A3PS

Rethinking Propulsion.

Flywheels for Drive Systems

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Alternative Propusion Systems and Energy Carriers –
Vehicle Integration and System Optimization

Vienna, 18th and 19th Nov. 2010

in cooperation with

bmvit

Outline

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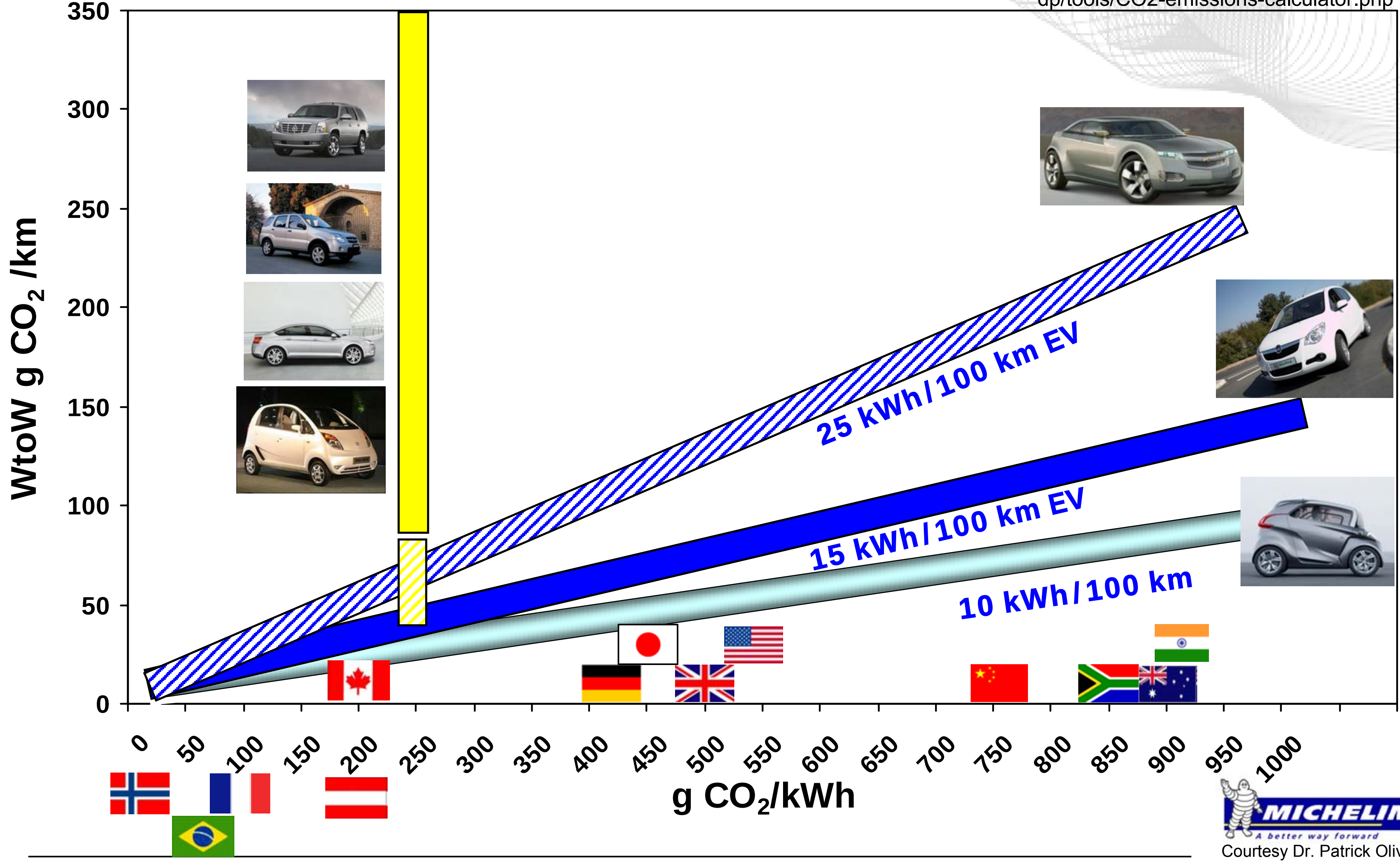
Why Electric Drive Systems?

