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JRC Contribution to EVE IWG

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25th Meeting of the GRPE Informal
Working Group on Electric Vehicles
and the Environment (EVE)

January 8th 2018, Geneva (CH)

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

Summary after Vienna (Oct. 2017), i.e. what's old:

- Literature review and ageing models;
- Implementation of the capacity fade models in TEMA;
- Battery durability scenarios presented;

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. 2018), i.e. what’s new:

- Finalisation of the durability scenario analysis;
- In-vehicle cross-validation of the model’s results against experimental data from Canada;

Performance based models (SotA)

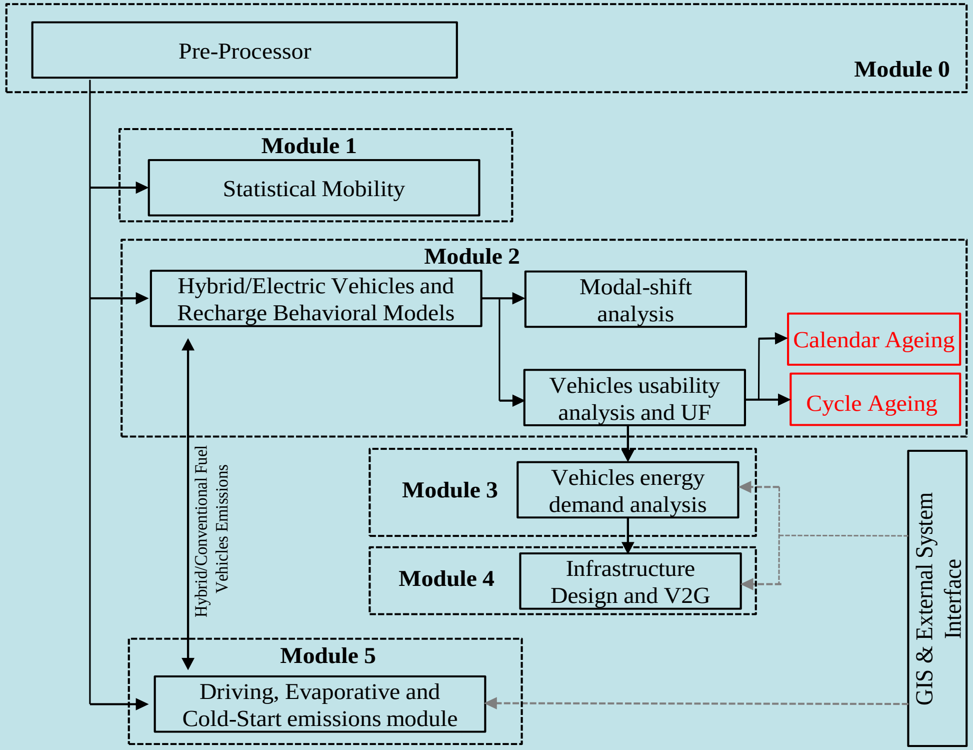
	Capacity fade		Power fade	
	Calendar	Cycle	Calendar	Cycle
$LiFePO_4$	Sarasketa-Zabala et Al. (2013/14);	Wang et Al. (2011); Sarasketa-Zabala et Al. (2013); Sarasketa-Zabala et Al. (2015);	Sarasketa-Zabala et Al. (2013);	
NCM + spinel Mn	Wang et Al. (2014);		-	-
NCM – LMO	-	Cordoba-Arenas et Al. (2014);	-	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 TEMA (assumptions, 1/2)

TEMA Structure



Module 0
Pre-Processor

Module 1
Statistical Mobility

Module 2
Hybrid/Electric Vehicles and Recharge Behavioral Models
Modal-shift analysis
Vehicles usability analysis and UF
Calendar Ageing
Cycle Ageing

Module 3
Vehicles energy demand analysis

Module 4
Infrastructure Design and V2G

Module 5
Driving, Evaporative and Cold-Start emissions module

Hybrid/Conventional Fuel Vehicles Emissions

GIS & External System Interface

Vehicle Electric Architecture (examples)

