HyTRAN

Hydrogen and Fuel Cell Technologies for Road Transport

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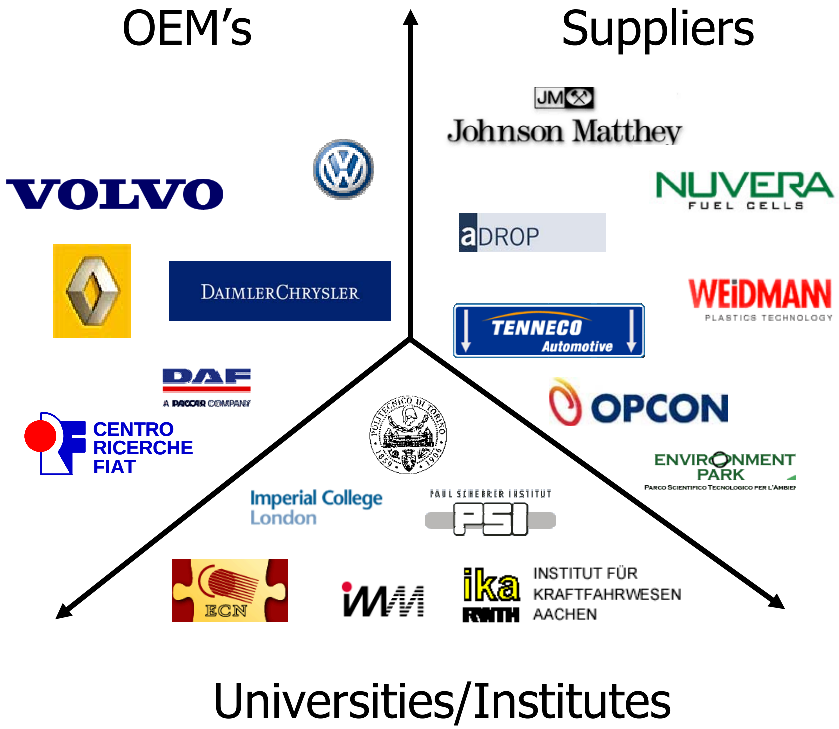
Volvo Technology Corporation

The HyTRAN project

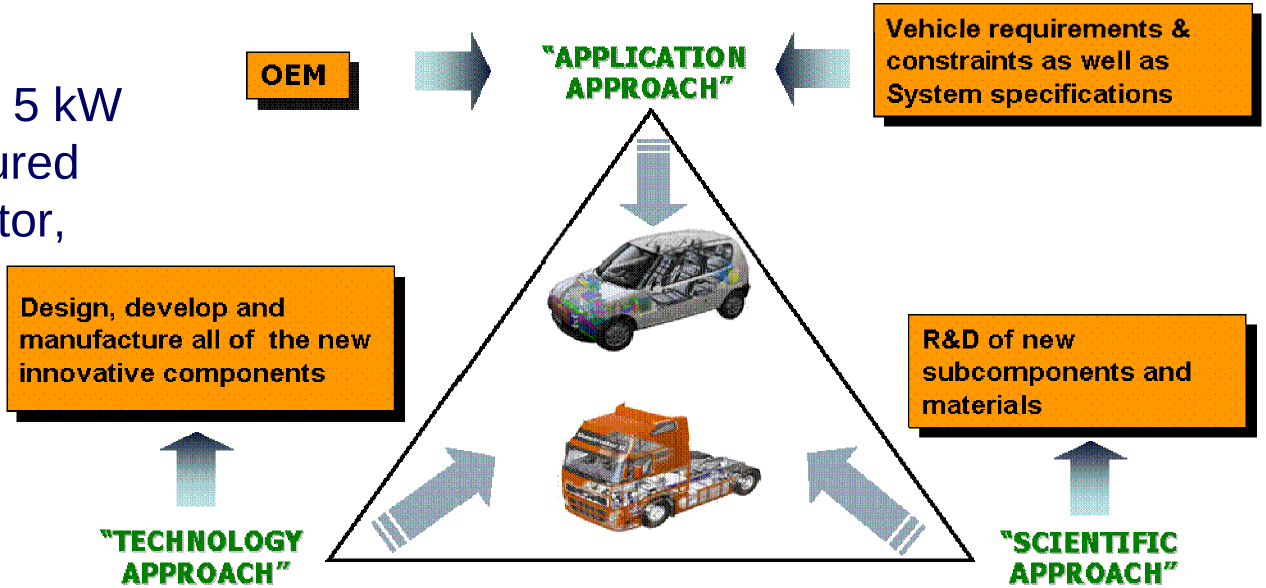
- **Program:** IP in FP6
- **Coordinator:** VOLVO
- **Total budget:** 16.8 M€
- **EU funding:** 8.8 M€
- **Partners:** 19
- **Countries:** 7
- **Duration:** 2004-2009



HyTRAN Objectives

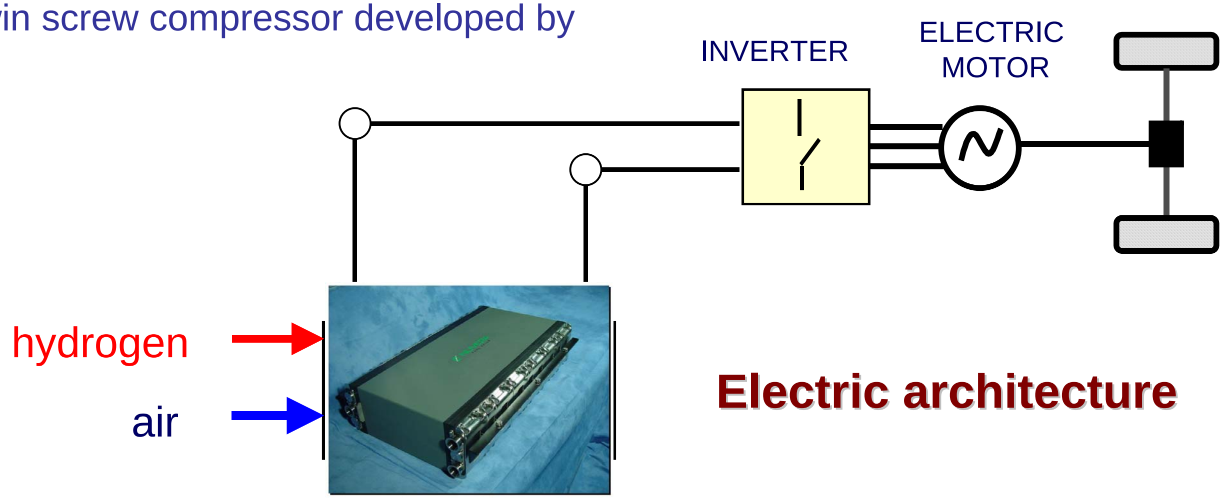
The overall objectives of HyTRAN are to advance the fuel cell technology towards a commercially viable solution in terms of performance and cost by developing components and systems for:

- Direct Hydrogen PEM Fuel Cell system, 80 kW power size, with innovative Fuel cell stack and Balance of Plants
- Auxiliary Power Unite, APU, Diesel reformat PEM Fuel Cell 5 kW system, including microstructured steam reformer, clean-up reactor, i stack and Balance of Plants

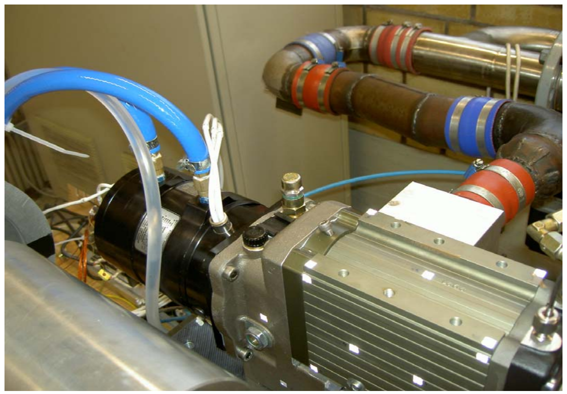


Panda HyTRAN

- **Design phase:**
  - Innovative vehicle layout
  - Powertrain components (innovative twin screw compressor developed by Opcon
  - Electric driveline (power electronics)
- **FCS integration**
  - Air system
  - Hydrogen line
  - Cooling system
  - Water management
- **Control of an innovative powertrain**



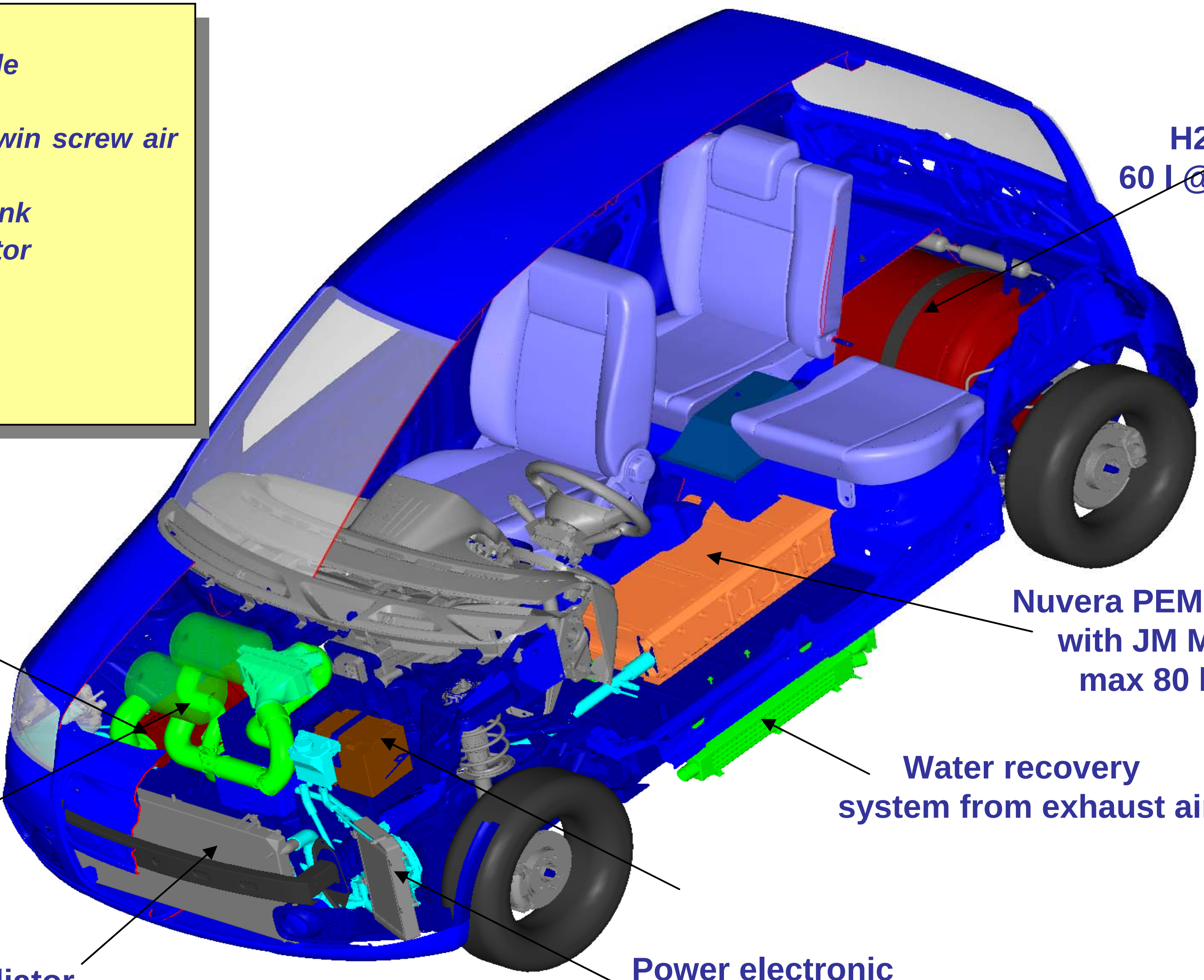
Electric architecture



Opcon air compressor

CHARACTERISTICS

- ***Full power fuel cell vehicle***
- ***80 kW PEM fuel cells***
- ***New generation Opcon twin screw air compressor***
- ***Carbon fiber hydrogen tank***
- ***AC induction electric motor***
- ***4 Seats***
- ***Max speed 130 km/h***
- ***Refuelling time < 5 min***
- ***Range (UDC) > 200 km***

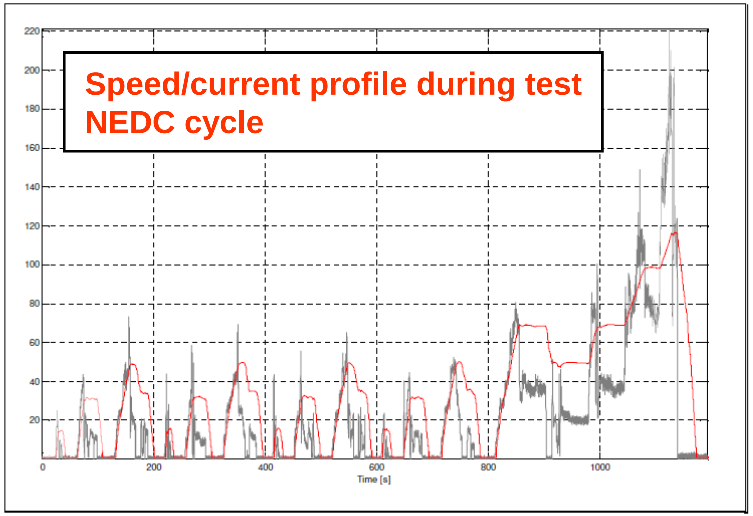


HyTRAN Panda main activities - Year 2009

- Final vehicle validation phase
  - ➢ Test on FIAT tracks for vehicle parameters identification
  - ➢ Test on roller bench for H_2 consumption measurement
  - ➢ Road testing in harsh conditions → participation to international competitions
    - Rally Montecarlo, 26-29 March 2009
    - EVS Viking Rally, 11-13 May 2009
  - ➢ Tests on the HyNor Roadway in the south of Norway

