The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION

BARCELONA 17th-20th November 2013

CSR / Environment

UNITED CHEMI-CON, INC.

Automobile Efficiency Improvements using Electrochemical Capacitor Energy Storage

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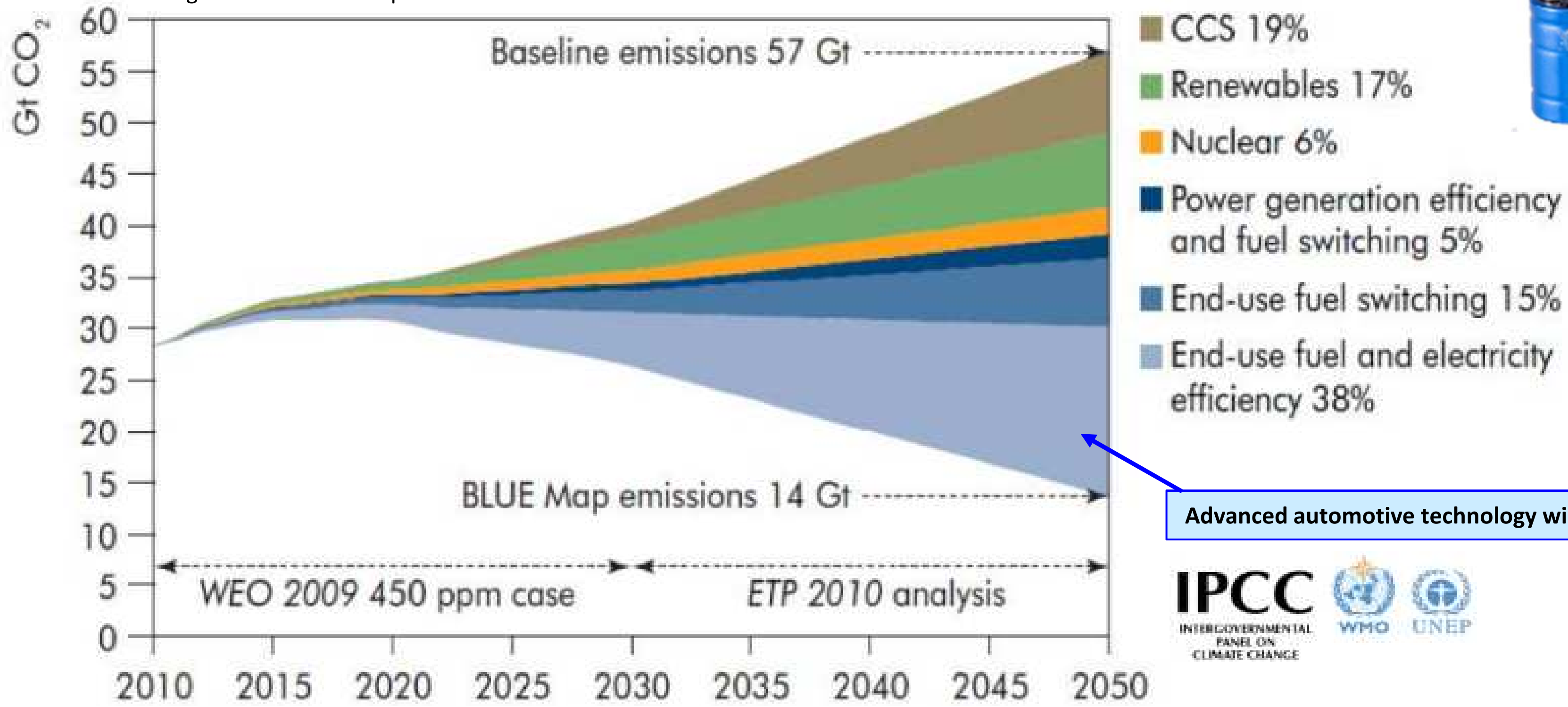
Topics to be presented

1. **Trend of Automotive Market**
2. **J08 Drive cycle and power profile**
3. **Why Electrochemical capacitor instead of Battery from the energy storage technology viewpoint?**
4. **i-ELOOP Energy Recovery System concept block diagram**
5. **Key components design parameters**
6. **Field Test data**
7. **DLCAP™ modules have been implemented in more passenger vehicles to improve fuel consumption.**
8. **DXE Series line up for Automotive Application**
9. **Conclusion**

1. Trend of automotive market

Figure-1 GHG IPCC report



Advanced automotive technology will be expected.

