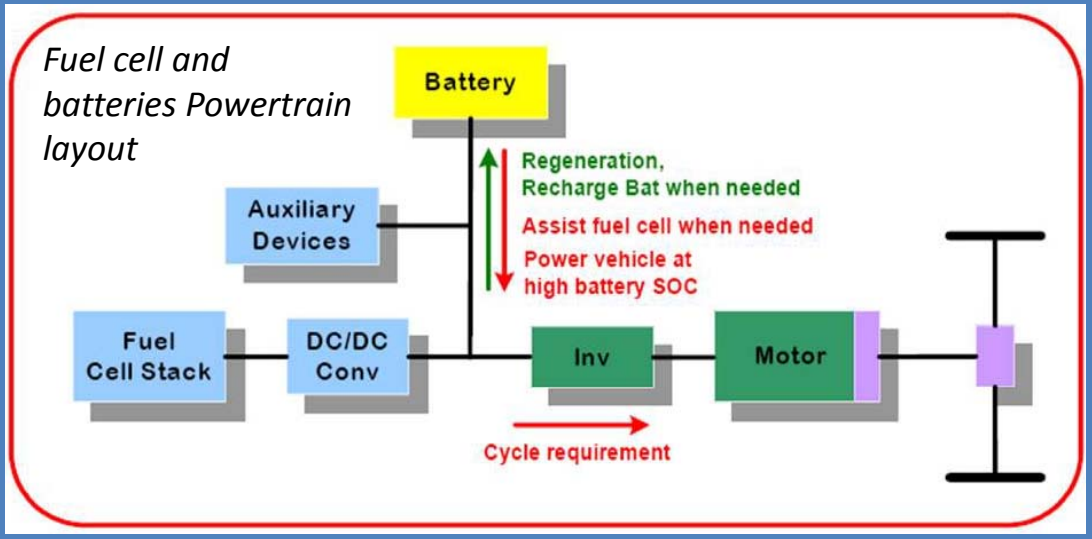
***Object**: development and comparison of two different level of powertrain hybridization (batteries and fuel cells)*

SOFT HYBRID

The fuel cell system (FCS) size is 25-30 kW, close to the electric motor size (30-35 kW) and the driving power is mainly supplied by FCS.

RANGE EXTENDER

The FCS is 5-10 kW power and it works as recharger of batteries and it supplies energy when the batteries' capacity is not sufficient.

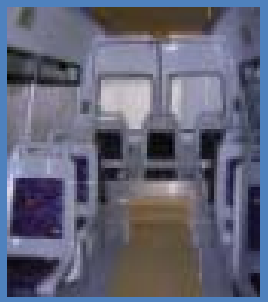


In both configurations an innovative compressed H_2 storage system and distribution will be developed

THE MINIBUS PROJECT: "H-BUS"

The project consists of following phases

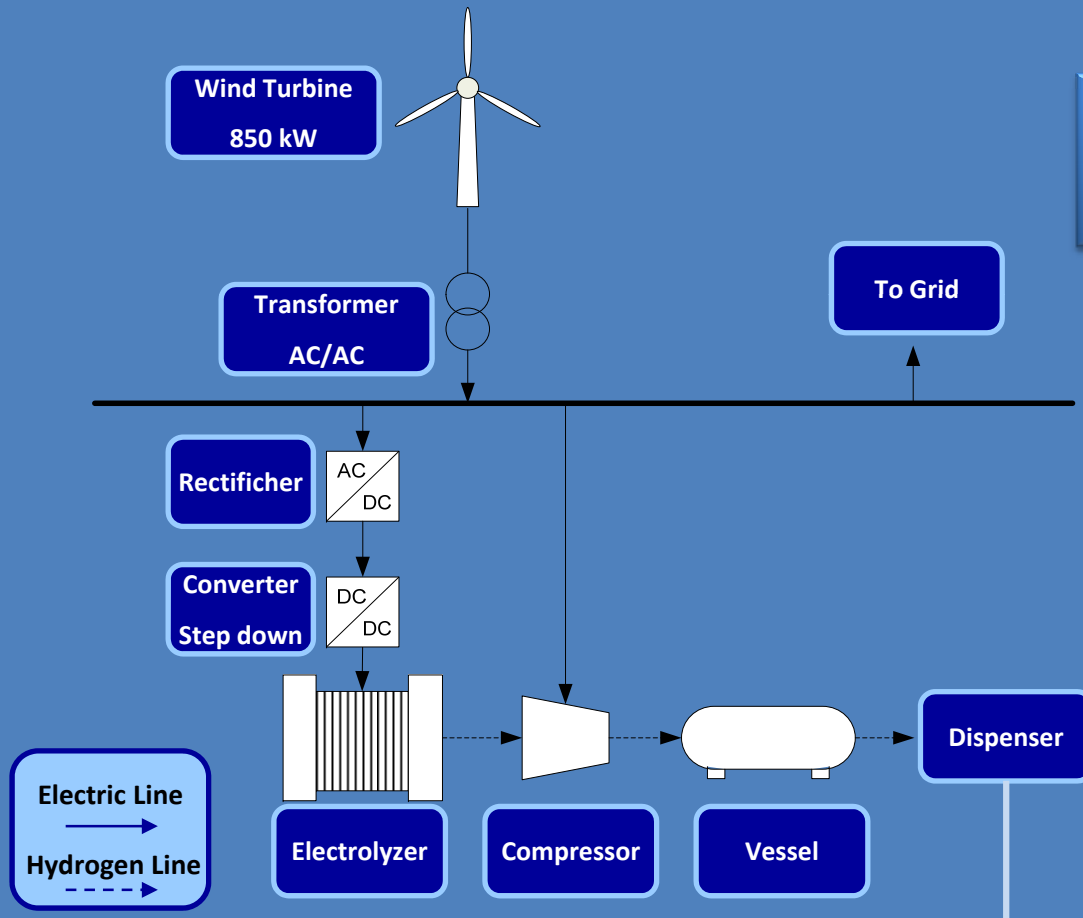
- Selection/study , design and test-bench of two hybrid powertrain
- Design and realization of on board compressed hydrogen storage. Hydrogen refueling station and dispenser realization
- Design, realization and test of innovative inverter with power switches
- Electronic control device and power management
- Test and optimization of selected powertrain. Prototype assembly (urban bus)



