The European Commission's science and knowledge service

Joint Research Centre

European Commission

EU-Commission
JRC Contribution to EVE IWG:
In-vehicle battery durability

E. Paffumi

33rd Meeting of the GRPE Informal Working Group on Electric Vehicles and the Environment (EVE)

January 13th, 2020, Geneva (Switzerland)

European Commission

Presentation Summary (1/2)

Follow-up of the JRC activities for contribution to the EVE IWG under the "in-vehicle battery ageing" topic

Current Status (Oct 2019), i.e. what's old:

- Development of further scenarios for in-vehicle battery durability:
  - Extending the battery architecture selections in the model
  - Comparison of capacity fade @5 years and @100,000km
- In-vehicle cross-validation of the model's results against experimental data from Canada: new data points

Presentation Summary (2/2)

Follow-up of the JRC activities for contribution to the EVE IWG under the "in-vehicle battery ageing" topic

Current Status (Jan 2020), i.e. what's new:

- Exploring power fade models already implemented in TEMA
- Exploring V2G ageing effect on top of normal usage of the vehicles
- Exploring new battery chemistry models

- Scientific paper on in-vehicle battery durability JRC TEMA platform in press open source in Case Studies on Transport Policy Journal

Performance based models (SotA)

	Capacity fade		Power fade	
	Calendar	Cycle	Calendar	Cycle
$LiFePO_4$	Sarasketa-Zabala et Al. (2013/14);	Wang et Al. (2011); Sarasketa-Zabala et Al. (2013); Sarasketa-Zabala et Al. (2015);	Sarasketa-Zabala et Al. (2013);	
NCM + spinel Mn	Wang et Al. (2014);		-	Wang et Al. (2014);
NCM – LMO	-	Cordoba-Arenas et Al. (2014);	-	Cordoba-Arenas et Al. (2015);

Calendar + Cycle (4 Combinations):

- **#1 ($LiFePO_4$): Sarasketa-Zabala et Al. (2013/14) model for calendar plus Wang et Al. (2011) model for cycle;**
- **#2 ($LiFePO_4$): Sarasketa-Zabala et Al. (2013/14) model for calendar plus Sarasketa-Zabala et Al. (2015) model for cycle;**
- **#3 (NCM + Spinel Mn): Wang et Al. (2014) for calendar plus Wang et Al. (2014) for cycle;**
- **#4 (NCM-LMO): Wang et Al. (2014) for calendar plus Cordoba-Arenas et Al. (2015) for cycle;**

Implementation of the performance based models into JRC TEMA (assumptions 1/2)

Vehicle Electric Architectures (examples)