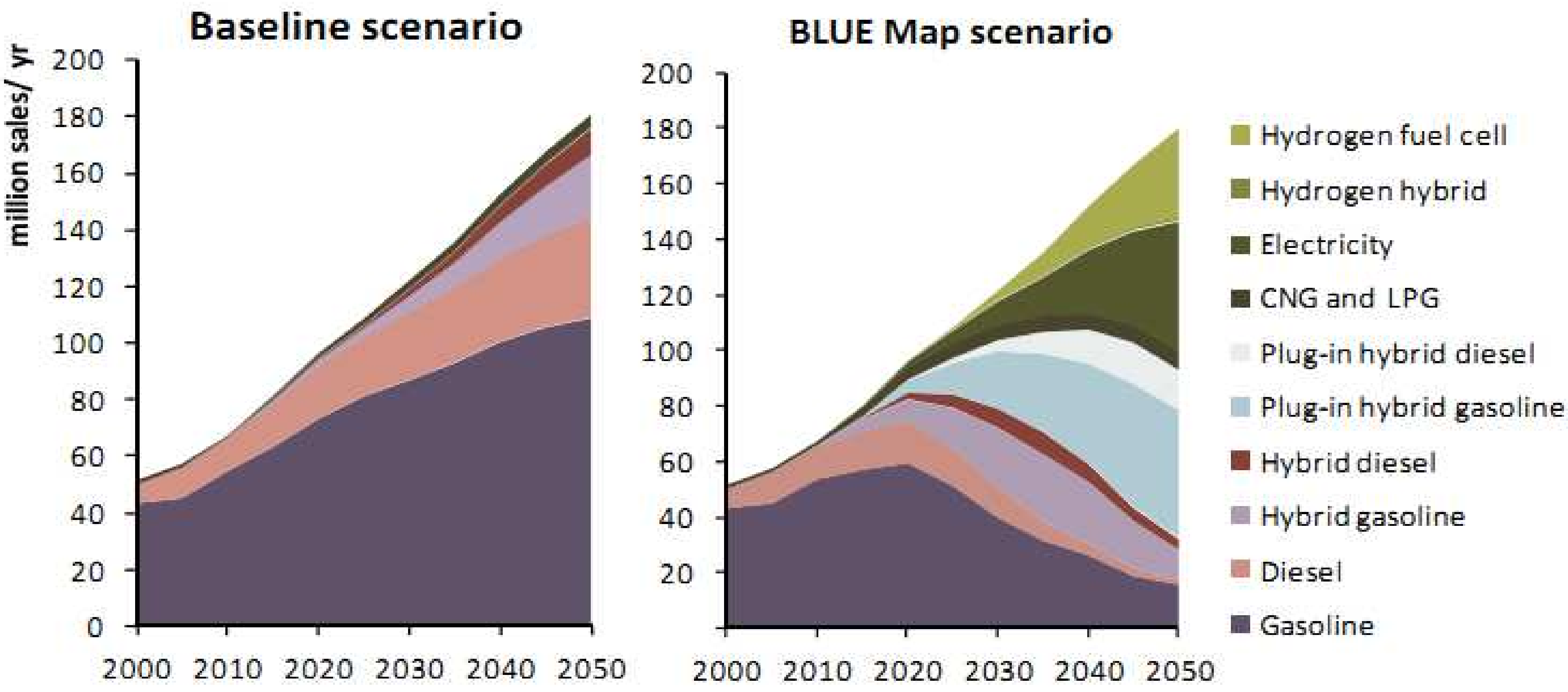
IPCC INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE WMO UNEP

Source: Energy Technology Perspectives 2010 Cork, 15 November 2010.

The IPCC has concluded that emissions must be reduced by 50% to 85% by 2050 if global warming is to be confined to between 2° C and 2.4° C. G8 leaders agreed at the Heiligendamm Summit in 2007 to seriously consider a global 50% CO2 reduction target.

1.1 Sales demand for light-duty vehicle by technology

Figure-2 Blue Map Scenario & Strategies to 2050



In the BLUE Map scenario advanced technologies, such as plug-in hybrid, all-electric and fuel-cell vehicles, dominate sales after 2030.

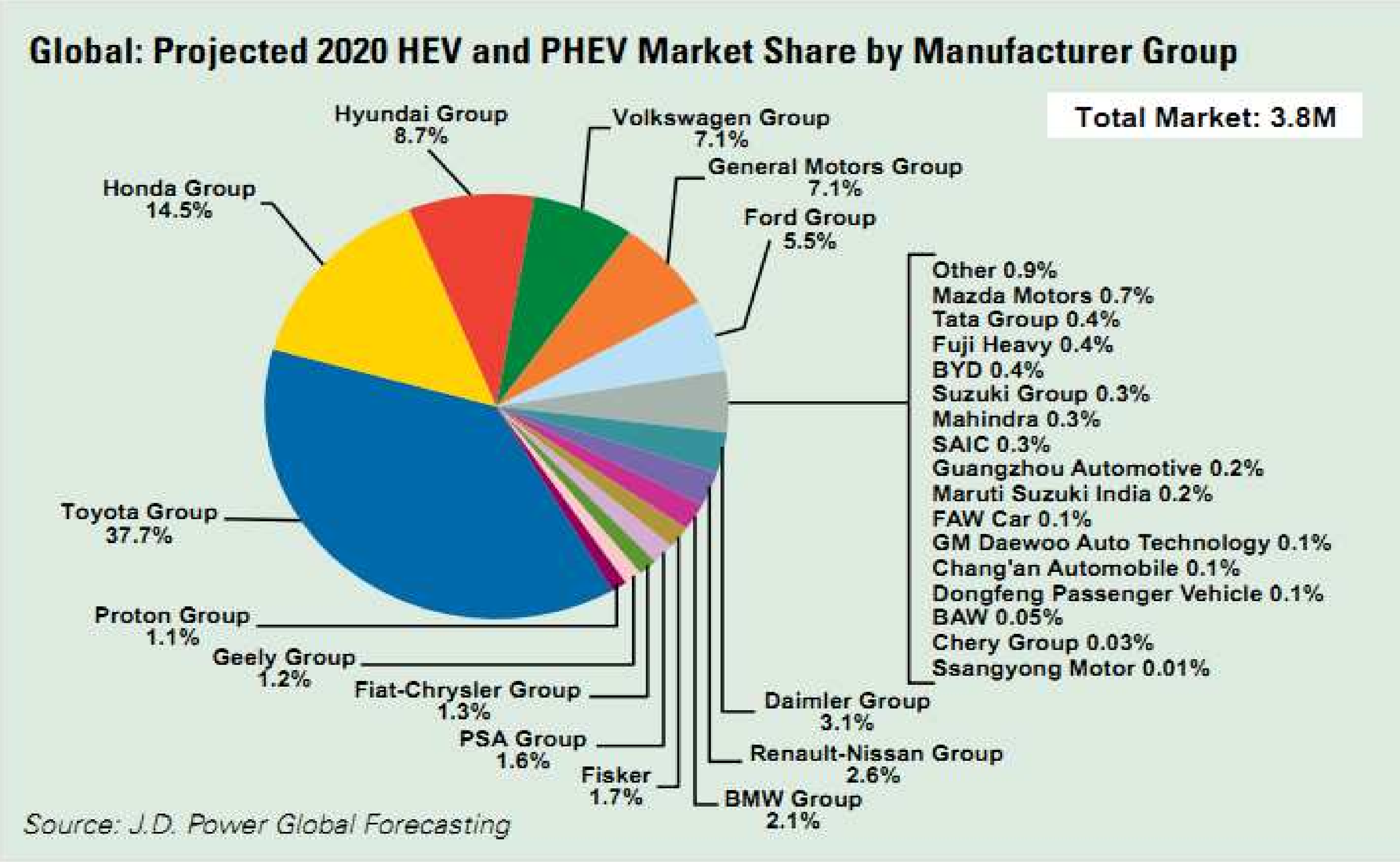
Source: Energy Technology Perspectives 2010 Cork, 15 November 2010. OECD/IEA-2012