PHEV

BEV 1

BEV 2

	Vehicle Type	Battery Size [Wh]	Battery Shape	No. of Cells [#] and Type	Reference Voltage [V]	Electric Architecture
T-Shaped	PHEV	16,000	T-shaped	192 – pouch	365	2P-96S
Parallelepiped	BEV 1	24,000	Parallelepiped	192 – pouch	360	48S-2P-2S
Flat-shaped	BEV 2	85,000	Flat	6,912 - cylindrical	345	16S-72P-6S

	Usable Energy at BoL [Wh]	Usable Energy at EoL [Wh]	Reserve [% of battery capacity]	Energy consumption [Wh/km]
T-shaped (PHEV)	12,000	9,600	25%	205
Parallelepiped (BEV 1)	18,000	14,400	15%	210
Flat-shaped (BEV 2)	63,750	51,000	15%	265

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

The models have been implemented by adopting the following assumptions:

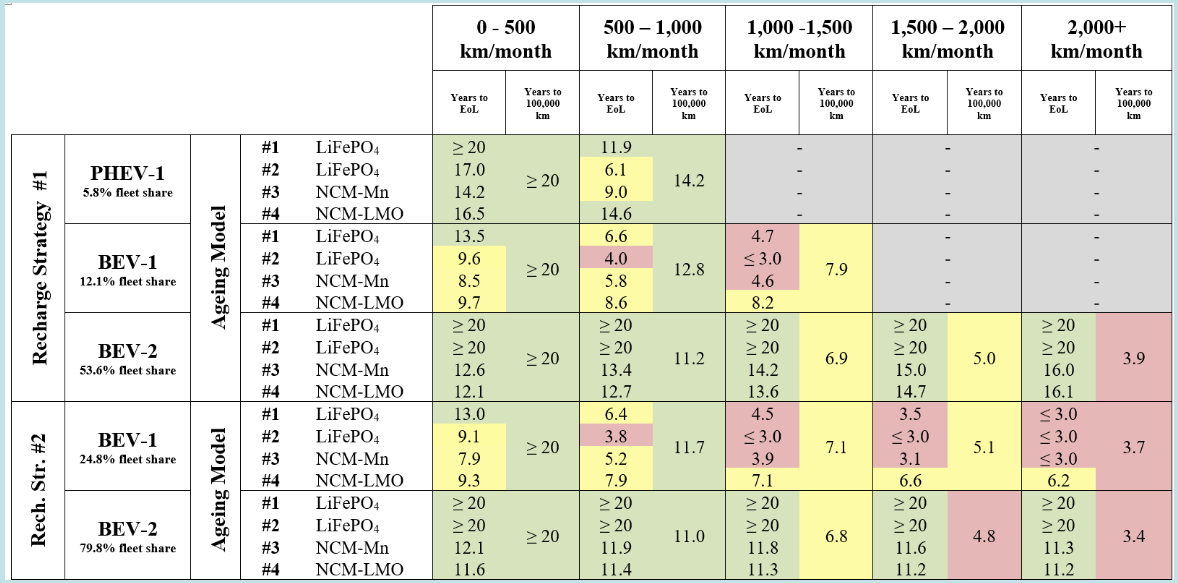
- **the calendar and cycle capacity fades are calculated at cell level (uniform ageing assumption);**
- **the model assumes average quantities in the reference period per each vehicle for DOD, C-rate, Ah-throughput and temperature;**
- **DOD and temperature are assumed equal to the battery values, consistently 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.:**

