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ELECTRIC VEHICLE POWERTRAIN SYSTEM OPTIMIZATION AND ITS INFLUENCE IN THE AUXILIARY POWER SYSTEMS

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3. DEFINITION OF CONSTANTS

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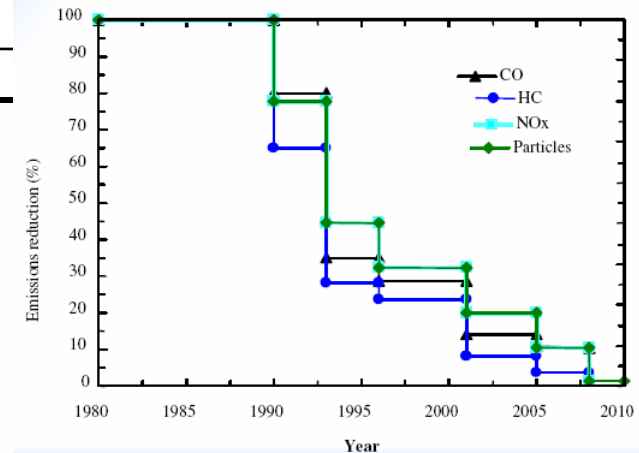
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- Necessity of fulfill the European standard about emissions reduction:

EURO CALENDAR						
Standard	Year	CO	Hydrocarbon	NOx	Suspended particles	
Euro 1	1993	4.5	1.1	8.0	0.36	
Euro 2	1996	4.0	1.1	7.0	0.25	
Euro 3	October 1999	2.1	0.66	5.0	0.10	
Euro 4	October 2006	1.5	0.46	3.5	0.02	
Euro 5	October 2009	1.5	0.46	2	0.02	
Euro 6	September 2014	-	-	-	-	

Quantities expressed in gr/kW/h.



- To fulfill the acquired compromises in 1997 Kyoto Protocol.

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- Energy consumption and climatic change.

1. PRESENT SITUATION

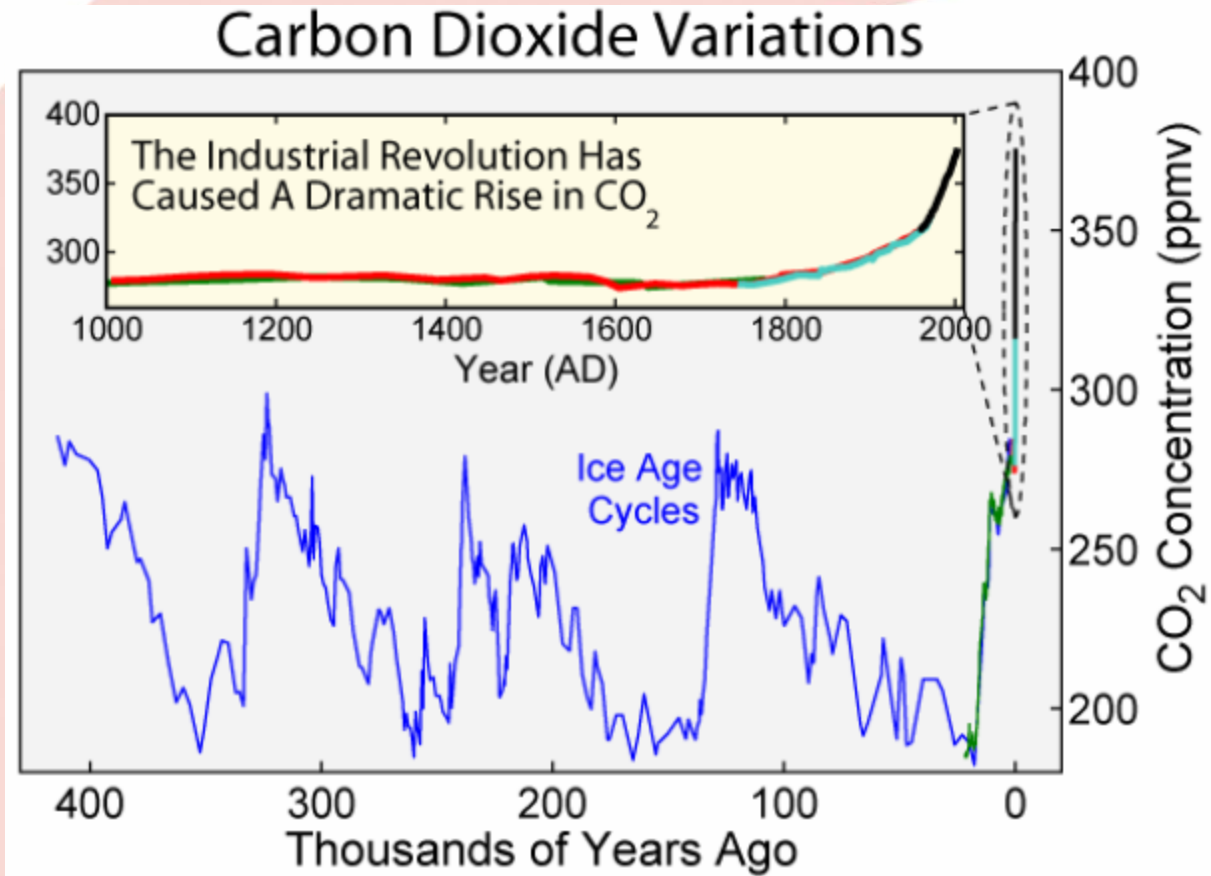
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Source: Petit Jr, et al. Nature, 1999;399:429