Obtained results – Year 2009

- Hydrogen consumption: 9 g/km on NEDC cycle (corresponding to 3.6 l/100 km of gasoline equivalent against the fuel consumption of 6.5 l/100 km of the gasoline Panda NP)
- Rally Montecarlo: 1100 km driven without any failure
- Viking Rally: 750 km lenght, 1° place for consumption league and 2° place for final league



APU Application

- Truck driver run electrical on-board equipment during resting, e.g. radio, phone, television, computer, freezer, microwave, air conditioning, cab ventilation, …
- At idle, diesel engines run at one of its most inefficient working points
- ~1.800 hours of idling per year and truck (in USA)
- More than 5.000 $ per year and truck
- U.S. trucks consume more than one billion gallons of diesel fuel during resting per year
- Emission from idling of long haul truck U.S. :
  - NOx: 180 000 tons per year
  - PM: 5 000 tons per year
  - CO2: 11 millions ton per year
- Upcoming laws restrict the idling time

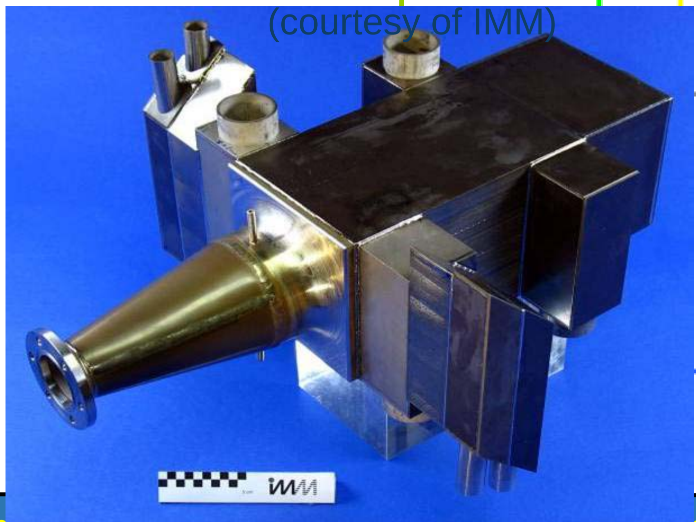
TP2 technical content

- 5kW Diesel FC-APU for vehicle application
- HyTRAN combines technology development and system integration work
  - Novel micro channel diesel Fuel Processor
  - Novel Twin Screw Air Compressor
  - Balance-of-plant components
  - System optimization and integration
  - System performance & control
  - Vehicle integration potential, cost
- Tested Lab prototype

Functionality of Fuel Cell APU

Water gas shift reactor prototype (courtesy of IMM)

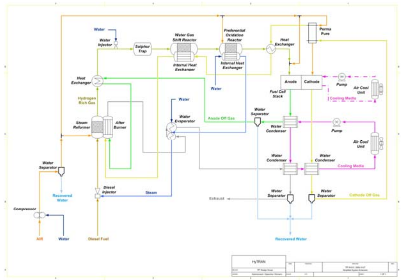
Preferential oxidation reactor prototype (courtesy of IMM)



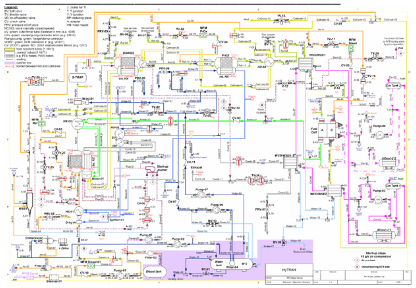
Steam reformer prototype (courtesy of IMM)

TP2 system integration work

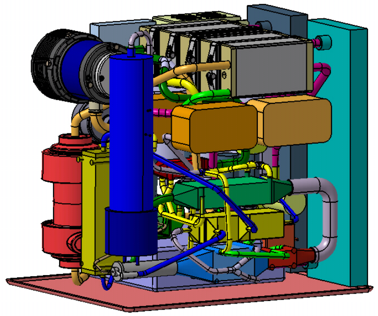
Idea – simplified schematic



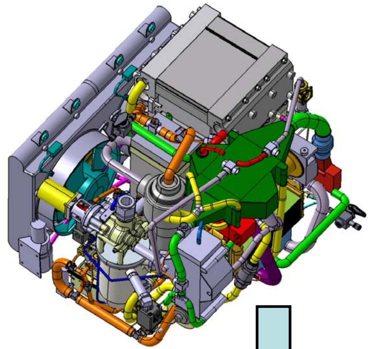
Complete system schematic after several design loops, simulations, sub-system testing and FMEA analysis



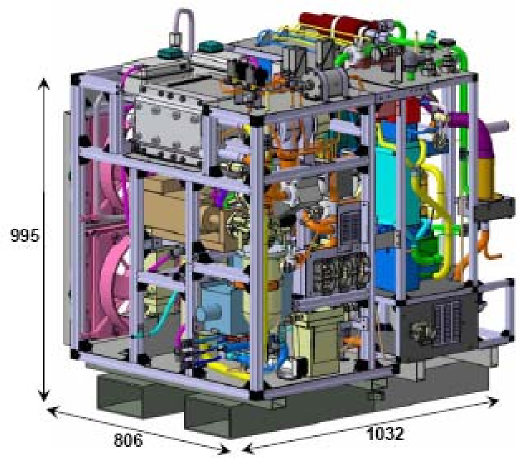
Simplified CAD model with black box components



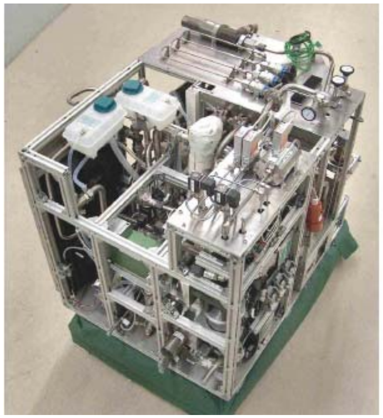
CAD model with real key component models