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

- **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;**

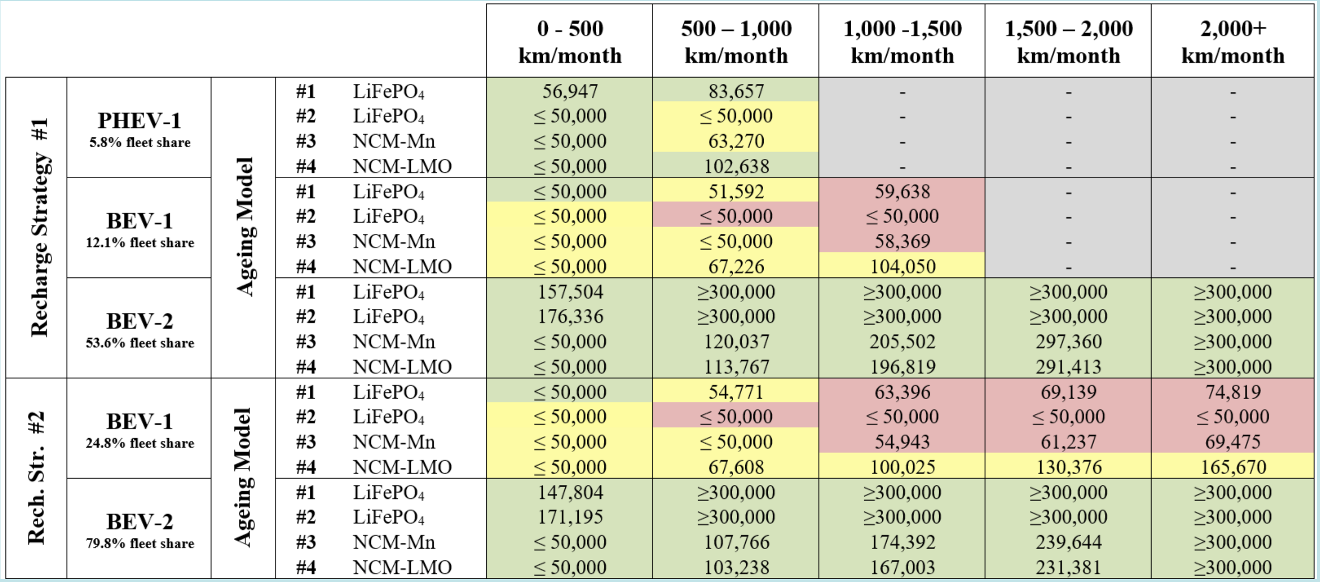
Results (Durability and EoL – tabulated)

Years of Life



					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 EoL	Years to 100,000 km	Years to EoL	Years to 100,000 km	Years to EoL	Years to 100,000 km	Years to EoL	Years to 100,000 km
Recharge Strategy #1	**PHEV-1** 5.8% fleet share	Ageing Model	#1	$LiFePO_4$	≥ 20	≥ 20	11.9	14.2	-		-		-	
			#2	$LiFePO_4$	17.0		6.1		-		-		-	
			#3	NCM-Mn	14.2		9.0		-		-		-	
			#4	NCM-LMO	16.5		14.6		-		-		-	
	BEV-1 12.1% fleet share		#1	$LiFePO_4$	13.5	≥ 20	6.6	12.8	4.7	7.9	-		-	
			#2	$LiFePO_4$	9.6		4.0		≤ 3.0		-		-	
			#3	NCM-Mn	8.5		5.8		4.6		-		-	
			#4	NCM-LMO	9.7		8.6		8.2		-		-	
	BEV-2 53.6% fleet share		#1	$LiFePO_4$	≥ 20	≥ 20	≥ 20	11.2	≥ 20	6.9	≥ 20	5.0	≥ 20	3.9
			#2	$LiFePO_4$	≥ 20		≥ 20		≥ 20		≥ 20		≥ 20	
			#3	NCM-Mn	12.6		13.4		14.2		15.0		16.0	
			#4	NCM-LMO	12.1		12.7		13.6		14.7		16.1	
Rech. Str. #2	**BEV-1** 24.8% fleet share	Ageing Model	#1	$LiFePO_4$	13.0	≥ 20	6.4	11.7	4.5	7.1	3.5	5.1	≤ 3.0	3.7
			#2	$LiFePO_4$	9.1		3.8		≤ 3.0		≤ 3.0		≤ 3.0	
			#3	NCM-Mn	7.9		5.2		3.9		3.1		≤ 3.0	
			#4	NCM-LMO	9.3		7.9		7.1		6.6		6.2	
	BEV-2 79.8% fleet share		#1	$LiFePO_4$	≥ 20	≥ 20	≥ 20	11.0	≥ 20	6.8	≥ 20	4.8	≥ 20	3.4
			#2	$LiFePO_4$	≥ 20		≥ 20		≥ 20		≥ 20		≥ 20	
			#3	NCM-Mn	12.1		11.9		11.8		11.6		11.3	
			#4	NCM-LMO	11.6		11.4		11.3		11.2		11.2	