OECD_The Organization for Economic Co-operation and Development-HQ/Paris France, 34 country
IEA-International Energy Agency _ Intergovernmental organization in France

1.2 Who are players of the advanced vehicles?

Just 3.88 million advanced vehicles in 2020, or only 5.5% of the 70.9 million passenger vehicles to be sold by that year.

Figure-3 Advanced vehicle market share at 2020.



2. J08 Drive cycle and power profile

Typical passenger Vehicle 1.53t(driver with one passenger) will have approx.,25% of total regenerative energy(610wh)

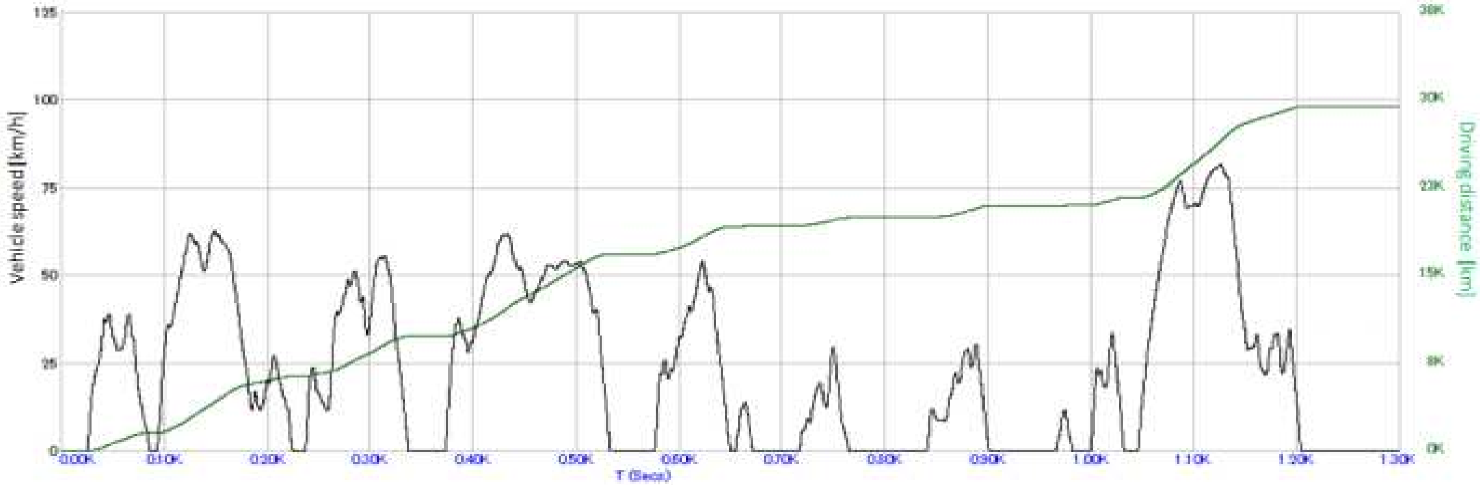


Figure-4. Japanese Drive cycle JC08 showing driving speed and distance travelled versus time. Each cycle lasts 20 minutes and covers approximately 30 km of distance.

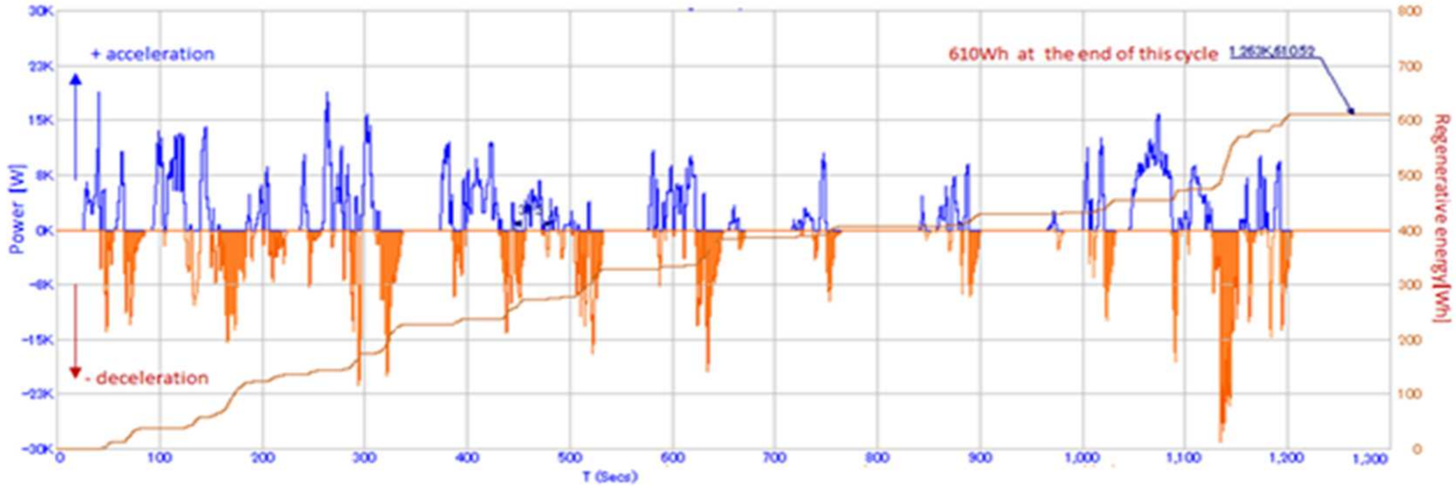


Figure5. Power profile for a 1.53 metric ton vehicle following the Japanese JC08 Drive cycle. Theoretical maximum recapture energy is 610 Wh. Only approximately 25% of this amount (150 Wh) is actually available to be recycled.