1.1. FUTURE

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1.1. FUTURE

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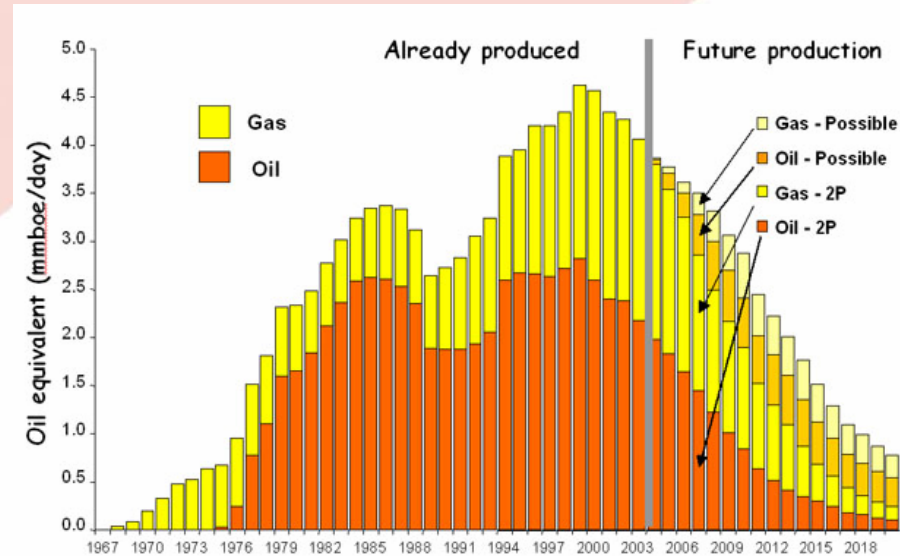
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- Nuclear power station useful life is finishing.
- Maximum production of cheap petrol.
- The dependence in natural gas is increasing (according to reserves/production 2001 → 62 years).
- Associate contamination growth to the fossil fuel consumption and join phenomena.
- OPEP high dependence.