- Global warming ⇒ reduction of fossil fuel use ⇒ CO_2 reduction: driving force in e.g. Europe & Japan.
- Independency from crude oil
  - USA: national security issue and CO2 reduction issue
  - China: use of huge black coals resources for mobility ⇒ contradiction to CO2 reduction
  - Brazil: efficient ethanol production safes cost and CO_2
- Where does it make sense to substitute fossil fuel based mobility with electric drive systems?
  - CO2 emissions for electricity production is low ⇒ introduce hybrid and electric vehicles to the market.

Comparison of Well to Wheel CO2 Emissions per km Driven with a Battery Powered Car (15 or 25 kWh/100 km) and ICE Powered Cars Using Fossil Fuels

Assumption: Grid-to-battery recharging efficiency η = 100 %

CO2 values from: http://www.sunearthtools.com/dp/tools/CO2-emissions-calculator.php



MICHELIN
A better way forward
Courtesy Dr. Patrick Oliva

Design Constraints for Electric Drive Trains

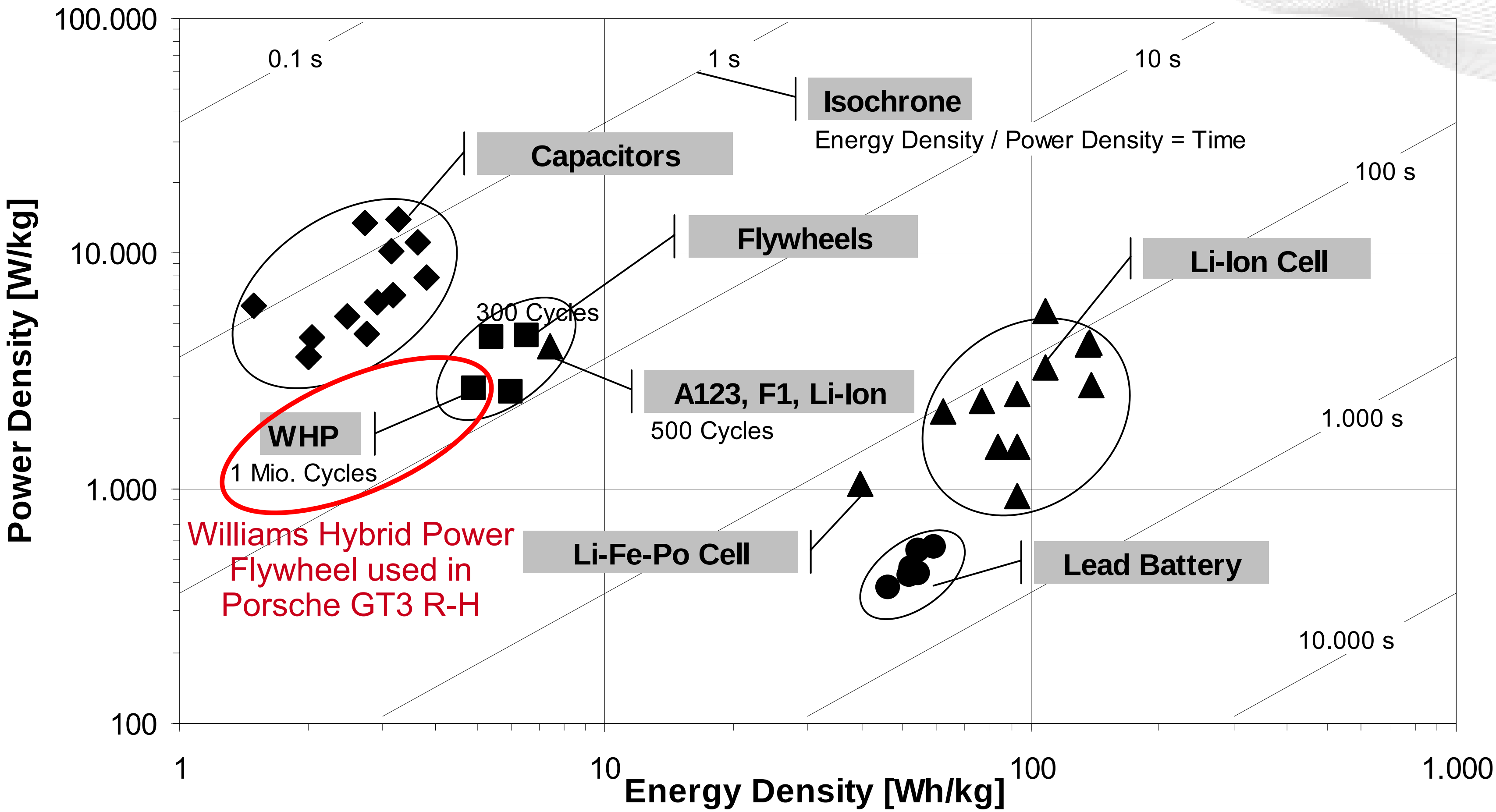
- Electric drive train ⇔ EV or hybrid vehicle
  - The customer expects the performance of an i.c. engine car
- The antipoles: i.c. engine versus electric vehicle
  - I.c. engine vehicle
    - Vehicle is limited by the power of the i.c. engine and not by the stored on board fuel energy ⇒ That's what the customer is used to.
  - Electric vehicle
    - Vehicle design is limited by the on board electric energy and <u>not</u> by the power of the electric motor(s)
      - Compromise has to be made between power (=fun to drive) and on board energy (=autonomy)
      - Key component is the electric storage device:
Safety, costs and weight, energy and power density, durability, etc.

