Battery & Cell Development
MAN Truck & Bus AG

Sebastian Kratzer | MAN Truck & Bus AG | 01.02.2017

Agenda

1

eMobility at MAN Truck & Bus AG

Political & social drivers for eMobility

Urban

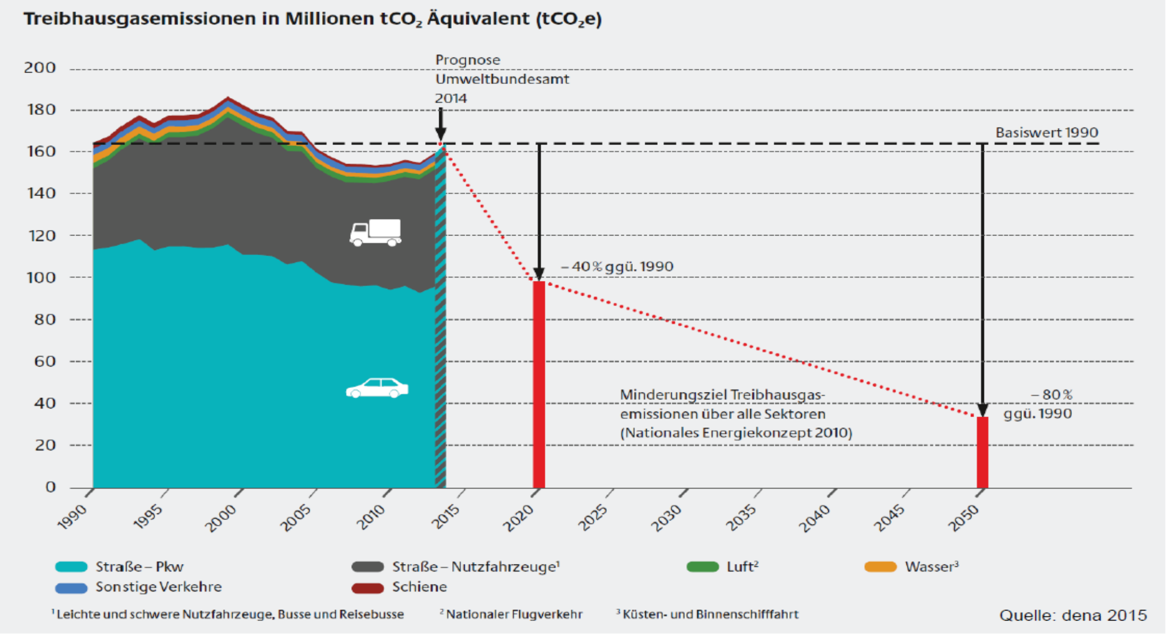
Entry restrictions / Emission
- Noise
- CO_2
- Air quality

