Rail Traction:
The economics of transiting towards
Hybrid & Hydrail

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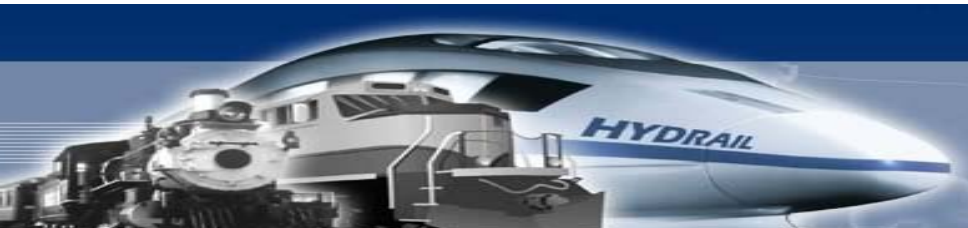
- **Why hybridise ?**
- **University of Pisa & Hybrid Technologies**
- **Economics of Hybridisation**
- **Towards Hydrail**



Conventional Rail Traction Technologies

- **Electric Traction (1881):**
  - Expensive infrastructure, Lower operating cost, renewable energy (?), regenerative braking (?)
  - **DC Electric Traction**
    - » 1.5kV / 3kV DC supply to railway locos.
  - **AC Electric Traction**
    - » Predominantly 25 kV AC supply; Regenerative [illegible]le; Presently most efficient mode.
    - » Upper-bound of the regenerated voltage is restricted by the catenary voltage – at higher speeds, leads to inability of the regenerated power to be fed to the grid.

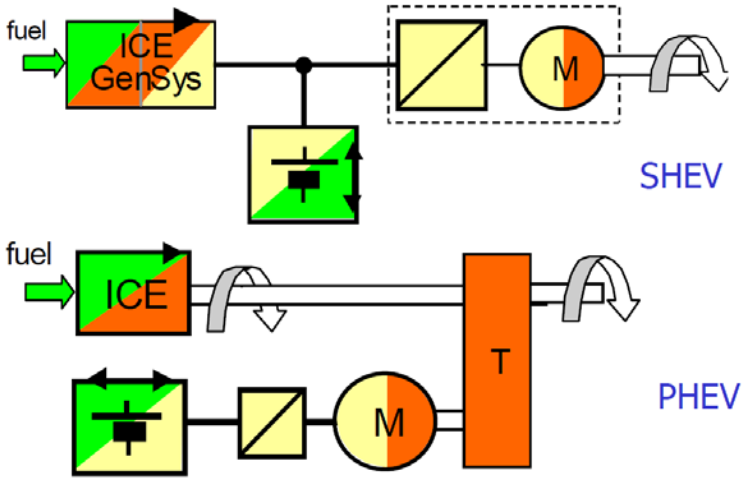
Conventional Rail Traction Technologies

- **Diesel Traction (1893):**
  - Oil-dependent, emissions, Flexibility of operations,
  - **Diesel-electric traction**

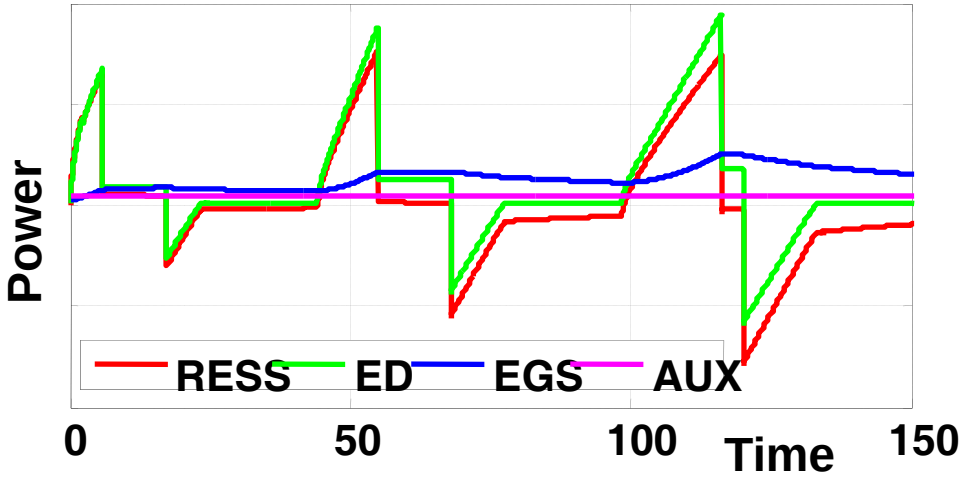
    - » Diesel engine + alternator/generator produces onboard electricity.
    - » Dynamic braking possible; more effective than regenerative braking (of electric traction) - avoids wear & tear of wheels & brake- blocks
    - » Can be most easily hybridised
  - **Diesel-mechanical & diesel hydraulic traction**
    - » Use mechanical or hydraulic transmission to power the wheels

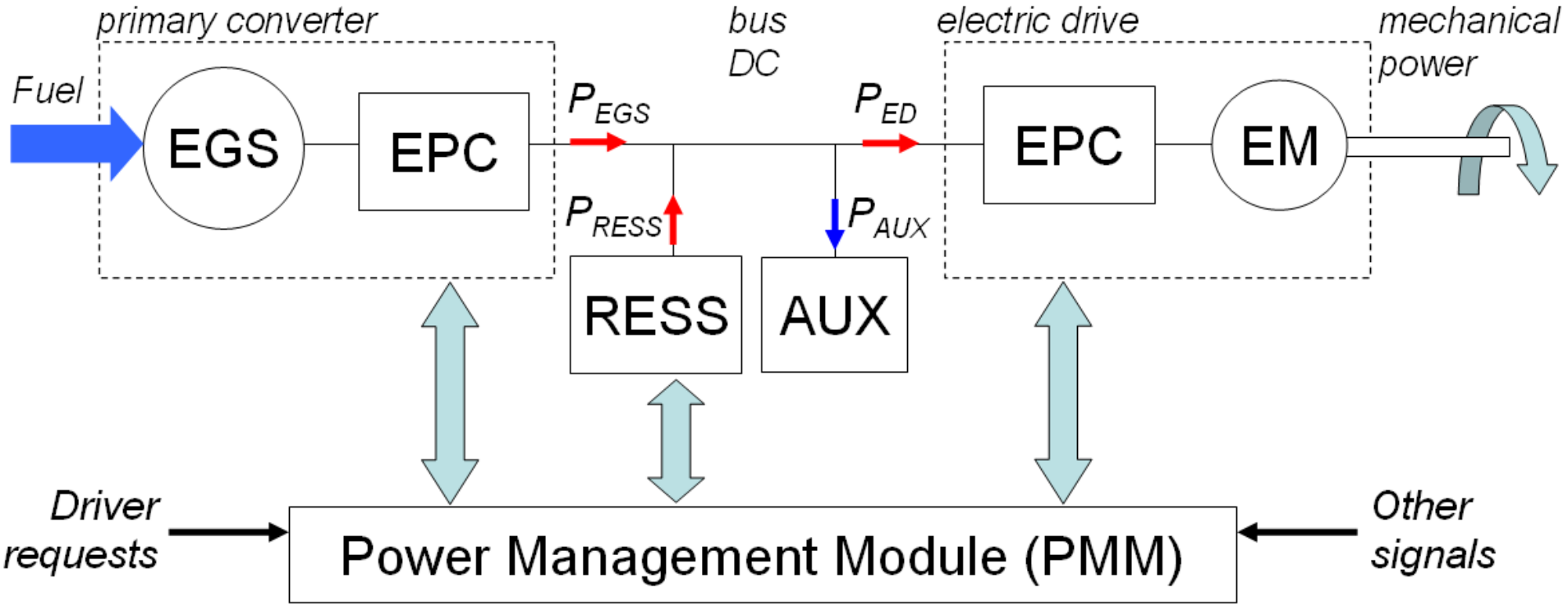
Hybrid Rail Traction

- **Hybrid :** *with more than one source of on-board power …*
  - » ICE + batteries, ICE + batteries + supercaps, fuel cells + batteries, fuel cells + batteries + supercaps
  - » *First used by Greeks/Romans/Vikings* on oar & sail powered boats
- Series / parallel architectures