Compromise: the best of both worlds ⇒ as a mid term solution hybrid vehicles with i.c. engines followed in a along run by fuel cells.

Design Constraints for Electric Drive Trains

- A) Today: i.c. engine vehicle with electric boost and recuperation
  - Goal is acceptable system cost ⇒ from micro up to plug-in hybrids
  - Occasional degradation of the e-system is hardly recognizable by the driver:
    - Aggressive driving or hot environment ⇒ over temperature of the batteries (40 °C!)
    - Wrong state of charge for boosting or recuperation
    - Imperfections of the electric propulsion system
  - Drive style has a big impact on energy consumption (up to 25 %)
- B) Tomorrow: electric drive system with i.c. engine support
  - Affordable electric storage system with high energy and power density ⇒ from EVs with range extender up to pure EVs
  - Occasional degradation of the electric propulsion system is unacceptable
    - 2 to 3 C discharge rate is the maximum for an "energy" battery (200 Wh/kg).
    - Either big expensive battery (Tesla, 54 kWh) to obtain high power output (good driving performance and 250+ km range)
    - Or small affordable "energy" batteries (8 to 12 kWh) for urban and commuter vehicles plus high power energy store: supercaps or flywheels (fun to drive and 80 km+ range)
  - Drive style has a lower impact than case A) on energy consumption : ⇒ High e-power gains high brake power recovery ⇒ better efficiency.

Ragone Plot for Electrical Energy Storage Systems (referred to mass)



Source: Dr. Armbruster, GT3 R Hybrid: Technology Champion and „Race Lab", AVL Tagung Motor & Umwelt Sept. 2010