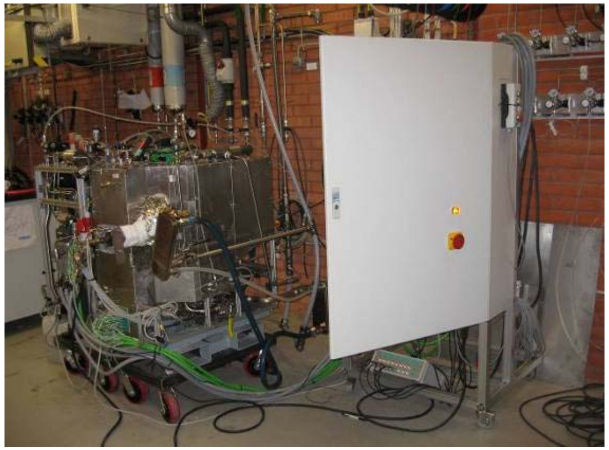
Final CAD model of the system



System built



System testing



WP 8300
Market Analysis
<u>Selected results</u>

Leader: Centro Ricerche FIAT

Partner: Imperial College London

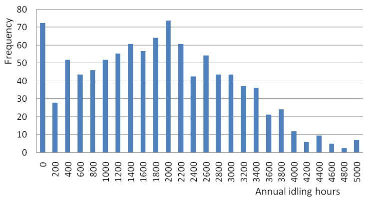
Diesel PEM FC APUs for trucks

- Strong market drivers for diesel APUs for trucks in California: “idling ban”
- The rest of the US and Canada will probably follow soon, with a total market size of 700,000 units
- In Europe, the market is not driven by regulation, but by demand for added comfort by the driver. Estimated market size: 100,000 units
- Potentially competing diesel APU technologies
  - Internal combustion engines – commercial
  - Solid-Oxide Fuel Cells – prototypes
  - PEM Fuel Cells – prototypes
  - Batteries – but these do not provide the same functionalities; not a direct competitor
- Each one of these technologies has strengths and weaknesses, and is a different stage of development
- The possible future market uptake has been studied using a dynamic simulation model developed specifically for the project HyTRAN

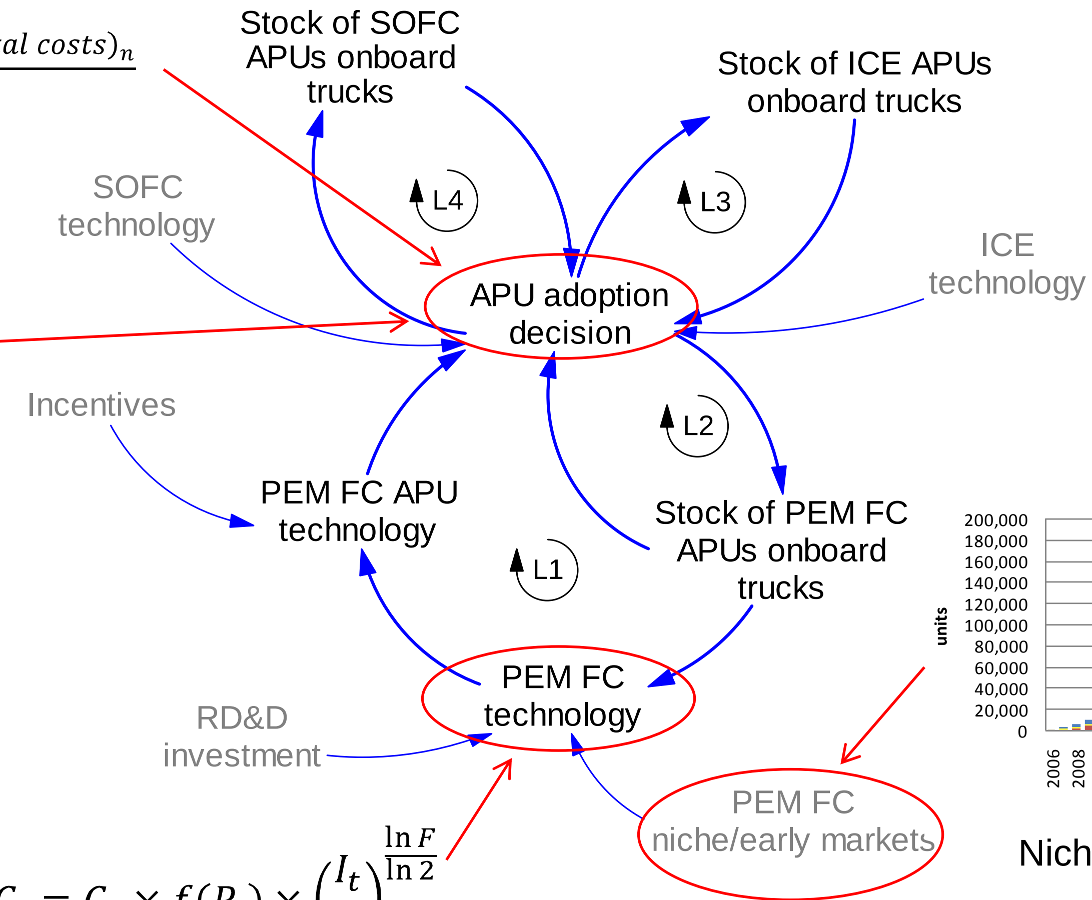
Diesel FC APU market model

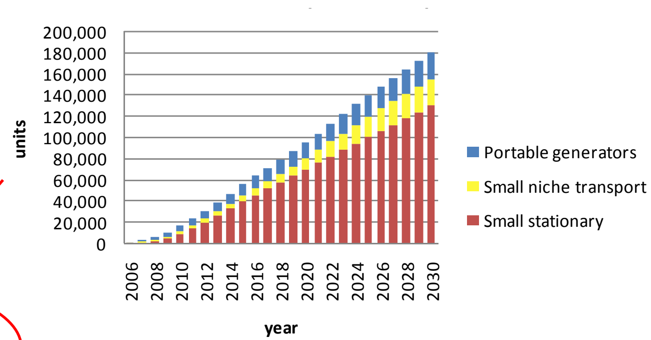
$$NPV = \sum_{n=1}^{2} \frac{(fuel\ savings)_n - (capital\ costs)_n}{(1+d)^n}$$

Net present value



Demand for auxiliary power





Niche market scenarios

$$C_t = C_0 \times f(P_t) \times \left(\frac{I_t}{I_0}\right)^{\frac{\ln F}{\ln 2}}$$