TCO
- € / km

Inter-Urban

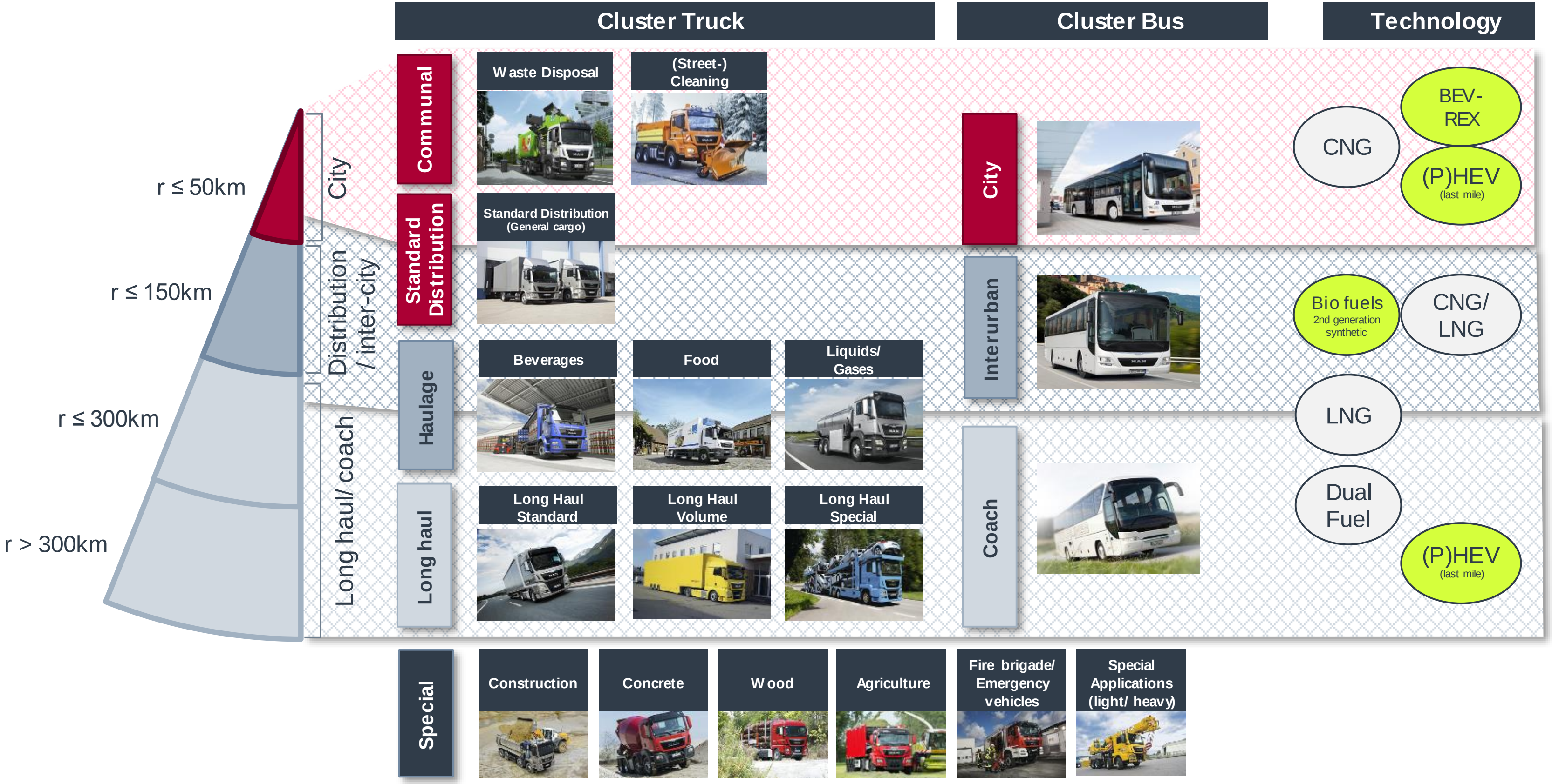
Fuel Consumption / Emission
- CO_2
- l/ km

TCO
- € / km



- Trend to **ban fossil Diesel** from cities & use of alternative fuels to reduce CO_2
- Trend to specify **full electric drivetrains** in low emission zones by 2025 latest
- **Hybrid** concepts support the reduction of CO_2 also in inter-urban applications
- **Last mile E-drive** will be required to reduce **"on the spot"** emissions and noise

MAN eMobility roadmap



2

Battery System Development

Battery System Development

Top Challenges for Commercial Vehicle eMobility

Key Facts Commercial Vehicle Market:

- Heavy vehicles (7,5t to 40t)
- High life time requirements (>1 Mio km in 10 years)
- Very high amount of vehicle variants (wheelbases, payloads, HEV, PHEV, BEV, etc.)
- Low vehicle quantities per variant (1/10 passenger cars)
- Product is only viable if there is a positive business case for the costumer (TCO >> Styling)

Challenges for eMobility / battery development:

- Big & powerful batteries required (HEV to BEV)
- Very high cycle life requirements (energy throughput)
- Drives high component diversification
- Higher part prices due to low quantities & variants
- Challenging street price targets for eMobility part costs

>> How to be successful in the early eMobility market ?!