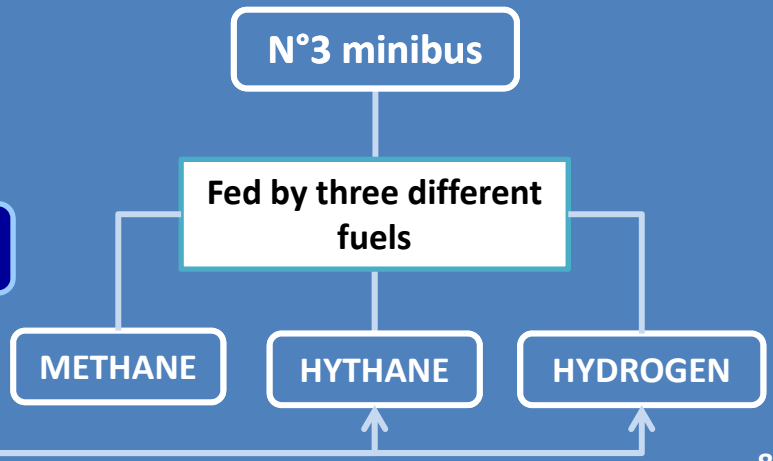
Electric motor: 30 kW (60 kW peak)
Maximum speed: 70 km/h
Seats : 27 + driver

THE MINIBUS PROJECT: "LCA of 3 different fuels "

A parallel project studies the environmental impact of three different fuels used for a minibus fleet: hydrogen, methane and "hythane" (a blend of hydrogen and methane).
In this case wind renewable energy plants is integrated with hydrogen production and storage systems.



The fleet consists of two kinds of minibus: traditional ICE for methane and hythane and hybrid (FC + batteries) for hydrogen.



THE MINIBUS PROJECT: "LCA study"

With the aim to compare the fuel alternatives, an LCA study of the production plant and buses has been carried out. In the LCA study of minibuses, the following fuel alternatives were studied:

1) **Conventional ICE-minibus fuelled with natural gas (NG)**

2) **ICE-minibus with biogas produced by biomass plant (BG)**

3) **ICE-minibus with a blend of CH_4 (80%) and H_2 (20%) (hydrogen is produced by electrolyzer using electric grid) (HY1)**

4) **ICE-minibus with a blend of CH_4 (80%) and H_2 (20%) (hydrogen is produced by electrolyzer using wind power) (HY2)**

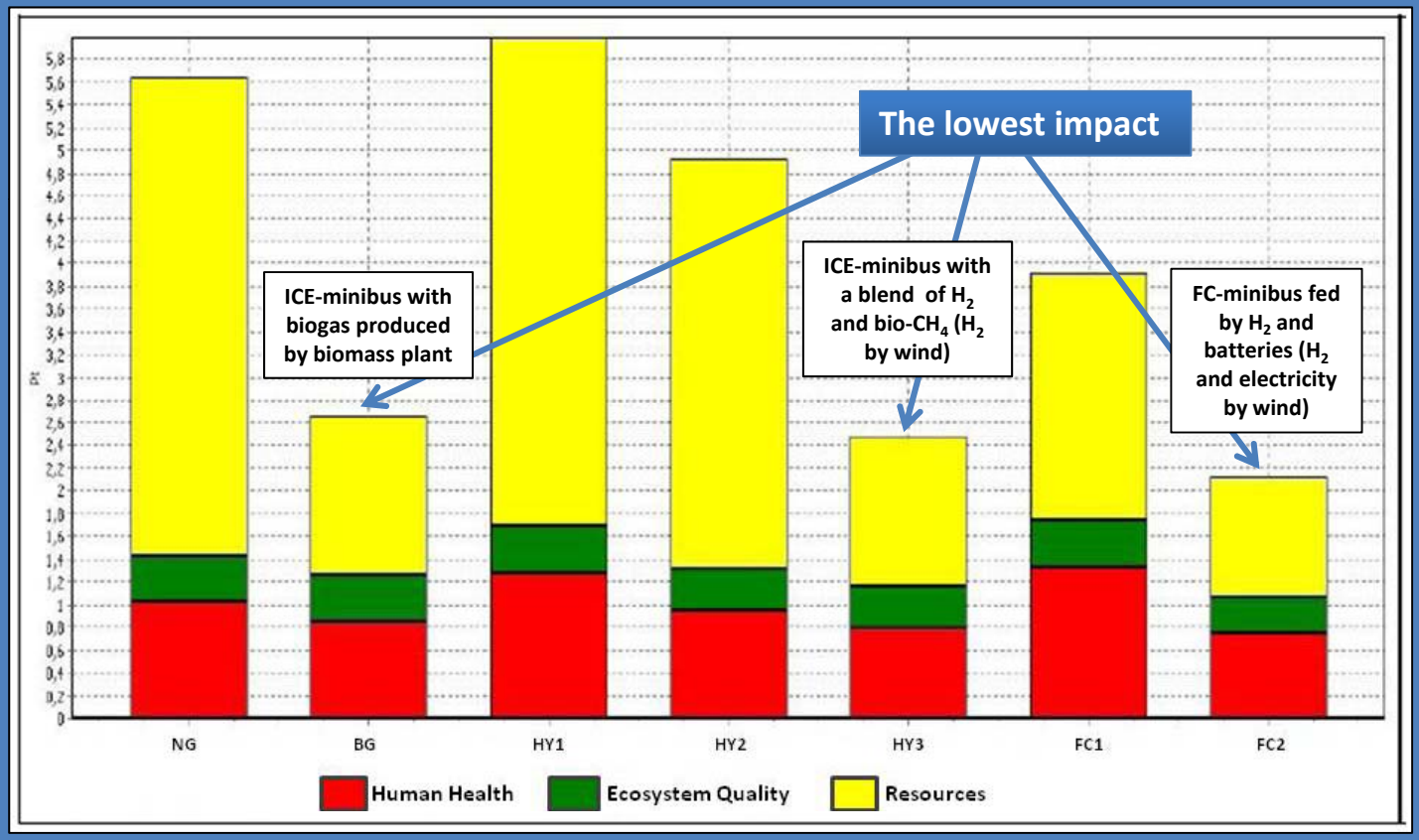
5) **ICE-minibus with a blend of 20% H_2 (hydrogen is produced by electrolyzer using wind power) and bio-CH_4 (HY3)**

6) **FC-minibus with hydrogen (wind power) and electricity (grid) (FC1)**

7) **FC-minibus with hydrogen and electricity stored in batteries (hydrogen and electric energy are produced using wind power) (FC2)**

