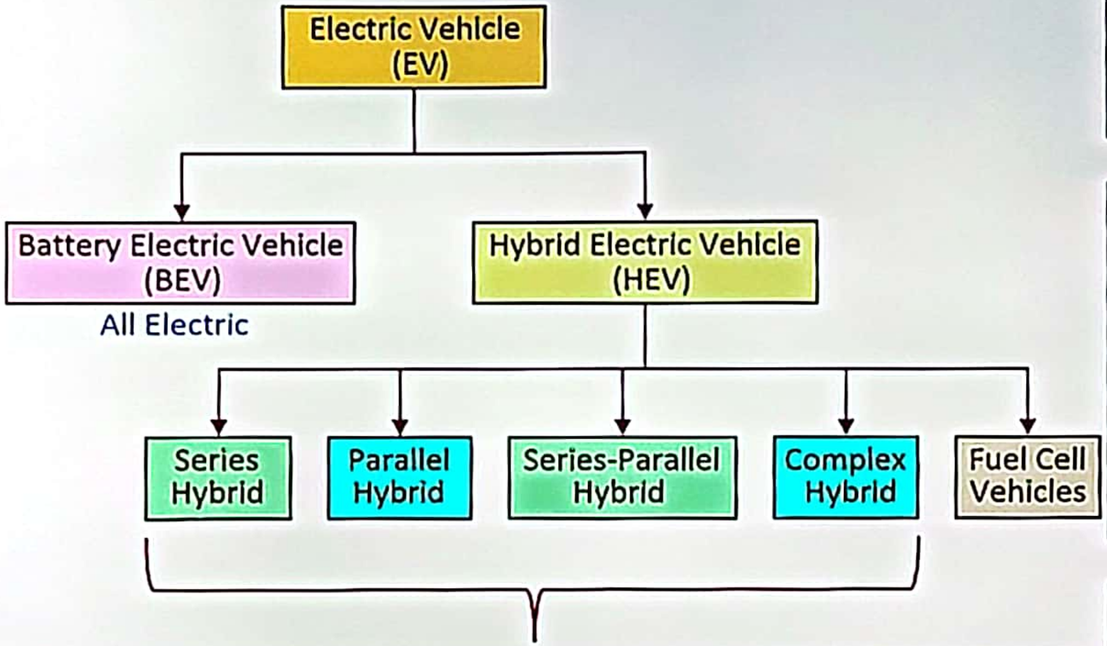
CLASSIFICATION OF ELECTRIC VEHICLES



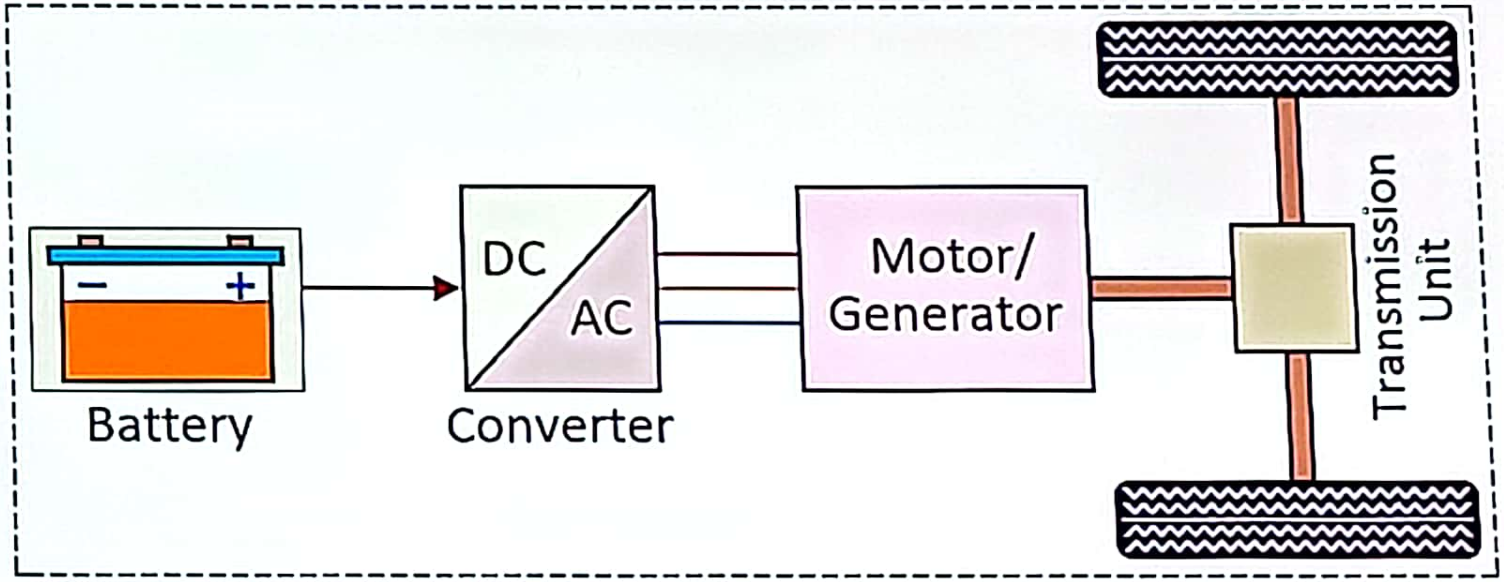
- BEVs are powered by batteries.
- They use electric motors.
- EVs produce zero emissions.

- HEVs are zero-emission EVs for short range (30-50 km).
- For longer trips, HEVs run on petrol / diesel.