2.1 Available regenerative energy with JC08

- **Typical passenger Vehicle 1.53t(driver with one passenger)**
- **Accumulated theoretical regenerative energy will be 610Wh**
- **150Wh (approx., 25% of total) will be actual available to be recycled.**

The efficiency of a storage system added to a vehicle is important and it determines the amount of fuel consumption reduction.

3. Why Electrochemical capacitor instead of Battery from the energy storage technology viewpoint?

2 Key points[1]:

1. Charge acceptance of 200A for 5 to 6 sec at the regenerative process

- Ni-MH has been rejected because 2 strings are needed. Size is too big.
- Lead Acid-Battery was also rejected becomes of the short life if it's met the requirements.

2. Life performance in the engine compartment to be expected.

- Li-Battery has > 4Kw/kg power density which can be implemented in this system
- However Charge acceptance may not perform when it's getting closer to EOL.
- The temperature in the engine compartment could be over 80℃ depend on the traffic jam and Idling stop.
- The rated maximum temperature of Li-battery is 60℃
- Li-Battery has been rejected because of the short life due to the temperature limitation.

3.1 Charge Acceptance

3.2 Comparison of Storage Technology

3.1 Charge Acceptance

J.R.Miller and A.D.Klementov, "Electrochemical Capacitor Performance Compared with the Performance of Advanced Lithium Batteries",

Figure-6. Charge acceptance efficiency

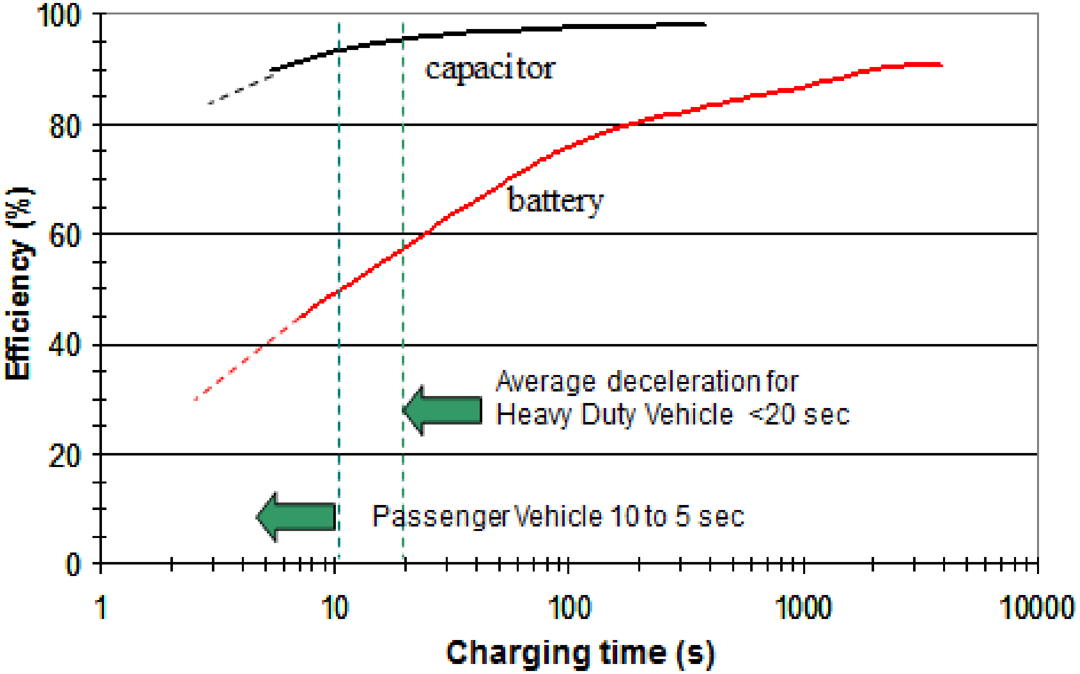


Table-1. Comparison of Li-Battery and Electrochemical Capacitor

Factor	State of the Art Lithium Ion Battery	Electro-chemical Capacitor
Charge time	~3-5 minutes	~1 second
Discharge Time	~3-5 minutes	~1 second
Cycle life	>15,000 @ 5C rate	>1,000,000
Specific Energy (Wh/kg)	80	5
Specific power (kW/kg)	1	10
Cycle efficiency (%)	<50% to >90%	<75 to >95%
Cost/Wh	$2/Wh	$20/Wh
Cost/kW	$150/kW	$50/kW

Source: The 17th International Seminar on Double Layer Capacitors and Hybrid Energy Storage Devices December 10-12, 2007, Deerfield Beach, FL

3.2 Comparison of Storage Technology

Table-2. Comparison table of energy storage technology [1]

	Capacitor		Lithium-ion batteries		Nickel-metal hydride bateries		Lead-acid storage batteries	
type	Electric double layer		HEV application		HEV application		Vent type	
Energy density(Wh/kg)	×	5～10	○	100～200	○	50～80	○	30～40
Voltage(V)	△	2.5	○	3～3.7	△	1.2	△	2
Maximum Output(W/kg)	○	10,000>	○	4,000	△	1,000～2,000	×	200
Resistance (mΩ)	○	1	△	2.5	△	3	△	5
Operating temperature (℃)	○	-30～70	△	-30～60	△	-30～60	○	-30～80
Cycle life (soc 0 ⇔ 100% @25℃)	○	1,000,000>	△	3,000>	△	1,000>	×	300>
Safety	○	—	△	—	○	—	○	—
Environmental load	○	—	×	Li,Co,Ni,Mn	×	Ni	×	Pb