Mileage @ EoL



					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
Recharge Strategy #1	**PHEV-1** 5.8% fleet share	Ageing Model	#1	$LiFePO_4$	56,947	83,657	-	-	-
			#2	$LiFePO_4$	≤ 50,000	≤ 50,000	-	-	-
			#3	NCM-Mn	≤ 50,000	63,270	-	-	-
			#4	NCM-LMO	≤ 50,000	102,638	-	-	-
	BEV-1 12.1% fleet share		#1	$LiFePO_4$	≤ 50,000	51,592	59,638	-	-
			#2	$LiFePO_4$	≤ 50,000	≤ 50,000	≤ 50,000	-	-
			#3	NCM-Mn	≤ 50,000	≤ 50,000	58,369	-	-
			#4	NCM-LMO	≤ 50,000	67,226	104,050	-	-
	BEV-2 53.6% fleet share		#1	$LiFePO_4$	157,504	≥300,000	≥300,000	≥300,000	≥300,000
			#2	$LiFePO_4$	176,336	≥300,000	≥300,000	≥300,000	≥300,000
			#3	NCM-Mn	≤ 50,000	120,037	205,502	297,360	≥300,000
			#4	NCM-LMO	≤ 50,000	113,767	196,819	291,413	≥300,000
Rech. Str. #2	**BEV-1** 24.8% fleet share	Ageing Model	#1	$LiFePO_4$	≤ 50,000	54,771	63,396	69,139	74,819
			#2	$LiFePO_4$	≤ 50,000	≤ 50,000	≤ 50,000	≤ 50,000	≤ 50,000
			#3	NCM-Mn	≤ 50,000	≤ 50,000	54,943	61,237	69,475
			#4	NCM-LMO	≤ 50,000	67,608	100,025	130,376	165,670
	BEV-2 79.8% fleet share		#1	$LiFePO_4$	147,804	≥300,000	≥300,000	≥300,000	≥300,000
			#2	$LiFePO_4$	171,195	≥300,000	≥300,000	≥300,000	≥300,000
			#3	NCM-Mn	≤ 50,000	107,766	174,392	239,644	≥300,000
			#4	NCM-LMO	≤ 50,000	103,238	167,003	231,381	≥300,000

Legend		
	🟥	EoL below 5 years;
	🟨	EoL between 5 and 10 years;
	🟩	EoL above 10 years;

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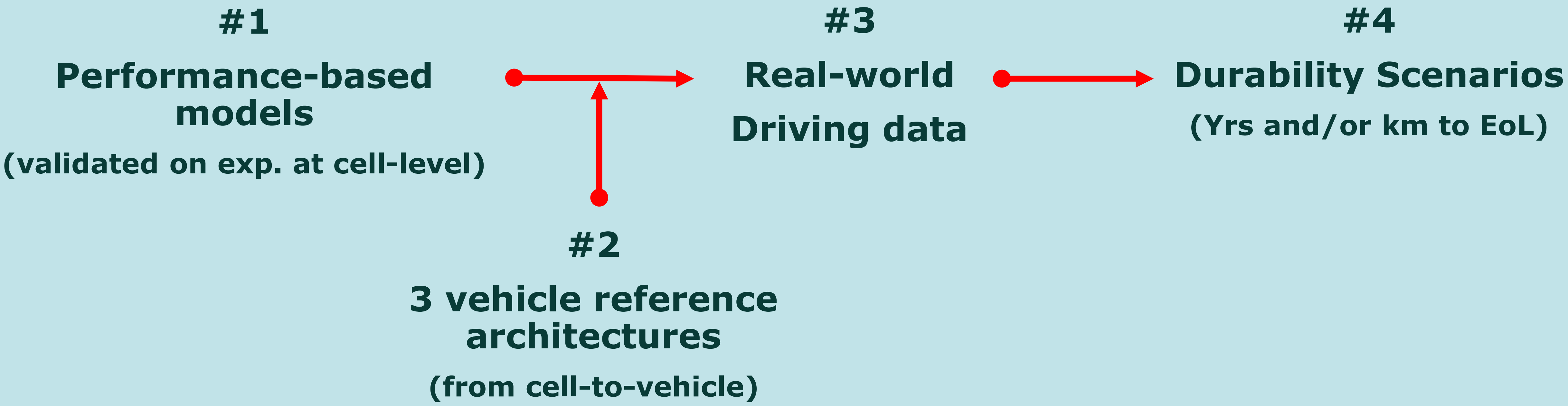
Summary of the logical passages



