C40 CITIES FINANCE FACILITY

UNDERSTANDING ZERO-EMISSION BUS MAINTENANCE

PART 1 – INTRODUCTION TO ZEBS

Funding partners:

Federal Ministry for Economic Cooperation and Development

CIFF CHILDREN'S INVESTMENT FUND FOUNDATION

UK Government

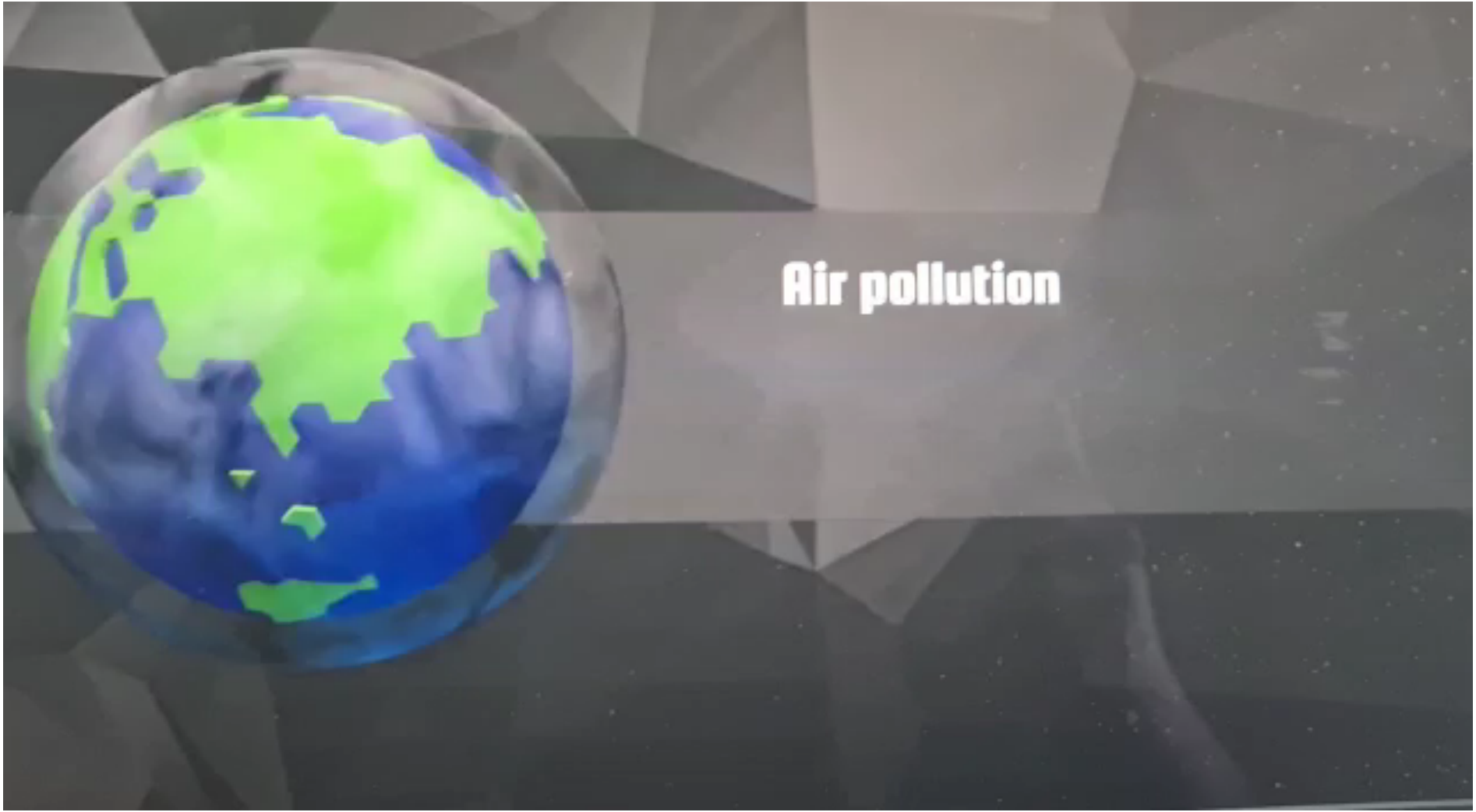
USAID FROM THE AMERICAN PEOPLE

Implementing agencies:

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

C40 CITIES

INTRODUCTION TO ELECTRIC BUSES


Air pollution

HISTORY: BATTERY POWERED VEHICLES

Late 1800 – Early 1900

- ❖Golden period for the EVs
- ❖Lead-acid powered Vehicles

By 1920

- ❖Market dominated by ICE vehicles
- ❖Long Range & High horsepower

2017 Onwards: EV30@30

- ❖Environmental Concerns
- ❖Renewed Interest In EVs

➢ **Reason for EV to ICE Transition**

- ❖ Heavy weight of batteries
- ❖ Short trip range
- ❖ Long charging time
- ❖ Poor battery life

ICE to EV Transition

Caution
Work in progress

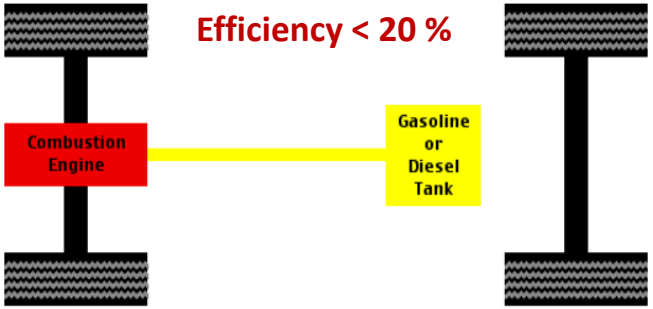
ELECTRIC BUSES AROUND THE WORLD

How does it work?

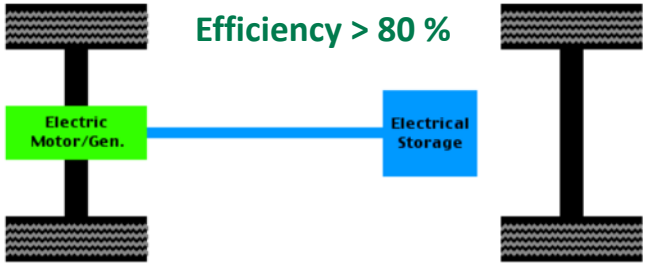
WHY ELECTRIC BUSES ?

	ENVIRONMENTAL IMPACTS				OPERATION & MAINTENANCE				CAPITAL INVESTMENTS AND O&M EXPENSES			
	Tail-pipe emissions	GHG emissions	Passengers comfort	Noise generation	Technological maturity	Autonomy	Impact on depot design	Maintenance activity	Vehicle cost	Fuel cost	Vehicle maintenance cost (Europe)	Vehicle maintenance cost (India)
Diesel	- - -	- - -	+	- - -	+ + +	+ + +	+ + +	+ +	+ + +	-	+ + +	-
Hybrid	- -	- -	+ +	- -	+ +	+ + +	+ +	+ +	+	+	-	-
CNG	-	-	+	-	+ +	+ + +	-	+ +	+ +	+ +	+ +	+
H_2 Fuel cell	+ + +	+	+ + +	+ +	-	+ + +	-	+ +	- -	- -	- -	N/A
Electric	+ + +	+	+ + +	+ +	+	+ +	-	+ + +	-	+ + +	+	+ + +

PERFORMANCE: EV VERSUS ICE VEHICLE

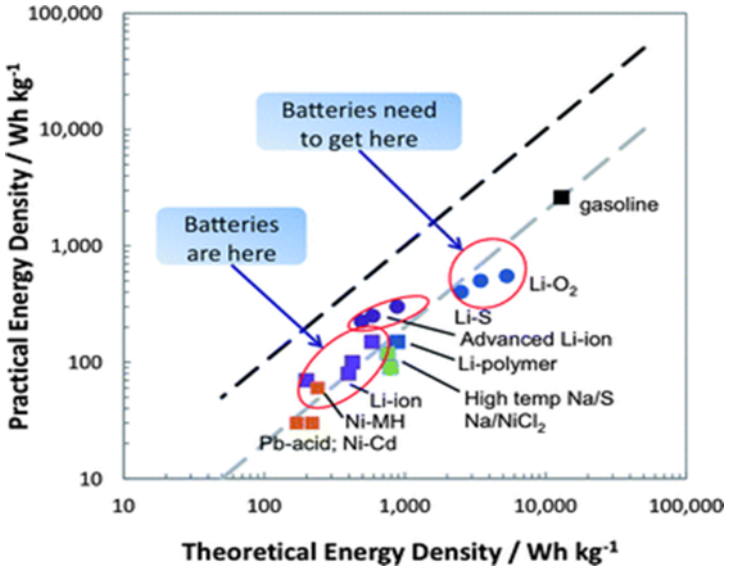


Stored Energy in Gasoline ~ 48 MJ/kg



Stored Energy in Battery ~ 0.4 MJ/kg

- Efficiency of EV is 5 to 6 times higher than that of ICE (Internal Combustion Engine) vehicles
- Gasoline is 100 times more energy dense than a battery

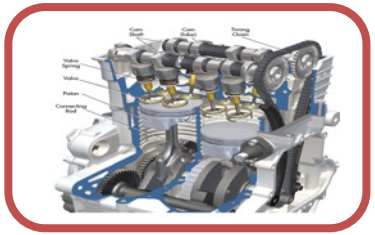


Source: ***Energy Environ. Sci.***, 2012,**5**, 7854; http://www.altfuels.org/backgrnd/altdrive.shtml; https://www.aps.org/publications/apsnews/201208/backpage.cfm