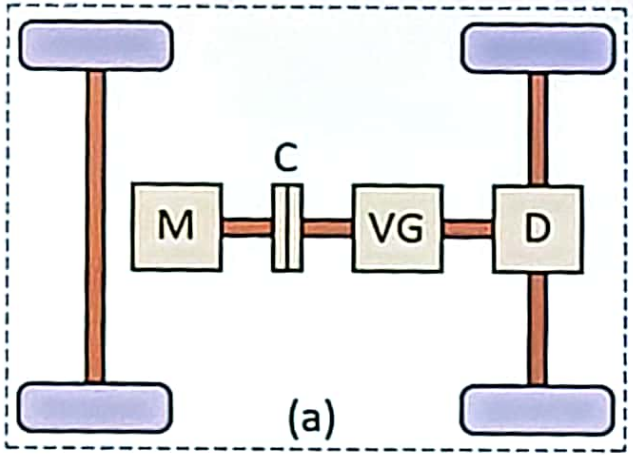
- HEVs are further classified according to configuration, share of electric, and energy source.

- All HEVs need to be plugged in to a power source to maximise their zero-emission capability.

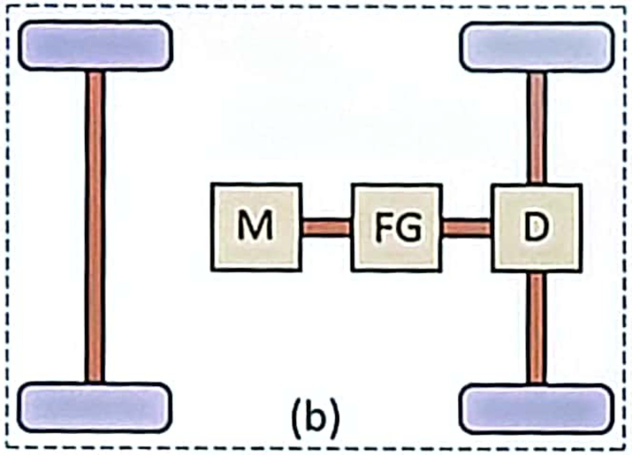
ELECTRIC VEHICLE CONFIGURATIONS



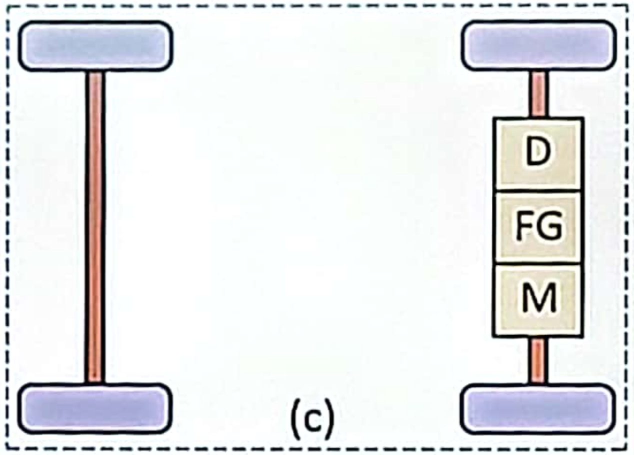
ELECTRIC VEHICLE CONFIGURATIONS



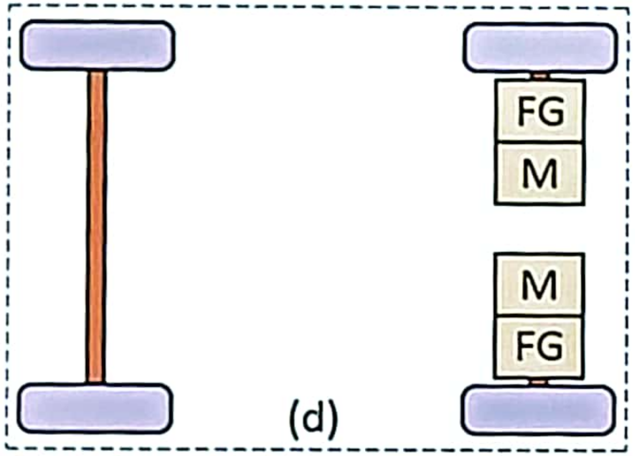
Clutch, Gearbox & Differential



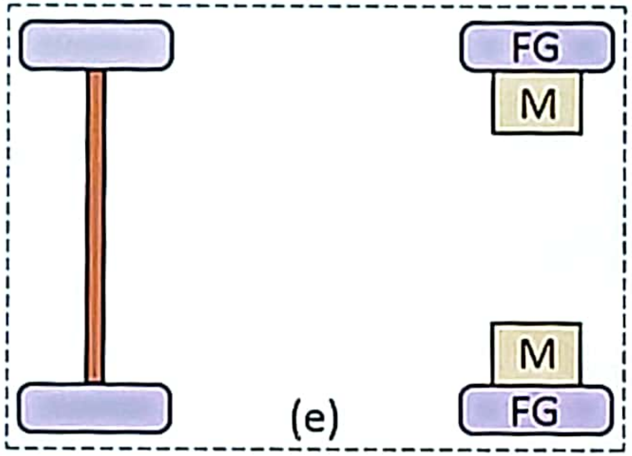
Fixed ratio GB & Differential



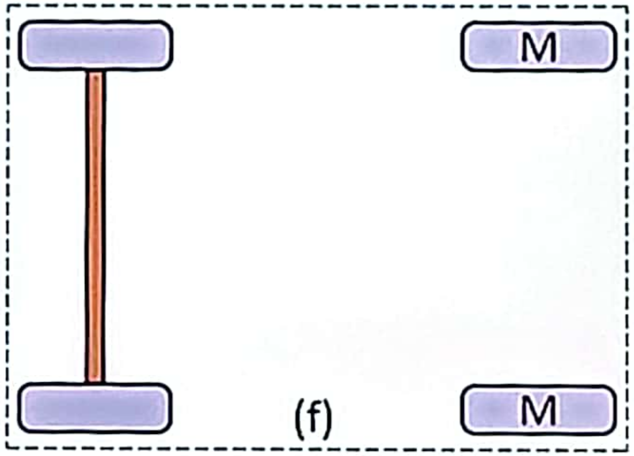
Integrated Motor, GB & Diff.