Battery System Development

MAN Approach to face the top challenges

- Modular battery systems to face HEV to BEV applications
  - Multi-Battery system for parallel battery operation
  - Energy- & power battery system
  - Standard BMS (HW & SW)
- Usage of passenger car NMC cells

>> Low amount of HW variants

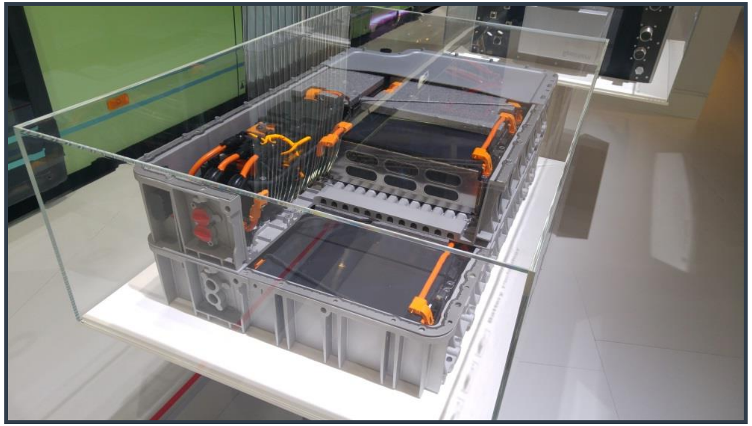
>> High flexibility in power & energy scalability

>> Low cost due to pooled quantities on cell- (VW Group) and pack level (multi battery system)

Battery System Development

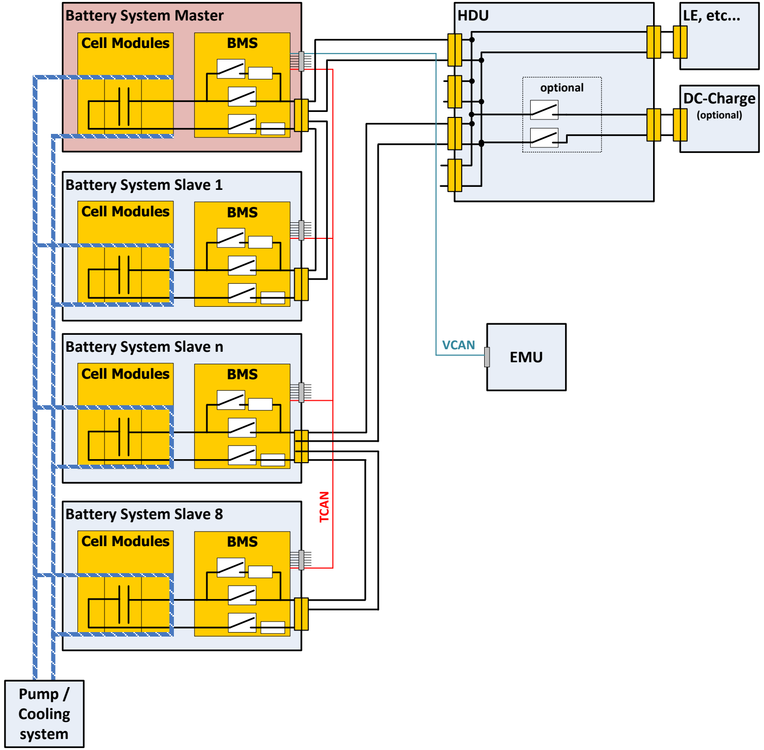
MAN High Power Battery System (IAA 2016)

Properties	Unit	Value
Cell / Module		
Form factor		Prismatic VDA PHEV2
Chemistry		NCM
Capacity	Ah	28
System		
Cell configuration		180s1p (15x 12s1p)
Enom	kWh	18,6
Voltage range	V	504 – 747
Dimensions	mm	1000x610x315
Weight	kg	230kg
Cooling		Water/Glycol
IP-Protection		IP67, IP6K9K, IxxD
Battery Management		
- Functional Safety	ISO26262	ASIL C Cell and HV-Safety
- Cell management		VW Group Cell Algorithms



Battery System Development

Multi Battery Architecture



Key Features:

- Scalable modular Energy / Power Concept
  - Modular increase power for HEV applications
  - Modular increase energy for PHEV/BEV applications
- Single battery pack management (Master)
- Active multi battery balancing
- Decentral safety architecture (Slave)

\>> No HW-Variants

\>> Stable vehicle interface, independent of application

Battery System Development

Challenges in parallel Multi Battery Systems

State Machine

- Most critical: connecting packs after driving (OCV differences)
- Managing (aggregation & deduction) of an overall valid system state in the master BMS