THE MINIBUS PROJECT : "LCA study"

The environmental impact has been studied in terms of Human Health, Ecosystem Quality and resources. The alternatives with the lowest impact are BG, HY3 and FC2 (all using renewable energy sources), while the alternatives with the highest impact are NG, HY1, HY2 and FC1 (all based on fossil fuels)

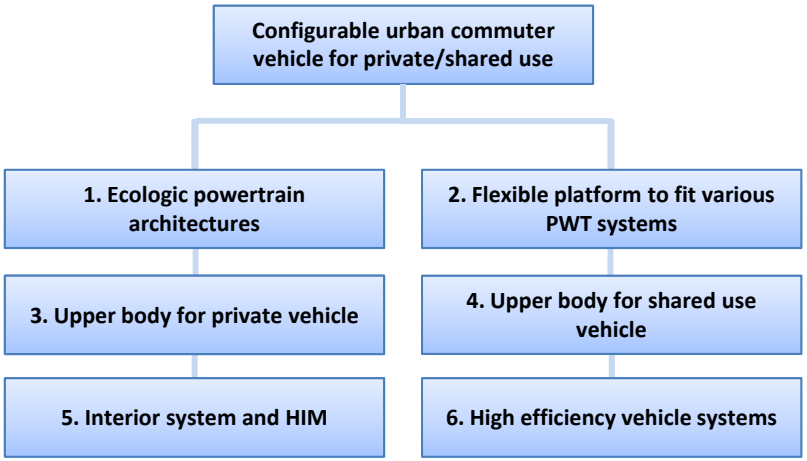


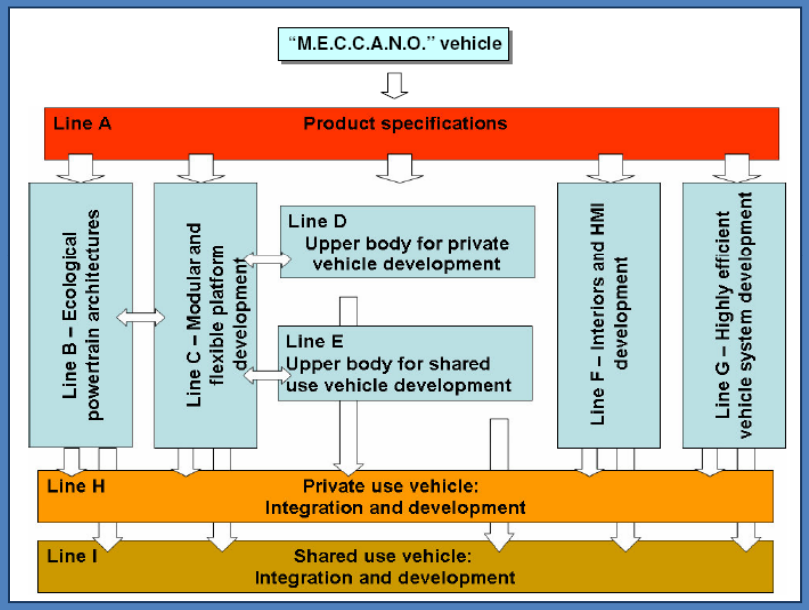
THE CITYCAR PROJECT: "MECCANO"

(A three years national plan coordinated by CRF)

***Object**: development of a highly evolved concept vehicle which offers competitive advantages in terms of optimized ergonomics, low running costs, high levels of safety, modularity and low environmental impact*

Technical specification of the prototype product service to be realized



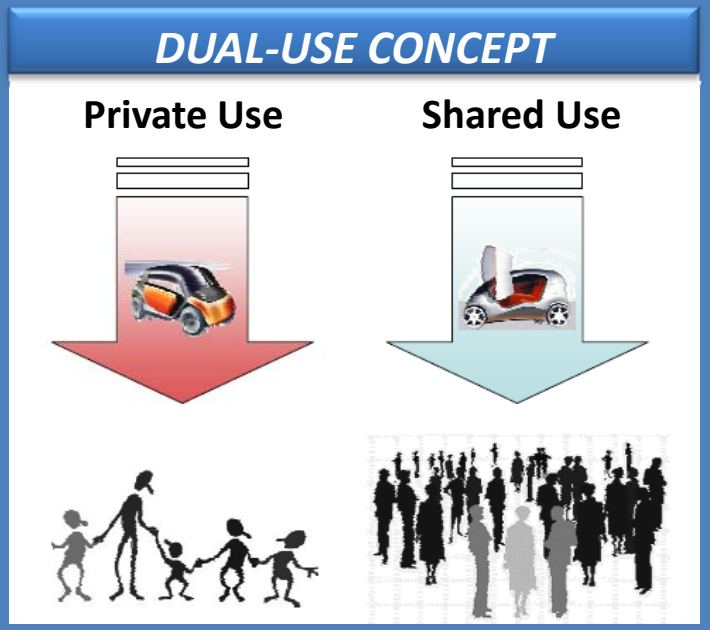


The vehicles will be provided with innovative components such as radio systems (information technology systems - ITS) able to broadcast with other similar vehicles and fleet managing station. This is a new concept of vehicle because is a high-tech product, equipped with hardware and chassis made with new light materials and with a platform having interchangeable upper bodies.

THE CITYCAR PROJECT: "MECCANO"

This new product wants to meet societies demand for reduced congestions, low road-space occupation and improved intermodality with public transportation systems. In this context, the vehicle is characterized by the following features:

- Very highly efficient propulsion system: full-power FC, plug-in battery electric, battery electric with auxiliary motor-generator (series hybrid) and parallel hybrid with methane fuelled ICE
- Compact body and short vehicle length (approx. 3m) with high vehicle habitability
- The best solutions for human-machine and machine-infrastructure interactions and communication personalized depending on the user and on the specific application
- Modular/flexible structure: mini-vehicles for private and public transport
- Development of a platform (lower body) with a highly flexible mechanical lay-out, able to adapt to the different innovative systems (electric, hybrid, bi-fuel propulsion, etc..)
- Development of two upper bodies and interiors made with different style and technologies in relation to the mission of use and to the volumes foreseen