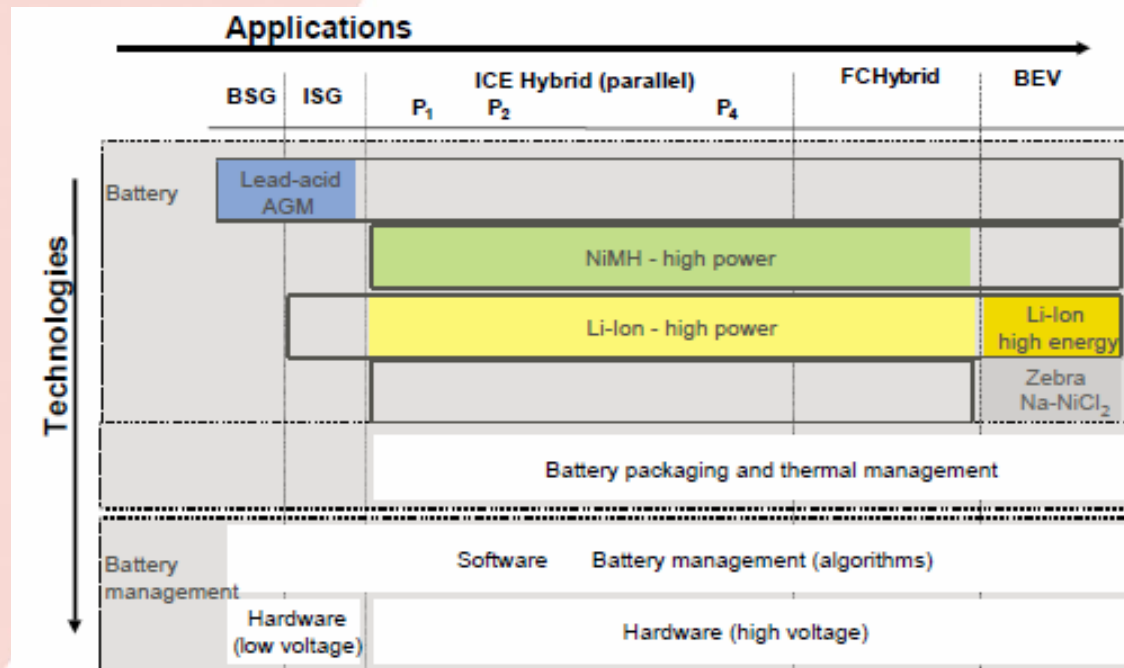


1.2. STORAGE SYSTEMS

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- Tipos:
 - Acid-lead battery
 - Regulator valve acid-lead battery
 - Ni-Mh battery
 - Li-Ion battery
 - Polymer-Ion battery
 - Ultracapacitors
 - Fuel cell
 - Flywheel
 - Hybrid storage systems
- Batteries and vehicle applications:



2. STUDY OBJECTIVES

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To establish some guidelines that provide a starting point in the energy system sizing of fuel cell vehicles (primary and secondary energy systems), considering the kind of driving cycle that is being utilized.

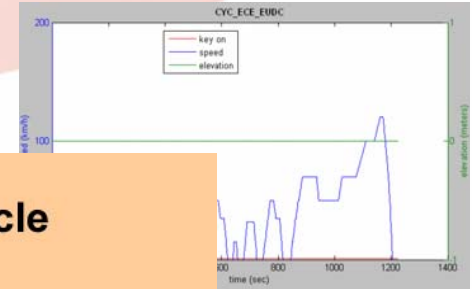
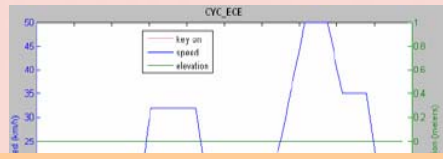
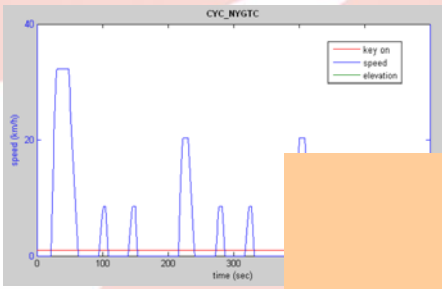
- To obtain an optimal result that minimize the hydrogen consumption in these fuel cell vehicles.

3. DEFINITION OF CONSTANTS

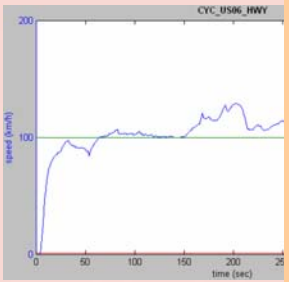
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- Operation cycles: Cycle 1 (most urban) to Cycle 6 (suburban)