Basic Vehicle: Porsche GT3 R

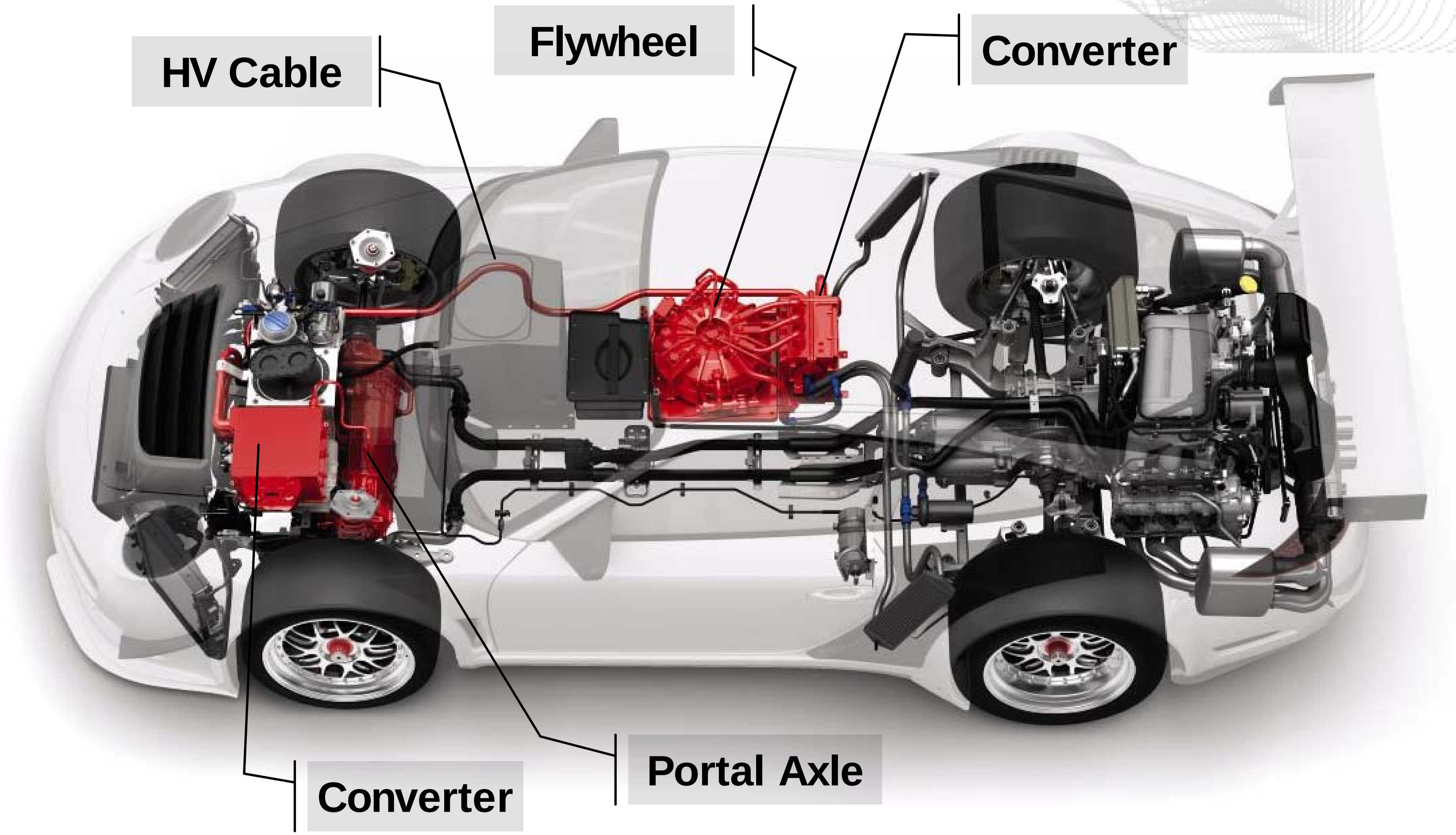
- Model year: 2010
- Motor: Flat six
- Displacement: 3996 ccm
- Power Output: 480 HP
- Vehicle Weight (race ready): 1.220 kg