#1

Performance-based models

(validated on exp. at cell-level)

#2

3 vehicle reference architectures

(from cell-to-vehicle)

#3

Real-world

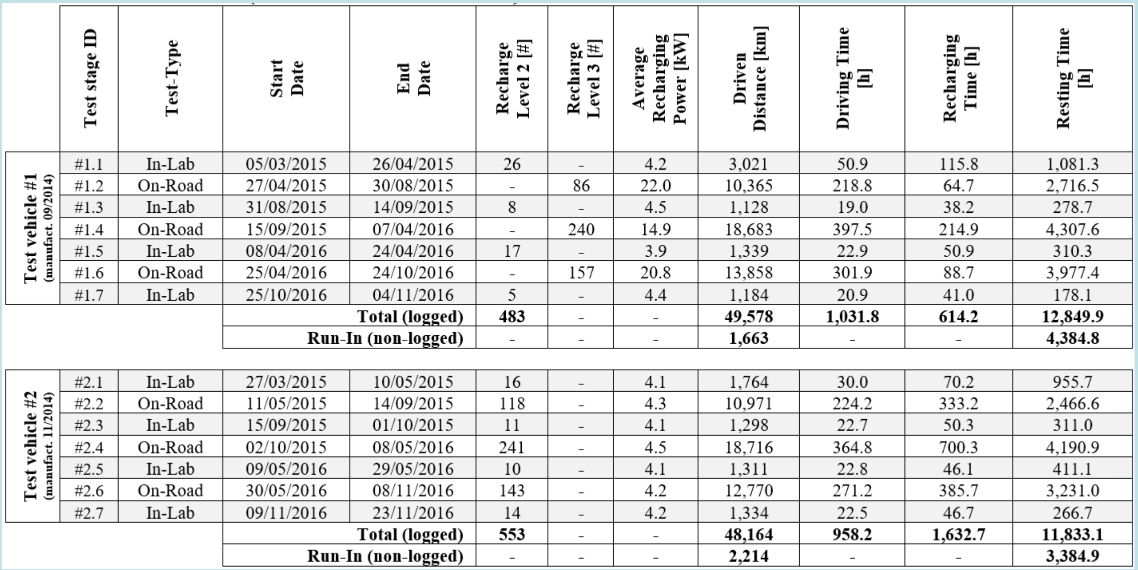
Driving data

#4

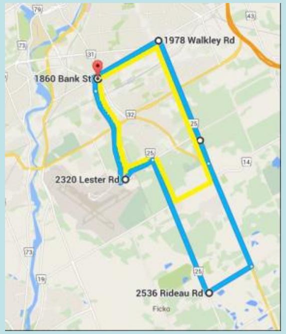
Durability Scenarios

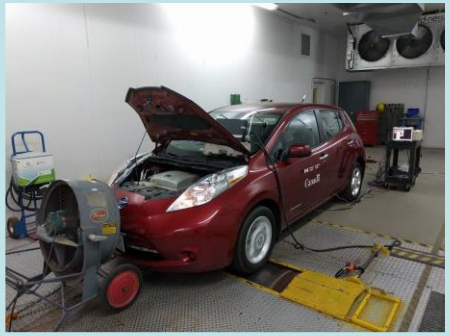
(Yrs and/or km to EoL)