[1] Source: Development of i-ELOOP Device" special edition #9: SKYACTIVE TECHNOLOY.
YR2012 No. 30 MAZDA TECHNICAL REVIEW

4. i-ELOOP Energy Recovery System concept

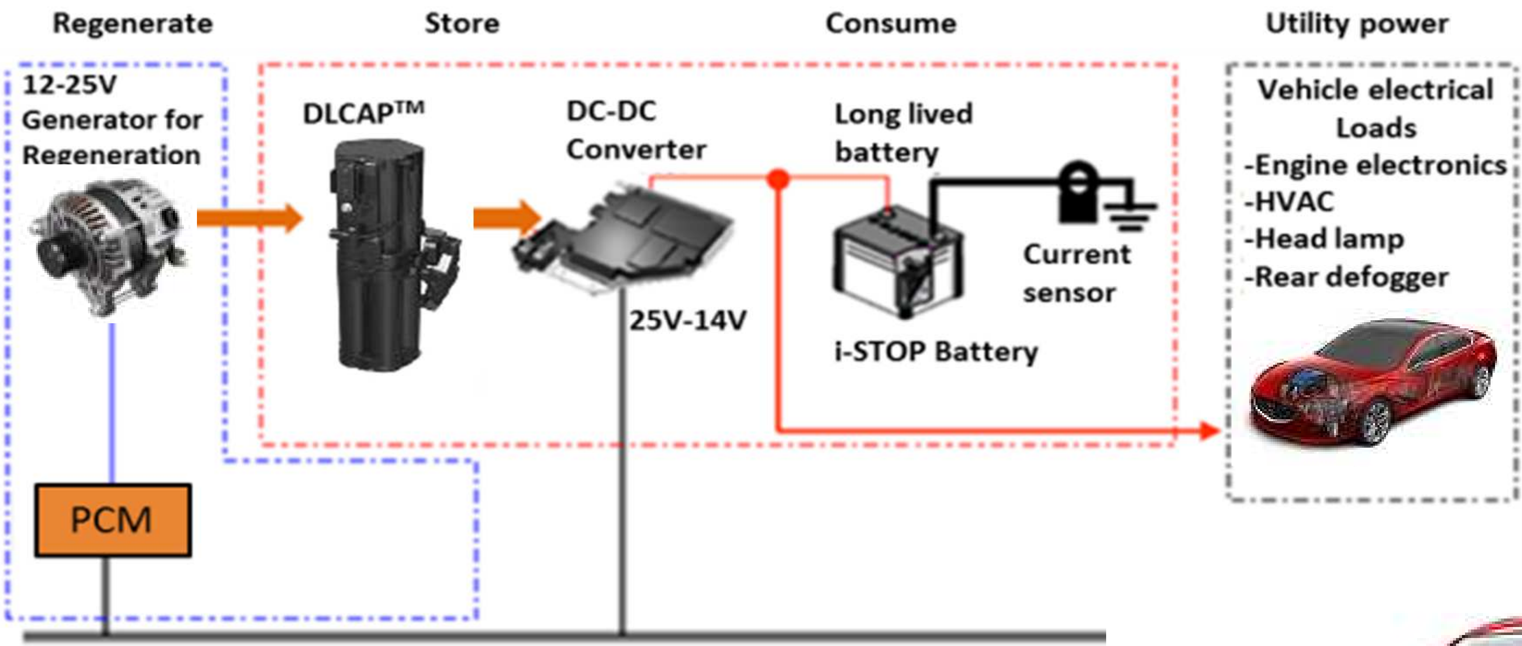


Figure 7: i-ELOOPTM system developed by MAZDA to improve vehicle fuel economy and degrease emission. Energy is stored in the DLCAPTM during regenerative braking that is used for utility power(the vehicle electrical load).

Table 3: Typical vehicle Utility load loads

Typical load	Current[A]
EPS	100
Air conditioner	30
Radiator fan motor	30
Fuel pump	8
ECU	10
Others (Audio, wipwer, lump, so on)	

Source: Jtec-R/Japan electronics Technology Research

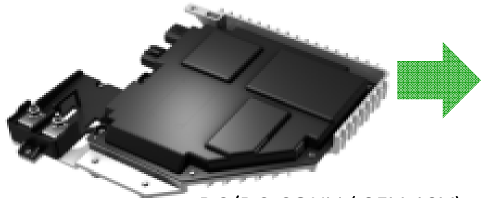
Typical average current will be 40A and typical utility power is 12V x 40A = 480W.

4.1 I-ELOOP System Concept visual

DLCAPTM module

- DLCAPTM module will be able to provide vehicle utility power for engine to provide 100% energy to driving.
- DLCAPTM module with Newly developed alternator at MAZDA will be able to improve approx., 10% fuel consumption at the frequent START/STOP driving mode.

Fig-8 Alternator will be completely stopped for cursing mode
DLCAPTM will supply all utility power.



DC/DC-CONV (25V-12V)

Battery charge
All utility: Car radio, Air Con, Head lamp, Winker and so on.

DLCAPTM will supply all utility and battery charging power during cursing mode

Courtesy of Mazda Motor Corporation.

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4.2 Capacitor module profile with J08 mode

The calculated annual energy savings based on driving 20 days a month x 12 months a year x 160 Wh x 49% is approximately 18.8 kWh.