BATTERY: COMPLEX FUEL TANK

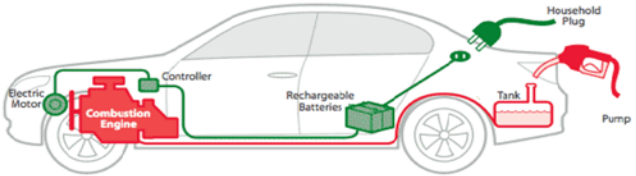
Gasoline Powertrain

- More Complex
- > 20,000 moving parts
- High Maintenance Cost



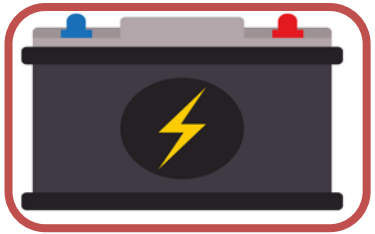
Simple Fuel Tank

Petrol / Diesel



Electric Powertrain

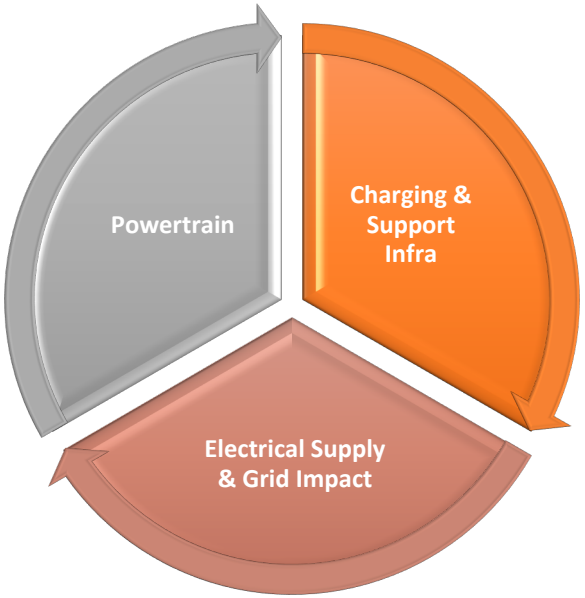
- Less Complex
- < 20 moving parts
- Low Maintenance Cost