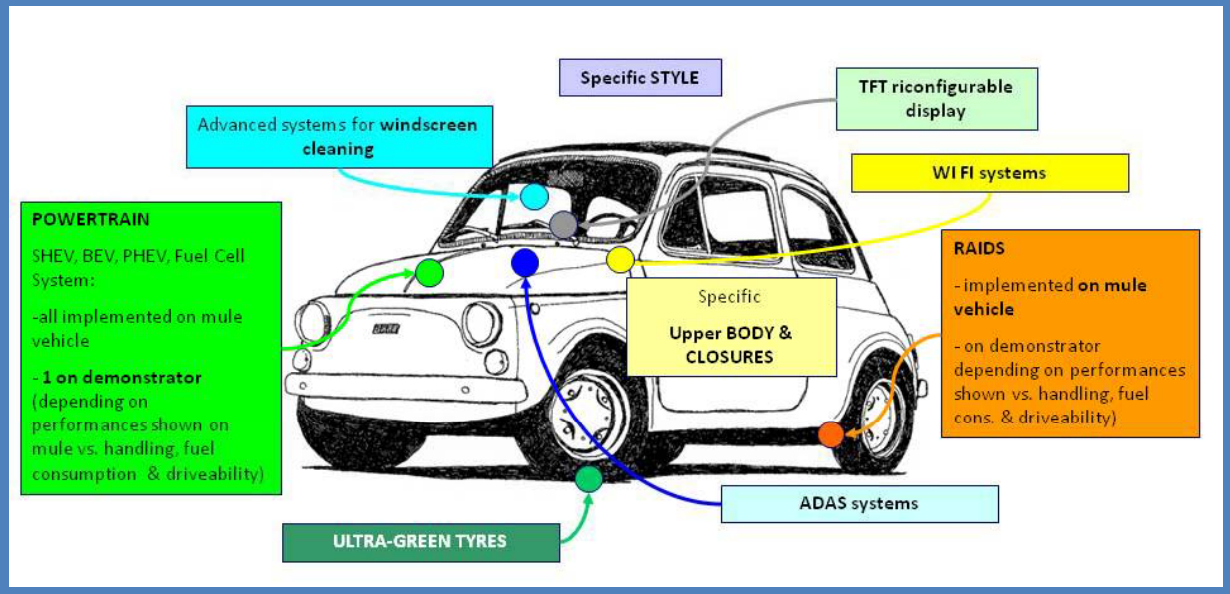
THE CITYCAR PROJECT: "MECCANO"

This dual-use concept (individuals as conventional car or as a means of personalized public transport) introduces radically new opportunities for vehicle design:

a) the development of a platform: chassis and low part of the vehicle can be configured in a highly flexible manner in order to accommodate the different propulsions

b) the design of 2 vehicle upper bodies and their relative interiors offering different styles and appropriate technologies.

Other solutions: driving assistance systems which are specific to the urban context, low-resistance tyres, innovative windscreen clearing solutions, WiFi control of the on-board systems, telematic communication between public vehicles and the infrastructure.



In MECCANO project several automotive companies are directly involved (FIAT, Michelin, Magneti Marelli, Marangoni, ecc.) in conjunction with research institutes.

THE BICYCLE PROJECT: "BHYKE"

(The project is in joint venture with TRE SpA)

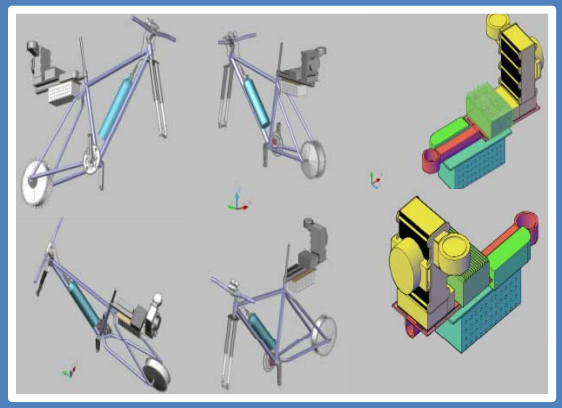
The aim: a representative sample of field test of hydrogen technology in transport sector and refuelling station from renewable energy

Characteristics

- pedal assistance
- provided with a 250 W FC
- provided with a hydrogen solid state storage cylinder of 900 Sl at 12 bar

Fixed targets

- range of 130-150 km
- total weight of 26 kg

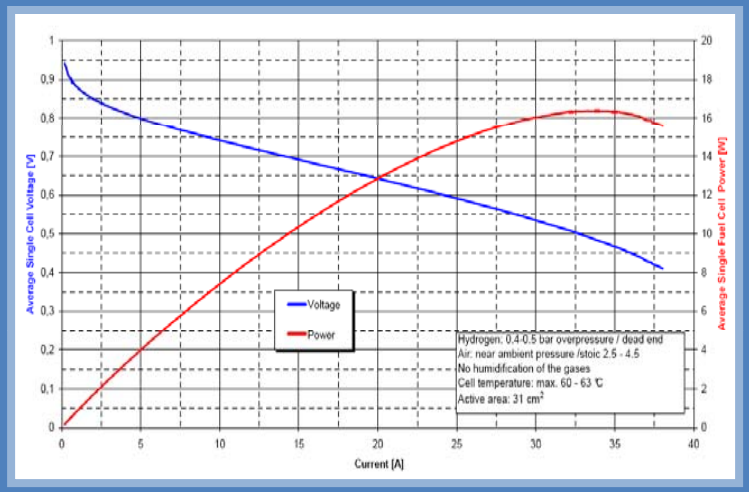


Bike	Technical Characteristic
Max. Power Output	250 W
Max. torque	15 Nm@66 rpm
Motor Voltage range	24V Regulated DC
Hydrogen Storage	Solid State
Hydrogen capacity	900 Sl@12bar
maximum range	150 km@pedal assist
Total Weight	26 Kg

THE BICYCLE PROJECT: "BHYKE"

PRINCIPAL (TECHNICAL AND ENERGETIC) ASPECTS OF THE PROJECT AND FUTURE STEPS

- ***Innovative design***: for the moment a commercial bike is used, but the next step will be the realization of a suitable frame that will be designed for FC and hydrogen application (H_2 tank will be integrated within the frame). A similar bike could be an industrial independent product
- ***Regenerative braking***: for the recovery energy lithium ion batteries (Li-Ion) and/or supercaps, having light weight and very small dimensions, will be used