PHEV 1

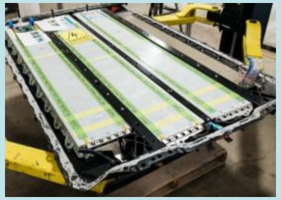
PHEV 2

PHEV 3

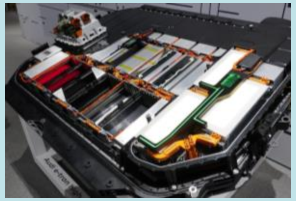
BEV 1

BEV 2

BEV 3



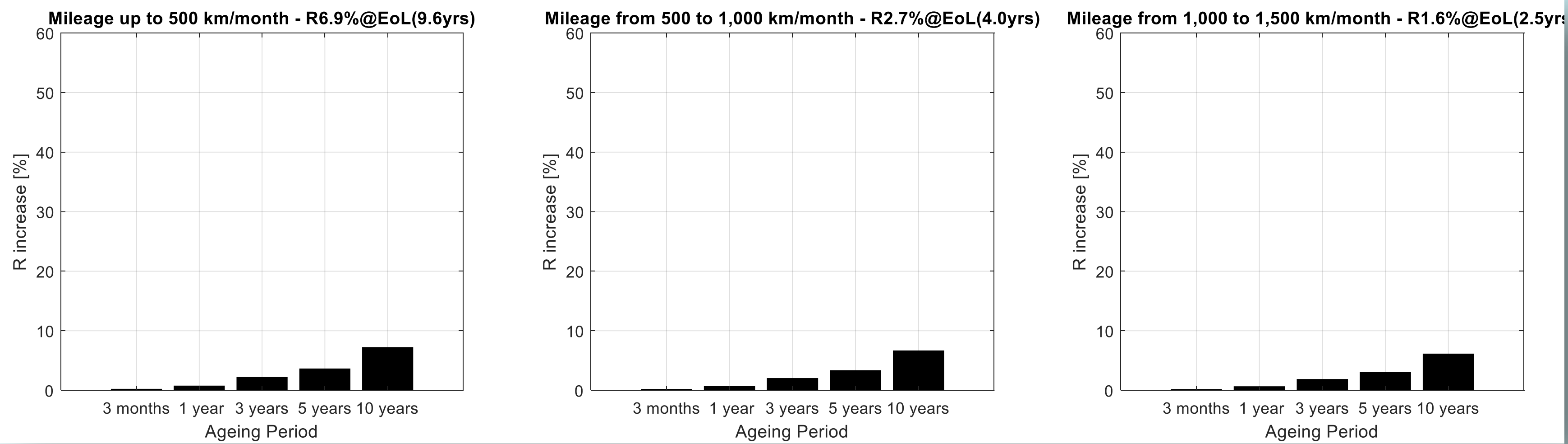
BEV 4



	Vehicle Type	Battery Size [Wh]	Battery Shape	No. of Cells [#] and Type	Reference Voltage [V]	Electric Architecture	Usable Energy at BoL [Wh]	Usable Energy at EoL [Wh]	Reserve [% of battery capacity]	Energy consumption [Wh/km]
T-Shaped	PHEV 1	16,000	T-shaped	192 – pouch	365	2P-96S	12,000	9,600	25%	205
Parallelepiped	PHEV 2	8,800	Parallelepiped	95-Prismatic	351	95S	6,600	5,280	25%	160
Parallelepiped	PHEV 3	12,000	Parallelepiped	80-Prismatic	300	80S	9,000	7,200	25%	194
Parallelepiped	BEV 1	24,000	Parallelepiped	192 – pouch	360	48S-2P-2S	18,000	14,400	15%	210
Flat-shaped	BEV 2	85,000	Flat	6,912 - cylindrical	345	16S-72P-6S	63,750	51,000	15%	235
Flat-shaped	BEV 3	75,000	Flat	4,416 - cylindrical	345	4S-46P-23|25S	56,250	45,000	15%	180
Flat-shaped	BEV 4	95,000	Flat	432 – pouch	396	4P-108S	71,250	57,000	15%	262

Calendar internal resistance increase model results LiFePO4 #2

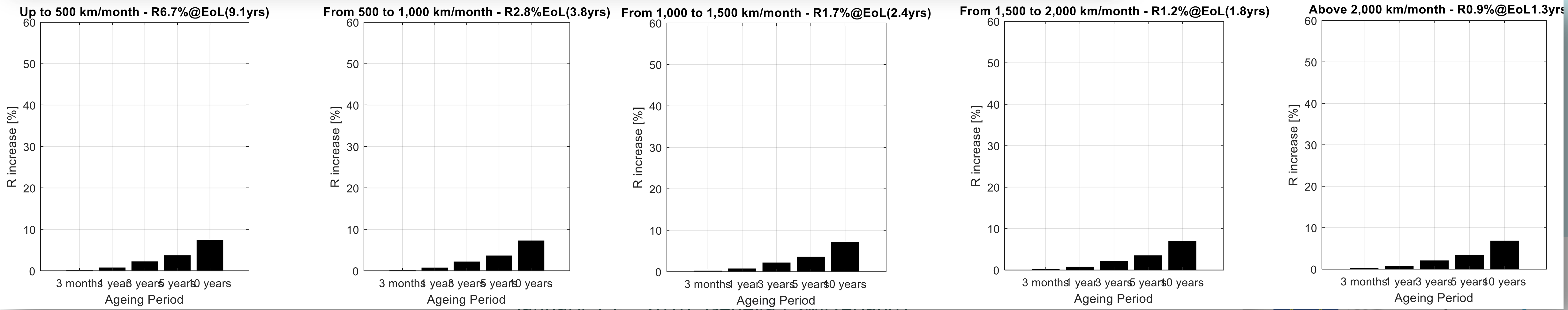
BEV 1 - Strategy #1



Saraskета-Zabala et Al. (2013)

$$R_{increase} = 1.29 \cdot 10^{11} \cdot e^{\left(\frac{-9194}{T}\right)} \cdot t$$

BEV 1 - Strategy #2



Calendar internal resistance increase model results LiFePO4 #2

Saraskete-Zabala et Al. (2013)