Complex Fuel Tank

http://www.circuitstoday.com/working-of-electric-cars; Images from Web

BUS TECHNOLOGY



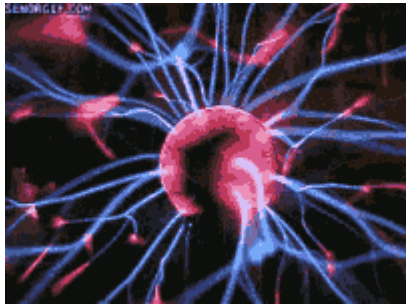
- Range & Routes

- Operational
- Schedule

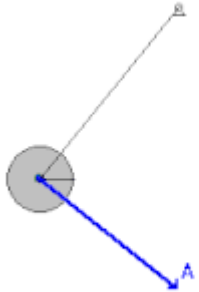
- Energy Demand
- & Supply

- Energy Access

ELECTRIC POWERTRAIN

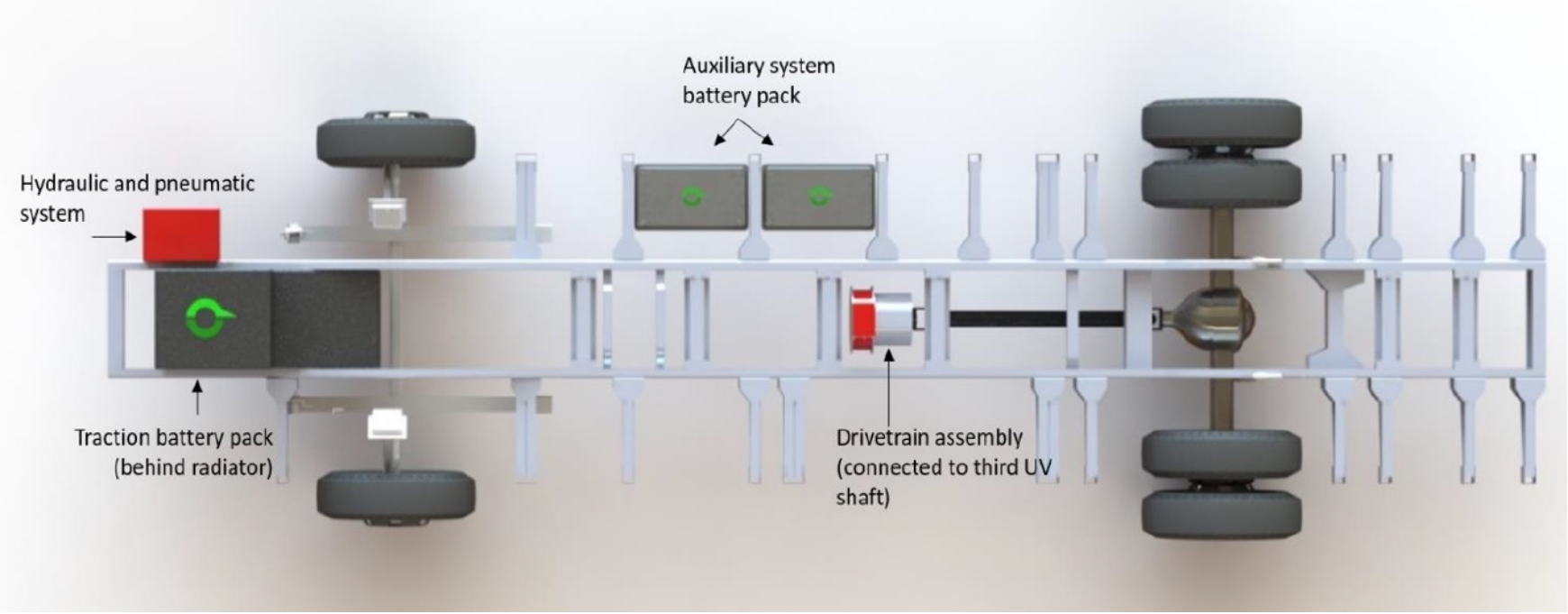


Electrical Energy

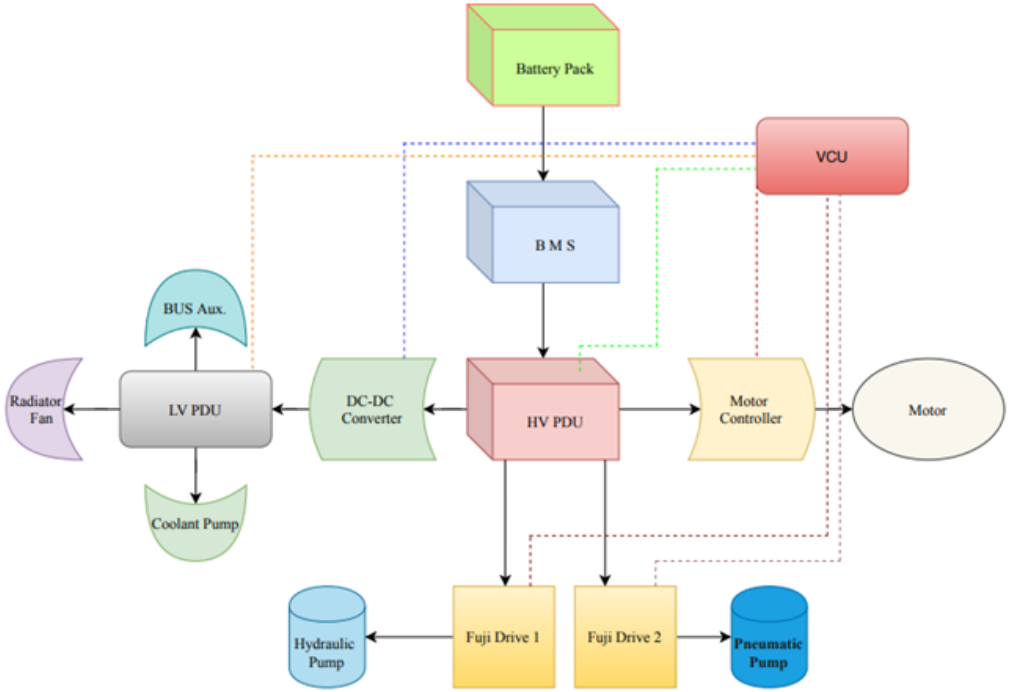


Mechanical Energy

POWER TRAIN DESIGN



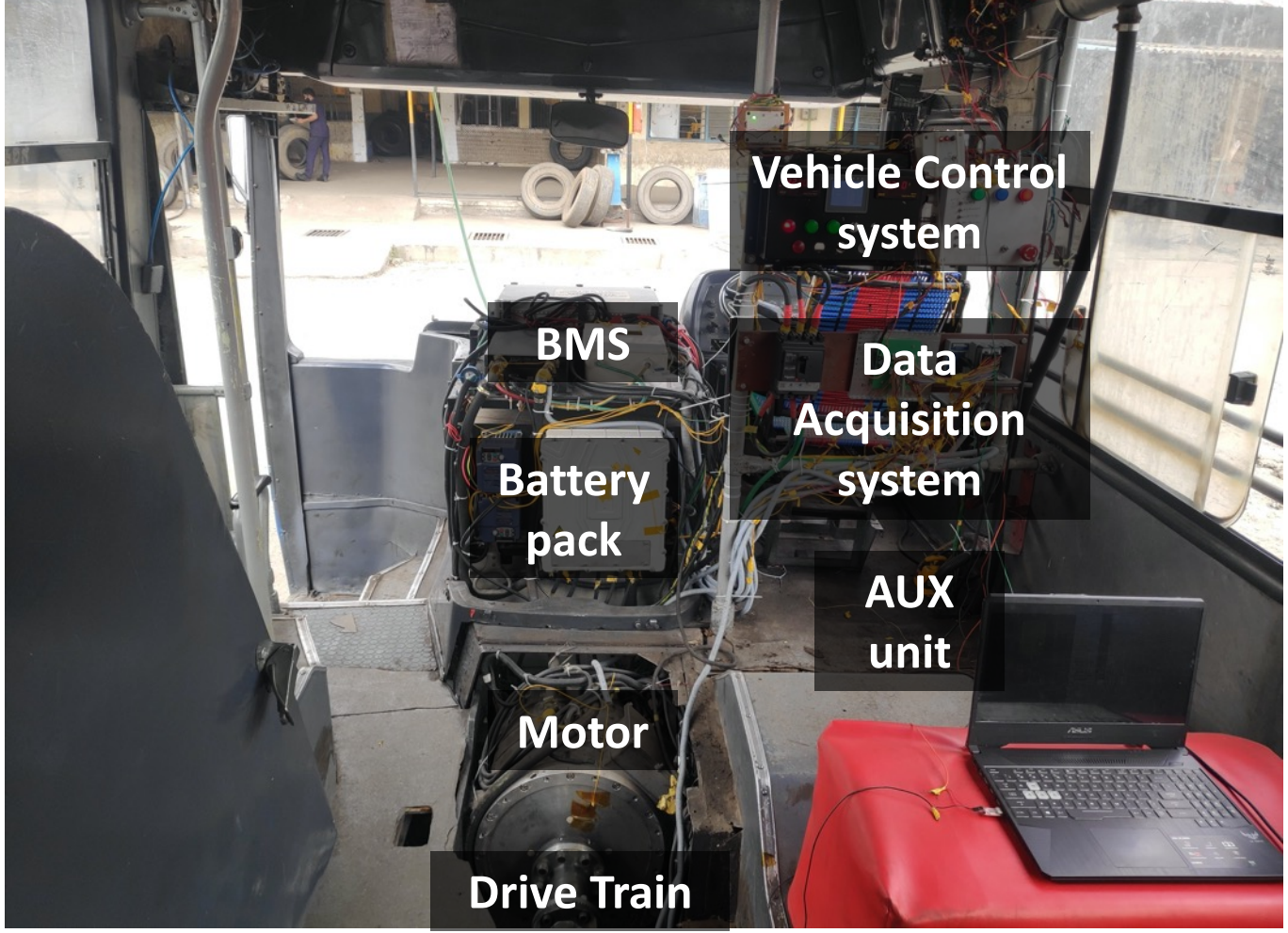
POWER TRAIN SCHEMATIC



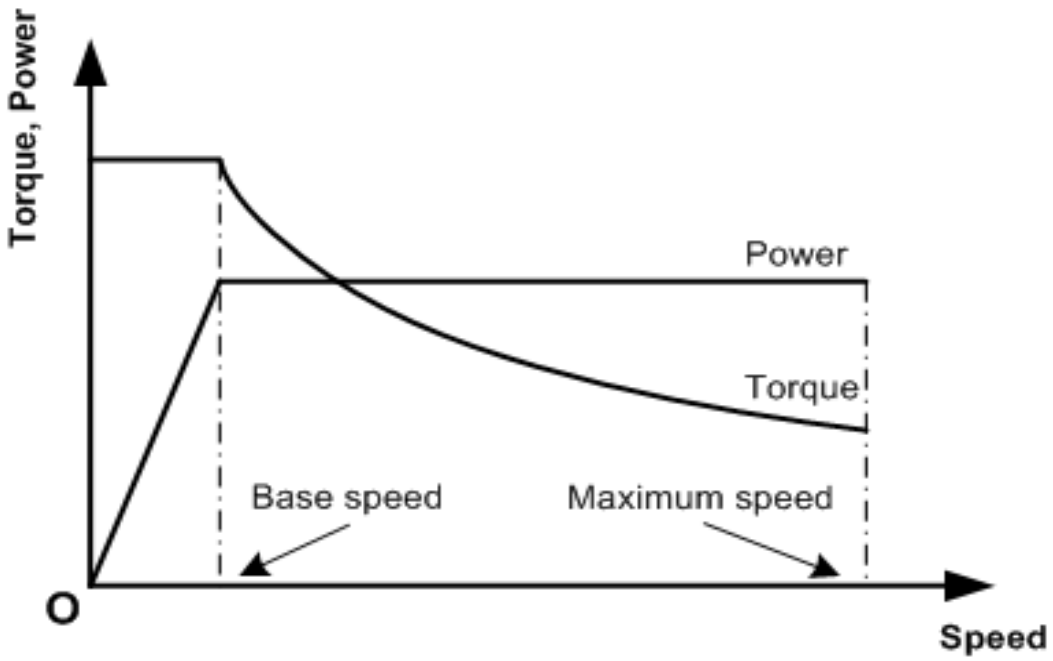
Major Components of Power Train

1. Battery Pack
2. Battery Management System
3. Traction Motor
4. Motor Controller
5. HV Power Distribution Unit
6. LV Power Distribution Unit
7. DC-DC Convertor
8. Vehicle Control Unit
9. Pneumatic System
10. Hydraulic System
11. Cooling System
12. Bus Aux unit
    - Compressor motor -> Compressor
    - Steering motor -> Steering
13. Lighting & Horn

POWER TRAIN COMPONENTS

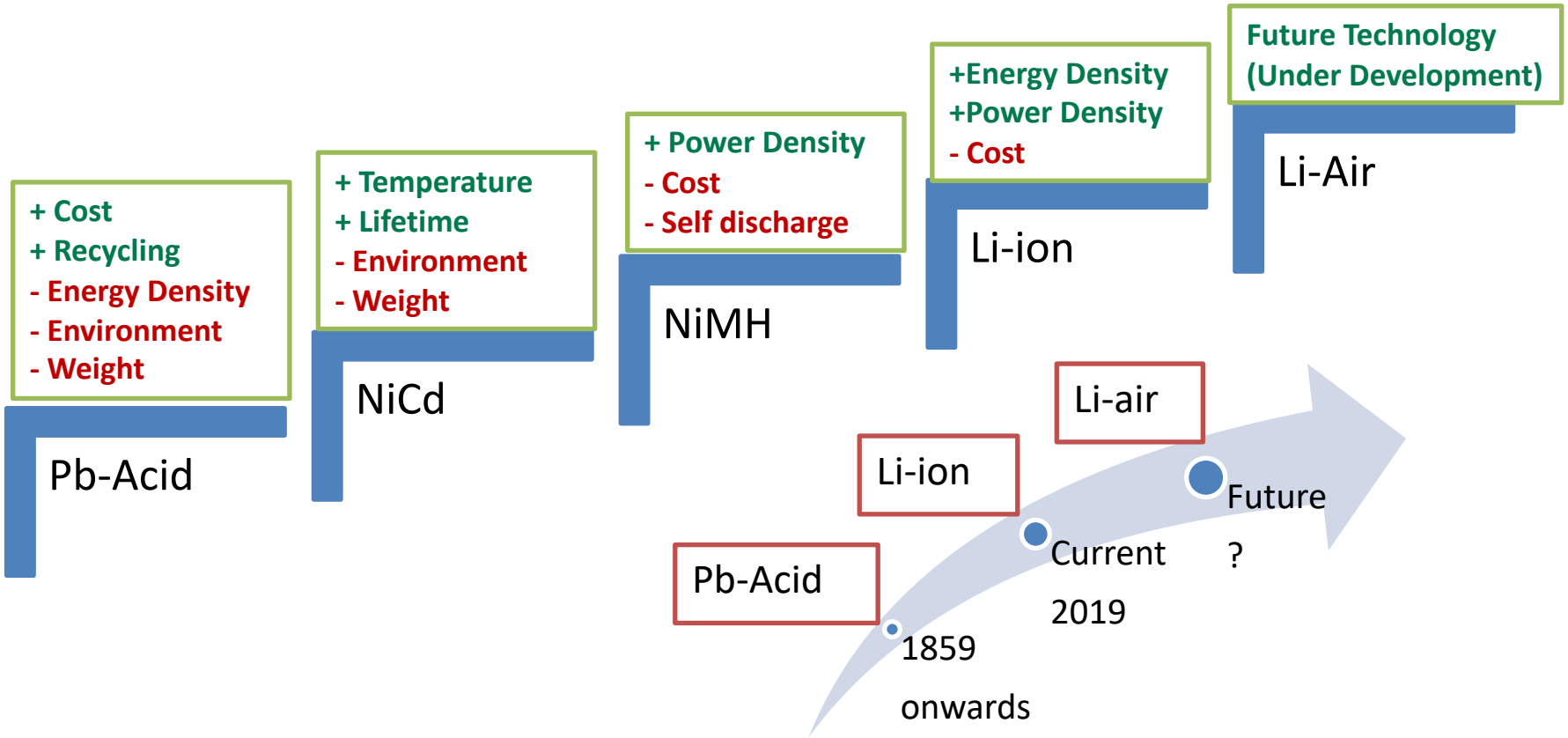


DESIRED OUTPUT OF ELECTRIC MOTOR DRIVE



- EV motor drive is expected to be capable of offering a high torque at low speed for starting and acceleration,
- And a high power at high speed for cruising.
- At the same time as wide as possible speed range, under constant power, is desired