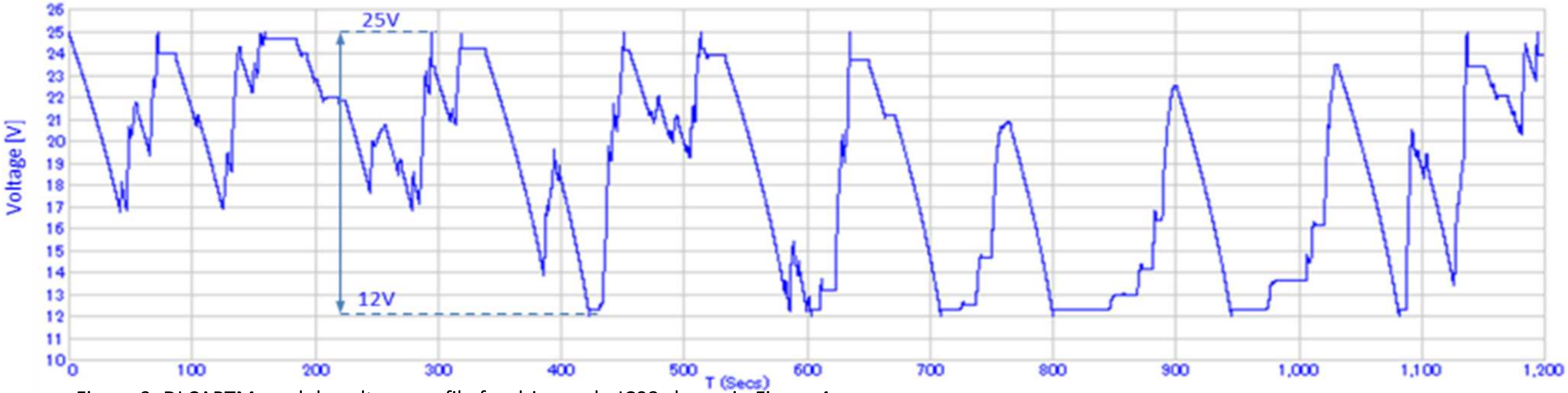


Figure 9: DLCAPTM module voltage profile for drive cycle JC08 shown in Figure 4.

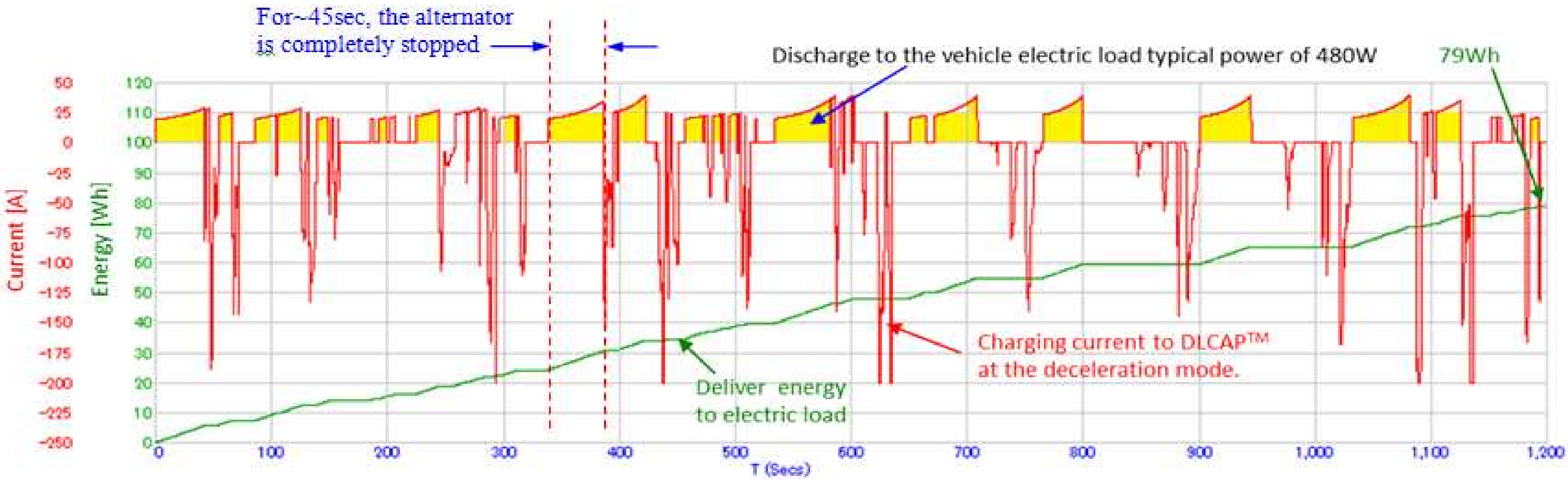


Figure 10: DLCAPTM discharge current and delivered energy to the vehicle electric load. Note a positive current peak is associated with discharge to the vehicle electric load and a negative current peak is associated with charge current to DLCAP™ module at deceleration mode. The capacitor charging current is limited to 200A due to the alternator requirement.

5 Key components design parameters

Table-4: Key parameters of the DLCAP™ module

rated voltage	25V
Capactance	120F
Typical ESR	9mΩ
Store Enegy	37.5KJ
Operating temperature	-30℃ to 70℃

DXE1200F f40x150mm

DLCAP™ module (10 cells of DXE1200F)

Figure 11. Nippon Chemi-Con DXE series 1200F /2.5V and DLCAP™ Module.