Diff. replaced by two motors



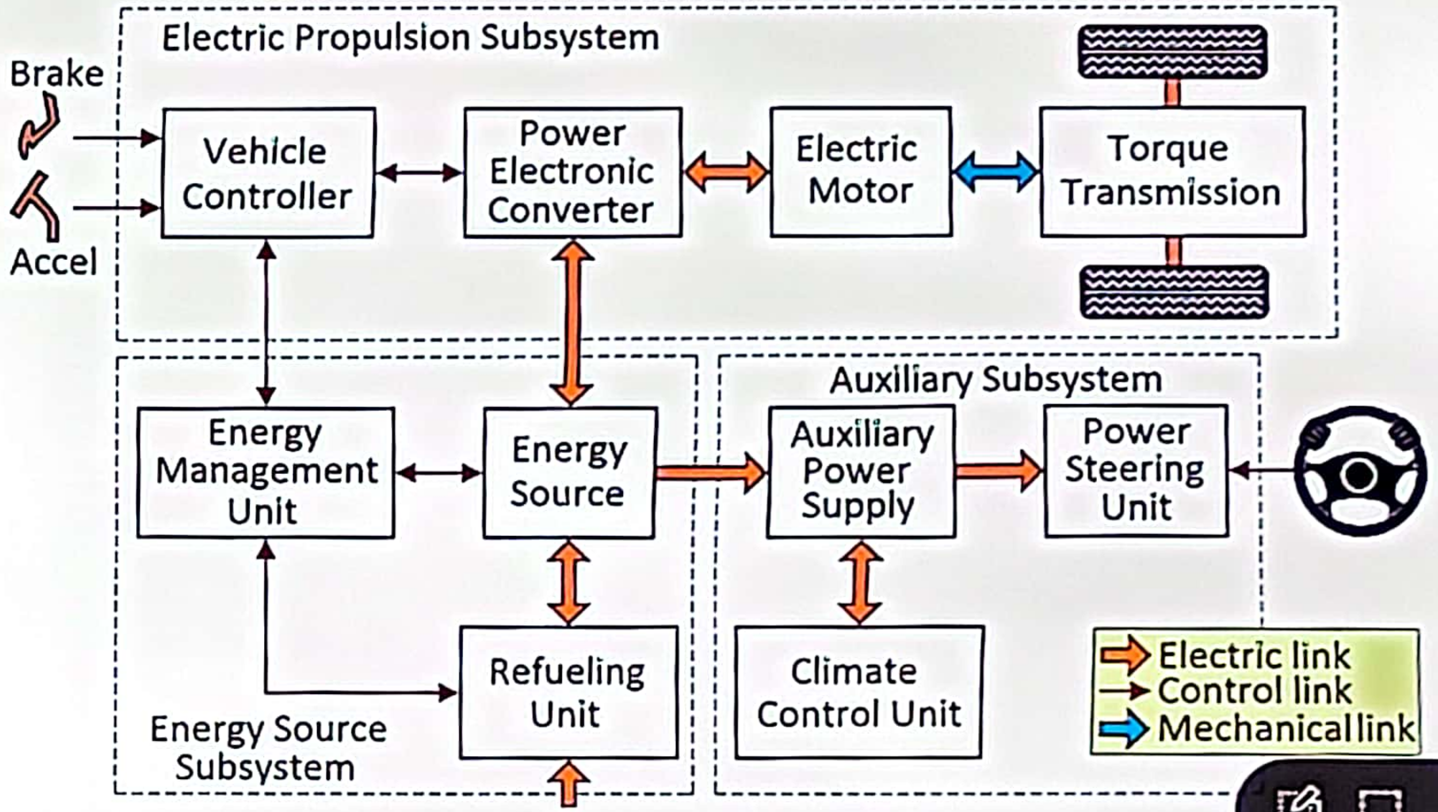
in-wheel drive with gear



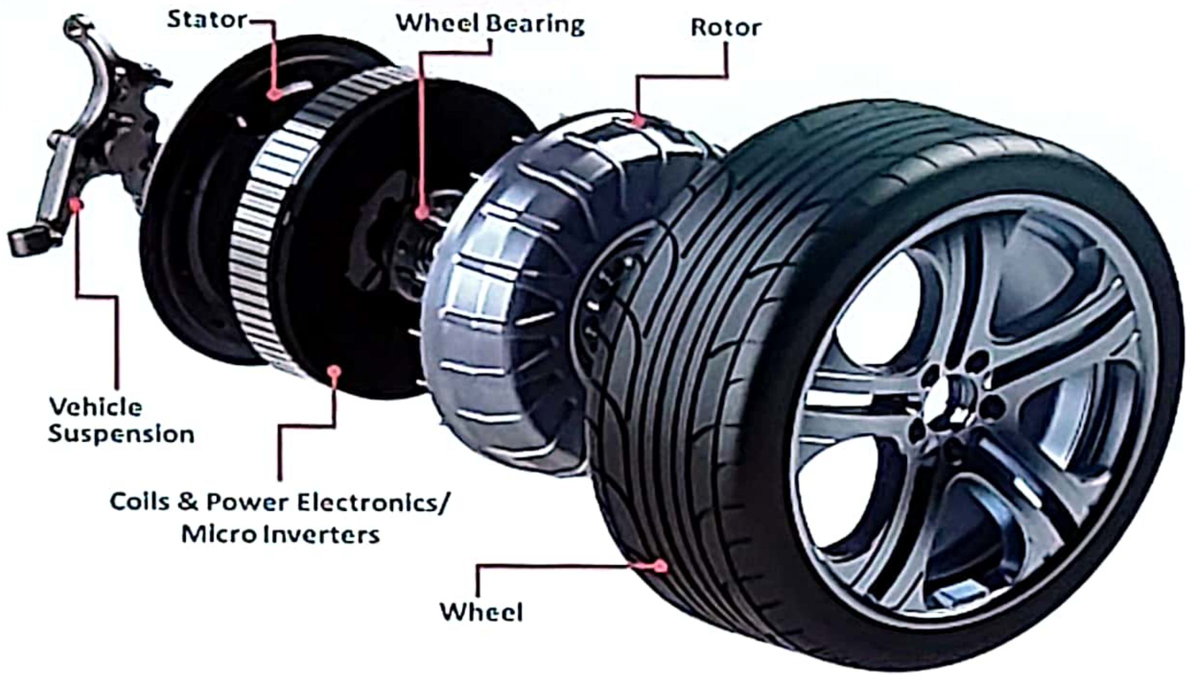
in-wheel drive, no gear

DRIVE TRAIN OF ELECTRIC VEHICLES

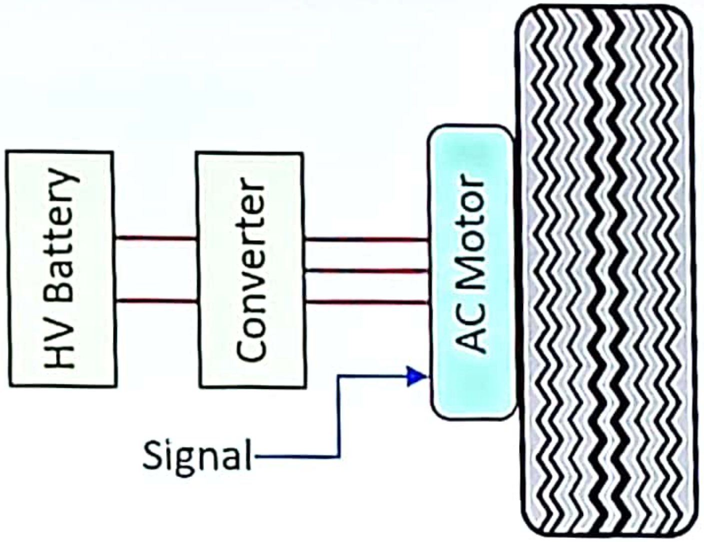
- An EV drivetrain consists of 3-major sub systems: propulsion, energy source, and auxiliaries.
- Propulsion includes: controller, power converter, motor, torque transmission and wheels.
- Energy source section includes: energy source, energy management unit and refilling unit.
- Auxiliary subsystem includes: power steering, climate control unit, and auxiliary supply.