Sate of Function (SoF) aggregation

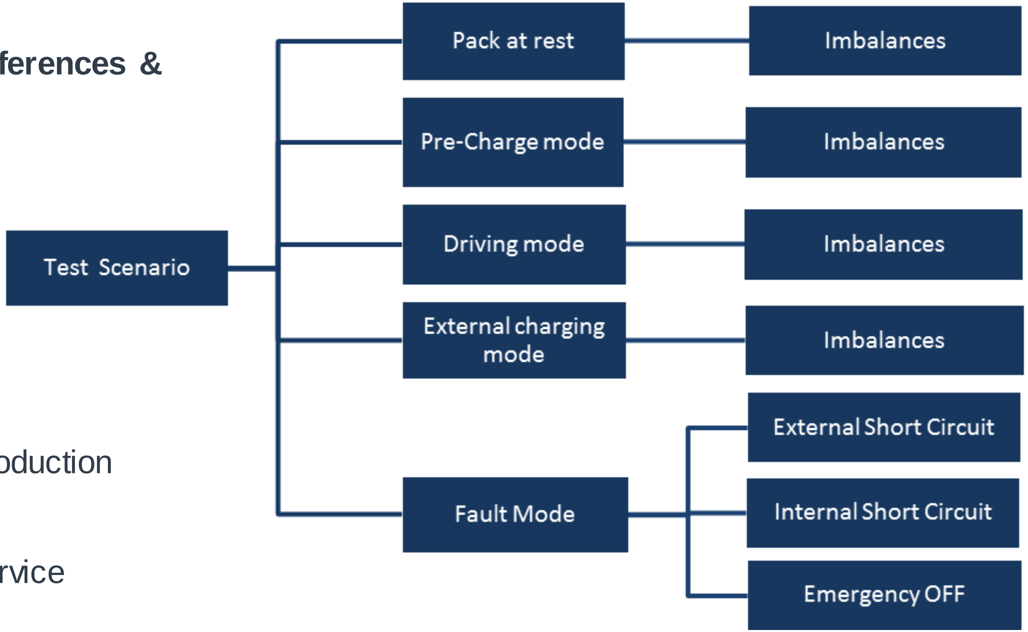
- Most critical: calculate valid current limits for the total system taking OCV and Ri differences into account
- Aggregation / Calculation of a SoF Signals in the master BMS

>> Handling of charge imbalances and equalization currents

Battery System Development

Challenges in parallel Multi Battery Systems

DoE test matrix to evaluate impact of OCV differences & equalization currents was investigated



Main imbalances to consider:

- Pack design driven imbalances:
  → e.g. Temperature distribution
- Cell design driven imbalances:
  → e.g. capacity & resistance variations in production
- Vehicle operation driven imbalances:
  → e.g. SoH differences after battery pack service

Battery System Development

Challenges in parallel Multi Battery Systems

The topic can be split into two issues

1) Build up of OCV differences due to imbalances
2) Reduction / relaxation of OCV differences

>> Issues lead to equalization currents between battery packs (driving, idle)