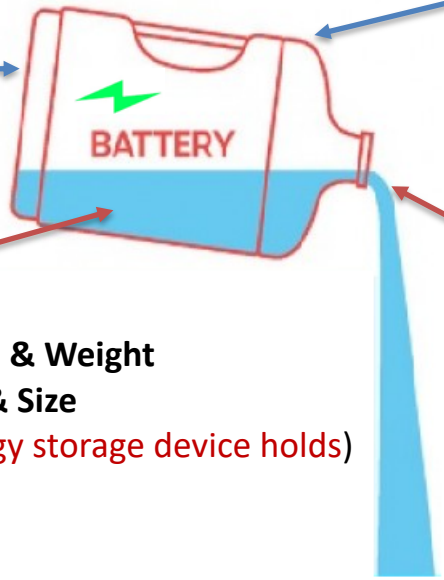
BATTERIES USED IN EVS



UNDERSTANDING PERFORMANCE INDICATORS

Environmental impact → Battery material and recycling potential

Pb-acid / Ni-Cd / NiMH / LIB



Safety

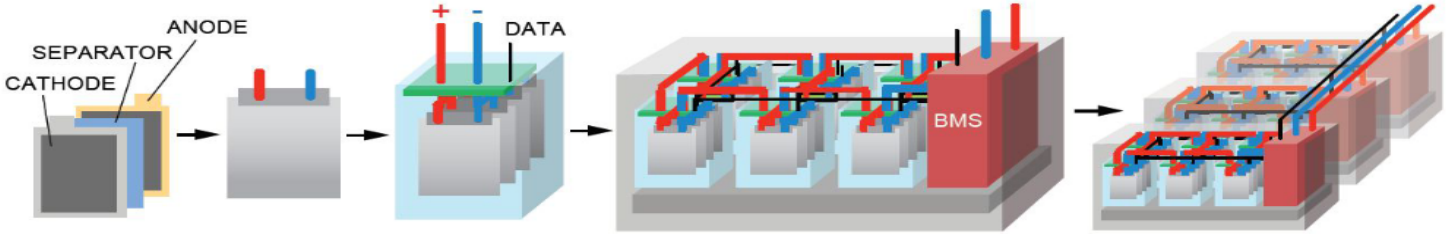
Cost

Battery Life

Specific Energy (Wh/kg) – Range & Weight
Energy Density (Wh/l) – Range & Size
(Total amount of energy an energy storage device holds)

Specific Discharge Power (W/kg) – Acceleration & Weight
Discharge Power Density (W/l) – Acceleration & Size
(Speed at which the power can be discharged)

INSIDE LIB BATTERY



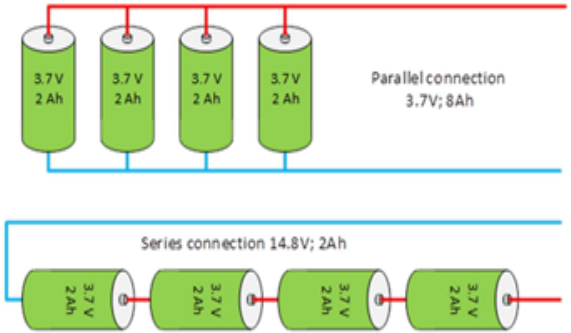
MONO-CELL
- BASIC CELL CHEMISTRY
- BASIC VOLTAGE LEVEL

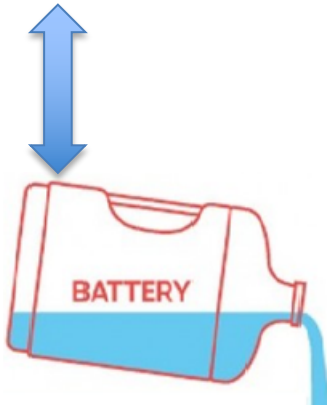
CELL
- STACK OF (e.g., 20) MONO-CELLS CONNECTED IN PARALLEL

MODULE
- MANY CELLS IN SERIES

BATTERY PACK
- SEVERAL MODULES OR
- MANY CELLS
- VOLTAGE: 400 V

BATTERY SYSTEM
- SEVERAL BATTERY PACKS IN PARALLEL
- ENERGY: >15 KWH

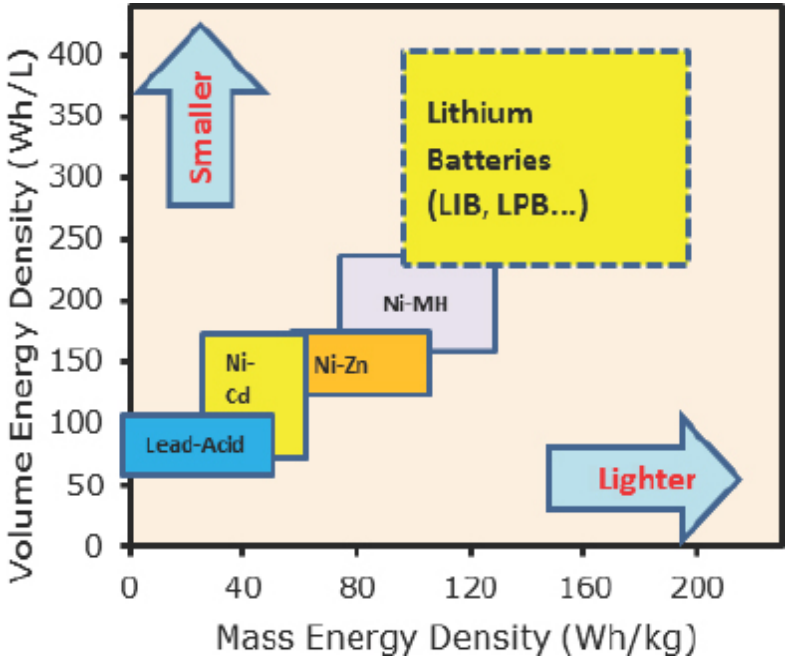


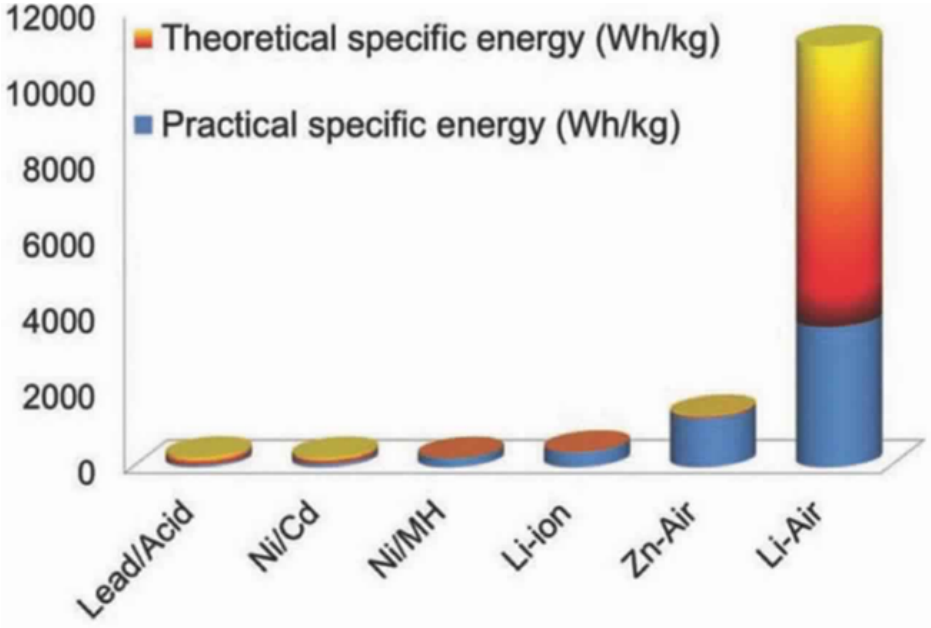


https://brandogsikring.dk/files/Pdf/FogU/Project%20BLUE%20BATTERY%20-%20Part%20I.pdf

WHY LIB FOR EVS?

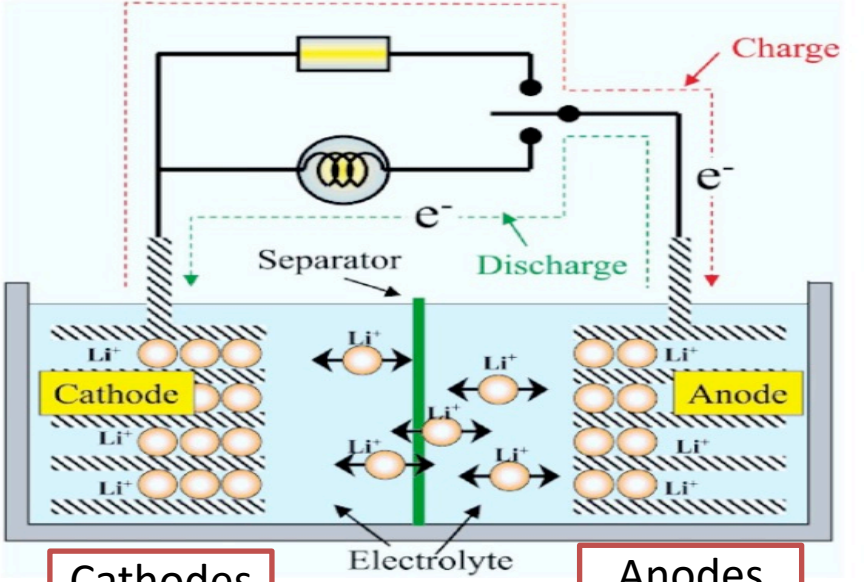
Key Performance Requirements: High Energy Density, Long Cycle Life, Light Weight, Small Size





https://www.sciencedirect.com/science/article/pii/S1369702114000741; Others from Web