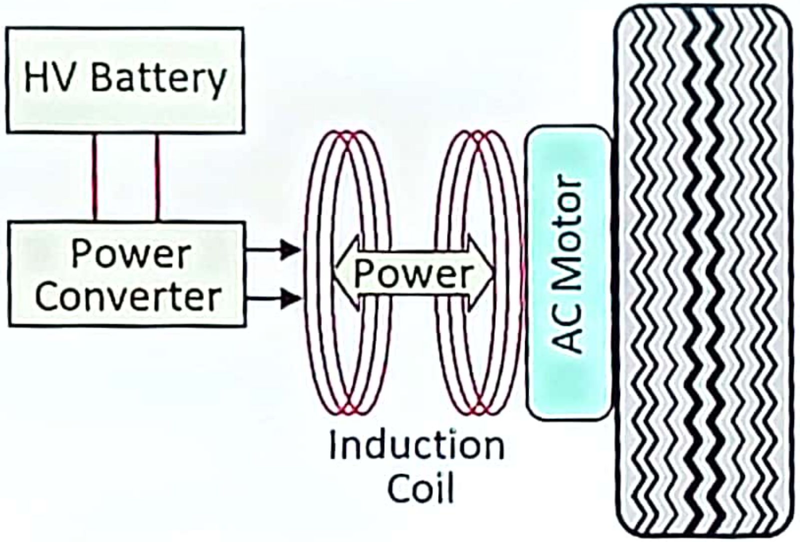
IN-WHEEL DRIVE ELECTRIC VEHICLE



IN-WHEEL DRIVE ELECTRIC VEHICLE



Conventional In-Wheel drive



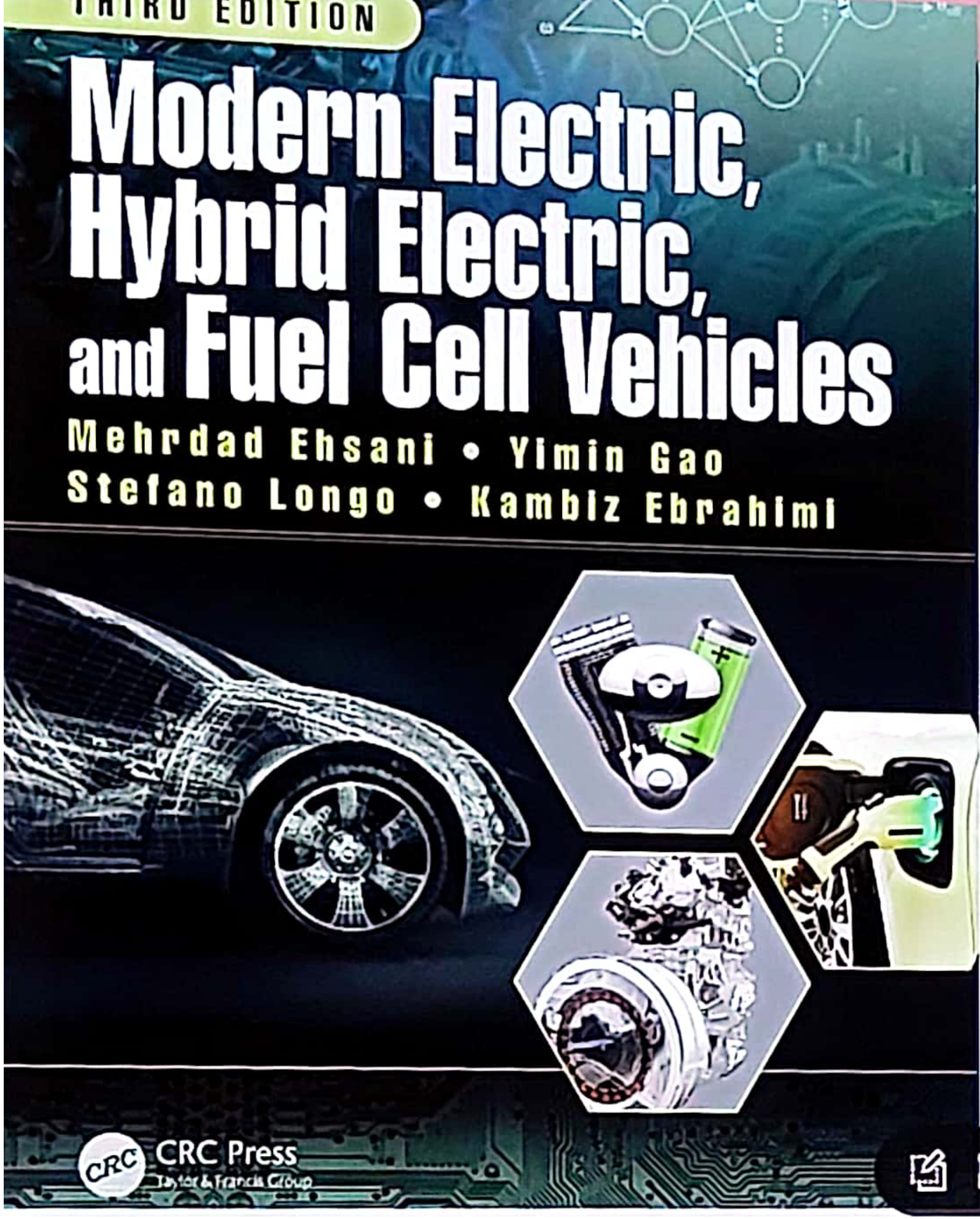
Wireless In-Wheel drive

FACTORS THAT AFFECT EV DRIVING RANGE

- Vehicle speed
- Driving style
- Auxiliary load
- Aerodynamics
- Vehicle weight
- Ambient temperature
- Battery capacity
- Battery cooling method
- Battery age
- Type of tyre
- Road conditions
- Terrain

IMPACTS ON BATTERY DUE TO ACCELERATION

- Acceleration of a vehicle represents an increase in its kinetic energy.
- During acceleration, battery energy is converted into kinetic energy of the vehicle.
- Kinetic energy of a moving body = $\frac{1}{2} mV^2$, where m = mass and V = velocity.
- As velocity increases with acceleration, K.E. increases by the square of the velocity.
- So, to reach 8 kmph requires four times the energy it takes to reach 4 kmph, not 2×.
- Besides, quick acceleration increase losses.
    - Higher speeds during acceleration leads to higher air resistance losses.