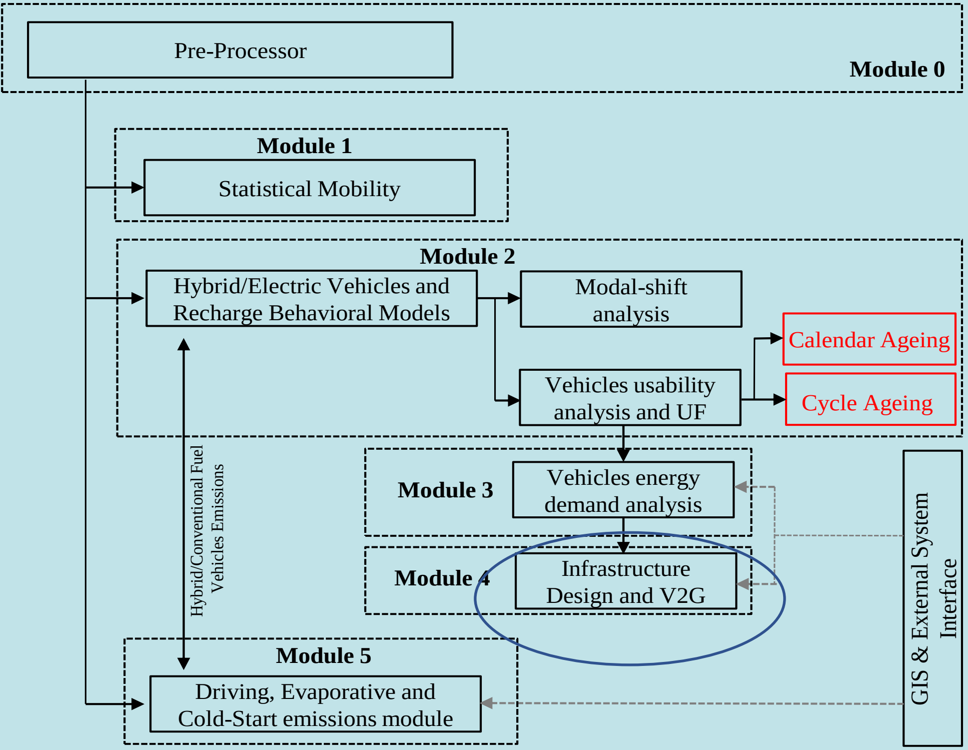
$R_{increase\ Cal}$ @ 80% capacity fade Years Driving to Set Threshold				0 - 500 km/month				500 – 1,000 km/month				1,000 -1,500 km/month				1,500 – 2,000 km/month				2,000+ km/month			
				$R_{increase}$ [%] @EoL 80%	Years to EoL	Years to 100,000 km	Years to 160,000 km	$R_{increase}$ [%] @EoL 80%	Years to EoL	Years to 100,000 km	Years to 160,000 km	$R_{increase}$ [%] @EoL 80%	Years to EoL	Years to 100,000 km	Years to 160,000 km	$R_{increase}$ [%] @EoL 80%	Years to EoL	Years to 100,000 km	Years to 160,000 km	$R_{increase}$ [%] @EoL 80%	Years to EoL	Years to 100,000 km	Years to 160,000 km
BEV-1	**Modena Prov.**	**Li-FePO4 (2013)**	Recharge Strategy #1	**6.9**	9.6	≥ 20	≥ 20	**2.7**	4.0	12.8	≥ 20	**1.6**	2.5	7.9	12.6								
			Recharge Strategy #2	**6.7**	9.1	≥ 20	≥ 20	**2.8**	3.8	11.7	18.7	**1.7**	2.4	7.1	11.4	**1.2**	1.8	5.1	8.1	**0.9**	1.3	3.7	6.0
			Recharge Strategy #3	**6.2**	8.7	≥ 20	≥ 20	**2.3**	3.6	11.7	18.7	**1.4**	2.3	7.2	11.5	**1.6**	2.9	5.2	8.4				
			Recharge Strategy #4	**6.3**	8.9	≥ 20	≥ 20	**2.5**	3.7	12.2	19.6	**1.5**	2.5	8.0	12.8								
			Recharge Strategy #5	**6.9**	9.4	≥ 20	≥ 20	**2.7**	3.7	11.3	18.0	**1.6**	2.4	6.9	11.0	**1.1**	1.7	4.9	7.9	**0.8**	1.2	3.6	5.8

Legend	
(red)	below 5.0 years;
(yellow)	above or equal to 5.0 and below 10.0 years;
(green)	above or equal to 10.0 years;