Hybrid Traction





Key drivers for hybridisation

- Energy costs escalating rapidly
  - » Train energy consumption dependent on gradients, maximum speeds & stopping patterns
  - » Typically constitute around 15-20% of total expenses; and growing
  - » Varies 19 - 33 kWh/1000 (German ICE, MEET project)
  - » Σ lifecycle energy costs >> original investment costs
- Reduce carbon footprint
- Economic sense

Hybrid Rail Traction

- Advantages over conventional technologies
  - » Regenerative braking (savings: from 10 to 25%)
  - » Prime mover operates at *efficient zone* of fuel maps
  - » Energy booster for achieving higher acceleration
  - » Can be run as ZEV
- Is most advantageous when the load varies considerably e.g. passenger services
- Hybridisation degree dependent upon duty cycle
  - » Benefits from downsizing prime mover negate weight of additional components
  - » Fuel savings >> 15 - 20%, emission reduction > 50%

- Why hybridise ?
- **Hybrid Vehicles & University of Pisa**
- Economics of Hybridisation
- Towards Hydrail

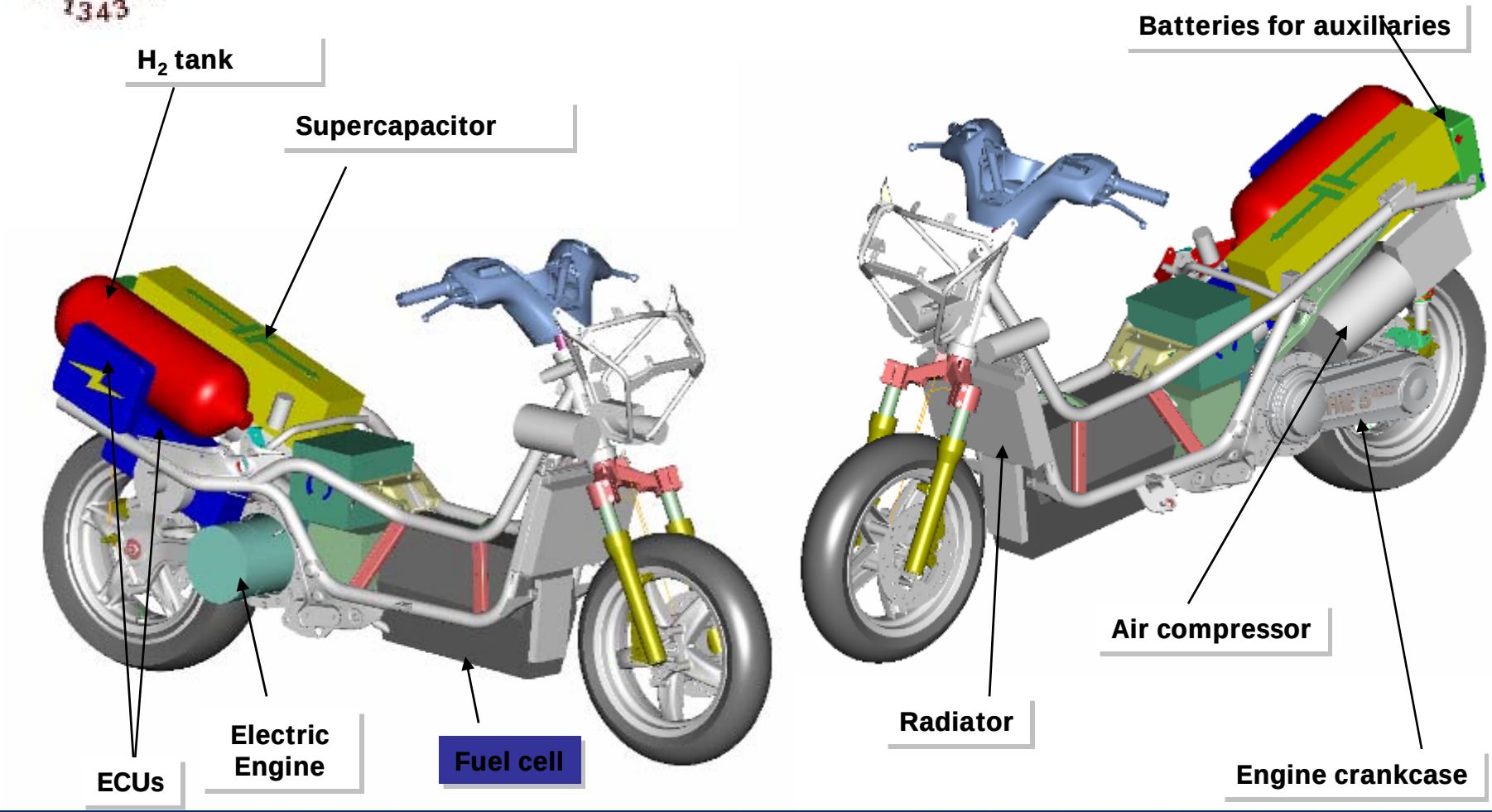