GT3 R Hybrid

- 2x 60 kW electric power (6 to 8 sec)
- Vehicle Weight (race ready): 1.350 kg

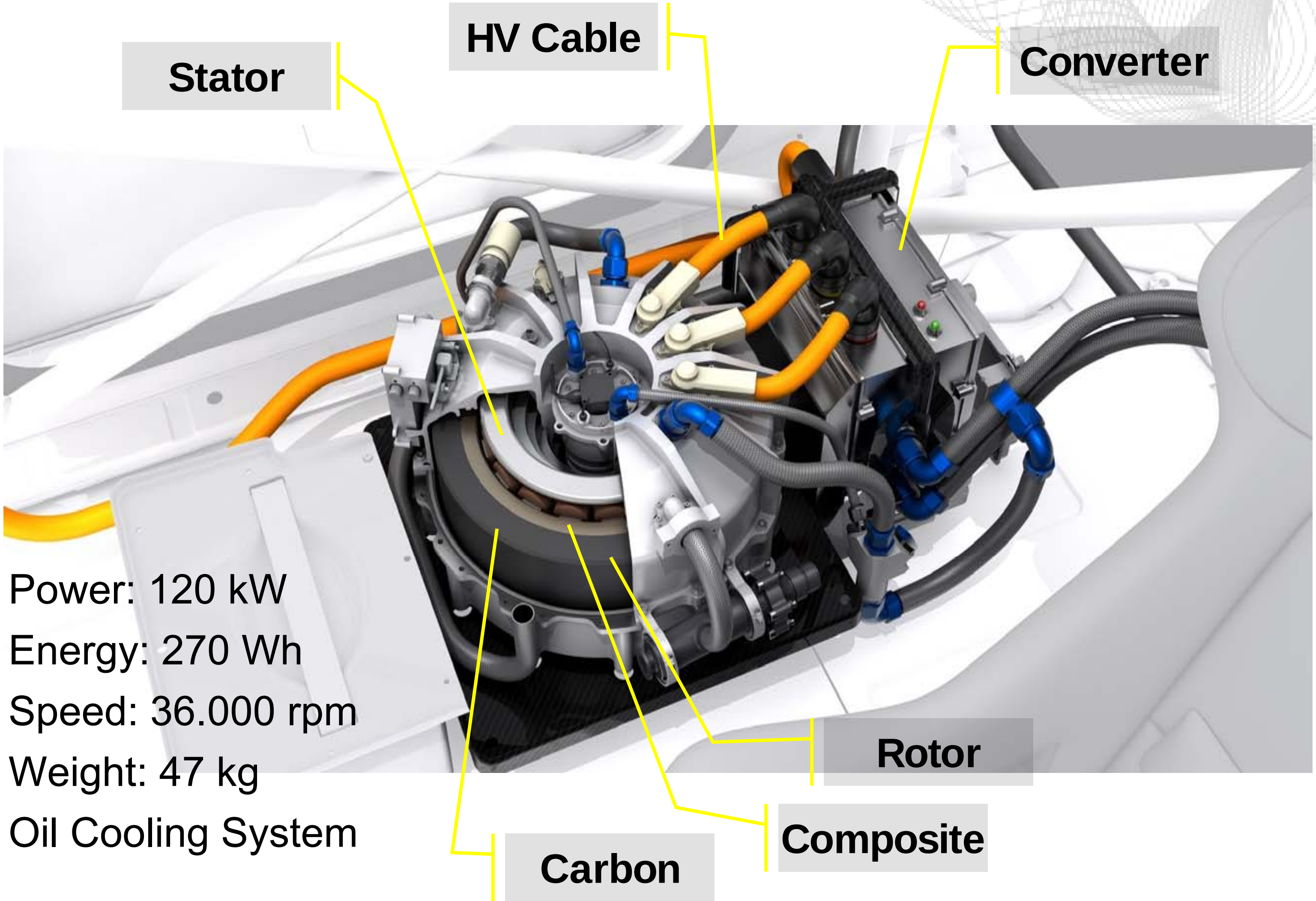
Source: Dr. Armbruster, GT3 R Hybrid: Technology Champion and „Race Lab“, AVL Tagung Motor & Umwelt Sept. 2010

GT3 R Hybrid: Parallel Hybrid



Source: Dr. Armbruster, GT3 R Hybrid: Technology Champion and „Race Lab", AVL Tagung Motor & Umwelt Sept. 2010

Williams Hybrid Power Flywheel



- Power: 120 kW
- Energy: 270 Wh
- Speed: 36.000 rpm
- Weight: 47 kg
- Oil Cooling System

Source: Dr. Armbruster, GT3 R Hybrid: Technology Champion and „Race Lab", AVL Tagung Motor & Umwelt Sept. 2010

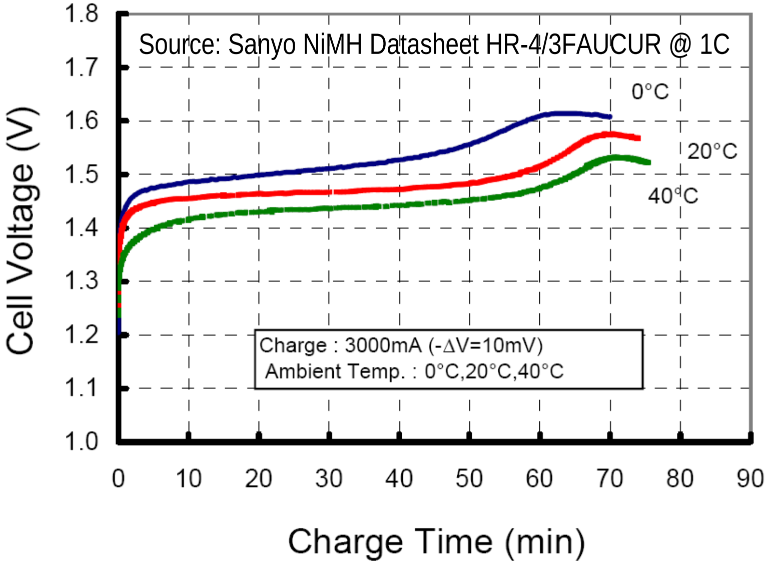
Electrical Characteristics of Batteries and Ultracapacitors