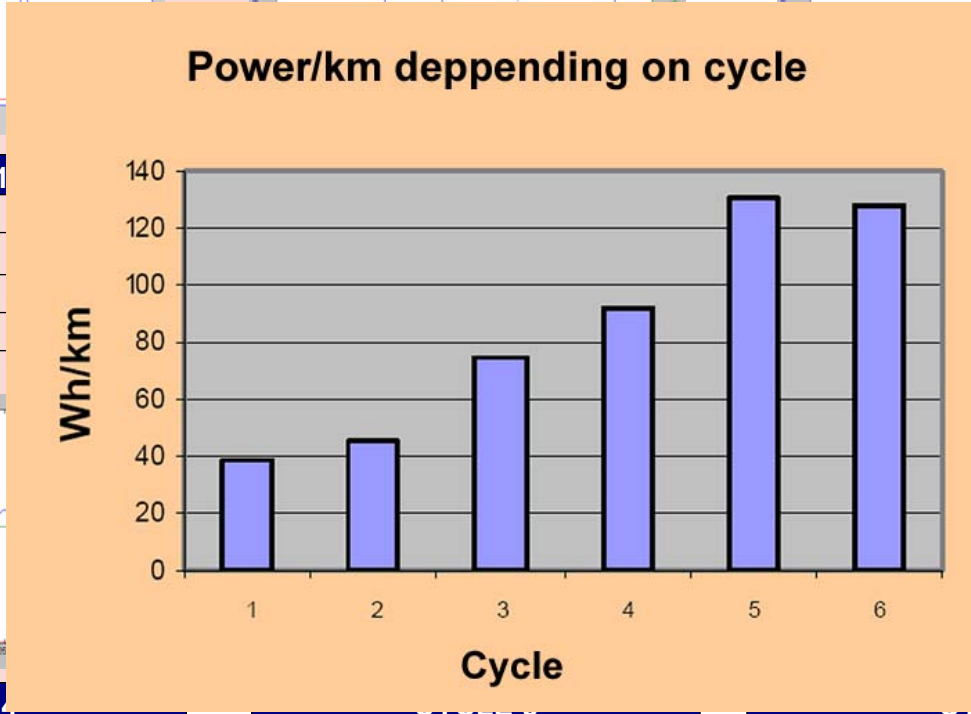
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CYCLE 1	
Duration	
Distance	
Max. Speed	
Max. Acceleration	

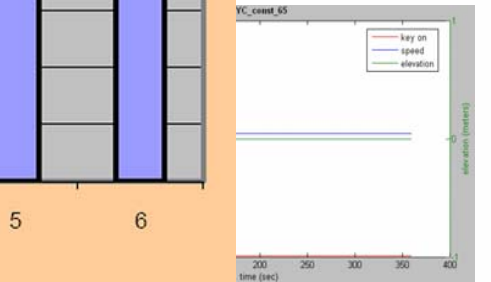


CYCLE 2	
Duration	400 s
Distance	6.95 km
Max. Speed	120 km/h
Max. Acceleration	0.83 m/s ²



CYCLE 3	
Duration	368 s
Distance	10.04 km
Max. Speed	129.3 km/h
Max. Acceleration	3.08 m/s ²

CYCLE 3 (MIXED)	
Duration	1225 s
Distance	10.93 km
Max. Speed	120 km/h
Max. Acceleration	1.06 m/s ²



CYCLE 6	
Duration	360 s
Distance	10.46 km
Max. Speed	104.61 km/h
Max. Acceleration	0 m/s ²

4.1. FIRST PHASE OF THE STUDY

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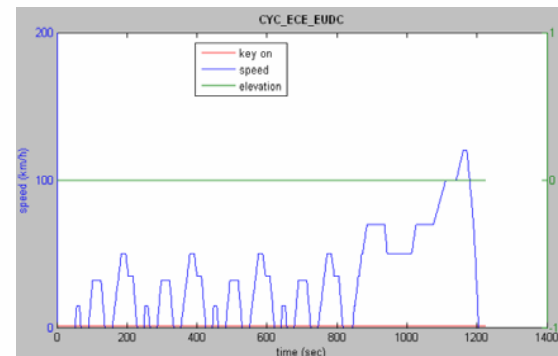
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- Evolution: from the conventional vehicle to the fuel cell one

Vehicle		Vehicle mass kg	Acceleration 0 to 100 km/h s	Max. Speed km/h	Autonomy km	Emissions g CO ₂ /km	Performance (η) %	Consumption l eq*/100km
Conventional	Otto	1366	12	185.3	516	206	9.8	8.6
	Diesel	1364	12	160.2	514	170	11.8	7.1
Hybrid	Pb-acid	1594	12	162.5	500	187	10.8	7.8
	Li-Ion	1287	11.9	162.8	500	146	13.8	6.1
Electric	Li-Ion	1647	11.9	164	522	0	42.1	2
	Ni-Mh	2579	12	161.6	489	0	30.1	2.8
	Pb-acid	2710	12	160.7	293.7	0	26.3	3.2
Fuel cell	Pb-acid	1752	11.9	160.8	500	0	20	4.2

*"equivalent liters of gasoline" represents the amount of energy equivalent in liters of gasoline.