Parallel-Hybrid scooter Prototype

HYS - Università di Pisa & Piaggio

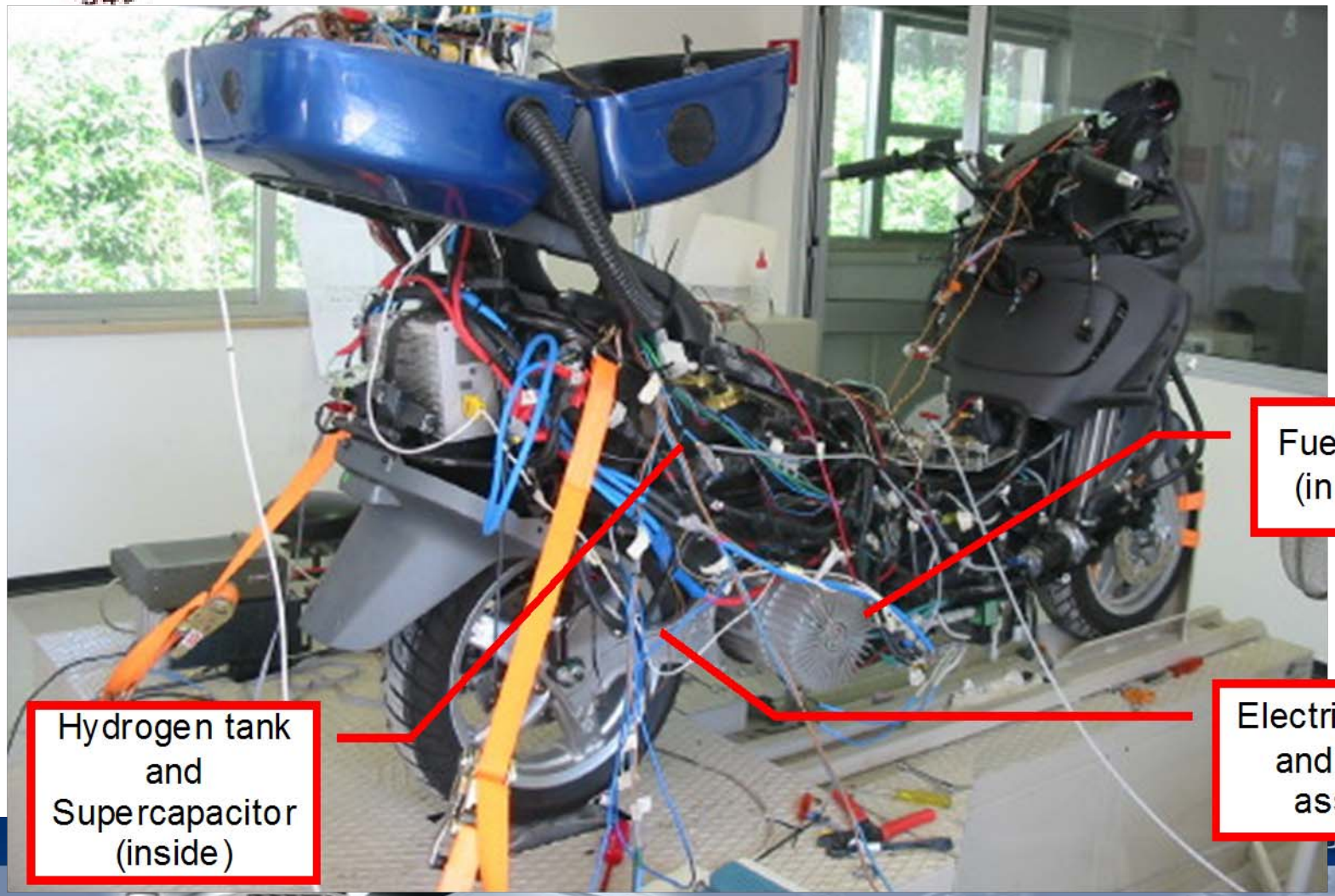
Vehicle Prototype

Hybrid drive-train

FC-based hydrogen Vehicle
(in the framework of EU funded FRESCO Project)
1- Layout study



FC-based hydrogen Vehicle
(in the framework of EU funded FRESCO Project)
2- vehicle under test at DSEA Labs

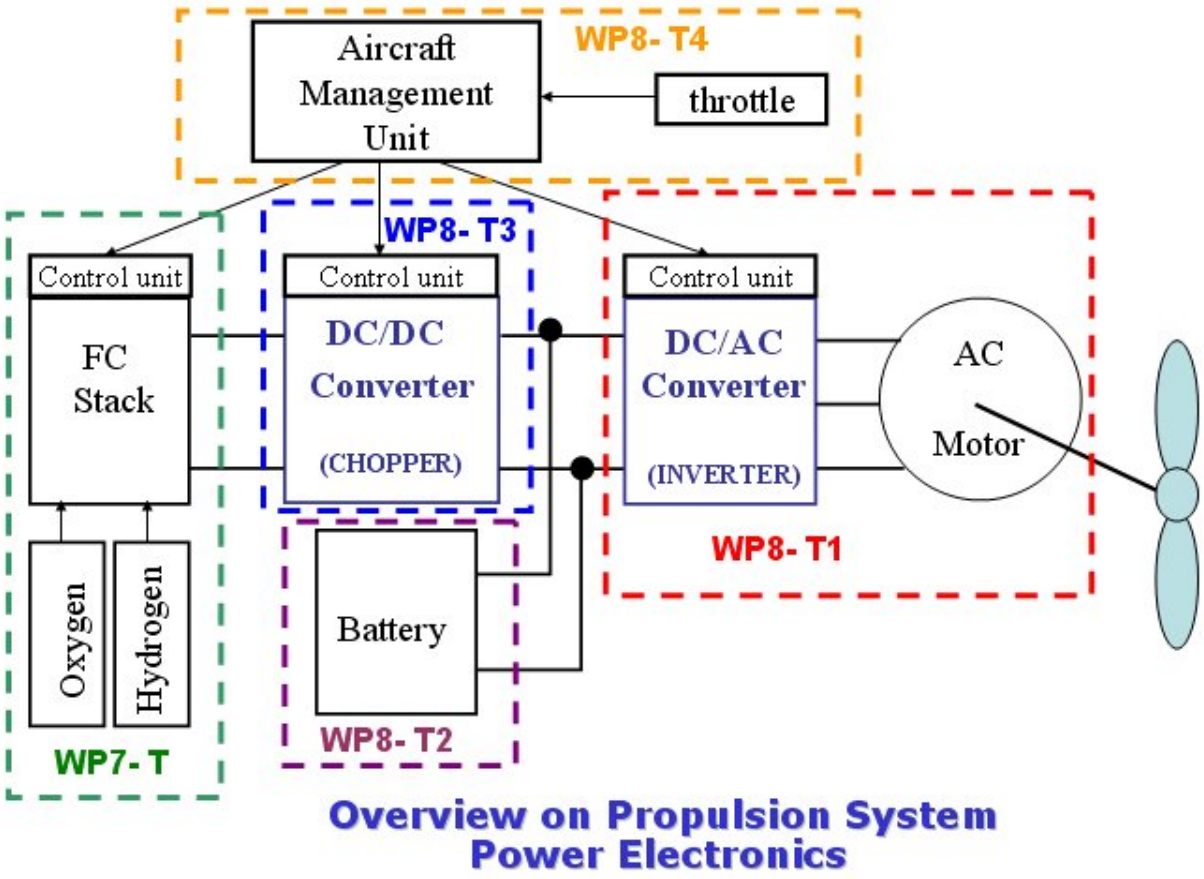


FC-based hydrogen Vehicle

(in the framework of EU funded FRESCO Project)

3 - vehicle being prepared for on-track tests

ENFICA-FC Project

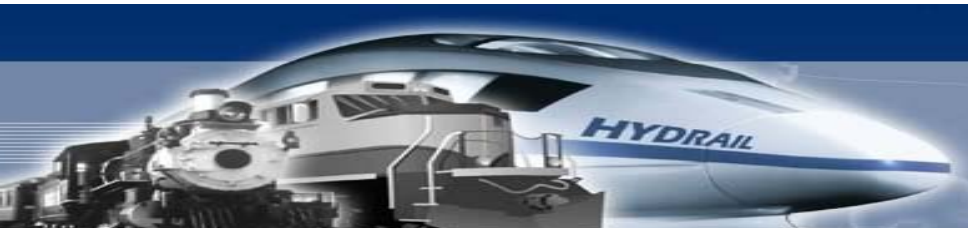


1) Technical specifications/acquisition:
   - Chopper
   - Inverter
   - Motor
   - Battery
2) Design and realisation of AMU
3) Power-train integration
4) Lab tests:
   - Of the electricity generation system loaded with resistors
   - Of the whole power train loaded with artificial mechanical load

ENFICA-FC Project

- On 26th May 2010, a new world record of 135 km/h for 45 minutes established, overcoming Boeing's 2009 record of 120 km/h for 20 minutes.
- Flew on fuel cells powered by H_2 gas @ 350 bar !