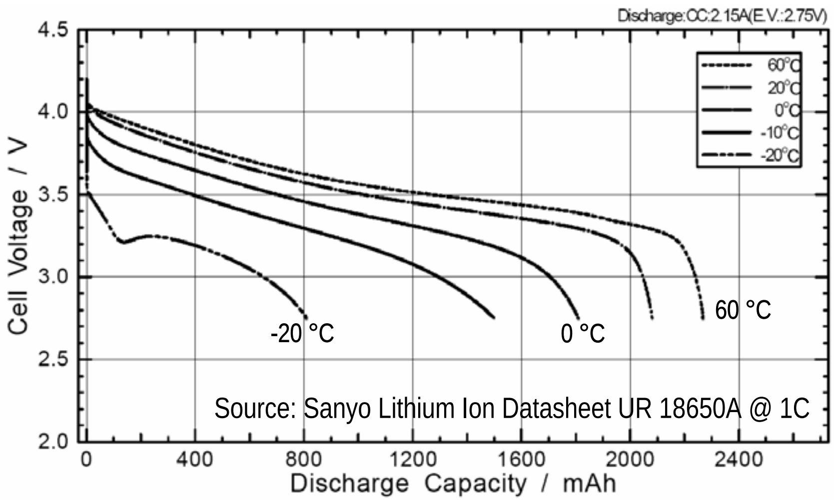
Maxwell TECHNOLOGIES   Oct. 12th, 2007   ***Energy Storage Technologies***

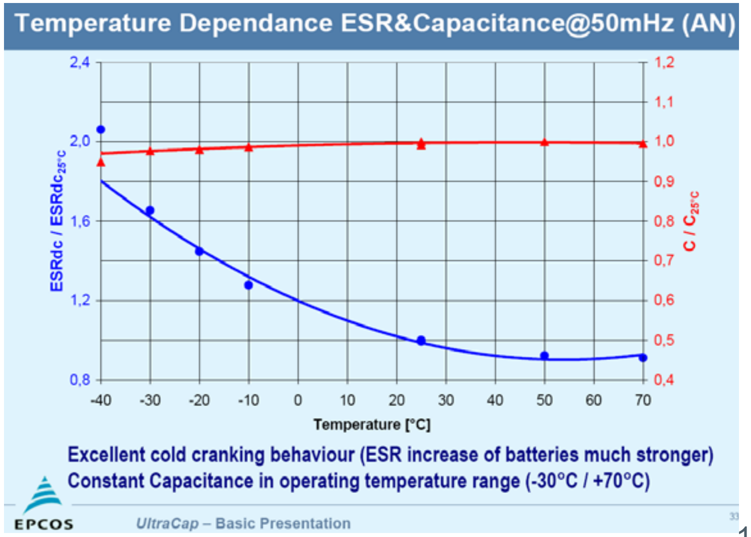
- Side-by-side energy storage technology comparison
  - Attributes of components to store 1MJ (278 Wh)
  - Polymer film type used in pulse magnetizers and inverters
  - Ceramics used in coupling and high frequency bypass

Capacitor Type	Current (pk/rms) (A)	Voltage (V)	Energy (Wh/liter)	Energy (Wh/kg)	Mass 1 MJ (kg)	Response Time (seconds)
Electrostatic Polymer Film Ceramic MLCC	200,000/300	900	0.03	0.024	12,000	10^{-9}
Electrolytic Aluminum electrolytic	?/40	450	0.087	0.019	15,000	10^{-4}
Electrochemical Carbon ultracapacitor	4,800/150	2.7	6.4	5.5	51	1
Electrochemical Lithium-Ion	2,000/150	3.8	286	123	2	10^{3}