    - Rolling resistance increases with speed.
    - Higher torque at the shafts increases frictional losses in the reduction gear.
    - Large current during acceleration increases I^2R losses and thermal stresses.


THIRD EDITION
Modern Electric, Hybrid Electric, and Fuel Cell Vehicles
Mehrdad Ehsani • Yimin Gao
Stefano Longo • Kambiz Ebrahimi
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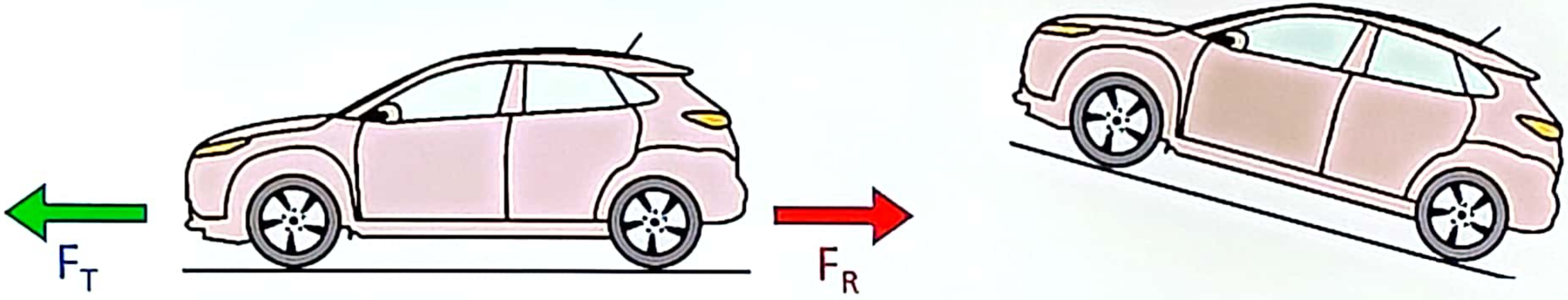
Taylor & Francis Group

FORCES ACTING ON A VEHICLE

❖ What are the forces acting on a moving vehicle?

1. On a flat road
2. On a gradient road



❖ Forces acting on a moving vehicle can be grouped as:

- Tractive (propulsion) effort ($\mathbf{F_T}$) $\Rightarrow$ force available to perform work
- Resistance forces ($\mathbf{F_R}$) $\Rightarrow$ forces opposing vehicle motion

FORCES ACTING ON A VEHICLE

- Tractive effort must be more than the sum of resistive forces, that include:
  - Rolling resistance
  - Aerodynamic drag (resistance)
  - Gradient (hill climbing) resistance
  - Acceleration