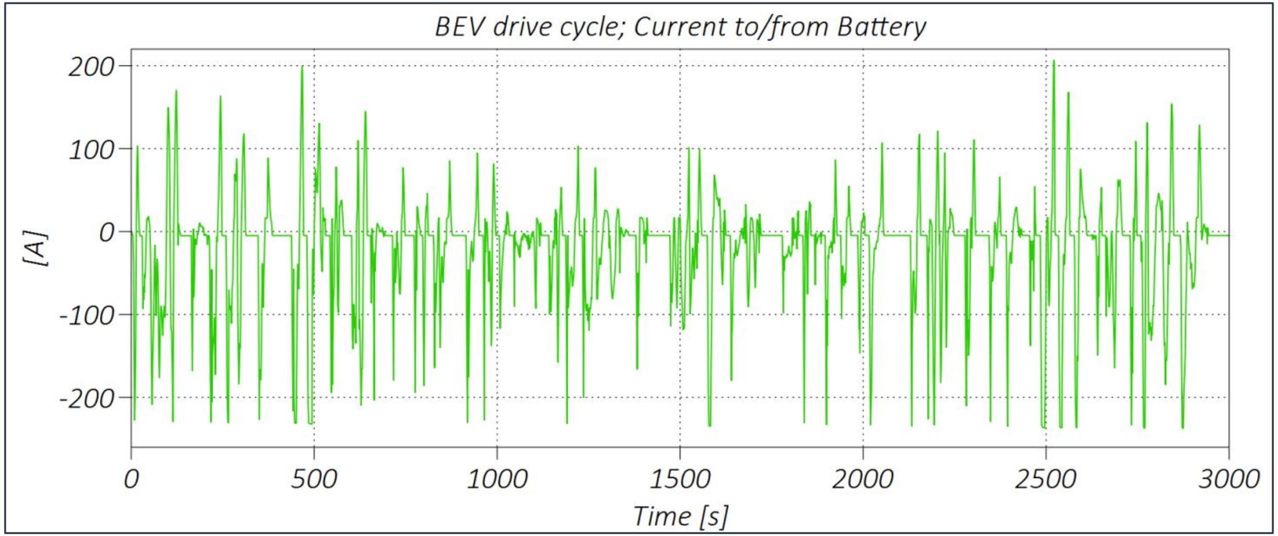
>> Issues must be addressed in BMS functionality to guarantee robust multi battery operation

Battery System Development

Challenges in parallel Multi Battery Systems

DoE test example based on MAN BEV drive cycle

Parameters	Value
Duration [s]	3000
Cell configuration	4p 180s1p
Max discharge current [A]	-237.2
Max charge current [A]	206.86
Mean current [A]	-21.34
SOC operating range [%]	70 – 53



Battery System Development

Challenges in parallel Multi Battery Systems

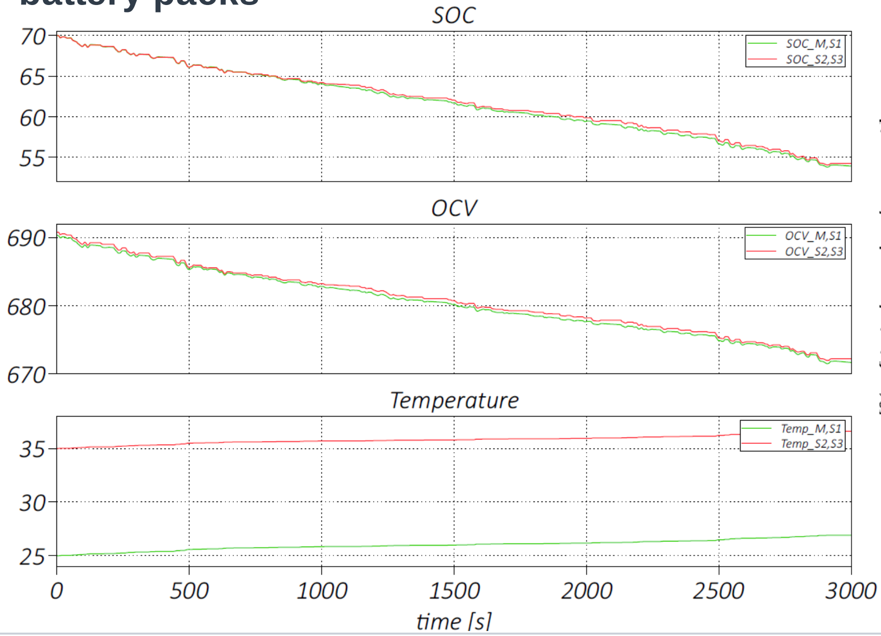
Test results for building up OCV differences while driving	ΔOCV after drive cycle
▪ Capacity deviation in cell production of +10%:	Δ0,2V OCV
▪ Internal resistance deviation in cell production of +5%	Δ0,1V OCV
▪ Cell temperature deviation of Δ10 K within all battery packs	Δ0,5V OCV
▪ 10V ΔOCV at beginning of test	+ Δ0,0V OCV
	total: Δ 0,8V OCV