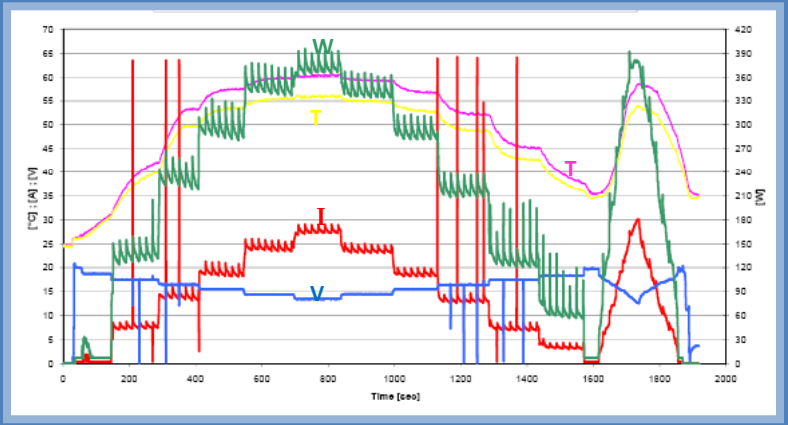
Stack System	Technical Characteristic
Max. Power Output	250 W
Voltage range	13.2 V – 20.2 V UDC
H2 Consumption	3.3 ln/min@full load
Hydrogen pressure	0.7 – 0.8 bar
Oxygen Supply	from ambient air
Air pressure	ambient pressure
Cell number	22 cells (31 cm2 active area)

- ***Range increase***: the pedal assistance allows to cover a larger distance with slopes. This private mean of transport offers high independence (in terms of time and way) from public transport, so in this case it is positive to encourage the use of private transport
- ***Diversification of end users***: the pedal assistance involves a wide audience including many user targets

THE BICYCLE PROJECT: "BHYKE"

PRINCIPAL (TECHNICAL AND ENERGETIC) ASPECTS OF THE PROJECT AND FUTURE STEPS

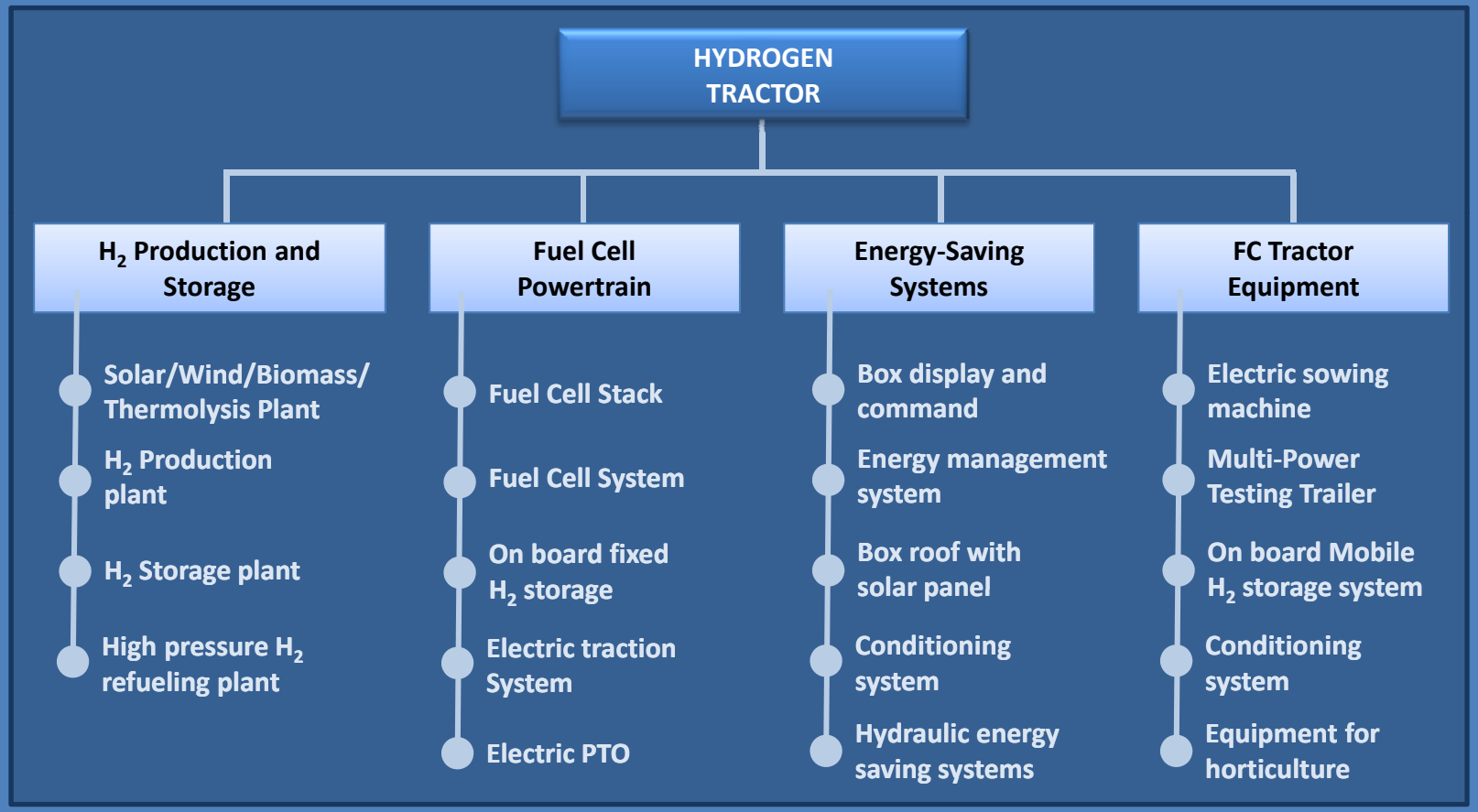
- ***Use of Renewable energy for H_2 production***: electricity from RES allows to reduce the amount of energy from the grid (produced by fossil fuels)
- ***Realization of a H_2 production and refueling station in the city***: this station will be provided by RES in the centre of the town so this action will require specific safety rule and architectural integration. This refueling station will provide H_2 for other FC vehicles (citycar, minibus) and could contribute to the increase amount of low environmental impact vehicles.
- ***Bike-sharing service***: the bike could be used by municipality for bike-sharing service ("MiBici" is a cycle mobility project for the EXPO 2015 that will be held in Milan)
- ***Diversification of use***: the pedal assistance bike could be used not only in the city context but also in touristic (sea or mountain) zone, small islands, parks, holiday village etc.