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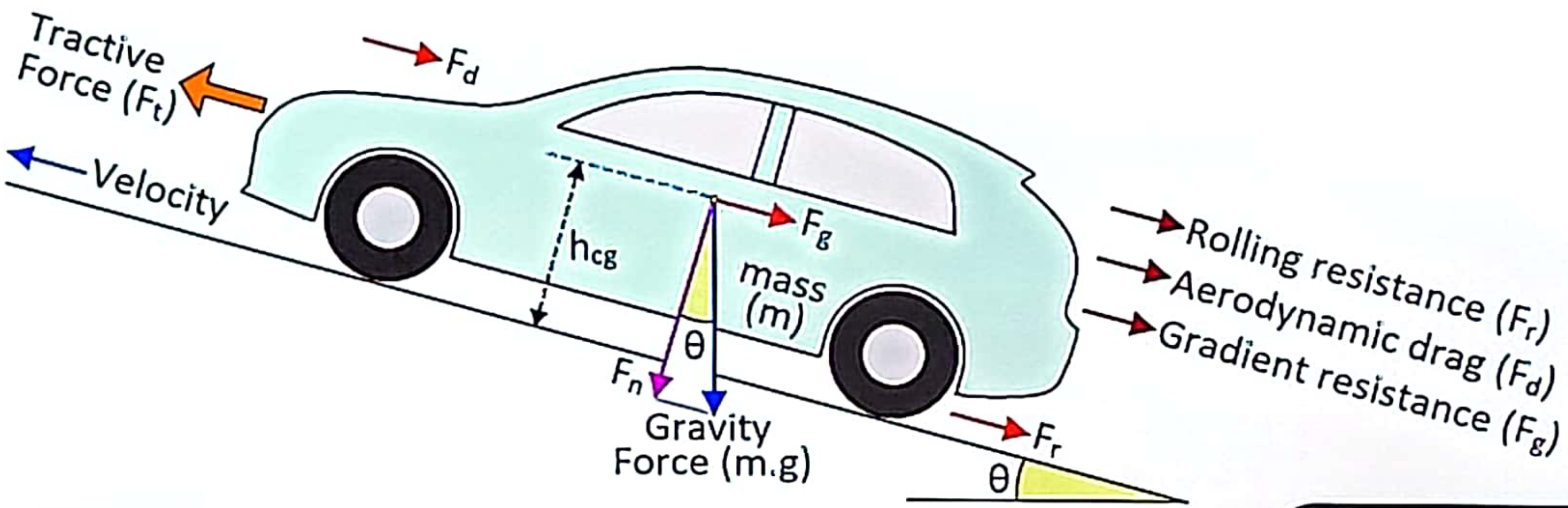
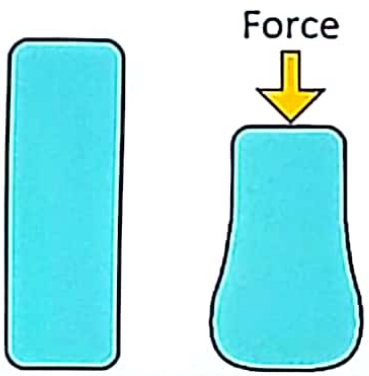
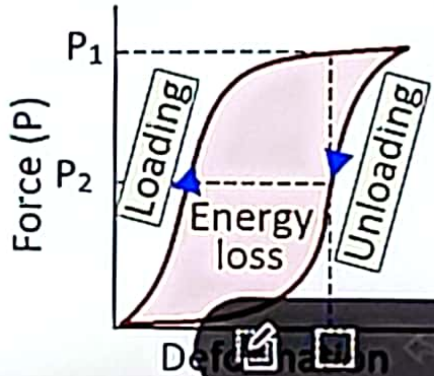


θ = Road slope (gradient) angle

ROLLING RESISTANCE

- However, when the tyre comes off the road, not all the stored energy is returned since some of this energy is used to heat up the tyre.
- The loss of stored energy due to the heating is called the *Hysteresis.*





ROLLING FRICTION (RESISTANCE)

- Rolling resistance (F_r) is proportional to the vehicle weight.
- On horizontal road, rolling resistance (in newton) is given as

$$F_r = M.g.C_r$$

- On a gradient road, rolling resistance is:

$$F_r = M.g.C_r.\cos(\theta)$$

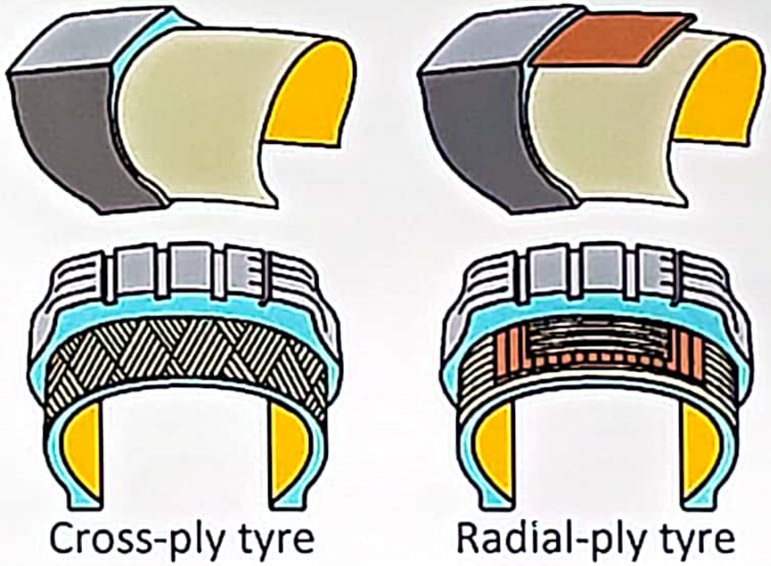
M = mass of vehicle (kg)
C_r = coefficient of rolling resistance
g = acceleration due to gravity (m/s^2)
θ = road slope (gradient) angle (rad.)