Source:http://www.ansoft.com/firstpass/pdf/CarbonCarbon_Ultracapacitor Equivalent_Circuit_Model.pdf, 6. Nov. 2010







Courtesy: UltraCap - Epcos - basic presentation.pdf, 22.3.2005

Temperature impact on Batteries and Ultracapacitors

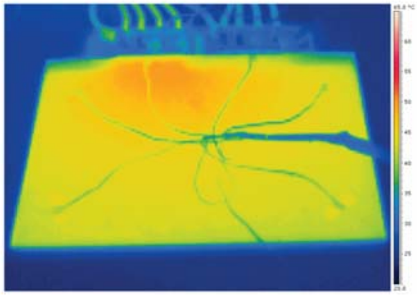
- Temperature limitations
  - Batteries :
    - NiMH: from -20 °C to 0°C as lower limit and +40°C to +50°C as upper limit
    - LiIon: from -30°C(?) to 0°C as lower limit and +50°C to +60°C as upper limit, anode (carbon) aging speeds up beyond 40 °C).
  - Ultracapacitors: from around -40°C up to +65°C, high self discharge rate
  - Flywheel (rotor of a motor) allows operation from around -30 °C up to around 100 °C

- Cell voltage V and internal resistance R_i (storage losses) limitations
  - V and R_i are considerably temperature dependent @ batteries and ultracapacitors $\Rightarrow$ increase of internal losses results in cooling problems
  - An electronic controller keeps the terminal voltage of the flywheel temperature independent $\Rightarrow$ increase in thermal losses results in no problems

Comparison of Battery with Ultracapacitor and Flywheel

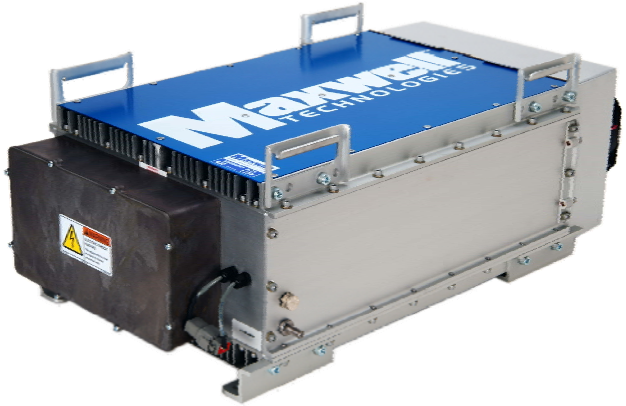
The GT3 R-H Flywheel performance should be achieved:
P = 120 kW for 8 sec (=267 Wh), **47 kg**, system duty cycle **V_T = 20 %**, oil cooled

Kokam Lithium battery
Type: SLPB 60460330H
3.7 V, 70 Ah, R_{ser} = 1 mΩ
1,95 kg * 1.5 ⇒ mounting
P_{vmax} = 160 W@ΔT = 40°C
R_{Th} = 0,25 °C / W



Maxwell Ultracapacitor
Type: BMOD0063 P125 B14
63 F, 125 V_{max} (=102 Wh),
60 kg, R_{ser} = 18 mΩ
3 in series: 375 V, 21 F, 54 mΩ
0.032 °C / W
375 V @ 320 A = 120 kW
222 V @ 541 A = 120 kW

	LiIon battery	**Ultracapacitor**
Cell Voltage	3.3V@600A	125 V
Current	600 A	320A=>541A
Number of Cells	61	3
Pack voltage	200 V	375 V
Pack power	**120 kW@8 s**	**120 kW@8 s**
Duty cycle	**20%**	**20%**
Pack energy	**14 kWh**	**410 Wh**
Total losses	9.76 kW	4.87 kW
Efficiency	92%	96%
DOD@80%SOC	1.91 %	375V=>222V
Cell weight	119 kg	60 kg
Pack weight	**180 kg**	**180 kg**
Cooling	water	air
Max. temp	**40 °C**	**65 °C**
Temp. Diff.	**40 °C**	**52 °C**



Source:http://www.maxwell.com/images/products/ultracapacitors/BMOD0063-6_low.jpg

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Thank you for your attention !

Questions?