UNDERSTANDING LIB

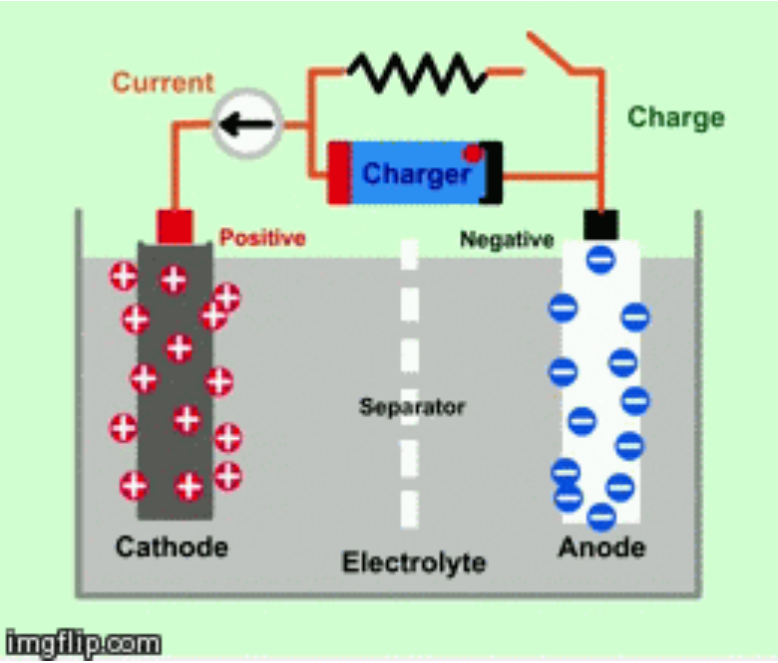


Cathodes

LCO/ NCA/ NMC/ LMO/ LFP

Anodes

Graphite/ LTO



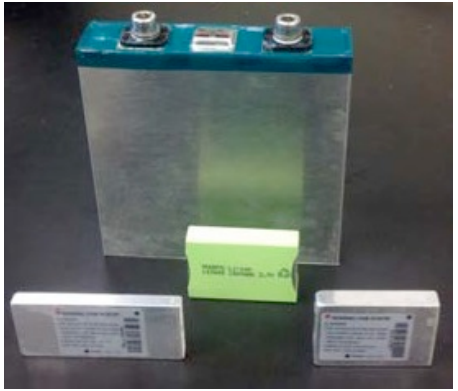
GIF: https://gifer.com/en/LCEZ; Other images from Web

TYPES OF CELLS

Different form factors for Li-ion cells

Cylindrical cells

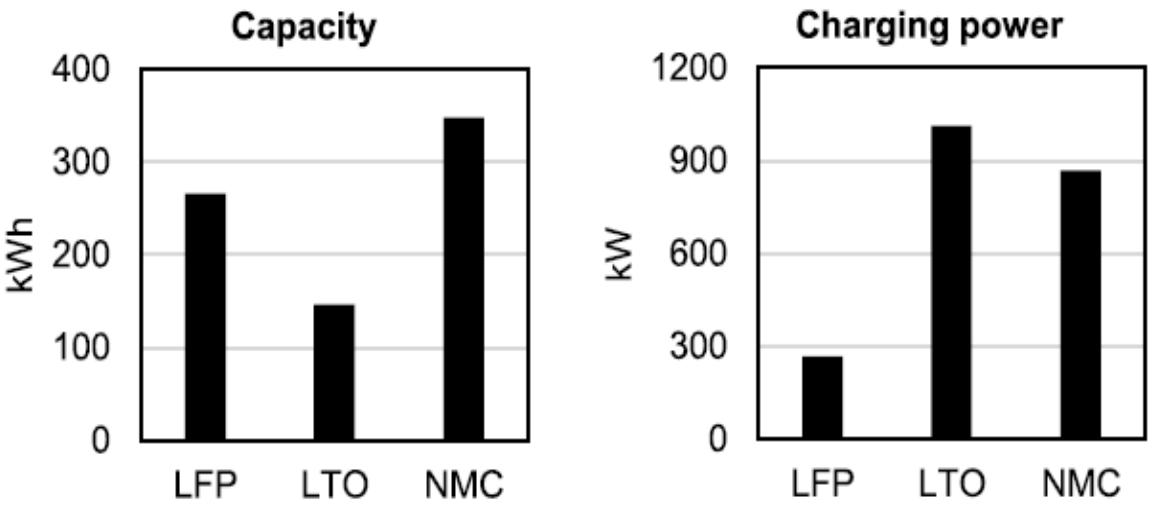
Prismatic cells



Pouch cells

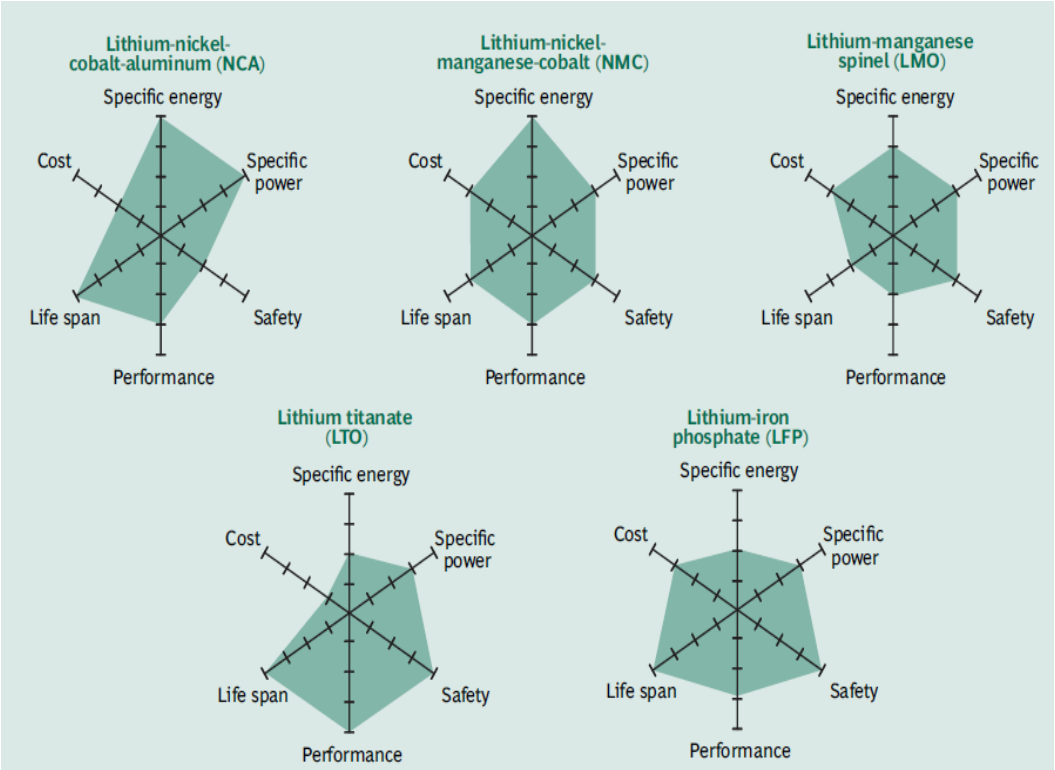
LIB VARIANTS

- Three Chemistries for Buses- LFP, LTO & NMC



Source: Göhlich, Dietmar & Fay, Tu-Anh & Jefferies, Dominic & Lauth, Enrico & Kunith, Alexander & Zhang, Xudong. (2018). Design of urban electric bus systems. Design Science. 4. 10.1017/dsj.2018.10`

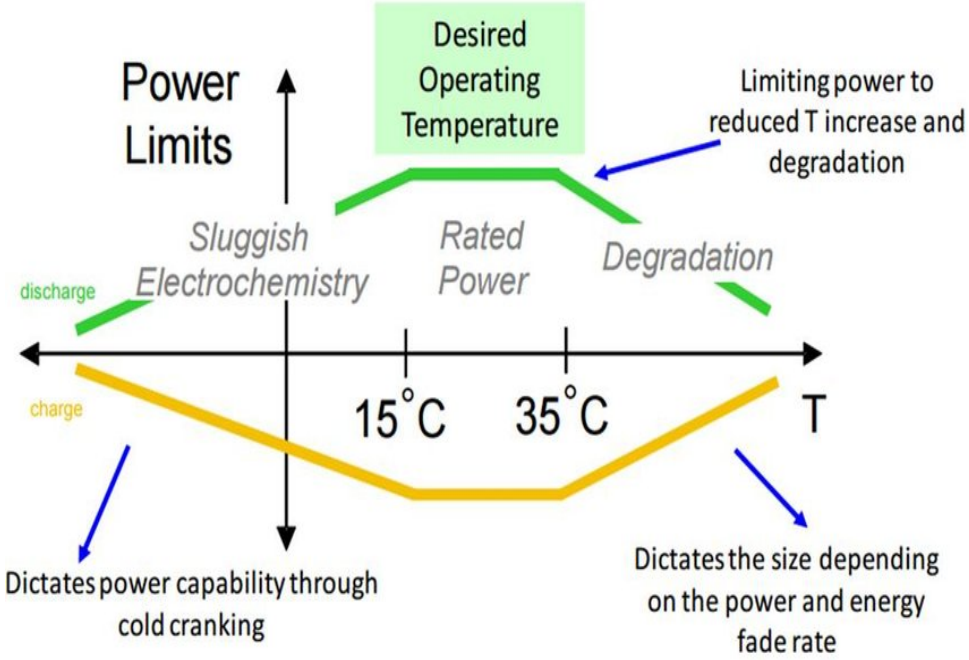
LIB VARIANTS: KEY PERFORMANCE PARAMETERS