THE TRACTOR PROJECT: "HY-TRACTOR"

(A three years national plan coordinated by CRF)

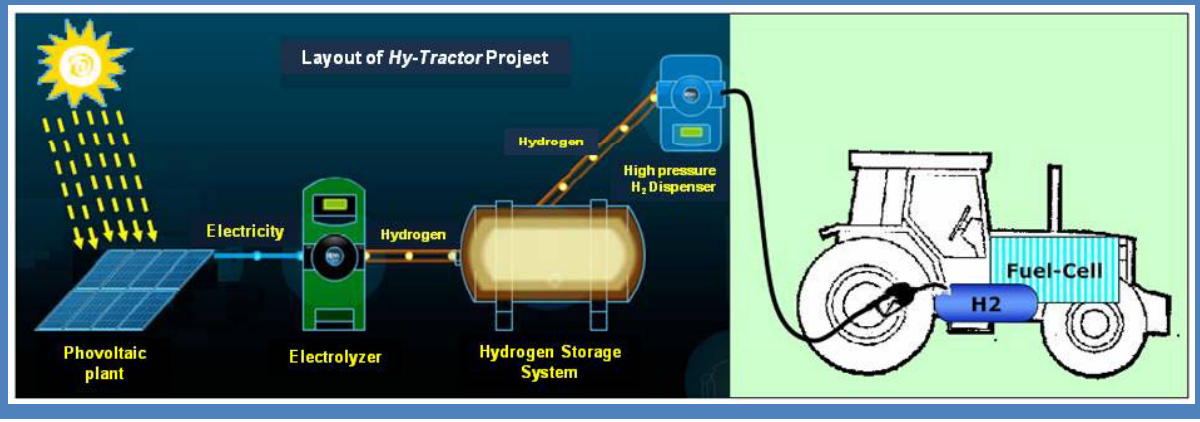
The tractor projects intends to demonstrate that the fuel cell can be applied in the farm context because hydrogen could be produced on site using different methods (biomass, wind or/and solar energy). In this case the hurdle of hydrogen distribution is avoided.



THE TRACTOR PROJECT: "HY-TRACTOR"

In order to demonstrate that fuel cell technology can be used also in farm sector *Hy-Tractor* project wants to develop a fuel cell tractor fed by hydrogen. In farm sector the hydrogen distribution is not a problem because hydrogen can be produced on site using the available renewable energies: wind, photovoltaic, biomass. The main activities are:

- Development of a hydrogen production and storage system based on: 1) photovoltaic/wind and electrolyzer 2) biomass, 3) low temperature thermolysis, 4) high temperature pyrolysis;
- Design and development of tractor equipped with fuel cell powertrain, on board hydrogen storage system and other needed auxiliary subsystems.
- Development of energy saving systems for efficiency increase. Some of these are: photovoltaic roof, high efficiency air-conditioning and external lights, hydraulic systems and power take-off (PTO) with electric drive.
- Replacement of hydraulic drive with electric drive, avoiding oil (that is a polluting substances) and increasing the check.
- Design of a *Multi-Power Testing-Trailer* able to carry out simultaneous tests on the traction, hydraulic system and electric devices
- Field test of the FC tractor during operation both in external sites and inside places (hayloft).



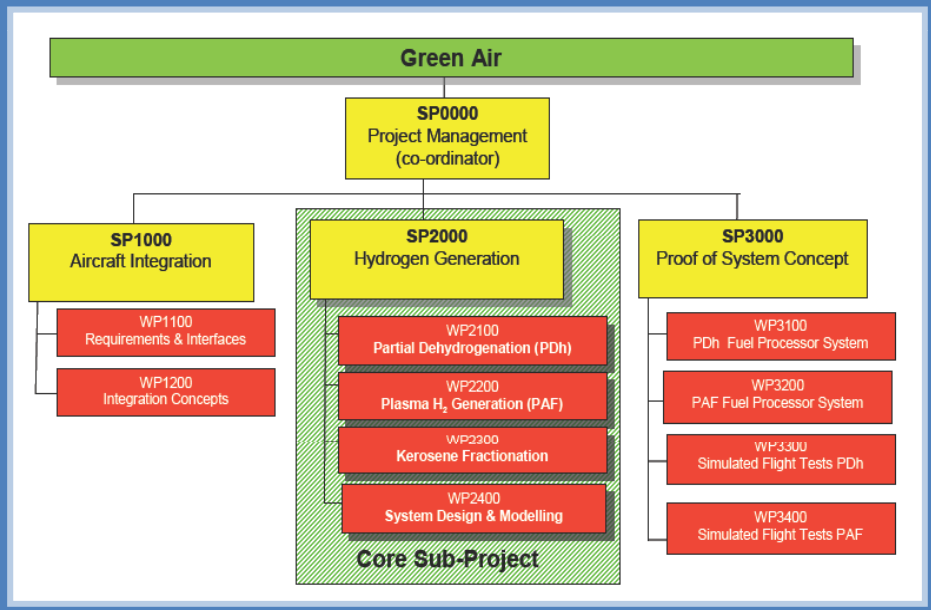
THE AIRBUS PROJECT: "GREENAIR"

(A three years European plan)

The airplane project concerns the on board H_2 production problem and the FC application APU. GreenAir is proposed and coordinated by EADS

Technical objectives

- guidance by EADS on requirements for implementation of the technology into aircraft (efficiency, durability, specific power, power density, safety issues etc.)
- elaboration of the fundamentals of two unconventional methods to generate hydrogen from kerosene on board an aircraft
- proof of concept with breadboard systems performing:
  - standard tests (conversion rates, efficiency, degradation, dynamics etc.)
  - special tests under simulated flight conditions (in particular vibration)
- the breadboard systems will be in the power range of 1 to 5 kW, in any case big enough to allow the scale-up results.



The project establishes links to the JTIs ("CLEANSKY" and "Fuel Cells and Hydrogen") to maximize synergies.