Table-5: Parameters of newly developed alternator for the Mazda i-ELOOP™ system

Valuable output voltage	12V to 25V
Maximu current	200A
Maximu output power	5KW

Figure 12. 12V to 25V valuable output Generator -Alternator used with the i-ELOOP™ system, [1]

6 Field Test data

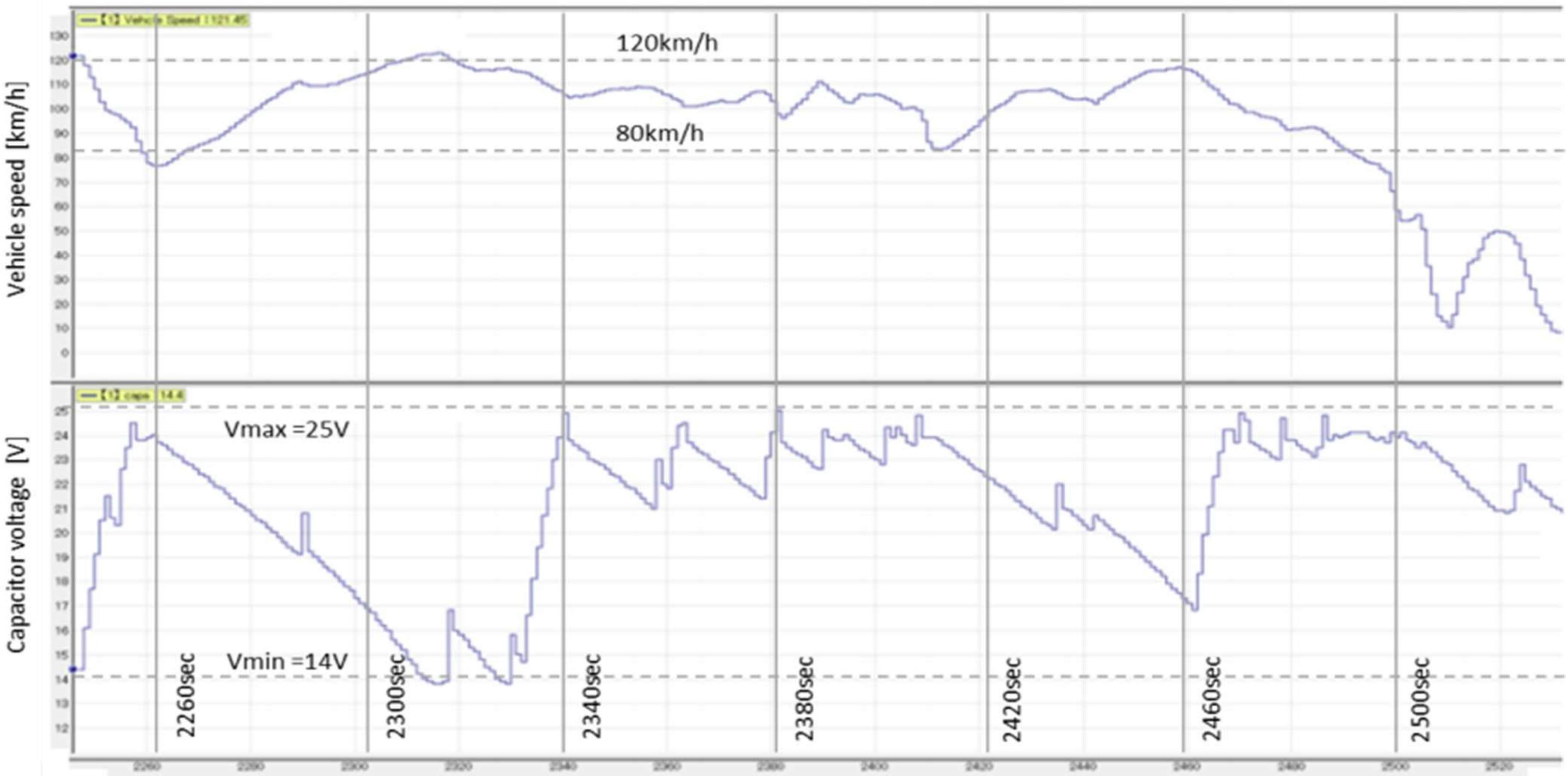
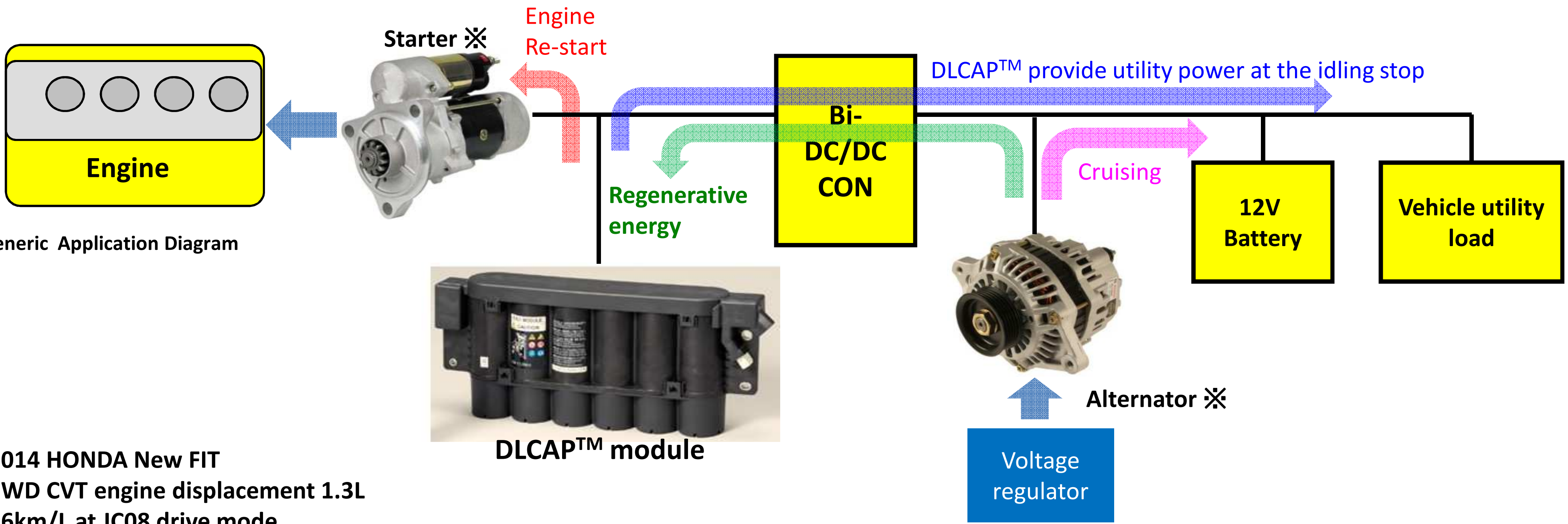