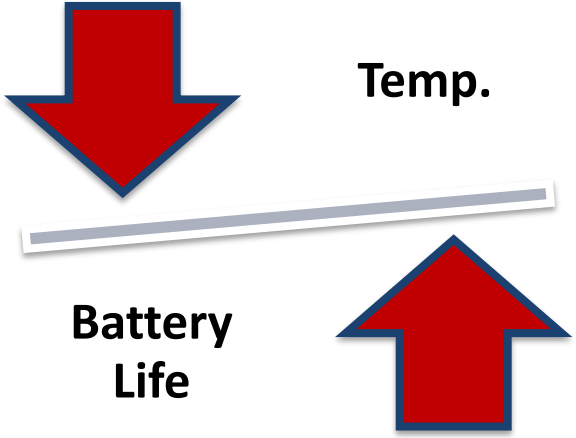


Balancing key performance parameters involves managing many trade-offs

https://www.greencarcongress.com/2010/01/bcg-20100108.html

LIB: EFFECT OF TEMPERATURE



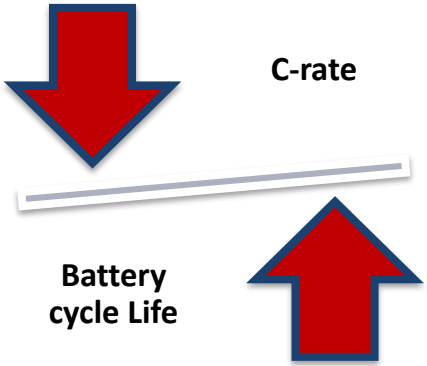


https://www.sciencedirect.com/science/article/pii/S1364032116301435

LIB: CHARGE RATE

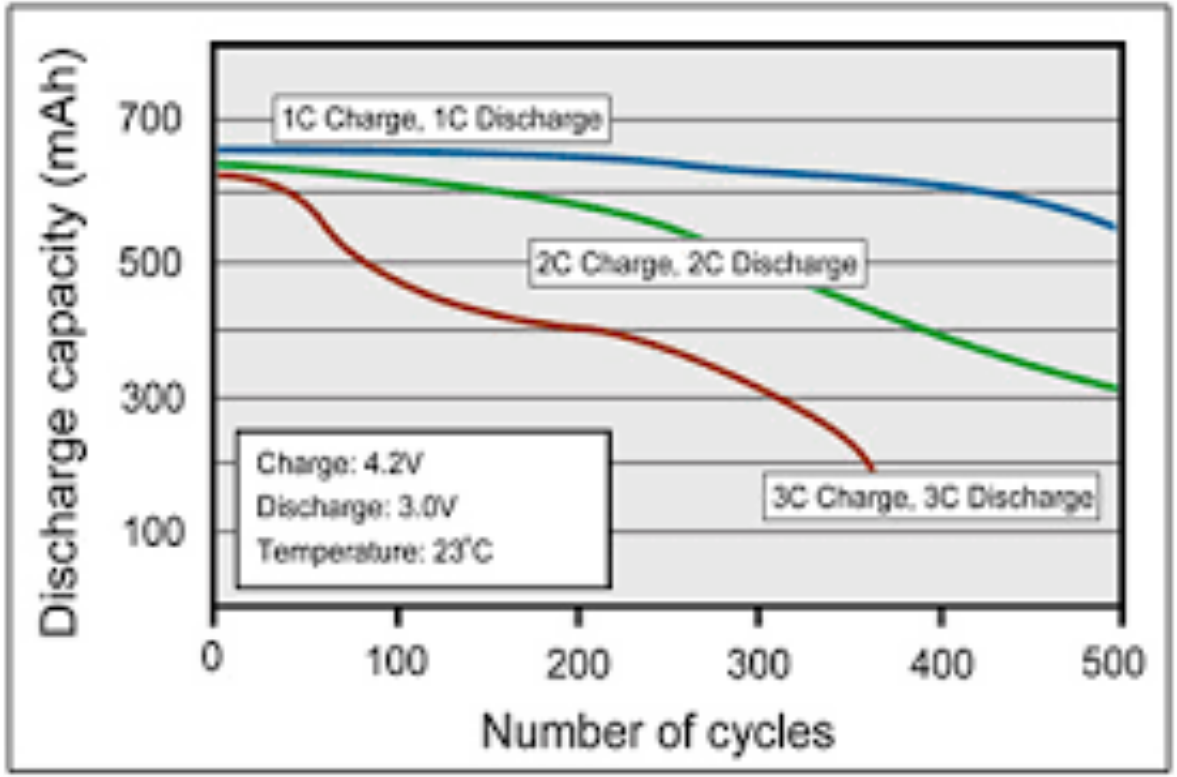
C-rate : Rate at which battery is charged / discharged

SOC : State of Charge (SoC) describes how full a battery is



https://batteryuniversity.com/learn/article/ultra_fast_chargers; https://modernsurvivalblog.com/alternative-energy/lithium-iron-phosphate-battery-cycles/; https://solarbuildermag.com/energy-storage/know-your-battery-specs-nameplate-capacity-10-kwh-vs-usable-capacity-7-kwh/

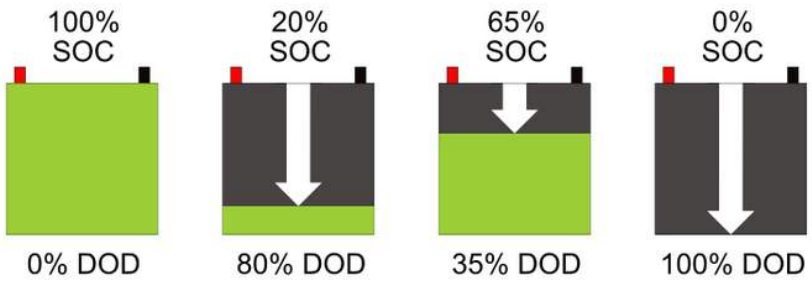
LIB: CHARGE RATE

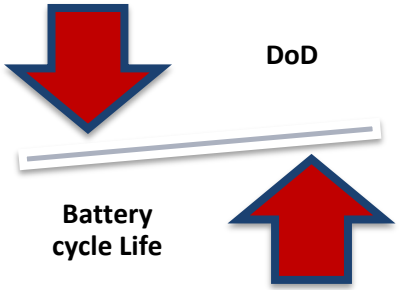


https://batteryuniversity.com/learn/article/ultra_fast_chargers; https://modernsurvivalblog.com/alternative-energy/lithium-iron-phosphate-battery-cycles/; https://solarbuildermag.com/energy-storage/know-your-battery-specs-nameplate-capacity-10-kwh-vs-usable-capacity-7-kwh/

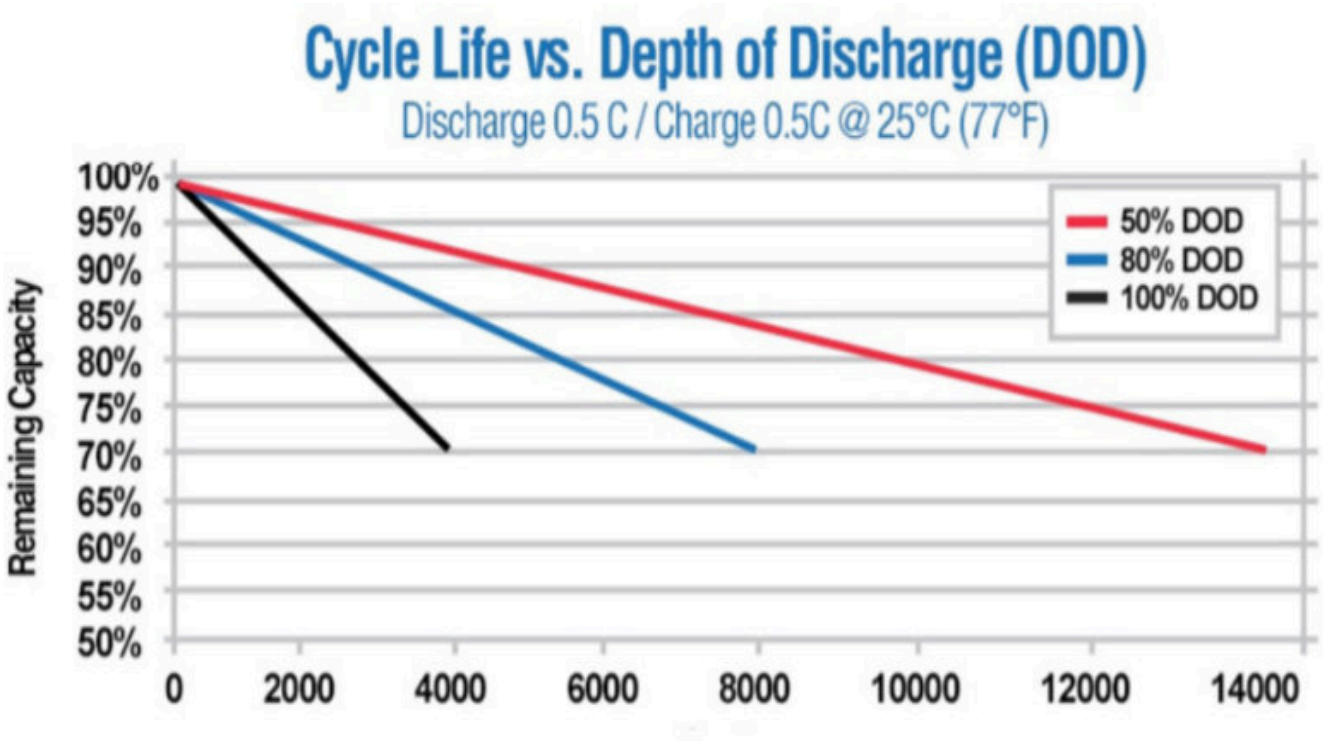
LIB: DEPTH OF DISCHARGE

DoD : **Depth of Discharge (DoD) measures how much of stored energy is used at each cycle**