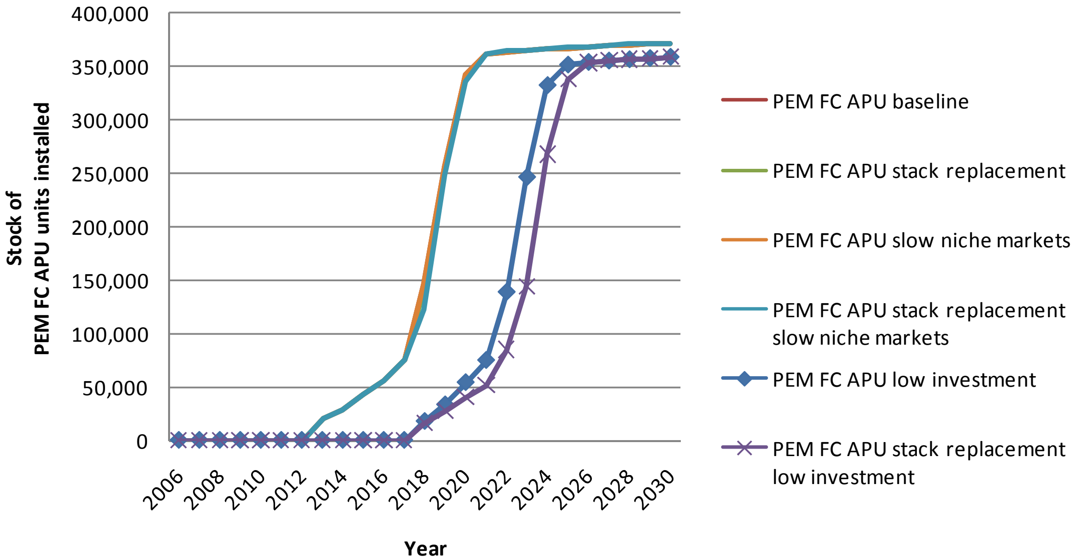
Learning curves

Hydrogen and Fuel Cell Technologies for Road Transport

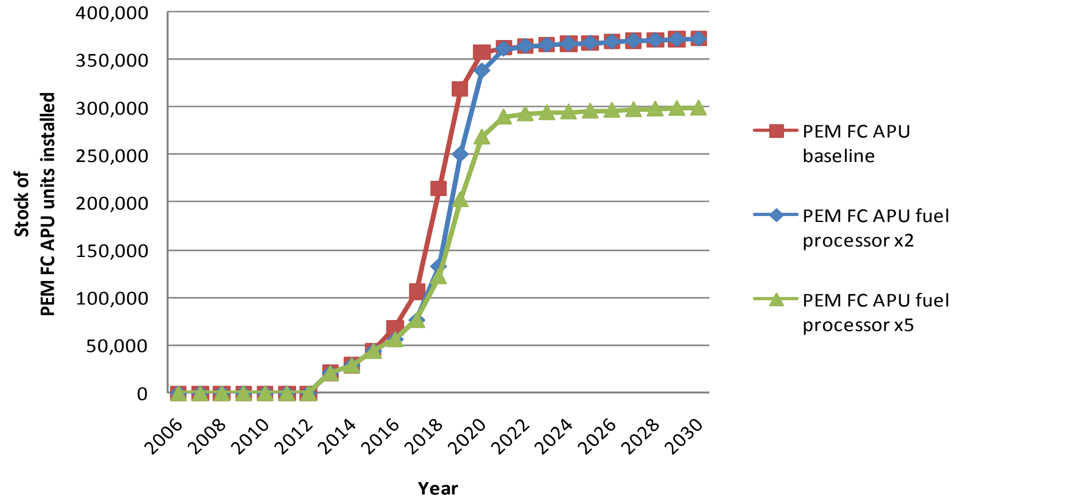
Diesel APU results: US market

Market uptake scenarios

Diesel PEM FC APU economics are quite good if compared to idling. Once minimum durability of 5,000 hours has been reached, market uptake can start and penetration can be fast. The most sensitive factor though is R&D investment, as underinvestment can slow down the process considerably.



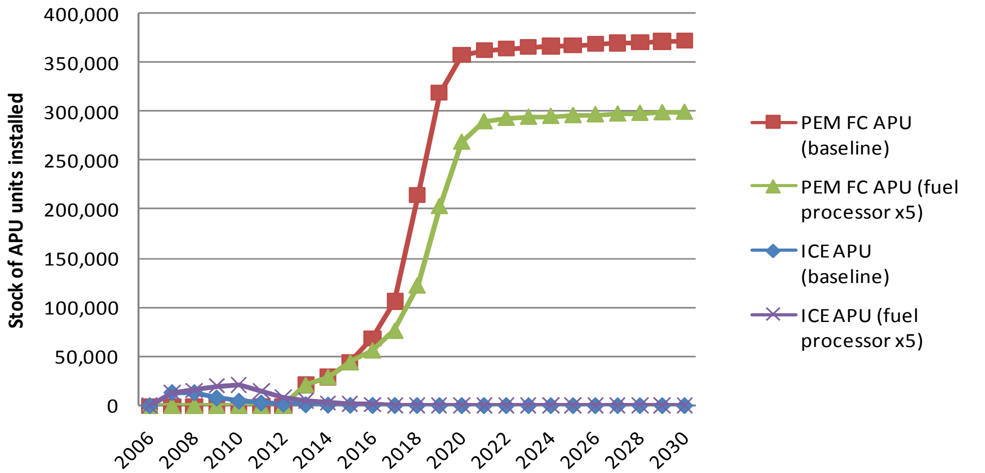
Cost of fuel processor is also important, but affects the final uptake level more than the penetration rate



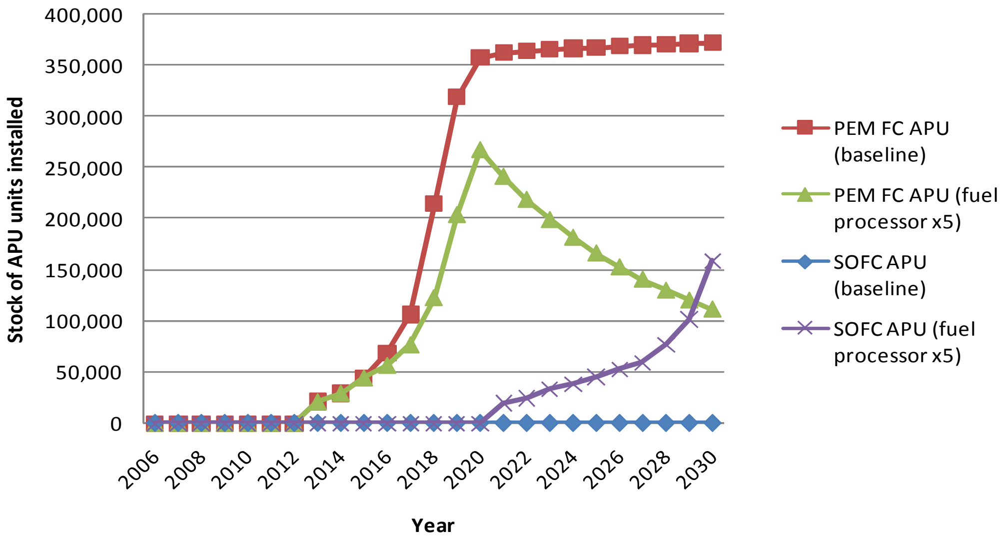
Diesel APU results: US market

Market uptake scenarios

Diesel PEM FC APUs, when developed, are also expected to soon outcompete ICE APUs