Figure 13: Field test data for driving on Hwy 405 California USA.
Source: “ Development of the i-ELOOP ” special edition #8: SKYACTIVE TECHNOLOY. 2012 No. 30 MAZDA TECHNICAL REVIEW

7. DLCAP™ modules have been implemented in more passenger vehicles to improve fuel consumption.



Generic Application Diagram

2014 HONDA New FIT
2WD CVT engine displacement 1.3L
26km/L at JC08 drive mode

Courtesy of Honda Motor Co.Ltd

NOTE: Cold start will be directly driven from 12V battery.

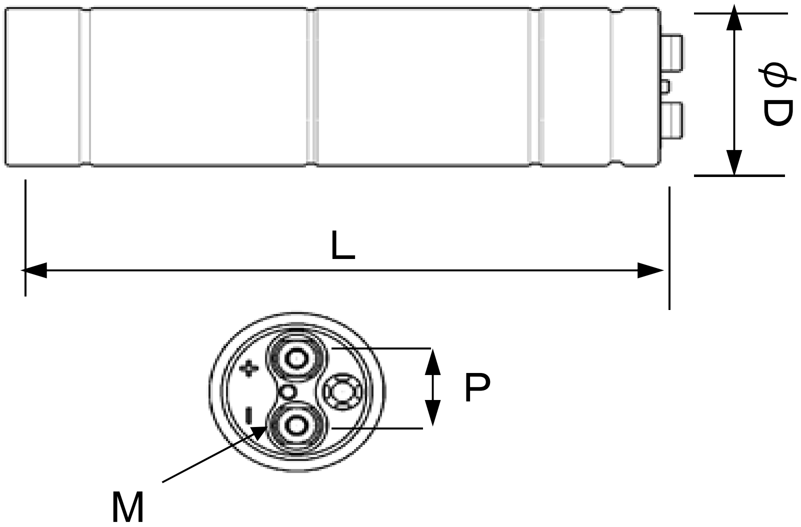
The DLCAP™ module has been adopted into New FIT recently.

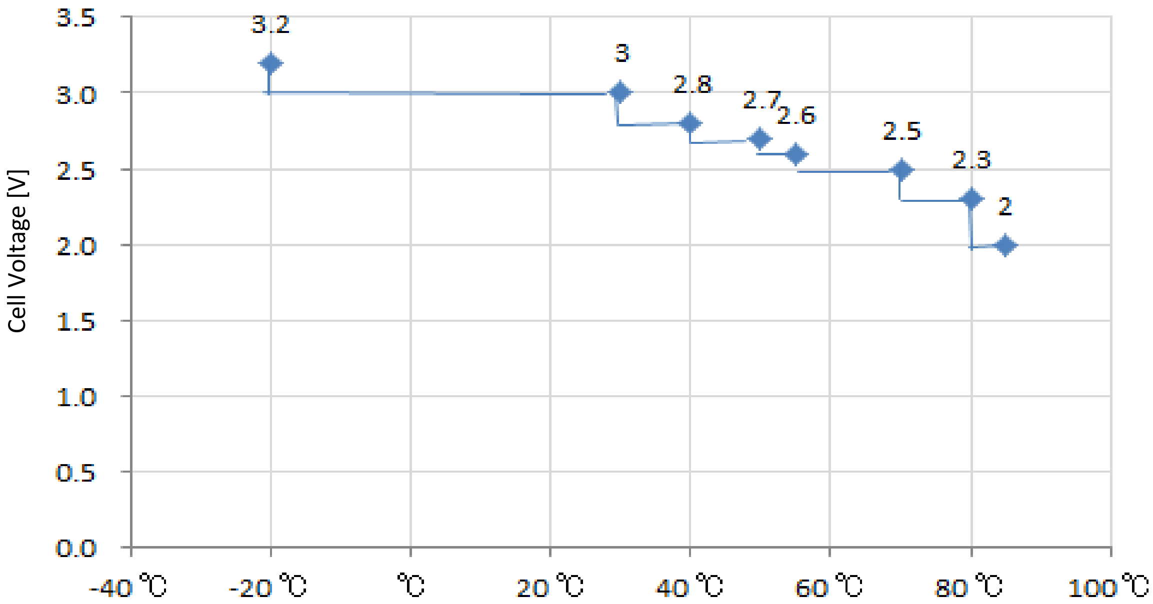
※Schematic illustration for reference only. Not to be confused with an actual design

8. DXE Series line up for Automotive Application

DXE3000F/Rated temperature: 70℃ at 2000Hrs ESR$_{DC}$ = 0.3mΩ

Rated Voltage		Capacitance [F]	Dimensions				ESR$_{DC}$(typ) [mΩ]	Remarks
			ϕD[mm]	L[mm]	P[mm]	M		
2.5V 70℃	**2.8V 40℃**	400	40	65	17	M5	2.0	Production
		800		105			1	Production
		1200		150			0.8	Production
		3000	63.5	**153**	26	M6	**0.3**	**YR 2014 Production**
		4000		172			**0.35** (Tentative)	Under development





9. Conclusion

- **The MAZDA passenger vehicle i-ELOOP energy conservation system using special Nippon Chemi-Con DLCAP™ electrochemical capacitors has demonstrated a 10% reduction in fuel consumption**
- **Electrochemical capacitors clearly are the superior storage system technology for this automotive application.**
- **DLCAP™ will continue to improve the cost performance to meet the automotive market demand.**

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Thank you

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