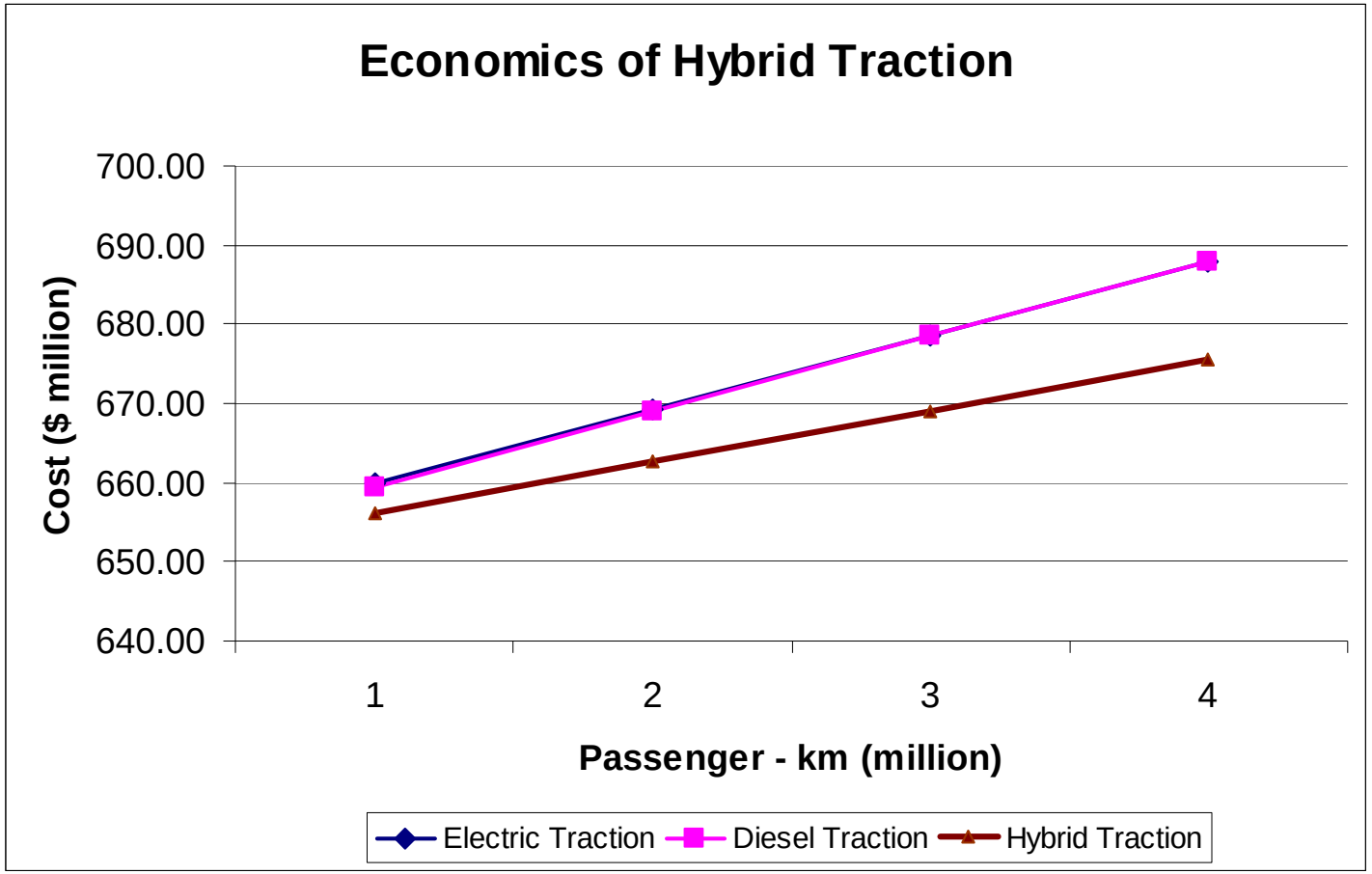
- Why hybridise ?
- Hybrid Vehicles & University of Pisa
- **Economics of Hybridisation**
- Towards Hydrail



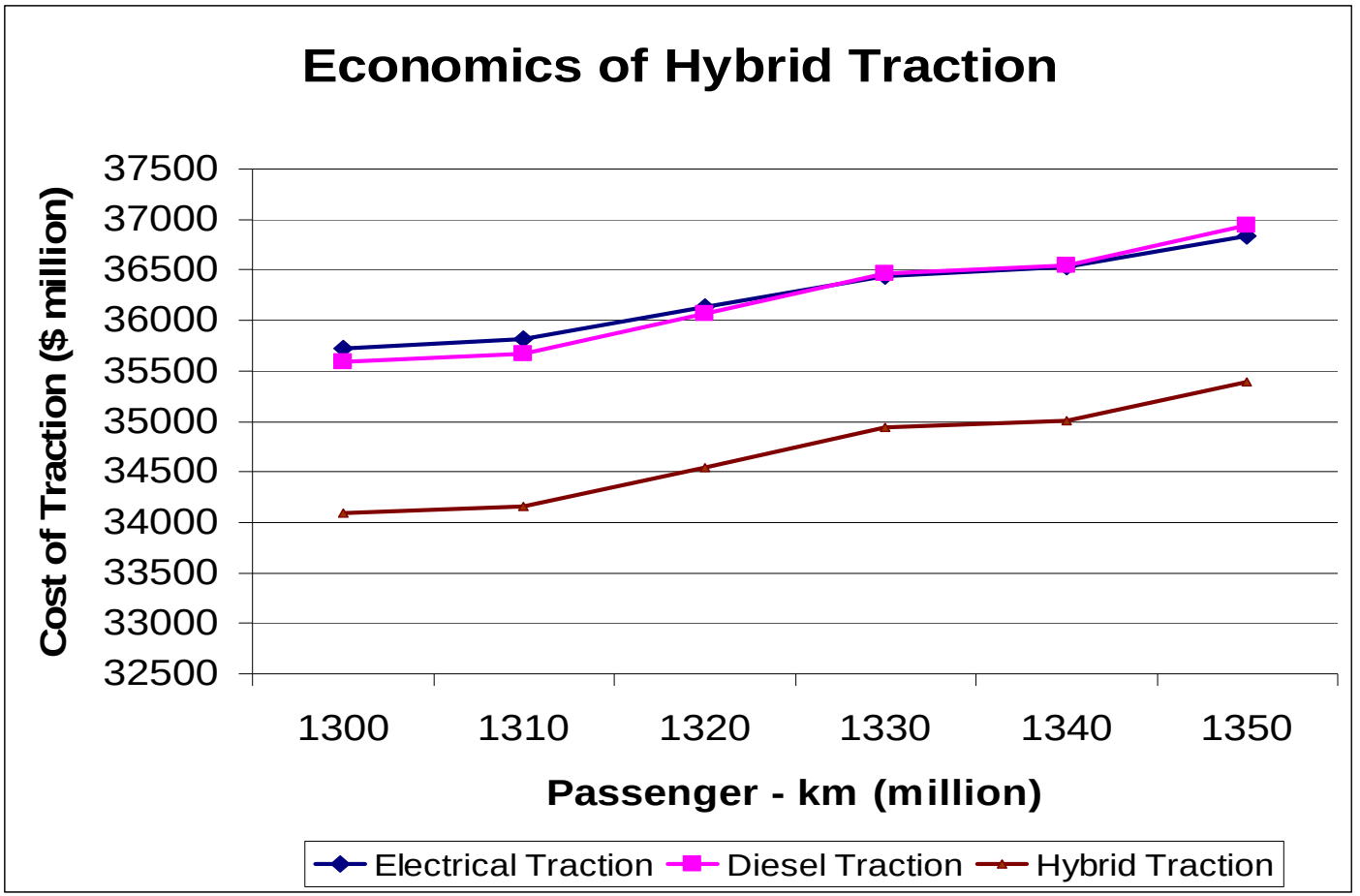
Economics of hybridisation: Case studies

- Scenarios
  - » Existing railway planning to switch to hybrid locos
  - » New railway, planning traction mode between electric, diesel & hybrid
  - Case A
    - To determine the break-even traffic of an existing railway, planning to switch to hybrid traction
      - » electric vs. diesel vs. hybrid
  - Case B
    - To determine the break-even traffic for a new railway
      - » electric vs. diesel vs. hybrid