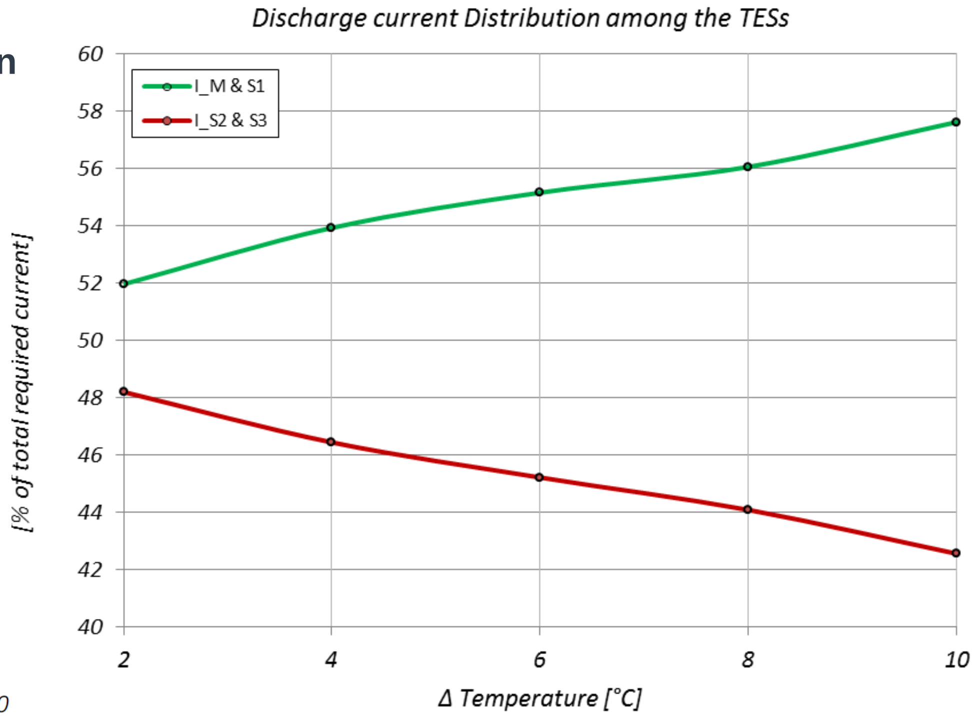
>> The impact of realistic imbalances to the multi battery system don't lead to sever system conditions (…in a "alternating" drive cycle)