CYCLE 3



4.2. SECOND PHASE OF THE STUDY

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Primary energy system characteristics

Characteristics Systems	Energy density	Power density	Performance	Cost
Fuel cell	Depends on stored fuel	1.4 kW/liter	60% (depending on type)	60 €/kW (approx.)
Thermal motor	Depends on stored fuel	1 kW/kg (Approx. depending on type)	20% (depending on type and operating point)	40 €/kW (approx.)
Sodio-Sulfur battery	110 Wh/kg	150 W/kg	75% (approx.)	150 €/kW (approx.)

Characteristics Systems	Energy density	Power density	Useful life (nº of cycles)	Cost
Flywheel	< 150 Wh/kg	2 kW/kg	unlimited	high
Ultracapacitor	1-10 Wh/kg	10 kW/kg (approx.)	> 500000	80 €/kW (approx.)
Pneumatic system	60 Wh/kg (approx.)	high	unlimited	middle
Hydraulic system	10 Wh/kg (approx.)	1.5 kW/kg	unlimited	middle
Lead-acid batteries	30-55 Wh/kg	150-900 W/kg	1000 (approx.)	15-30 €/kW
Others batteries	50-22 Wh/kg (depending on type)	30-200 W/kg (depending on type)	200-2000 (depending on type)	80-200 €/kW (depending on type)

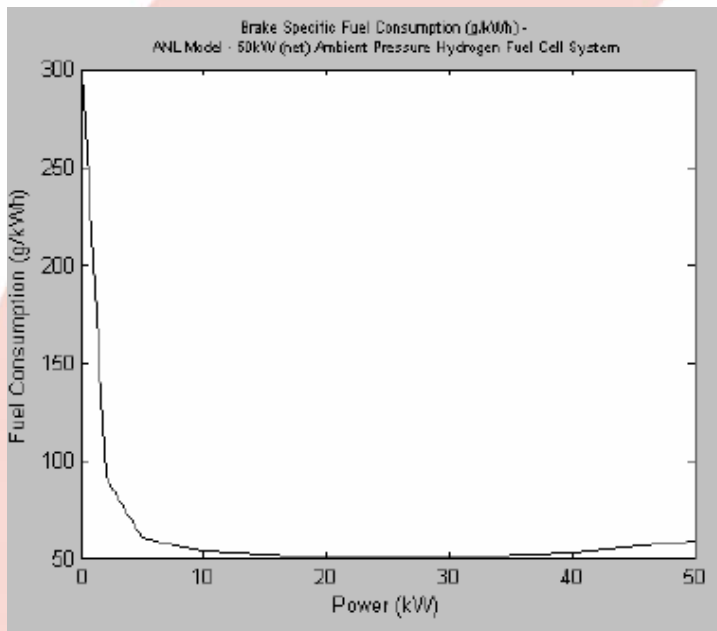
Auxiliary energy system characteristics

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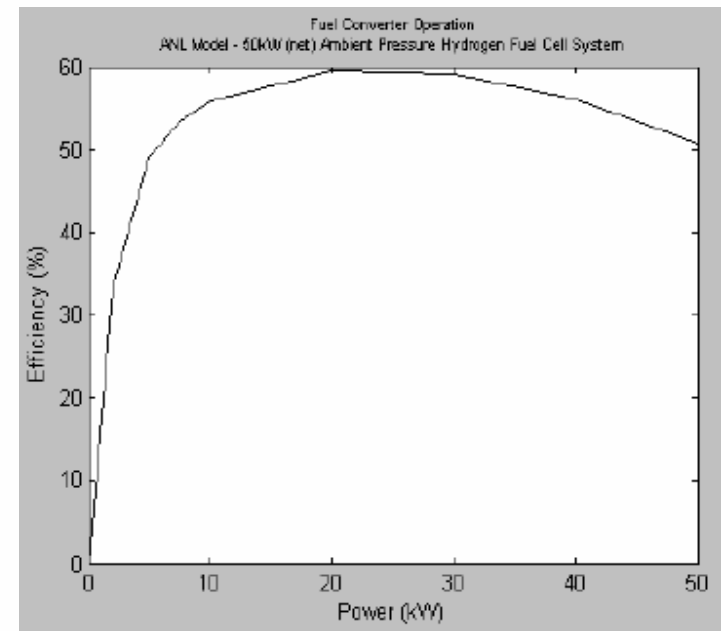
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- Example: 50kW FUEL CELL