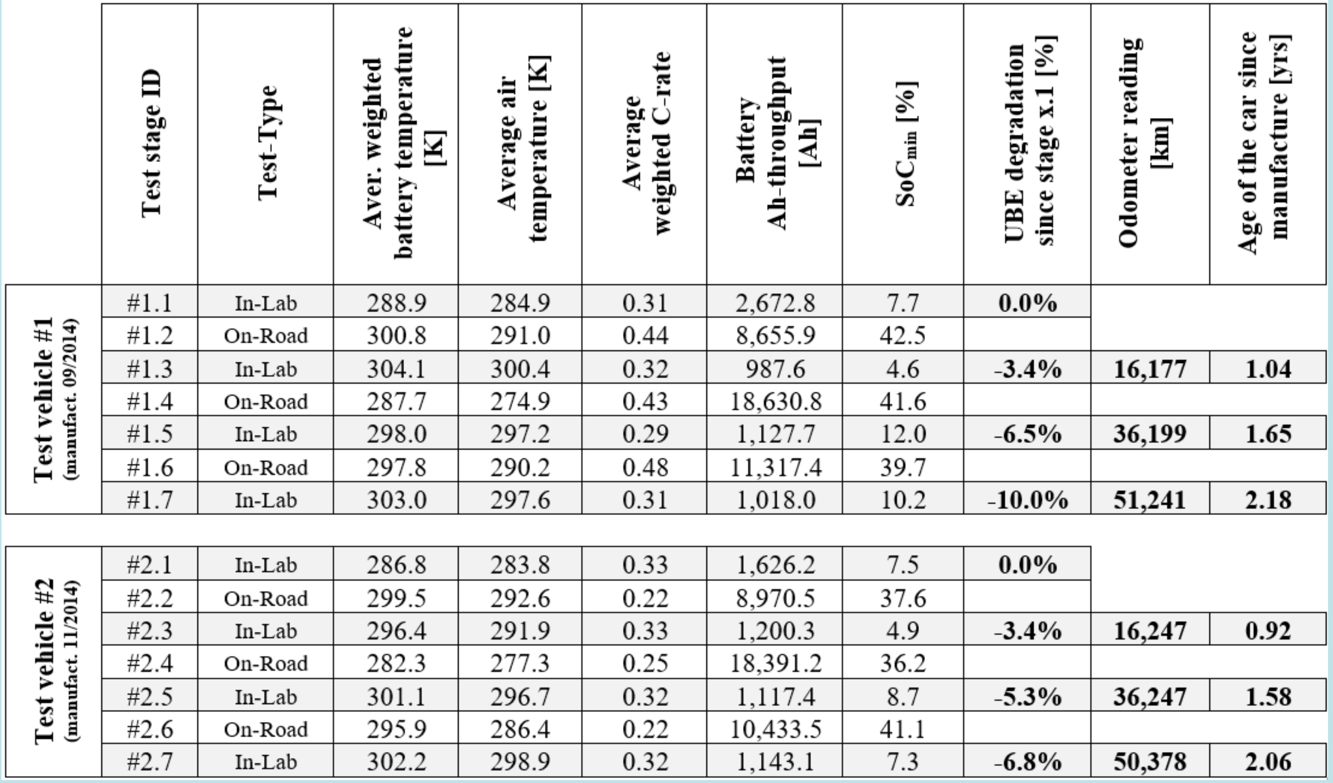
Experimental data from Canada (description)