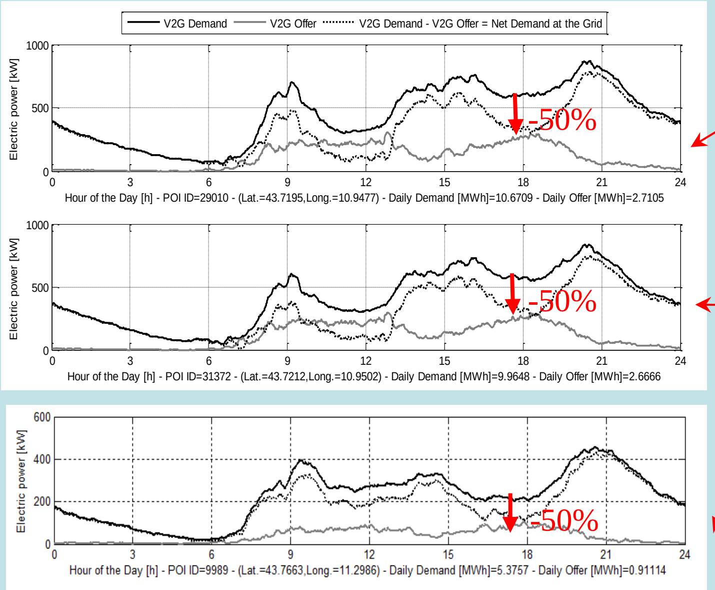
$$R_{increase} = 1.29 \cdot 10^{11} \cdot e^{\left(\frac{-9194}{T}\right)} \cdot t$$

Infrastructure design and V2G in JRC TEMA

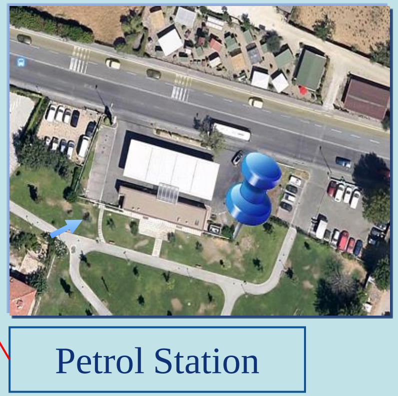
TEMA Structure



De Gennaro Michele, Paffumi Elena, Martini Giorgio, Energy, vol. 82(C), pages 294-311, 2015



Results:
V2G application



Medium Size Vehicle & on-peak strategy

Province of Firenze

Sharing 2% of battery energy if parked but not recharging at given POI. Peaks shaving up to 20% - 25% depending on the POI

V2G ageing assessment with JRC TEMA

Modena Database EoL @ 80% capacity fade Li-Ion NCM-LMO (2015) Years Driving to Set Threshold V2G					0 - 500 km/month			500 – 1,000 km/month			1,000 -1,500 km/month			1,500 – 2,000 km/month			2,000+ km/month		
					Years to EoL	Years to 100,000 km	Years to 160,000 km	Years to EoL	Years to 100,000 km	Years to 160,000 km	Years to EoL	Years to 100,000 km	Years to 160,000 km	Years to EoL	Years to 100,000 km	Years to 160,000 km	Years to EoL	Years to 100,000 km	Years to 160,000 km
Recharge Strategy #1	V2G POI	BEV-1	0%	NCM-LMO (2015)	9.7	≥ 20	≥ 20	8.6	12.8	≥ 20	8.2	7.9	12.6						
			2%		9.5	≥ 20	≥ 20	8.6	12.8	≥ 20	8.3	7.9	12.6						
			20%		9.4	≥ 20	≥ 20	8.6	12.8	≥ 20	8.2	7.9	12.6						
Recharge Strategy #2	V2G POI	BEV-1	0%	NCM-LMO (2015)	9.3	≥ 20	≥ 20	7.9	11.7	18.7	7.1	7.1	11.4	6.6	5.1	8.1	6.2	3.7	6.0
			2%		9.1	≥ 20	≥ 20	7.7	11.7	18.7	7.0	7.1	11.4	6.6	5.1	8.1	6.1	3.7	6.0
			20%		8.5	≥ 20	≥ 20	7.3	11.7	18.7	6.8	7.1	11.4	6.5	5.1	8.1	6.2	3.7	6.0

Legend

(red)	EoL below 5.0 years;
(yellow)	EoL above or equal to 5.0 and below 10.0 years;
(green)	EoL above or equal to 10.0 years;

Summary of the logical passages

#1

Performance-based models

(validated on exp. at cell-level)

#2

Vehicle reference architectures

(from cell-to-vehicle)

#3

Real-world Driving data

#4

Durability Scenarios

(Yrs and/or km to EoL)

Generalising JRC TEMA in-vehicle battery durability model: is it possible?