LIB: EFFECT CHARGE RATE & DOD



https://ba
iron-phos
10-kwh-vs-usable-capacity-7-kwh/

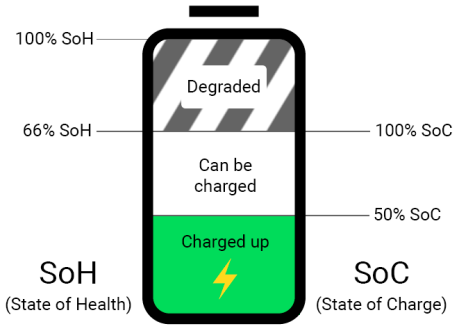
LIB: STATE OF HEALTH

SOH Indicates

- Performance of the battery
- Useful lifetime of the battery consumed

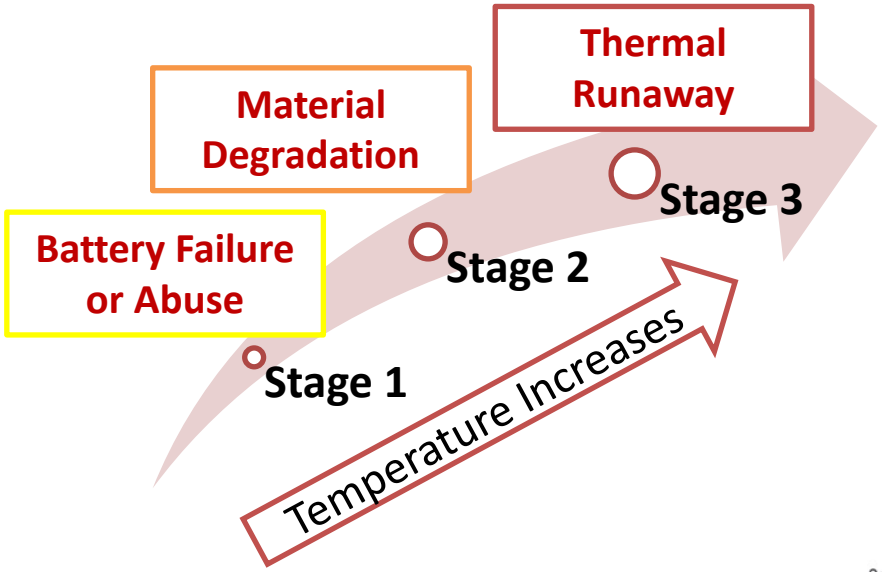
Any Arbitrary parameter defined by the Battery Management System

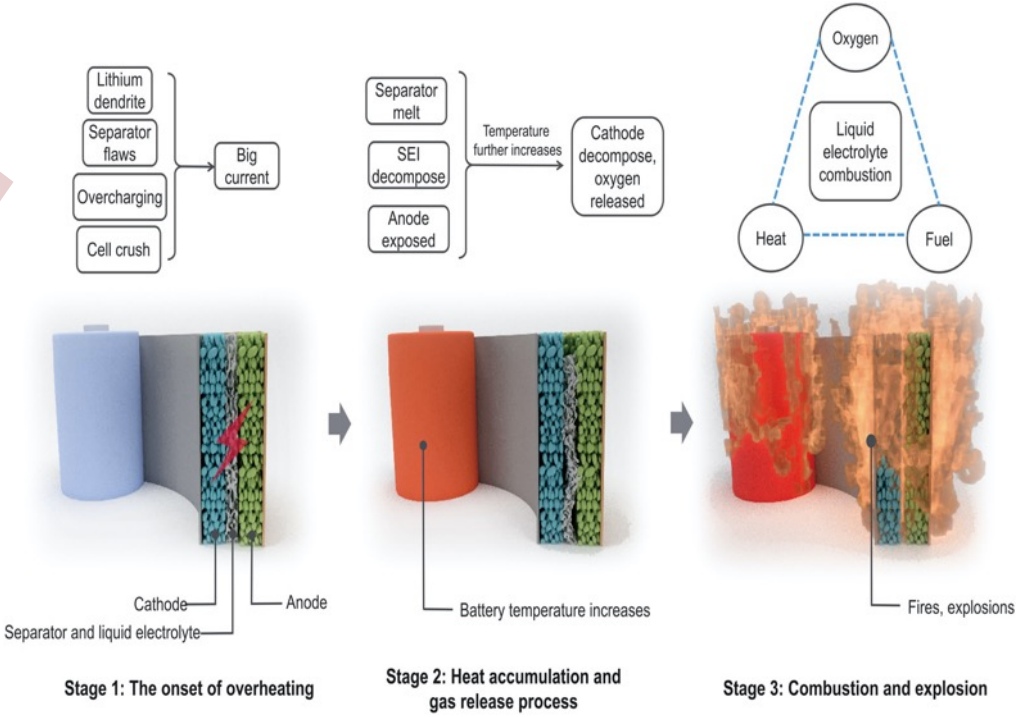
- Internal resistance / impedance / conductance
- Capacity
- Voltage[2]
- Self-discharge
- Ability to accept a charge
- Number of charge–discharge cycles
- Age of the battery
- Temperature of battery during its previous uses
- Total energy charged and discharged



SOH does not correspond to one physical parameter but a combination !

LIB SAFETY: THERMAL RUNAWAY

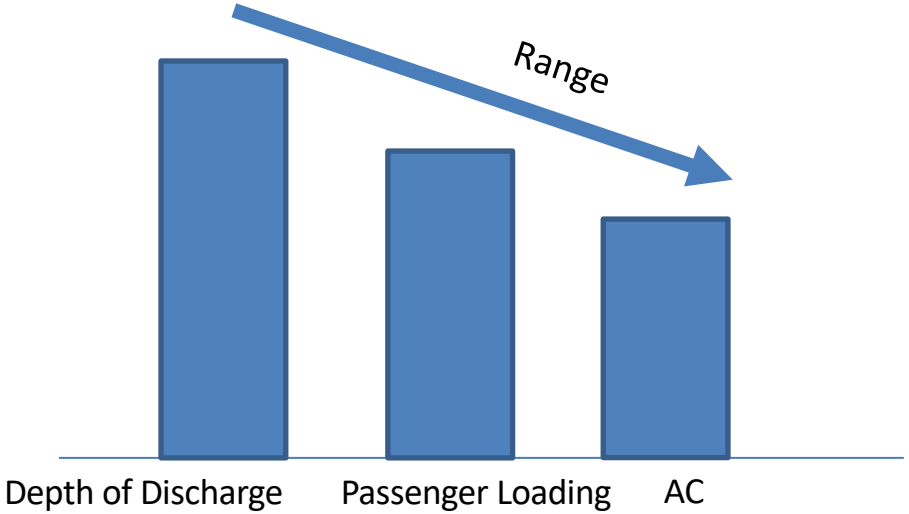




Battery Management System (**BMS**) – To monitor and protect Li-ion battery during operation

https://advances.sciencemag.org/content/4/6/eaas9820.full;

BATTERY PERFORMANCE VS RANGE



Reduction in Range	Factor to be used
Maintain 80 % depth of discharge	0.8
100 % passenger loading	0.85
AC Bus	0.92

DC SERIES MOTOR

- Motor is capable of producing high initial torque.
- The easy speed control and sudden load increase bearing capacity make these motors a good choice.
- But the high maintenance due to the brushes and commutators is a major drawback

BRUSHLESS DC MOTOR (BLDC)

- High starting torque, high efficiency and low maintenance
- Used as Hub motors or belt driven
- Permanent magnets are used

Brushless DC Motor (BLDC)

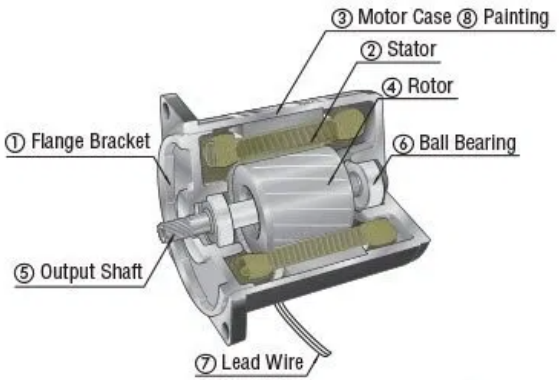
PERMANENT MAGNET SYNCHRONOUS MOTOR

- Similar in construction to the BLDCs.
- But the major difference is in the back emf.
- PMSM has a sinusoidal back emf whereas BLDC has trapezoidal one.
- They have a high power rating and can be used in high-performance applications such as buses

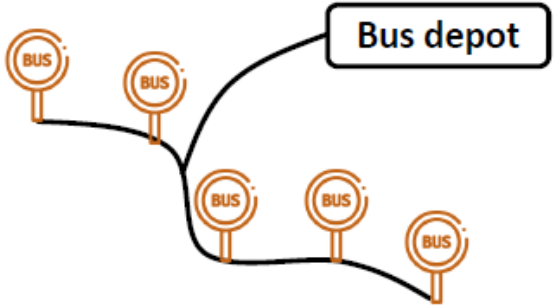
THREE PHASE INDUCTION MOTOR

- Induction motors don’t have a high starting torque.
- It is cheap as compared to the other available options.
- Very high efficiency and can withstand rugged environmental conditions.
- Tesla Model S uses this type of motor

Three Phase Induction Motor

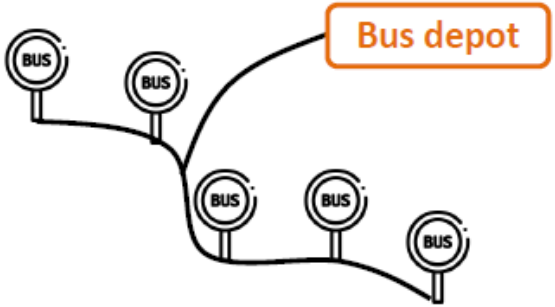


CHARGING TYPES



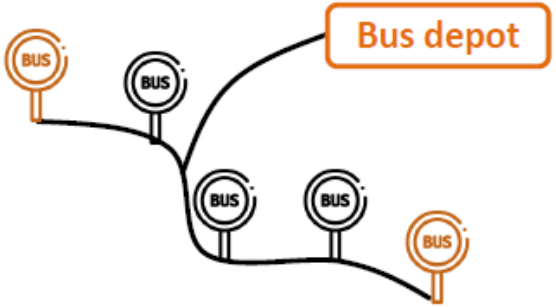
Opportunity charging

- Recharging is enough for a one-way trip or less
- Recharging at bus stops and/or at bus terminals
- Little impact on bus operation