	Test stage ID	Test-Type	Start Date	End Date	Recharge Level 2 [#]	Recharge Level 3 [#]	Average Recharging Power [kW]	Driven Distance [km]	Driving Time [h]	Recharging Time [h]	Resting Time [h]
Test vehicle #1 (manufact. 09/2014)	#1.1	In-Lab	05/03/2015	26/04/2015	26	-	4.2	3,021	50.9	115.8	1,081.3
	#1.2	On-Road	27/04/2015	30/08/2015	-	86	22.0	10,365	218.8	64.7	2,716.5
	#1.3	In-Lab	31/08/2015	14/09/2015	8	-	4.5	1,128	19.0	38.2	278.7
	#1.4	On-Road	15/09/2015	07/04/2016	-	240	14.9	18,683	397.5	214.9	4,307.6
	#1.5	In-Lab	08/04/2016	24/04/2016	17	-	3.9	1,339	22.9	50.9	310.3
	#1.6	On-Road	25/04/2016	24/10/2016	-	157	20.8	13,858	301.9	88.7	3,977.4
	#1.7	In-Lab	25/10/2016	04/11/2016	5	-	4.4	1,184	20.9	41.0	178.1
				Total (logged)	**483**	-	-	**49,578**	**1,031.8**	**614.2**	**12,849.9**
				Run-In (non-logged)	-	-	-	**1,663**	-	-	**4,384.8**
Test vehicle #2 (manufact. 11/2014)	#2.1	In-Lab	27/03/2015	10/05/2015	16	-	4.1	1,764	30.0	70.2	955.7
	#2.2	On-Road	11/05/2015	14/09/2015	118	-	4.3	10,971	224.2	333.2	2,466.6
	#2.3	In-Lab	15/09/2015	01/10/2015	11	-	4.1	1,298	22.7	50.3	311.0
	#2.4	On-Road	02/10/2015	08/05/2016	241	-	4.5	18,716	364.8	700.3	4,190.9
	#2.5	In-Lab	09/05/2016	29/05/2016	10	-	4.1	1,311	22.8	46.1	411.1
	#2.6	On-Road	30/05/2016	08/11/2016	143	-	4.2	12,770	271.2	385.7	3,231.0
	#2.7	In-Lab	09/11/2016	23/11/2016	14	-	4.2	1,334	22.5	46.7	266.7
				Total (logged)	**553**	-	-	**48,164**	**958.2**	**1,632.7**	**11,833.1**
				Run-In (non-logged)	-	-	-	**2,214**	-	-	**3,384.9**