THE AIRBUS PROJECT: "GREENAIR"

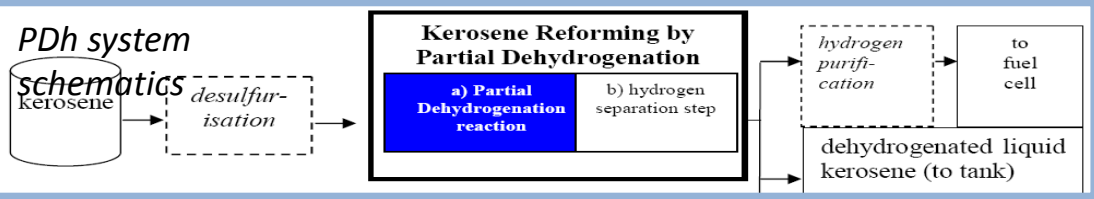
GreenAir is addressing to one of the key problems for FC application aboard an aircraft: the generation of H_2 from Jet fuel (Kerosene) which will be the aeronautic fuel for the next decades. While "mainstream" fuel processors (autothermal reforming) have been intensely investigated already, GreenAir is focusing on novel and unconventional methods to overcome some hurdles of "mainstream" reforming technologies:

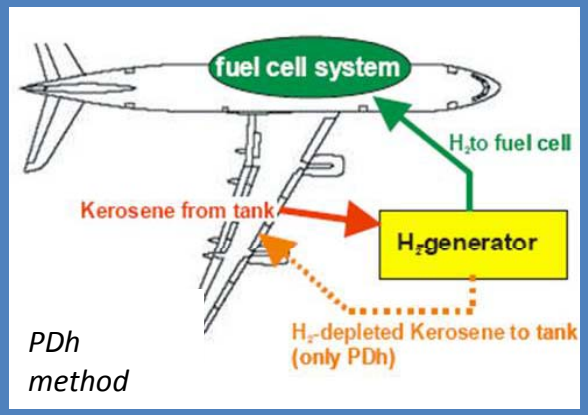
1. ***Partial Dehydrogenation fuel processing (PDh)***
2. ***Microwave plasma assisted reforming (PAF)***

The main appeal of PDh for H_2 generation aboard an aircraft is the simplicity of the process and the low temperatures if compared with other reforming processes. PDh offers the following benefits:

- reduced system complexity
- increased system reliability, safety, lifetime
- lower system volume and mass
- lower energy consumption
- lower system startup time
- higher system dynamics

PDh system schematics



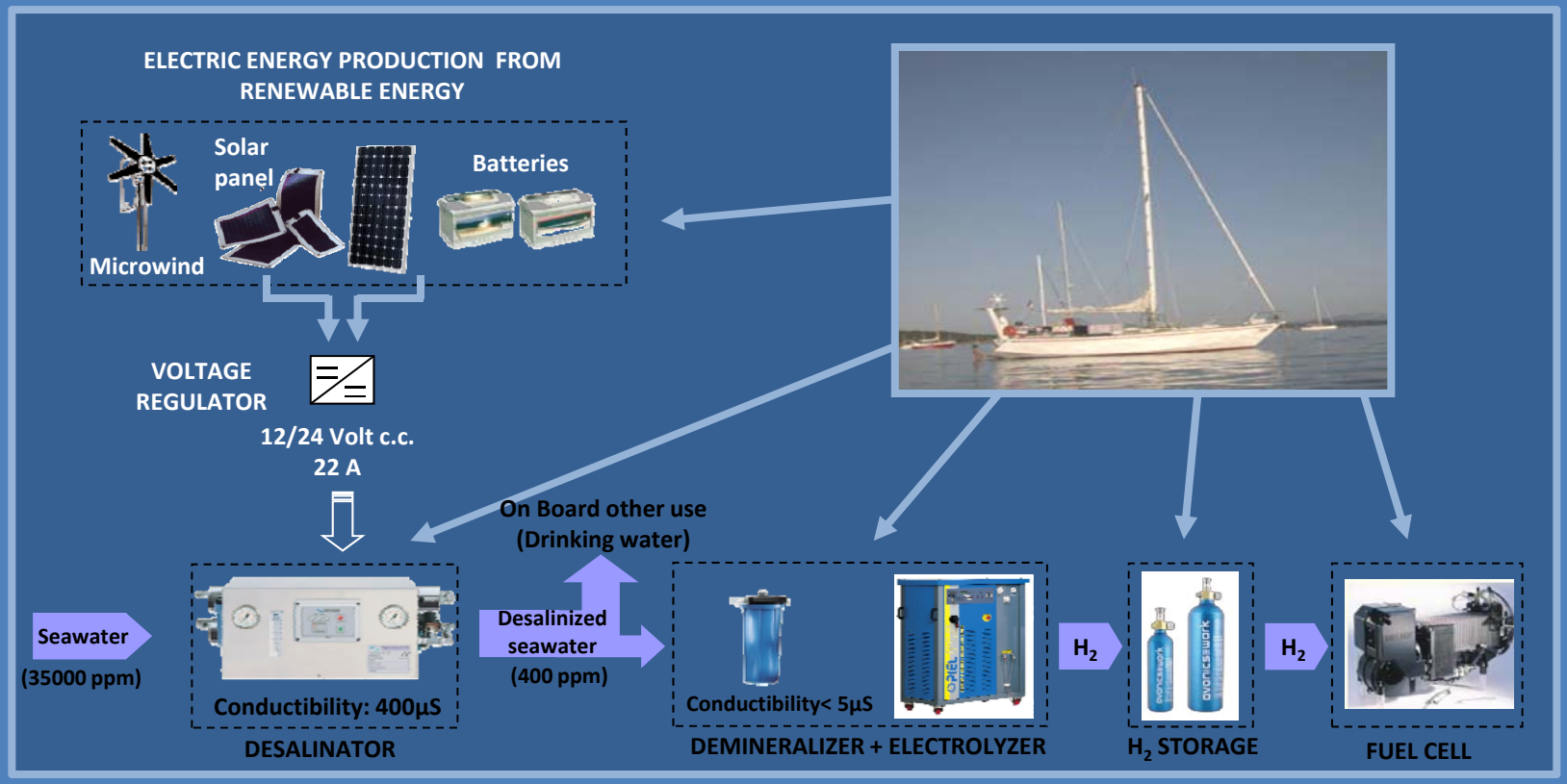


PDh method

THE SHIP PROJECT: "GREENSHIP"

(A three years national plan)

The aim of the project is to investigate the influence and effects of marine environmental on the FC and its auxiliary systems performance. The marine environmental is very aggressive in terms of humidity, temperature, salinity and corrosion of the on board devices. In order to investigate these effects different materials are being studied. During the project marine critical conditions will be simulated in a "Dry Corrosion Test Cabinet" and different accelerated tests will be implemented.