Economics of hybridisation: Case A



Economics of hybridisation: Case B



Examples of hybrid locomotives/trains

- America
  - » Rail Power (2004)
  - » GE (2008)
  - » BNSF (2009)
- Asia
  - » JR East (2007): Orders for 10 more this year
  - » RTRI (2007)
  - » JR Freight (Toshiba, 2010)
- Europe:
  - » France (Bombardier, 2007) Ten French regions ordered 144 hybrid trains
  - » UK
  - » Holland (Alstom, 2009)

Transiting to hybrids

- Increasing number of railways are switching to hybrid powered trains
- Manufacturers
  - » Bombardier
  - » Hitachi
  - » Toshiba
  - » Mitsubishi
  - » Alstom
  - » Siemens
  - » ABB

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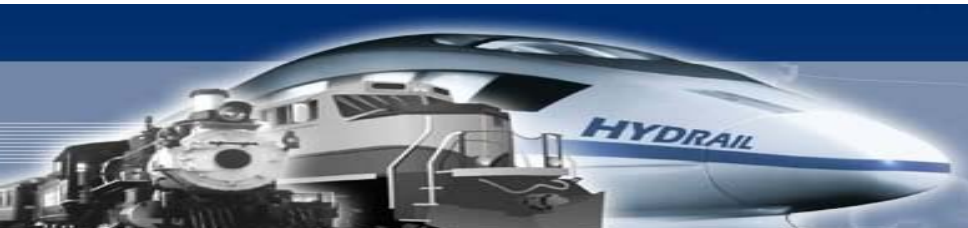
- **Towards Hydrail**

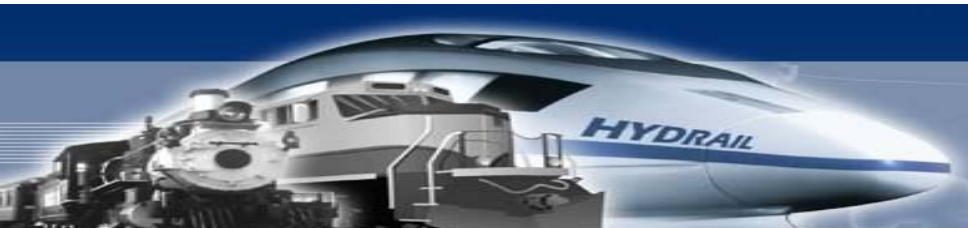


How to kickstart Hydrail ?

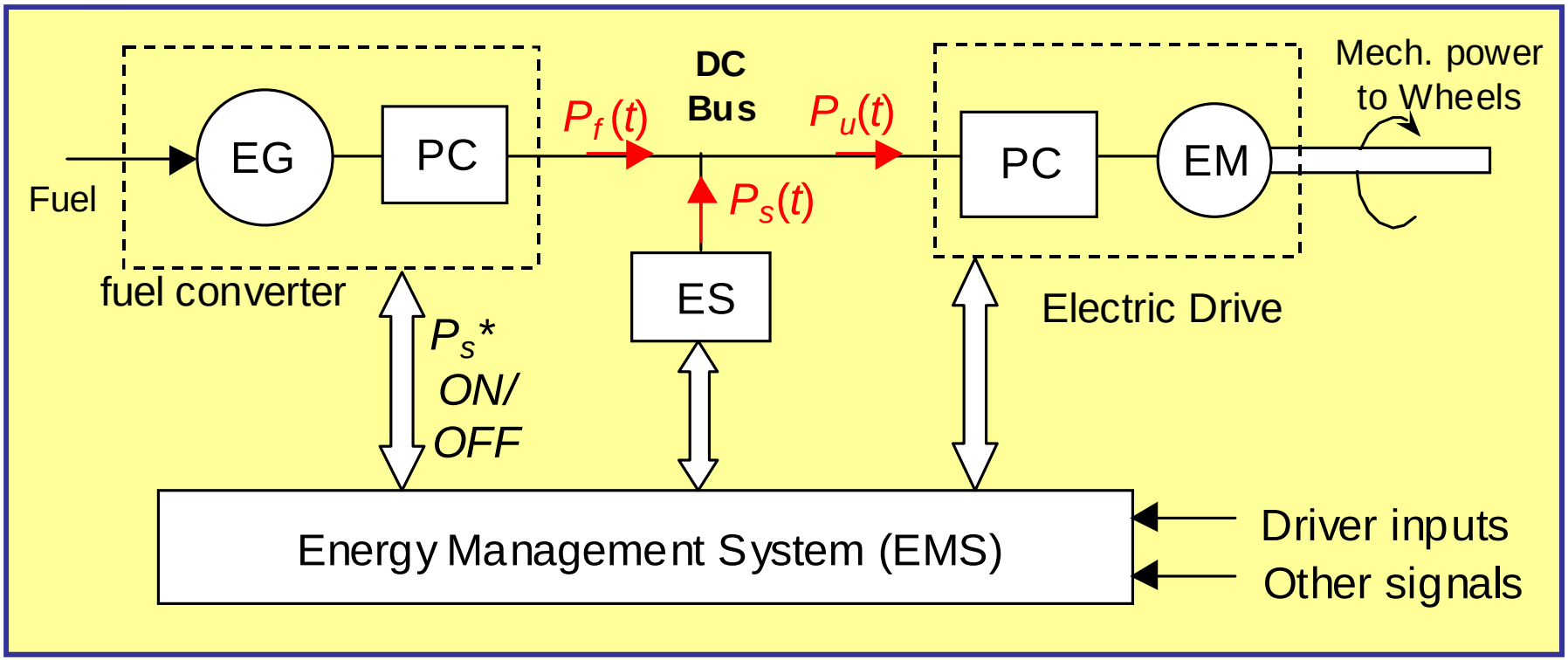
- Costly FC-based generation system (approx 5000 €/ kW vs. 50 $/kW for ICEs)
- FC stack life is still well behind that of ICEs
- Some technical issues still to be solved (low temp storage, system reliability etc.)
- Inadequate hydrogen production & infrastructure
- Too many standards and regulations

So what can we do *today*?

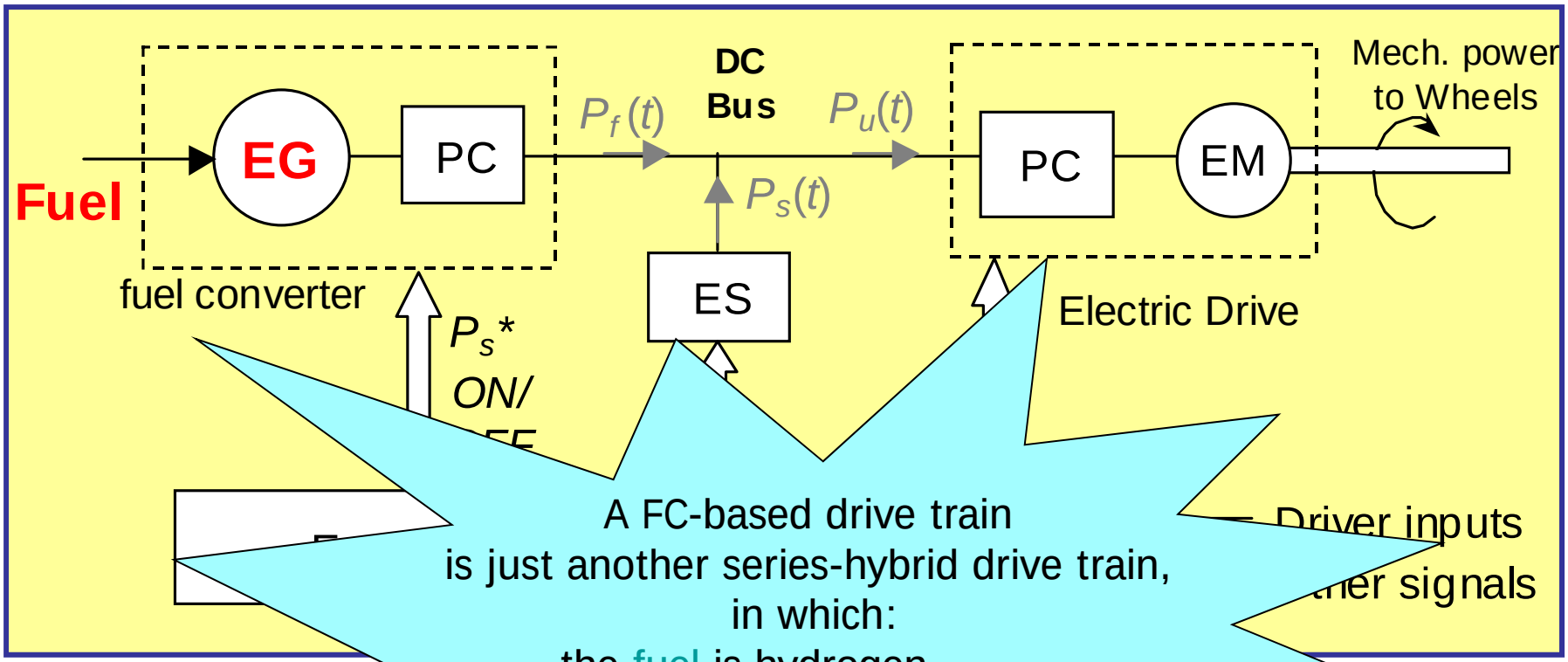
- Build prototypes and demonstrators
- Make people realise that it's a *safe* technology
- Adopt technologies that can be adapted to hydrail later, with the minimal inputs
- This could be possible by adopting *hybrid* propulsion