Fuel consumption (g/kWh)
depending on power (kW)



Efficiency (%) depending
on power (kW)

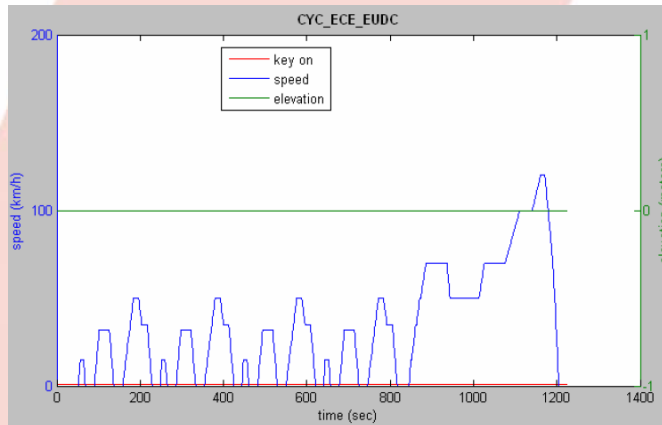
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- Simulation of different fuel cell vehicles depending on the auxiliary energy system.

CYCLE 3



Storage system	Battery Power Kw	Performance (η) %	Consumption l eq*/100km
Ni-mh	20	21	4
Li-Ion	12	27.6	3.1
Pb-acid	20	20	4.2
ultracapacitor	55	23.4	3.6

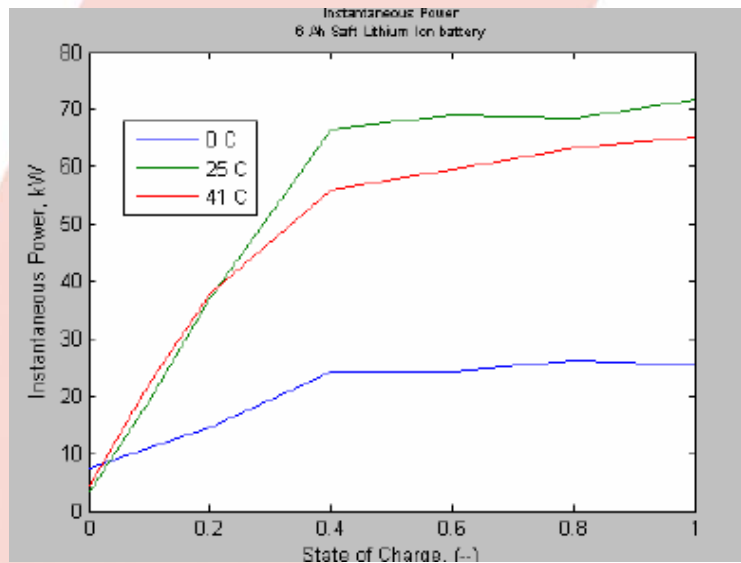
*"equivalent liters of gasoline" represents the amount of energy equivalent in liters of gasoline.

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- Characteristics of the selected configuration:
FUEL CELL with LI-ION BATTERY



Power (kW) vs. State of charge for different temperatures

Energetic system	
electric motor	55 kW
fuel cell	12 kW
batteries li-Ion	20 kW (approx. 0°C)
energetic density	56.1 kW/kg
Vehicle mass	1295 kg (100%)
battery weight	41 kg (3.1%)
fuel cell weight	130 kg (10%)
Autonomy	500 km
Energetic consumption	270.6 Wh/km
Performance	27.6%
Battery price	460 €