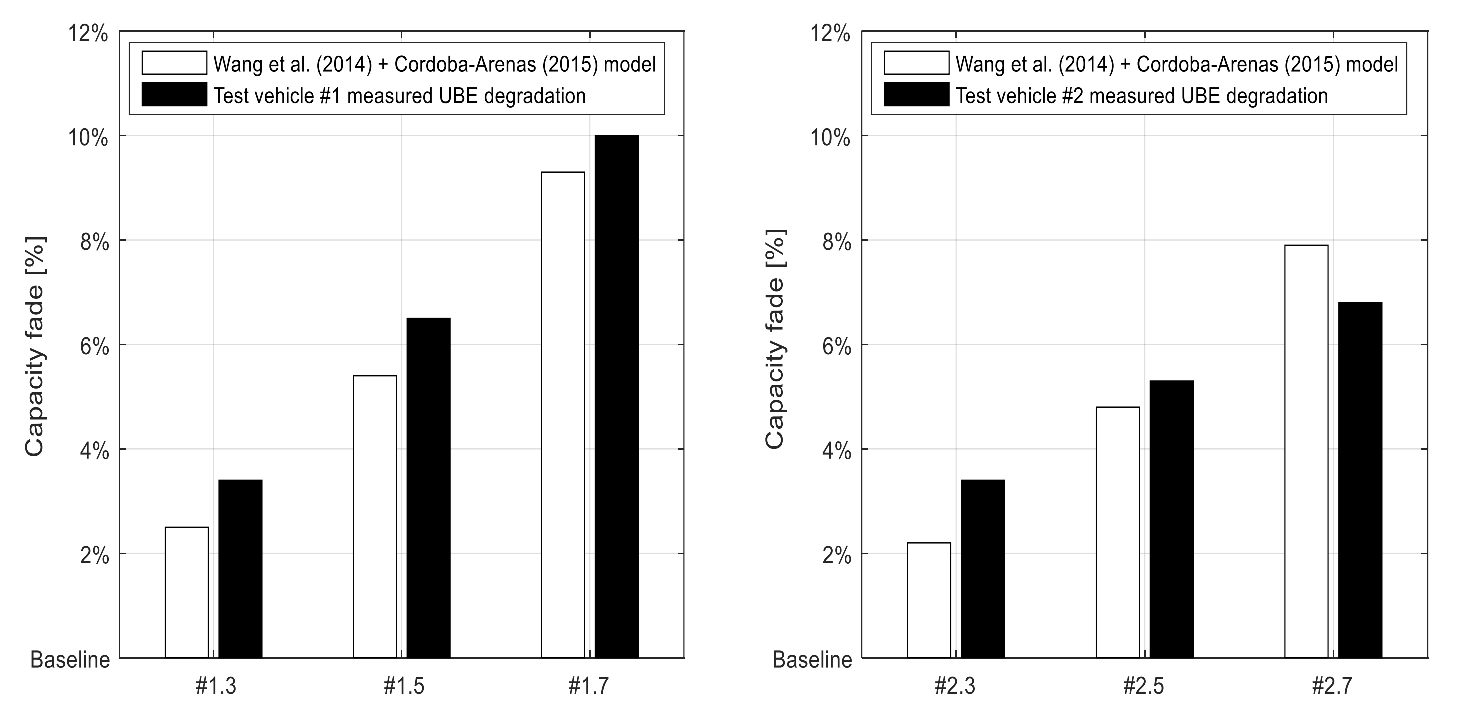
	Test stage ID	Test-Type	Aver. weighted battery temperature [K]	Average air temperature [K]	Average weighted C-rate	Battery Ah-throughput [Ah]	SoC_{min} [%]	UBE degradation since stage x.1 [%]	Odometer reading [km]	Age of the car since manufacture [yrs]
Test vehicle #1 (manufact. 09/2014)	#1.1	In-Lab	288.9	284.9	0.31	2,672.8	7.7	**0.0%**		
	#1.2	On-Road	300.8	291.0	0.44	8,655.9	42.5			
	#1.3	In-Lab	304.1	300.4	0.32	987.6	4.6	**-3.4%**	**16,177**	**1.04**
	#1.4	On-Road	287.7	274.9	0.43	18,630.8	41.6			
	#1.5	In-Lab	298.0	297.2	0.29	1,127.7	12.0	**-6.5%**	**36,199**	**1.65**
	#1.6	On-Road	297.8	290.2	0.48	11,317.4	39.7			
	#1.7	In-Lab	303.0	297.6	0.31	1,018.0	10.2	**-10.0%**	**51,241**	**2.18**
Test vehicle #2 (manufact. 11/2014)	#2.1	In-Lab	286.8	283.8	0.33	1,626.2	7.5	**0.0%**		
	#2.2	On-Road	299.5	292.6	0.22	8,970.5	37.6			
	#2.3	In-Lab	296.4	291.9	0.33	1,200.3	4.9	**-3.4%**	**16,247**	**0.92**
	#2.4	On-Road	282.3	277.3	0.25	18,391.2	36.2			
	#2.5	In-Lab	301.1	296.7	0.32	1,117.4	8.7	**-5.3%**	**36,247**	**1.58**
	#2.6	On-Road	295.9	286.4	0.22	10,433.5	41.1			
	#2.7	In-Lab	302.2	298.9	0.32	1,143.1	7.3	**-6.8%**	**50,378**	**2.06**

Source: Presentation from Transport Canada @ EVE-22 (Ann-Arbor, April 2017)

Experimental data from Canada (Validation)

In-vehicle validation of the models (assumptions):

- **Uniform T, DoD, C-rate and Ah-throughput;**
- **T, DoD @ battery level;**
- **C-rate and Ah-throughput @ cell level;**
- **$Q_{loss-total} = Q_{loss-cal.} + Q_{loss-cycle}$ - Reserve(10%);**
- **NCM-LMO model (closer to real LEAF chemistry i.e. $LiMn_2O_4$ with $LiNiO_2$)**



The results will be described in the scientific paper:
“Capacity fade of Lithium-ion automotive batteries under real-world use conditions”, planned for submiss. in Jan. 2018.

Thank you for the attention

Q&A

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