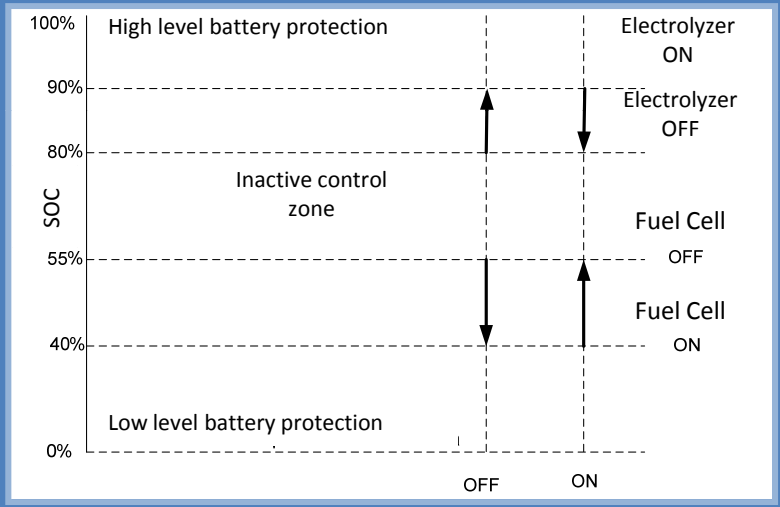


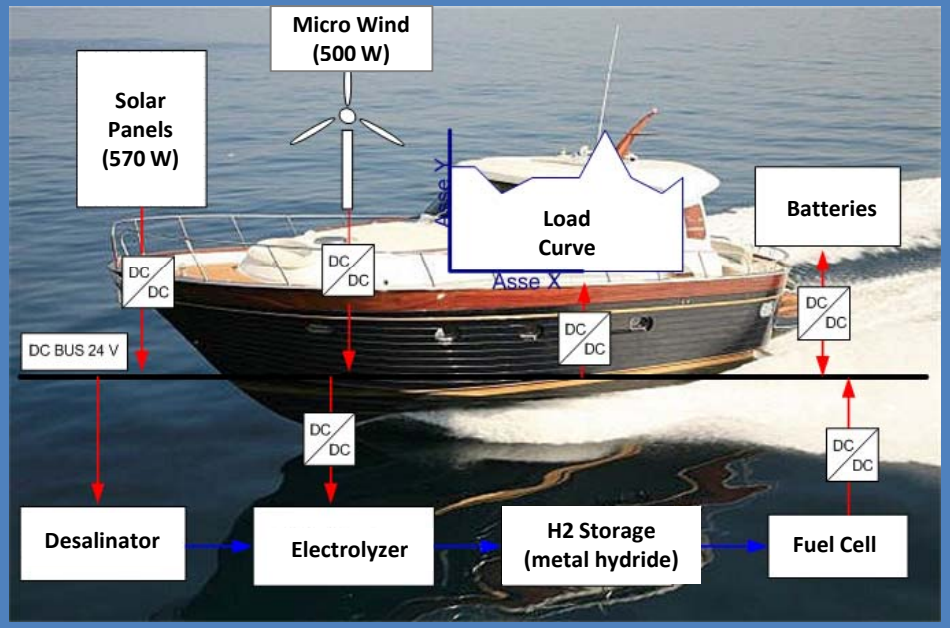
THE SHIP PROJECT: "GREENSHIP"

RES and FC application on the ship

It is possible to store solar/wind energy producing hydrogen and using batteries. The produced H_2 is used in a FC.

The interaction between an electrolyzer, that uses seawater, and solar panel and/or microwind has been studied by a simulation tool.





Energy strategy

Batteries are used like energy buffer.

The energy coming from solar/wind is converted in H_2 only when batteries are charged because the H_2 production efficiency is lower than batteries accumulating process.

- *When batteries are in discharging and SOC is 80-90% the surplus energy is utilized in the electrolyzer*
- *When batteries are in charging and SOC is < 80% the electrolyzer is switched on until SOC is 90%*
- *When batteries SOC < 40% the produced H_2 is utilized in the FC*
- *When batteries SOC is 55% the FC is switched off*
- *When RWE are not sufficient FC can recharge batteries and cover the load at the same time*

In the inactive control zone the surplus energy is going to batteries with the aim to increase the process efficiency

THE SHIP PROJECT: "GREENSHIP"

Accelerated Tests in the "Dry Corrosion Test Cabinet"

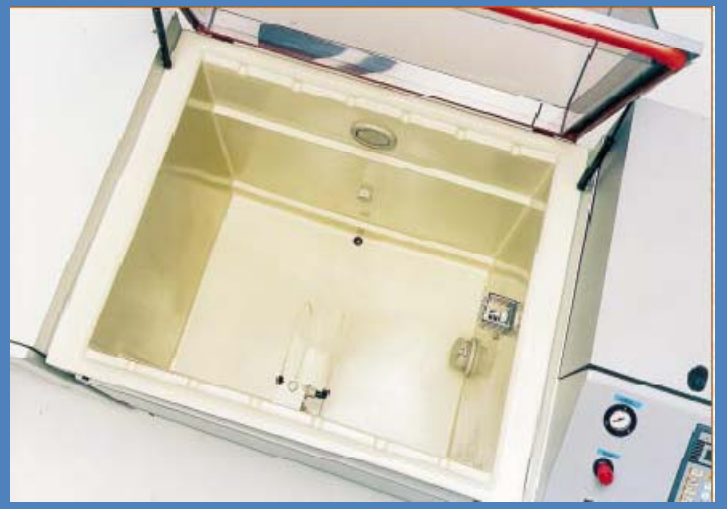
FC stack will be characterized under normal condition using conventional tests (polarization, ….)

FC stack and its auxiliary systems will be subjected to first ageing test in the Dry Corrosion Test Cabinet.

After the cabinet test the FC will be tested again under normal condition in order to evaluate decay due to corrosion and saline environmental.

If stack performance are good it will be subjected under another ageing test and so on until the stack death.

Stack and auxiliary systems will be subjected to post mortem tests with the aim to evaluate the critical factors.



CONCLUSIONS

Projects presented in this work explain the direction of European policy and CNR ITAE regarding fuel cell technology application in the transport sector.

As shown all fields of transport are involved and this highlights the purpose to investigate the possibility to use really innovative devices like fuel cells with the aim to reduce greenhouse gases.

In order to determinate the best solution, in terms of infrastructures and conceptual changes to bring to whole system, different approaches are investigated: fuel cell full power and hybrid powertrain. On the basis of projects' results it will be possible to draw some conclusions about the best role of fuel cell in the transport sector.

THANK YOU