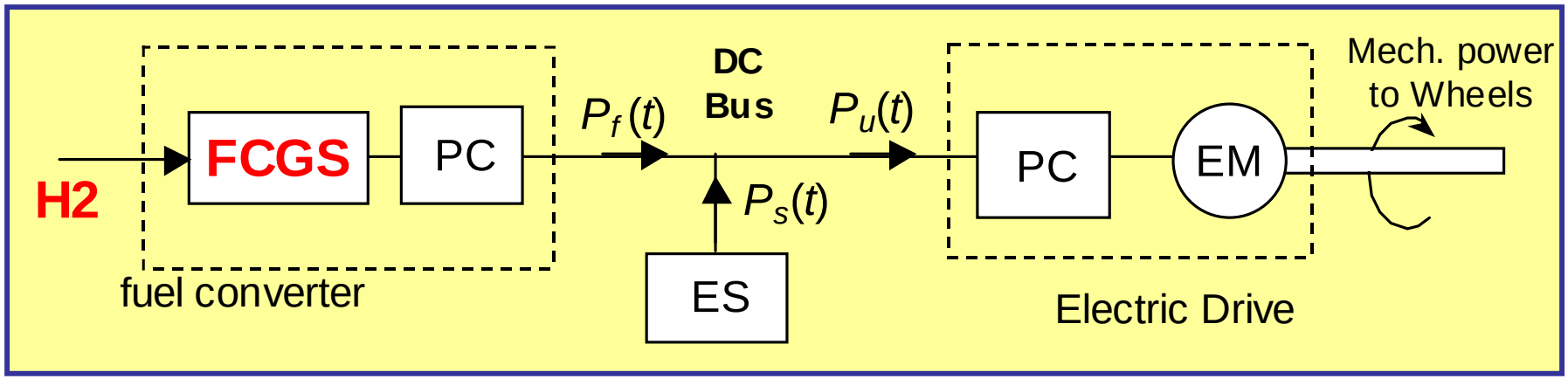
Series-hybrid trains



A FC-based drive train



Pure FC-based propulsion or hybrid solution?



Pure FC-loco

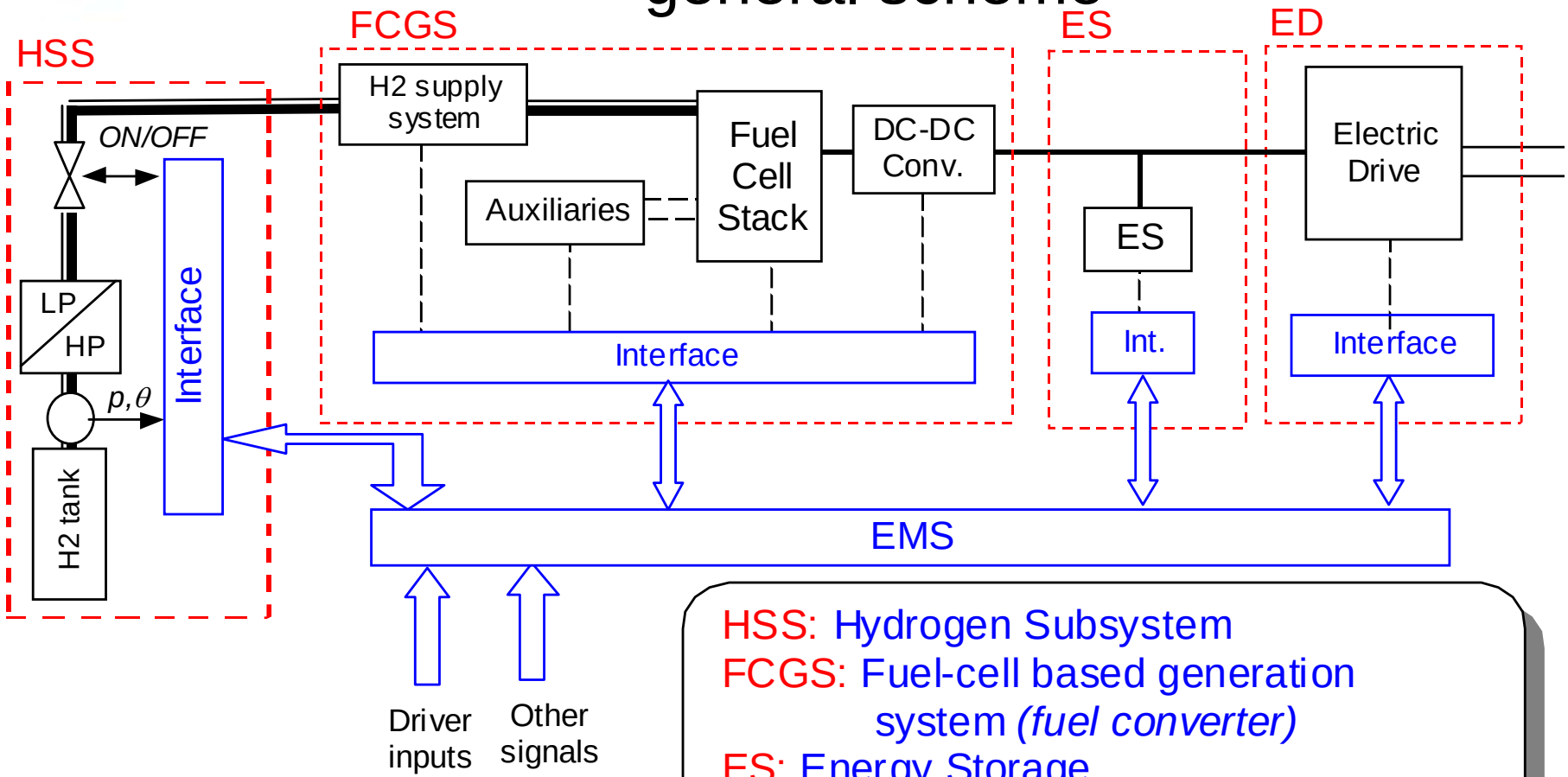
- Avoids additional cost & weight of energy storage

Hybrid FC-loco solution

- Reduced size of FC (reduction increases with variation in duty cycle)
- Lower costs, higher life

Hybridisation works better when the duty cycles and load fluctuates more: best solution for suburban or intercity trains or shunters.