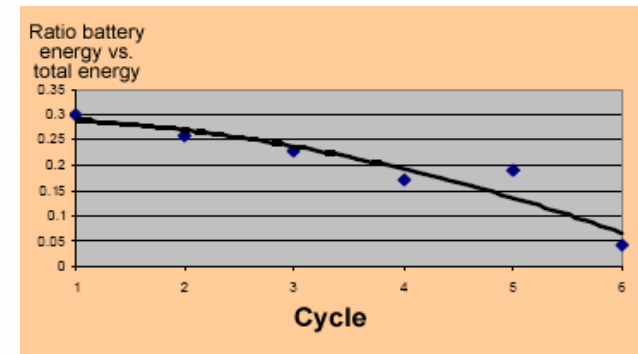
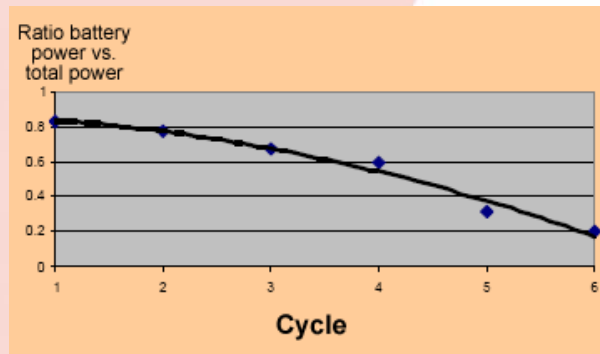
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- Size the energy system components of the FUEL CELL VEHICLE WITH LI-ION BATTERY selected in the previously phase in order to get the maximum energy efficiency according to the cycle that is simulated.

	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
Battery power (kW)	25	25.5	25	25	28	17
Fuel cell power (kW)	5	7	12	17	60	65
Battery energy (kJ)	242	157	1604	668	1409	300
Fuel cell energy (kJ)	560	448	5380	3251	7165	5848



Urban cycles → auxiliary power system plays an important role, due to the high variability in demand.

Suburban cycles → importance of auxiliary power system decreases because of the energy demand becomes more constant.

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- Comparison of fuel cell vehicles optimally designed for a specific cycle in the rest of the operating cycles.

Consumption expressed in equivalent liters of gasoline every 100 km.

	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
Vehicle optimally designed for cycle 1	5.7	3	no	no	no	no
Vehicle optimally designed for cycle 2	7.3	2.8	no	no	no	no
Vehicle optimally designed for cycle 3	9.9	3.6	3.1	no	no	no
Vehicle optimally designed for cycle 4	9.7	4.3	3.3	2.9	no	3.7
Vehicle optimally designed for cycle 5	18.2	10.5	4	4.1	4	3.6
Vehicle optimally designed for cycle 6	9	4.2	3.5	3.2	no	3.3

“no” appears when vehicles fail in completing successfully the cycle due to the small size of their fuel cells.

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- Comparison: fuel cell vehicle optimally designed for each cycle vs. conventional vehicles.

Vehicle		Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
Otto	Consumption l eq*/100km	43.1	10.8	8.6	7	7.9	7.1
	Efficiency	1%	4.8%	9.8%	14.8	18.7	20%
Diesel	Consumption l eq*/100km	33.1	8.6	7.1	6.1	7.1	6.1
	Efficiency	1.3%	6%	11.9%	17%	20.8%	23.7%
Fuel cell	Consumption l eq*/100km	5.7	2.8	3.1	2.9	4	3.3
	Efficiency	7.6%	18.5%	27.4%	35.8%	37%	44%

*"equivalent liters of gasoline" represents the amount of energy equivalent in liters of gasoline.

6. CONCLUSIONS

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- A starting point for the sizing of the energy system in fuel cell vehicles has been provided. The values of the ratio "batteries power / total power" range from 80% in urban cycle up to 20% in suburban cycle.
- It has been noticed the great importance of a correct sizing; with consumption differences respect to the optimal design that reach 3.75 times.

	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
Vehicle optimally designed for cycle 1	5.7	3	no	no	no	no
Vehicle optimally designed for cycle 2	7.3	2.8	no	no	no	no
Vehicle optimally designed for cycle 3	9.9	3.6	3.1	no	no	no
Vehicle optimally designed for cycle 4	9.7	4.3	3.3	2.9	no	3.7
Vehicle optimally designed for cycle 5	18.2	10.5	4	4.1	4	3.6
Vehicle optimally designed for cycle 6	9	4.2	3.5	3.2	no	3.3

- Fuel cell vehicle performance is superior to the conventional ones.

THANKS FOR YOUR ATTENTION!!!!



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