#1

Performance-based models

(validated on exp. at cell-level)

- Predefined calendar and cycling models (Model 1 to Model 5)
- Fitting equations and parameters for calendar and cycling ageing

#2

Vehicle reference architectures

(from cell-to-vehicle)

- Predefined reference architectures
- Customised: parameters (still to check this possibility)

#3

Real-world Driving data

- Predefined different EU duty cycle and recharging strategies
- Customised: average information (see table of inputs)

#4 Durability Scenarios

(Yrs and/or km to EoL)

- Predefined different vehicle technologies
- Predefined different recharging strategies

Hierarchical relation of the variables (tentative)

Level 1 (highest influence) →

- **Electrical architecture of the battery;**
- **Li-Ion chemistry;**
- **Driving pattern / mileage, i.e. *time, SOC, DOD, Ah, C-rate;***

Level 2 (high influence) →

- **Environment temperature for the calendar ageing (No active BMS)**

Level 3 (mid-to-low influence) →

- **Environment temperature on the cycling ageing if BMS active**

Is the phenomenon fully comprehended? NO → More efforts needed

Input/output of in-vehicle battery durability module of JRC TEMA platform

	Input to JRC TEMA
General parameters	• Age of the car since manufacture [yrs] • Run-in km • Vehicle technology (BEV, PHEV) • EoL threshold for capacity fade and power fade
Environmental parameters	• Ambient temperature max and min for each month of the year [°C]
Duty cycle parameters	• Average number of trips per month • Average driven distance [km] • Average driving time [h] • Average driving speed [km/h] • Average energy consumption [Wh/km] • Average resting time without charging [h] • Average parking time [sec]
Charging data	• Average recharging time [h] • Recharging power [kW] • Charging mode/level • Average number of recharge per month
Battery parameters	• Battery chemistry • Battery architecture (no. of modules, no. of cells, cell voltage, cell current, series/parallel connection i.e. 48S-2P-2S etc.) • Reference battery voltage [V] • Battery capacity [Wh] • Battery reserve [%] • Average weighted battery temperature [°C] • Battery temperature min and max (BMS) [°C] • Average battery SoC min driving [%] • Average battery Delta SoC during charging [%] • Average battery SoC parking no charging [%]

HV battery chemistry	**Output from JRC TEMA**			
	Capacity fade		**Power fade**	
	Calendar	Cycle	Calendar	Cycle
$LiFePO_4$	Sarasketa-Zabala et Al. (2013/14);	Wang et Al. (2011); Sarasketa-Zabala et Al. (2013); Sarasketa-Zabala et Al. (2015);	Sarasketa-Zabala et Al. (2013);	
NCM + Spinel Mn	Wang et Al. (2014);		-	-
NCM – LMO	-	Cordoba-Arenas et Al. (2014);	-	Cordoba-Arenas et Al. (2015);

Thank you for the attention

Q&A

Contacts Info:
EC DG JRC DIR-C ETC Sustainable Transport Unit
elena.paffumi@ec.europa.eu

European Commission

Implementation of the performance based models into JRC TEMA (assumptions, 2/2)

The models have been implemented by adopting the following assumptions:

- **the calendar and cycle capacity fades are calculated at cell level (uniform ageing assumption);**
- **the model assumes average quantities in the reference period per each vehicle for DOD, C-rate, Ah-throughput and temperature;**
- **DOD and temperature are assumed equal to the battery values, consistently with the uniform fade assumption, whilst the C-rate and Ah-throughput are scaled from the battery level down to the cell;**
- **the battery temperature is regulated by the BMS between 22 °C and 27 °C during the driving and recharging phases (cycle capacity fade modelling), whilst it assumes the ambient temperature in the parking phase (calendar capacity fade modelling);**
- **The model capacity fade is calculated at the net of the capacity fade reserve. i.e.:**

$$Q_{loss\text{-}total} = Q_{loss\text{-}calendar} + Q_{loss\text{-}cycle} - Reserve$$

- **5 recharge strategies adopted:**
  - ✓ **Str. 1 = Long Stop Random AC;**
  - ✓ **Str. 2 = Short-Stop Random DC;**
  - ✓ **Str. 3 = Night AC - Str. 4 = Smart AC;**
  - ✓ **Str. 5 = Long-Stop AC 3-phases;**

- **5 vehicle segments:**
  - ✓ **B-segment BEV**
  - ✓ **3 D-segment premium BEV**
  - ✓ **B-D segment PHEVs**
  - ✓ **2 additional BEVs (i.e. A-segment + D-segment SUV)**