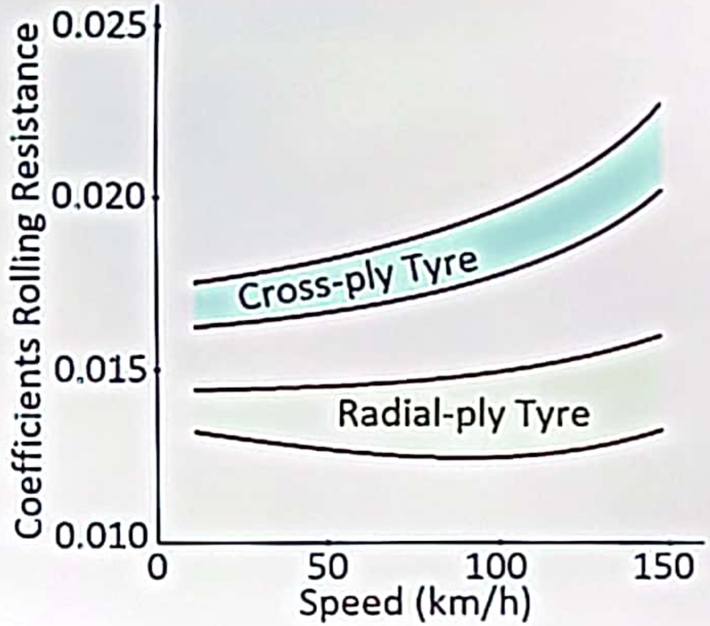
- Coefficient of rolling resistance depends on
  - tyre type (radial/cross ply), tread geometry and tyre material
  - tyre inflation pressure and tyre temperature
  - road roughness and road material
  - presence of liquids on the road + velocity

OPTIONS TO REDUCE ROLLING RESISTANCE

- Low body weight of vehicle
- Correct pressure in tyres
- Low rolling resistance tyres (radial-ply instead of cross-ply tyre)

  (In cross-ply, more rubber will be compressed, hence, more heat will be produced)





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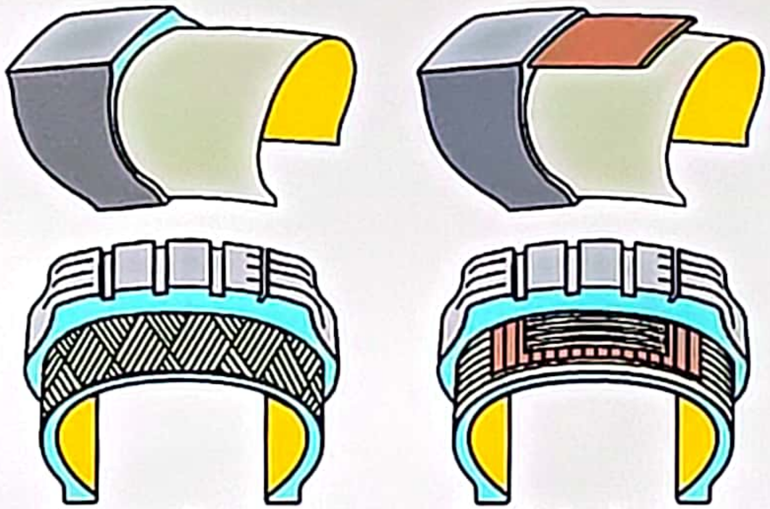

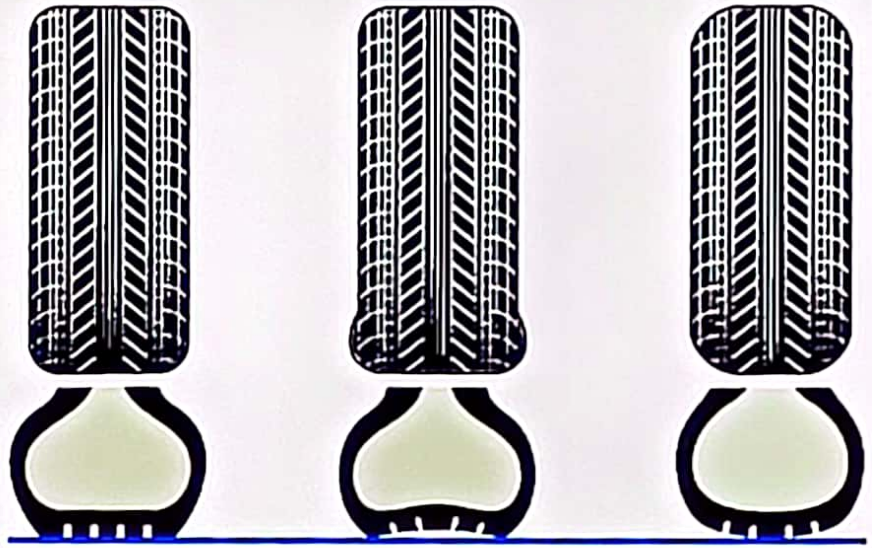

- A tyre with a recommended pressure of 35 psi, but inflated to only 28 psi, will increase its rolling resistance by 12.5%.

AERODYNAMIC DRAG

- Aerodynamic drag is an opposing frictional force which acts upon objects as they travel through the air.
- It is a function of the vehicle frontal area, shape, and protrusions.
- Aerodynamic drag is calculated as: $\boxed{F_d = \frac{1}{2}\cdot\rho\cdot A\cdot C_d\cdot V^2}$

ρ = air density (kg/m^3)
A = vehicle frontal area (m^2)
C_d = air drag coefficient
V = vehicle speed (m/s)