Depot charging

- Recharging is enough for several hours / plural round-trips
- Recharging overnight (usually)
- May have some impact on bus operation (autonomy)



Mixed charging

- Recharging at bus terminals during operation hours and at bus depots (usually at night) for full battery charge
- 2 battery technologies may be required (adapted recharge performance)
- Little impact on bus operation

CHARGING TYPE

Depot Charging Only/Slow Charging	Depot Charging + Opportunity Charging
Lesser cost of charging infrastructure	Need additional charging infrastructure. Cost may go up.
May need extra fleet to cover along high demand corridors	Adherence to service schedules with lesser fleet size
High upfront cost due to large battery	Lower battery size can be used resulting in lower bus cost

HARGERS


650mm
1850mm
400mm
900mm
EVA080K


POWER CONTROL SYSTEM
PROTERRA
125
V2G
125 kW PCS
CHARGING DISPENSERS


heltox


FB 73

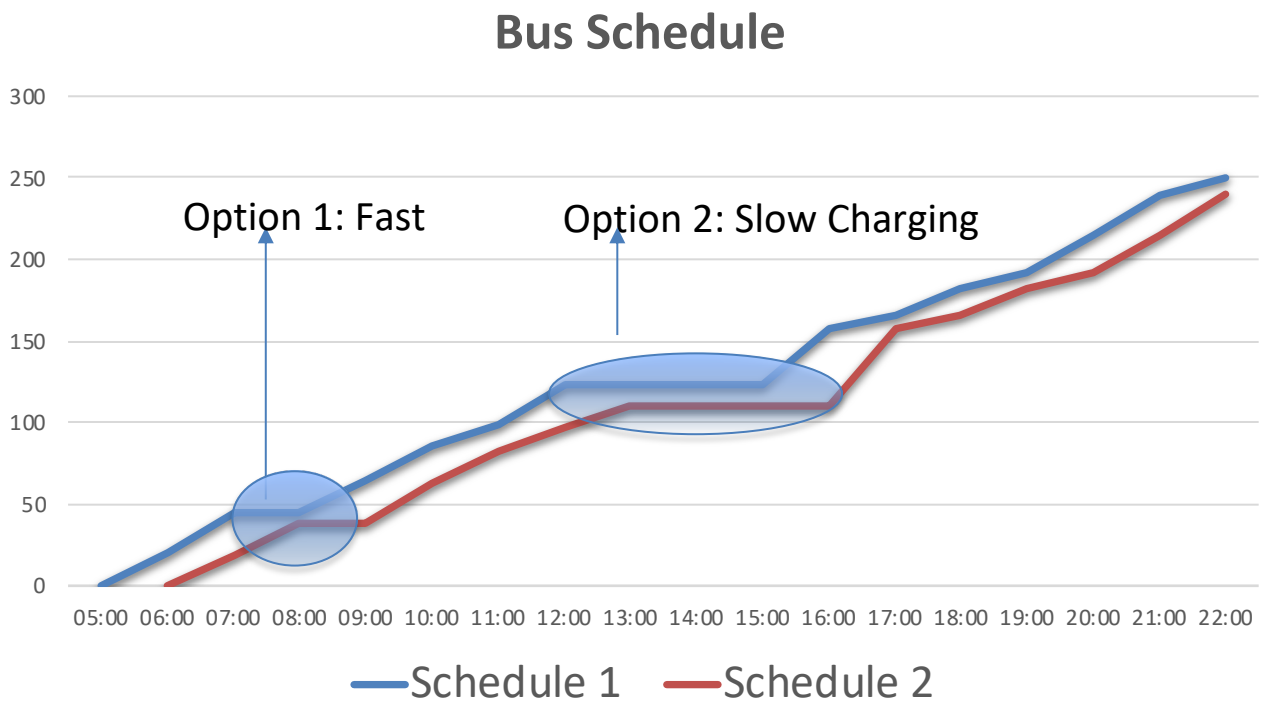
TYPES OF CHARGERS

- **Slow charging with a charging power of less than 50 kW (20 – 50 kW), and**
- **Fast charging with a charging power of 50-150 kW**
- **Ultra Fast Charging with a charging power >150 kW**

CHARGING STANDARDS

- The Japanese CHAdeMO standard,
- The European Combined Charging Standard (CCS), which is also applied in North America, and
- The Chinese GB/T standard or protocol.

CHARGING STRATEGIES



CITY BUS ELECTRIFICATION

CITY BUS ELECTRIFICATION

Operational characteristics

- Bus routes topography
- Urban density
- Bus routes length and depot location

Direct and indirect costs

- Capital investment (buses and electric infrastructure)
- Operational expenses (electricity and recharging activities)
- Maintenance expenses (new activities and spare parts)

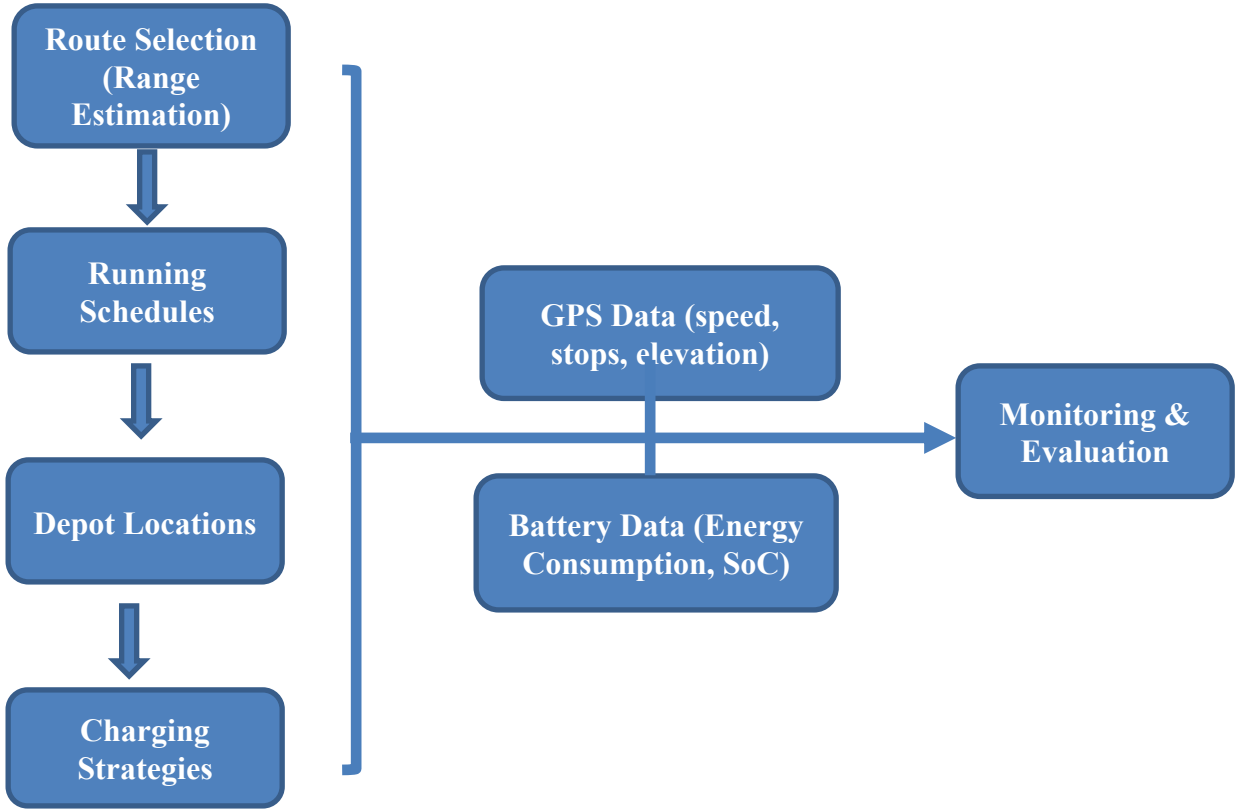
Recharge strategy

- "Fast" / Opportunity charging
- "Slow" / Depot charging
- Impact on deadhead and bus fleet

Battery autonomy

- Diesel / GNV = 250 to 350 km
- Electric battery = 30 to 240 km
- Battery lifespan

APPROACH FOR DEPLOYING E-BUSES



ROUTE SELECTION CRITERIA

Ridership

Daily Kms

Replacement Ratio

TCO

REPLACEMENT RATIO

This ratio is calculated as the ratio of the daily total kms travelled by a bus along specific route to the available or calculated range taking into consideration the depth of discharge, use of AC, passenger loading and battery degradation over time.

TOTAL COST OF OWNERSHIP

- Total Cost of Ownership- TCO is the Present Value of capital cost plus the Present Value of operating costs.
- Capital costs include that of E-bus and charging infrastructure
- Operational costs are the major cost components that make up the input.
- TCO provides an understanding of the various components that affect the overall economic performance of an E-bus over its lifetime.
- TCO is the key information that bus operators would need to know, since they will procure the E-buses.


GRACIAS
GRACIAS
GRAZIE
THANK YOU
ARIGATO
MULTUMESC
GRAZZI
MERCI
KOP KHUN
GRACIAS
TERIMA KASIH
SHUKRAN
OBRIGADO
SPASIBO
TODA
TAKK
XIEXIE
MULTUMESC
NANDRI
MERCI
DANKE
TODA
KIITOS
OBRIGADO
TERIMA KASIH
SPASIBO
GRACIAS
HVALA
DANKE
DAW-DYEH
TACK
NANDRI
HVALA
KOP KHUN
HVALA
KIITOS
SPASIBO
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ARIGATO
GRACIAS
GRAZIE
SPASIBO