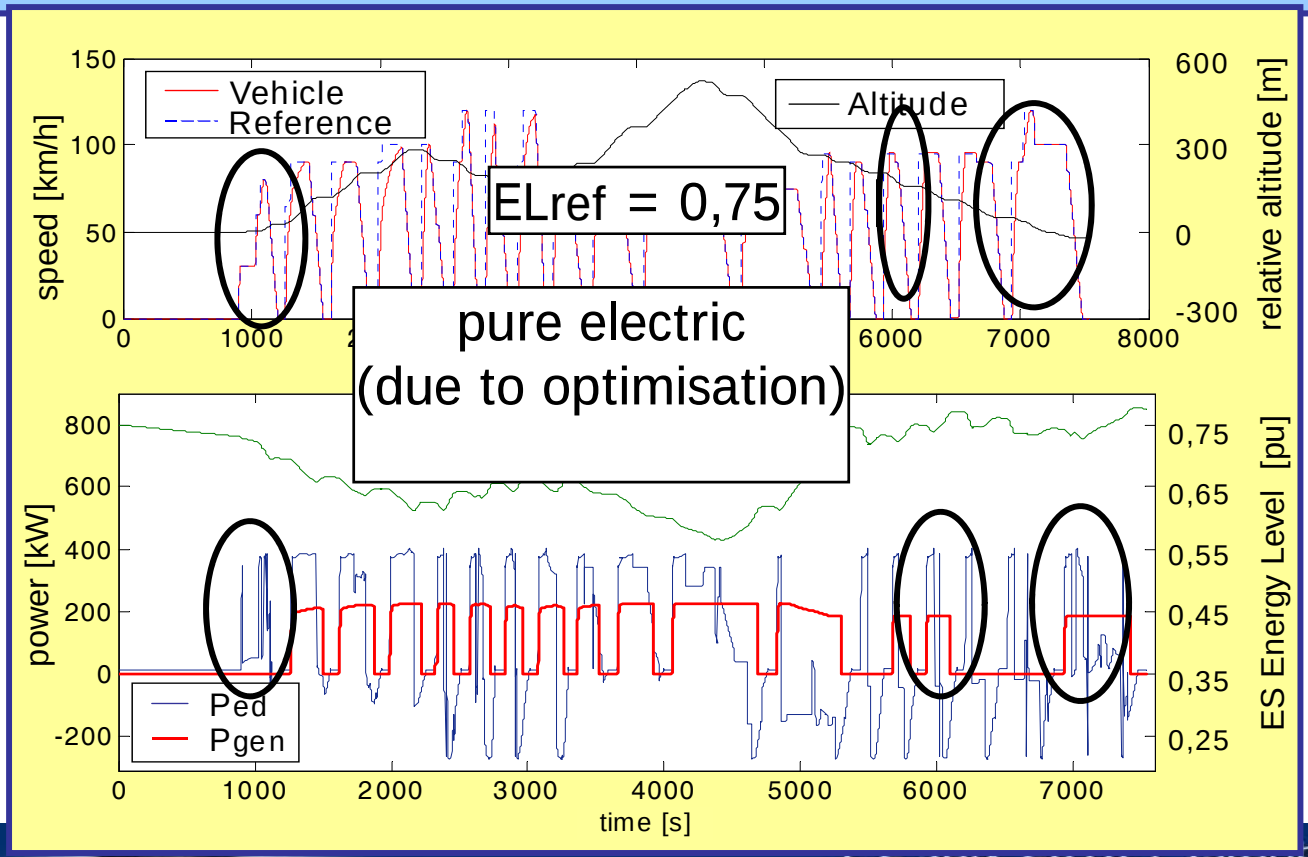
Hydrogen Fuel-cell based propulsion general scheme



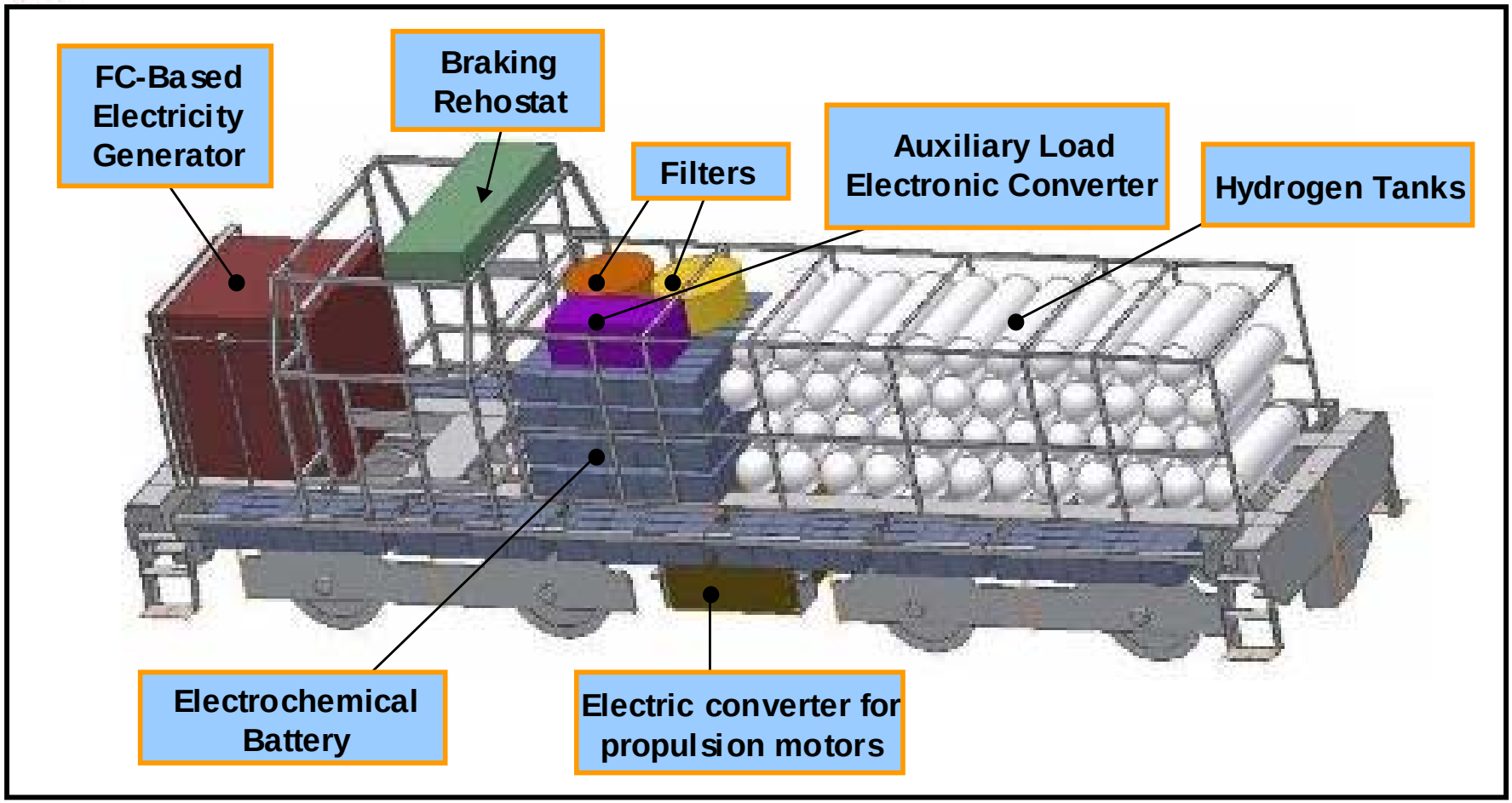
HSS: Hydrogen Subsystem
FCGS: Fuel-cell based generation system *(fuel converter)*
ES: Energy Storage
ED: Electric Drive