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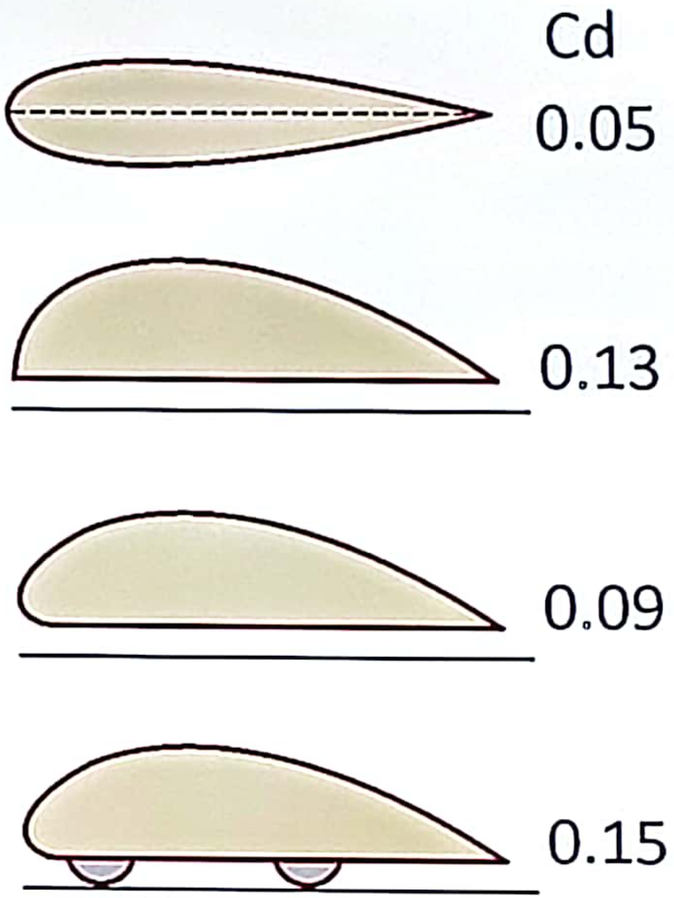
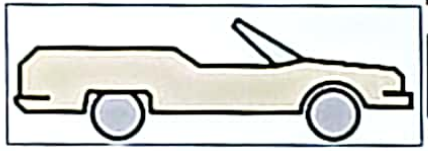
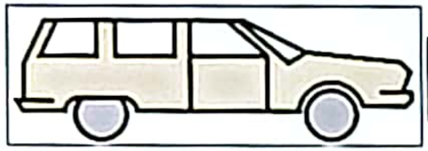
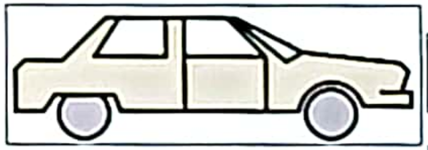
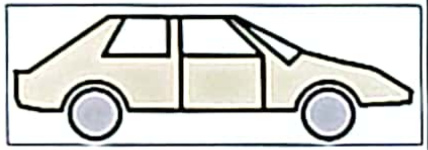
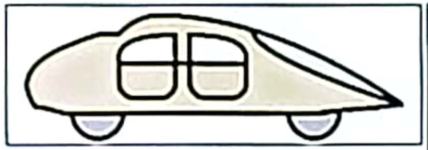
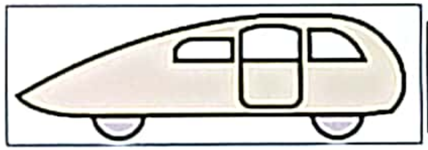
V = vehicle speed (m/s)

- Sources of Aerodynamic Resistance:
  - Turbulent air flow around vehicle body
  - Friction of air passing over vehicle body
  - Air flow through vehicle components
- Drag coefficient will increase due to open windows, bumpers, side mirrors, headlights, wheel wells, wheel fairing, luggage carriers etc.
- Sealed wheel wells and tight mudguard (fenders) minimize aero drag.

STREAMLINED BODY TO REDUCE DRAG



DRAG COEFFICIENTS IN VEHICLES

	Vehicle Type	Coefficient of Aerodynamic Drag
	Open convertible	0.5 – 0.7
	Van body	0.5 – 0.7
	Ponton body	0.4 – 0.55
	Wedged-shaped body Headlamps + bumpers integrated into body	0.3 – 0.4
	Headlamp and all wheels in body, covered underbody	0.2 – 0.25
	K-shaped (small breakaway section)	0.23
	Optimum streamlined design	0.15 – 0.2

NITROGEN IN VEHICLE TYRES

- Air is 78% nitrogen, 21% oxygen and the rest is water vapor, CO_2 etc.
- N_2 leaks out of the sidewall three times slower than oxygen.
- Nitrogen is a dry inert gas and hence, it is less reactive than oxygen.
- Oxygen oxidizes the rubber in the sidewall.
- Moisture/oxygen oxidizes the rubber and promotes corrosion of steel rims.
- Tyre pressures will remain more stable for long duration as nitrogen is less likely to migrate through tyre rubber than is oxygen.
- The result is that all materials that come into contact with the compressed gas inside the tyre are less subject to oxidation corrosion.
- Moisture present in air causes pressure variations with tyre temperature.
- For 10°C change in ambient temperature, tyre pressure will vary by 1 psi.

POWER DRAWN FROM EV BATTERIES

- When a vehicle goes up or down a slope, its weight produces a component of force that is always directed downward.
- This gradient force (F_g) is a function of vehicle mass and slope angle, given as:

$$F_g = M.g.\sin(\theta)$$

θ = road slope angle (rad)
M = vehicle mass (kg)
g = gravitational acceleration

- Vehicle acceleration can be represented as

$$F_a = \lambda.M.\frac{dV}{dt}$$

λ = rotational inertia constant

- Total tractive effort required to overcome all resistive forces + acceleration:

$$F_T = F_r + F_d + F_g + F_a$$

- Traction power (P_T) required: $P_T = F_T.V$ 　 V = vehicle speed (m/s)
- Total power drawn from the battery: $P_B = P_T + P_{aux}$ 　 P_{aux} = aux. consumption

(auxiliaries include: AC (cooling/heating), lights, horn, music system etc.)

IMPACTS OF AC ON THE EV DRIVING RANGE

- Auxiliary system in a standard car can consume energy up to 15%.
- Most of the energy is utilised for heating and cooling of the car interior.
- Air cooling + heating systems on EVs are different than ICE vehicles.
- Typical power consumption by AC system in an EV is around 2^{+} kW.
- The AC system in an EV can reduce the drive range by 33 -35%.

Accessory	Range Impact	Comments
Air Cooling	up to 30%	dependents on ambient temp., cabin size
Heating	up to 35%	dependents on ambient temp., cabin size
Power Steering	up to 5%	
Power Brakes	up to 5%	
Defroster	up to 5%	depending on use
Power Steering, Lights, Horn, Music Player	up to 5%	depending on use