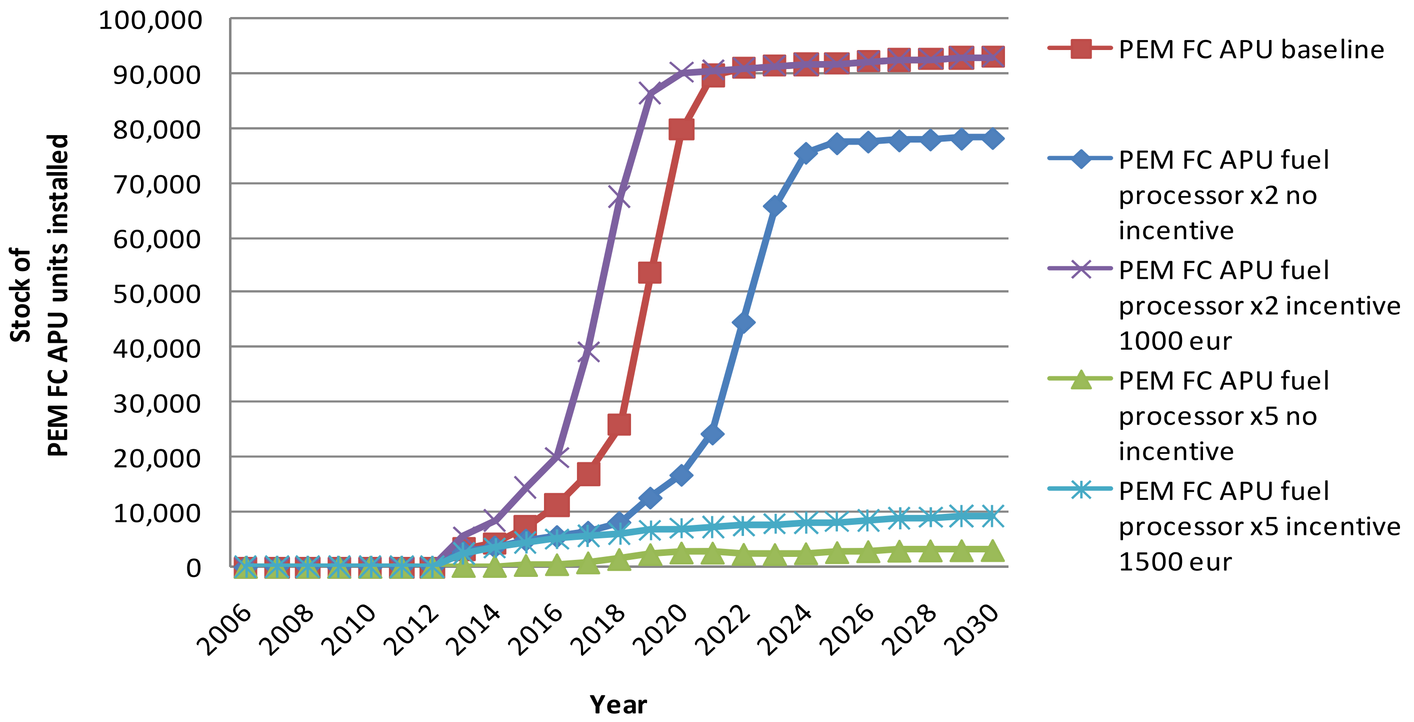
However, diesel SOFC APUs can be a much stronger competitor, particularly in the long term. The width of the window of opportunity for diesel PEM FC APUs is strongly influenced by the relative R&D funding compared to SOFC diesel APU technology



Diesel APU results: EU market

Market uptake scenarios

Uptake of diesel PEM FC APUs in Europe may start early, but the weaker market drivers mean that it would be slower than in the US. Incentives may be required and high capital cost may significantly hinder penetration



H_2 PEM FC powertrains for cars

- Due to the need to cut CO_2 emissions, improve atmospheric air quality and move away from oil, ultimately highly efficient, ultra low emission powertrains for cars will be needed
- The electric powertrain seems ideal, but the question is: battery electric or hydrogen fuel cell?
- Comparing the lifecycle costs of the 3 following options provides important indications
  - Pure battery electric powertrain (BEV)
  - “Pure” hydrogen fuel cell powertrain (hybrid configuration) (FCEV)
  - Hydrogen fuel cell/ battery electric plug-in hybrid (FCHEV)
- The comparison is first done on a generic vehicle platform and generic driving cycle, and then behavioural aspects are also taken into account (i.e.: distributions of average daily distances driven by car types) particularly using the UK as a case study

H_2 PEM FC powertrains for cars

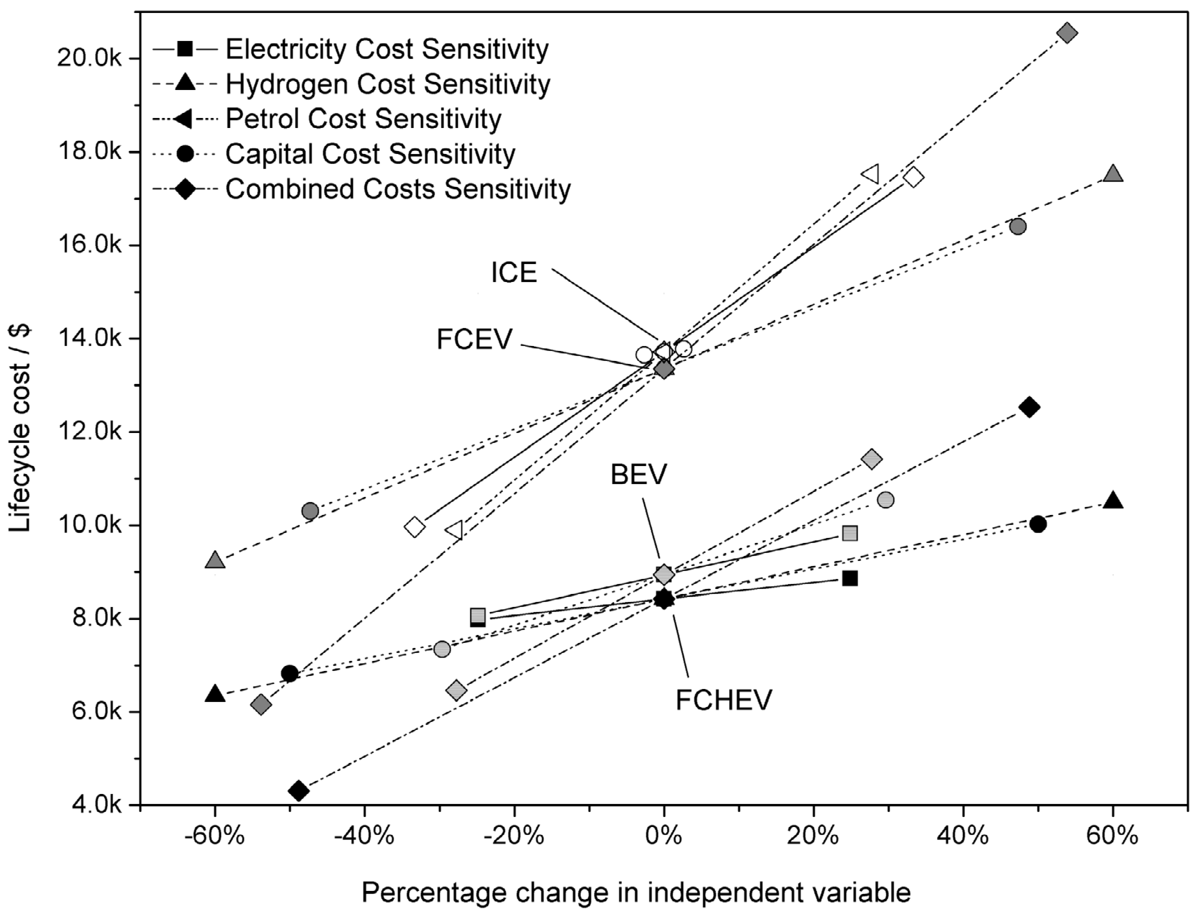
Lifecycle cost sensitivity of various powertrains for a generic saloon car:

- 80 kWe peak power
- 20 kWe mean power (@ 70 mph)

BEV: 25 kW battery

FCHEV: 20 kW fuel cell, 6 kW battery, 50:50 usage

The FCHEV is an important option that should not be overlooked

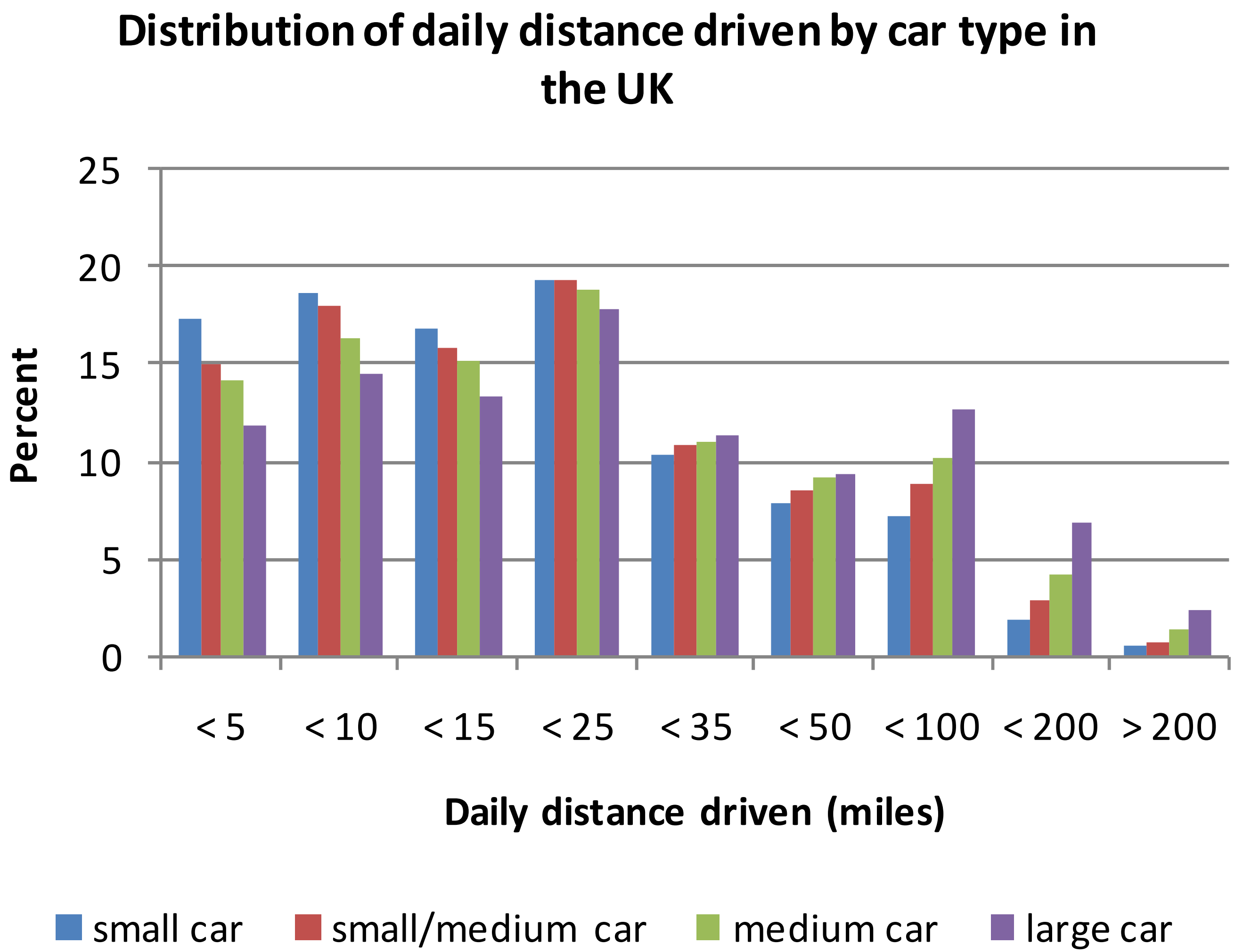


H_2 PEM FC powertrains for cars

Data extracted from the UK National Travel Survey

It appears that different types of cars are indeed used differently

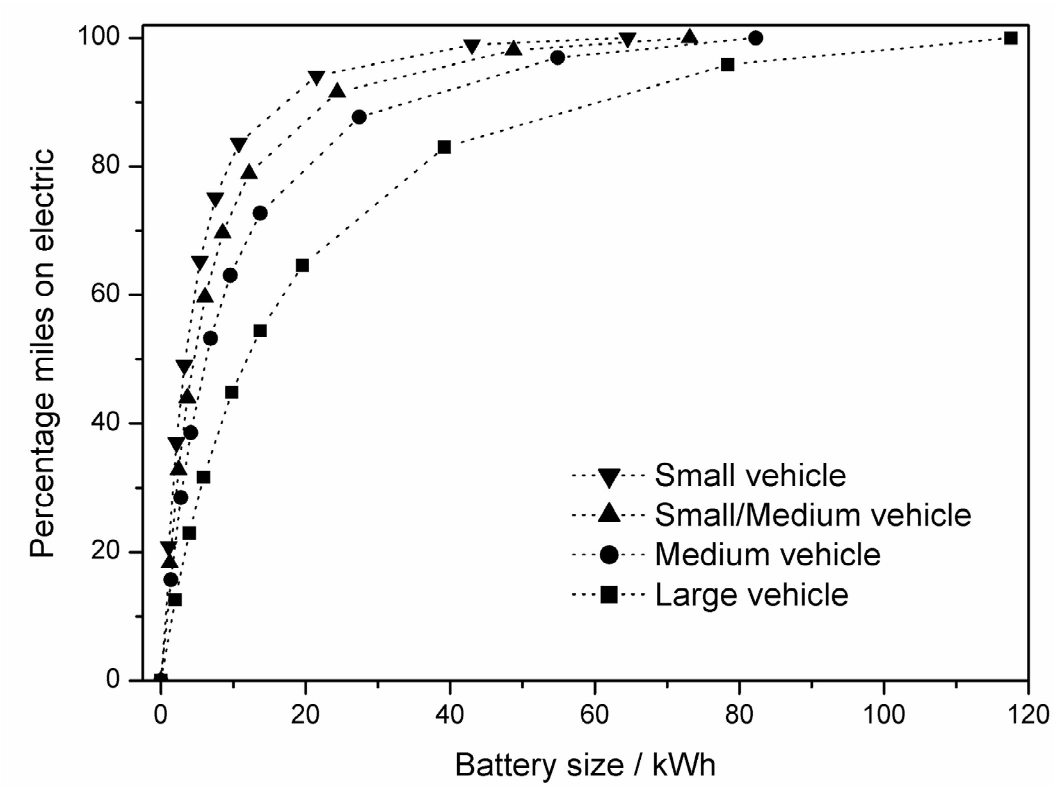
This has important implications for the optimum powertrain configuration



H_2 PEM FC powertrains for cars

Due to both vehicle characteristics and driver behaviour, the percent of miles driven on electricity only changes across vehicle types for the same battery size

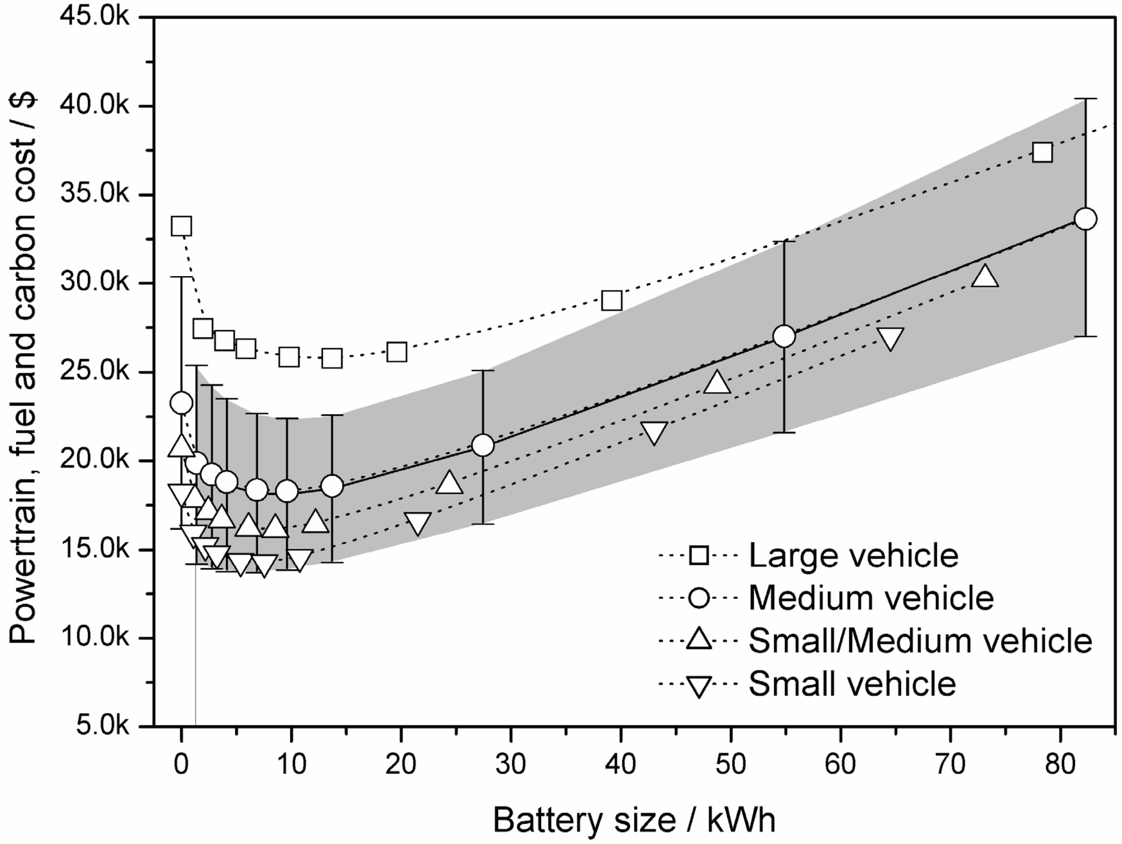
National Travel Survey	Small	Small / Medium	Medium & Average	Large
Market Segments	Super-mini	Lower medium	Multi purpose	Luxury
Equivalent ICE mpg	51	45	40	28
Equivalent ICE $gCO_2\ km^{-1}$	150	170	190	275
Peak power required / kW	62.7	71	80	114
Average power required / kW	15.7	17.8	20	29
H_2 consumption / MJ $mile^{-1}$	1.55	1.76	1.98	2.82
Electricity / MJ $mile^{-1}$	0.77	0.88	0.99	1.41



H_2 PEM FC powertrains for cars

- Overall lifecycle costs increase with vehicle size
- However, optimum battery size doesn't change dramatically: 4-8 kWh for a small vehicle, 6-14 kWh for a large vehicle
- The role of PEM FCs increases with the vehicle size, as a higher percent of total mileage is driven on hydrogen

Powertrain lifecycle cost as a function of battery size for the 4 vehicle types considered



Additional information

The complete analysis for diesel PEM FC APU has been published on:

Contestabile, M. (2009). "Analysis of the market for diesel PEM fuel cell auxiliary power units onboard long-haul trucks and of its implications for the large-scale adoption of PEM FCs" Energy Policy doi:10.1016/j.enpol.2009.03.044.

Results of the powertrain analysis have been presented:

Offer G. J., Contestabile M., Howey D., Clague R., Brandon N. P. (2009). "Techno-economic and behavioural analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system in the UK" Eleventh Grove Fuel Cell Symposium, London, UK

And have been submitted for publication (currently under review)

For further questions: marcello.contestabile@imperial.ac.uk