Battery System Development

Challenges in parallel Multi Battery Systems

Test result of different cell temperatures between battery packs

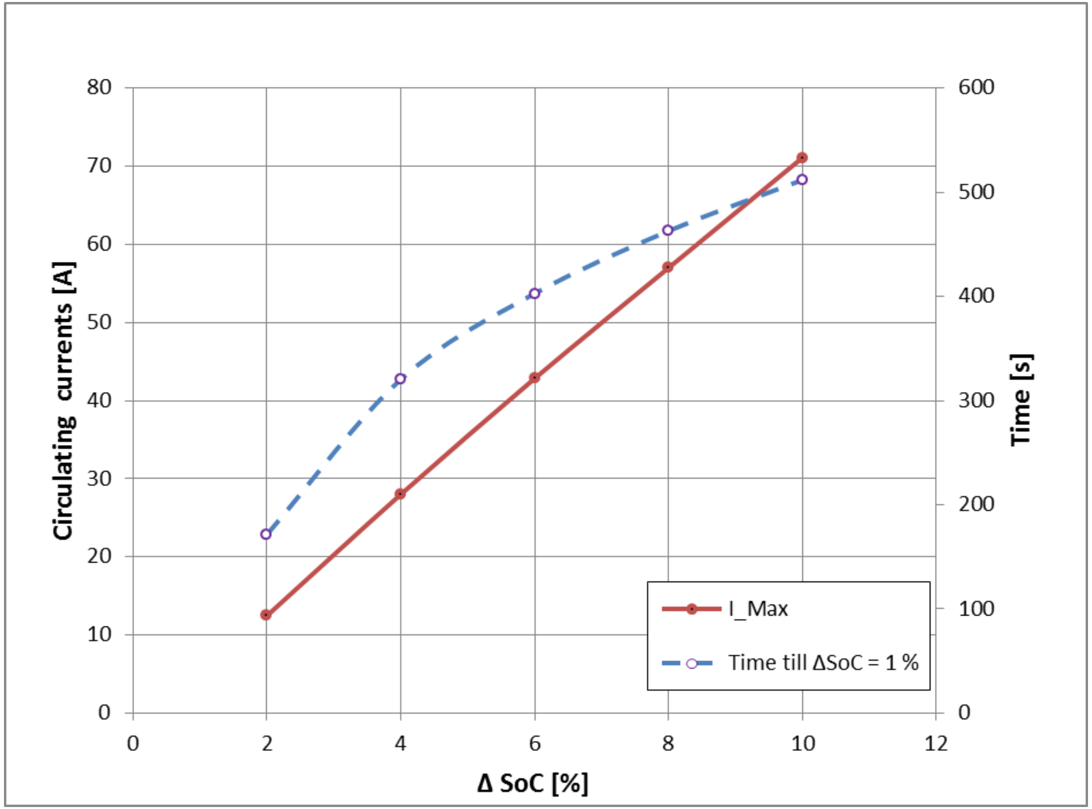




Battery System Development

Challenges in parallel Multi Battery Systems

Test results for relaxation of OCV differences while idle



>> Aspect has to be addressed in BMS development

3

Cell Development

Cell Development

Top Challenges for Commercial Vehicle eMobility

Commercial Vehicles have different cell requirements:

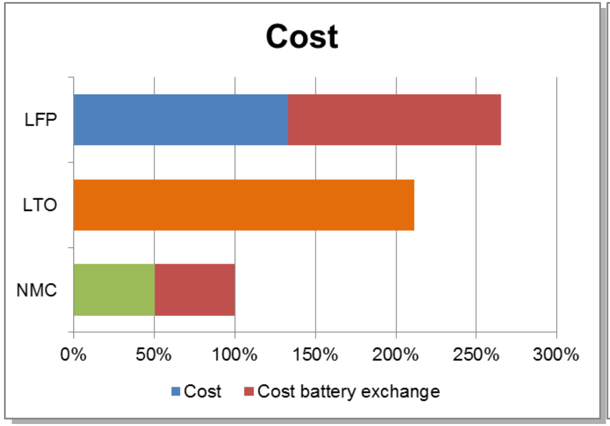
Value	Unit	Car	Truck / Bus
Life time	y	10	10 - 15
Mileage / Life time	km	160.000	Truck: 1.500.000 Bus: 800.000
Energy Throughput (P)HEV	kAh	90 - 120	500 - 900
Energy Throughput BEV	kAh	70 - 100	~ 460
Peak Current Duration	s	10	10 - 30

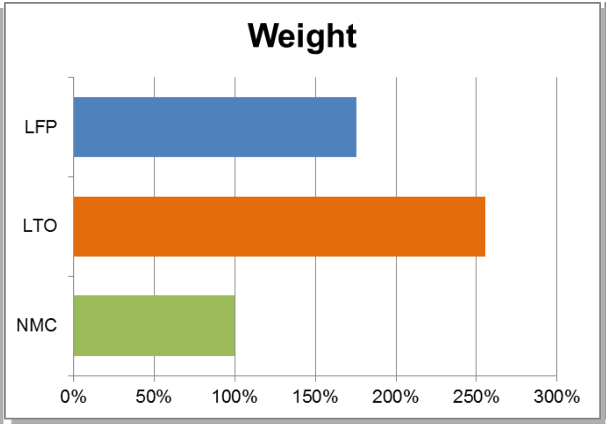
>> Key Question: What is the right cell for CV Applications ?

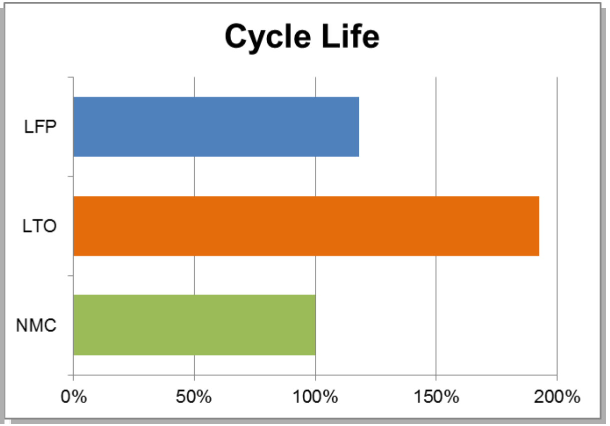
Cell Development

Chemistry cost evaluation

Comparison of different chemistries in CV application:







>> Reuse of passenger car NMC cells leads to big price advantage

>> In some applications maybe one battery exchange per vehicle life is necessary

>> MAN will use NMC for most applications due to overall cost-value ratio

Battery Cell Development

MAN High Power Battery System (IAA 2016)

Cell Data:
- Samsung 28Ah PHEV2, NCM, Prismatic
- EOL Criteria PKW: 1.600 cycle 1C/1C, 80% SOH

Cycle Profile MAN (Cell level):

TGX Long Haul HEV:

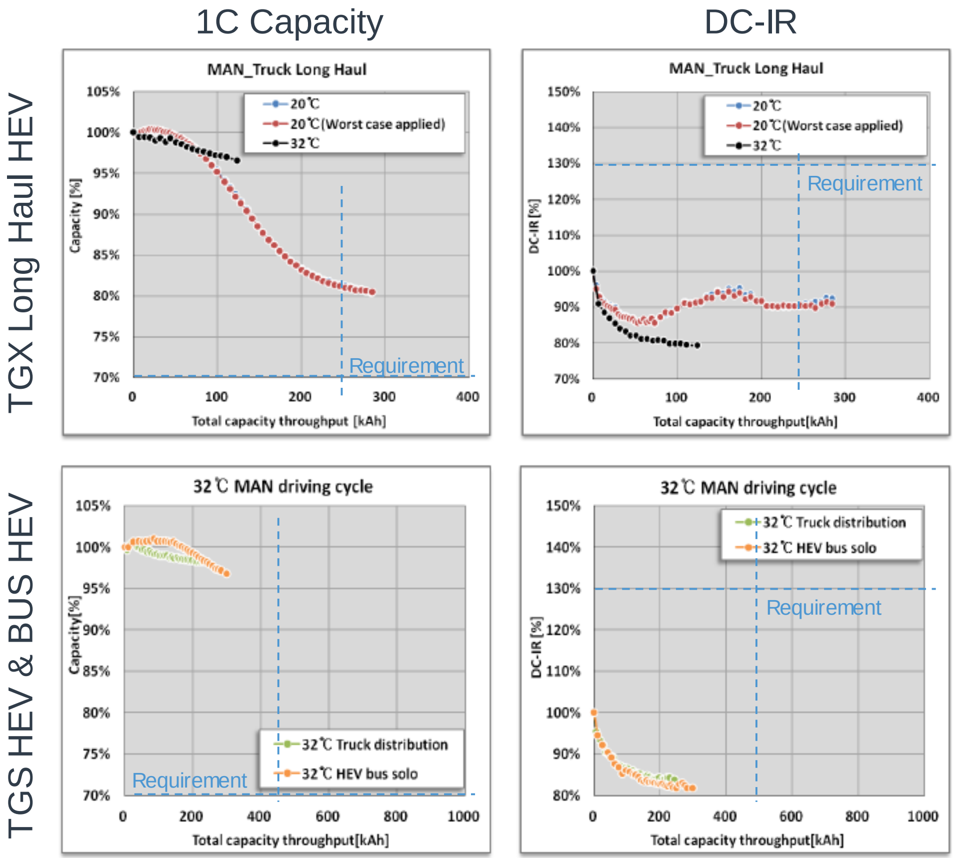
Imax (Chg/Dchg)	Irms	DOD
180/140 A	60 A	30 %

TGS Distribution HEV :

Imax (Chg/Dchg)	Irms	DOD
180/250 A	50 A	10 %

City Bus Solo HEV:

Imax (Chg/Dchg)	Irms	DOD
190/300 A	66 A	18 %



Summary

- A switch of urban public transportation (Bus) and logistic transportation (Truck) to full BEV solutions will happen quite fast in European cities → up to 50% share in 2020 to 2025
- Long range CV HEV applications will be the second solution for a long time (payload VS. energy density requirements)
- New battery system concepts are required to fit to the specifics of the CV market
- Parallel multi battery systems are feasible if done properly
- LFP is most common in CV-application at the moment (China & EU) but NMC is competitive too, especially if synergies to the passenger car components can be achieved.

Thank you for your attention