Electro-mechanical hybrid trains may be already competitive (1)

Track FAENTINA (Firenze-Faenza) 100km – 17 intermediate stops
Comparison of Hybrid and conventional vehicles in terms of consumption and emissions



“Vettore Idrogeno” Project: FC-based Vehicle – Preliminary layout



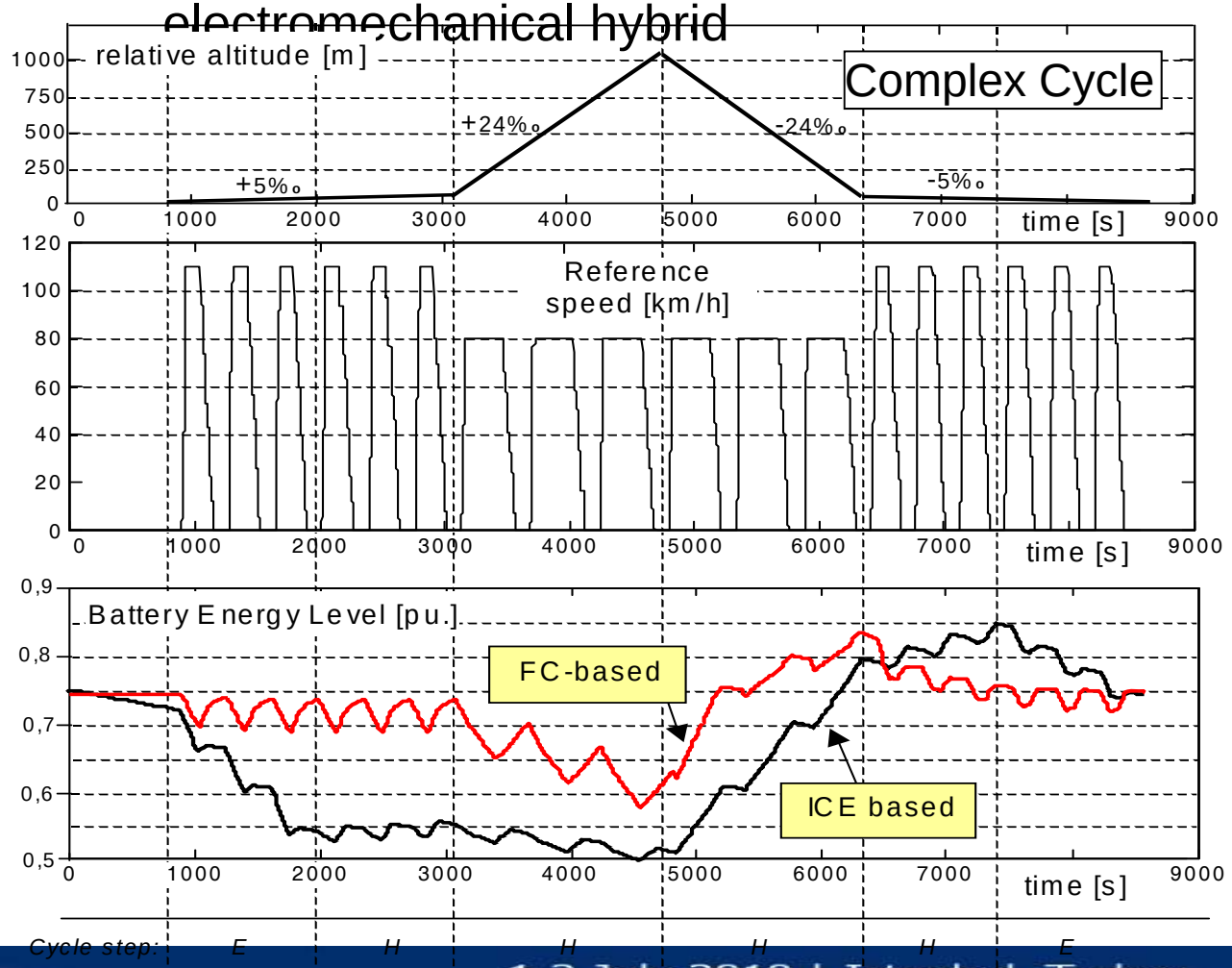
3) FC-based hydrogen Locomotive (study)

2 – Performance analysis in comparison with electromechanical hybrid

Simulation Results (auxiliaries enclosed)

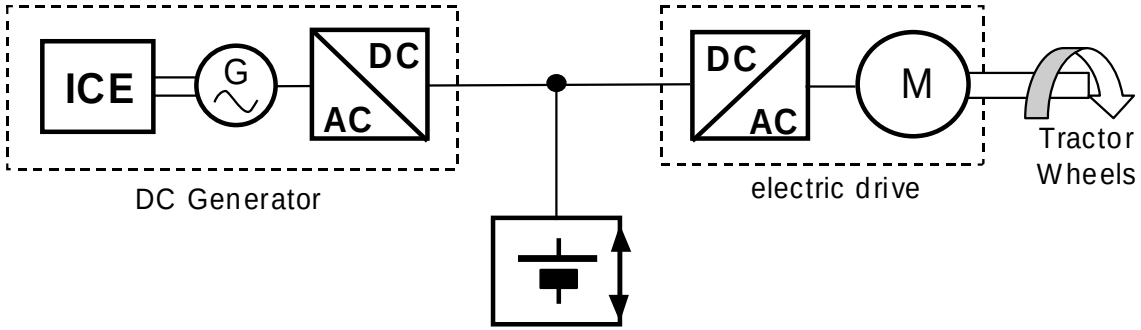
ICE-based	[kg/km]
Fuel Consumption	**0.48**
CO_2	**1.5**
	[g/km]
NOx	**10.8**
HC	**0.02**
CO	**0.3**
PM	**0.02**

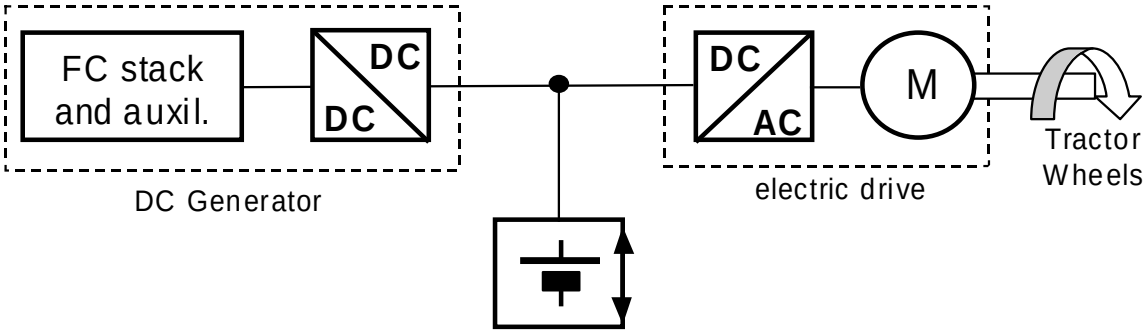
FC-based	[kg/km]
Fuel Consumption	**0.18**



E = pure electric mode (only for the ICE-based)
H = hybrid mode

Hydrogen Fuel-cell based propulsion
An *evolutionary* approach





Introduction of Hybrid propulsion in railway may:

- give immediate advantages in terms of fuel consumption
- give some zero-emission range
- *pave the way towards FC-based hybrid propulsion*

Questions?

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