



Battery technology for Electric Vehicles

Cell chemistry, Economics and Performance

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14

of 20 most polluted world-cities in India

Air quality in Indian cities

36%

NOx emissions due to vehicles

20%

PM2.5 emissions in Delhi due to vehicles

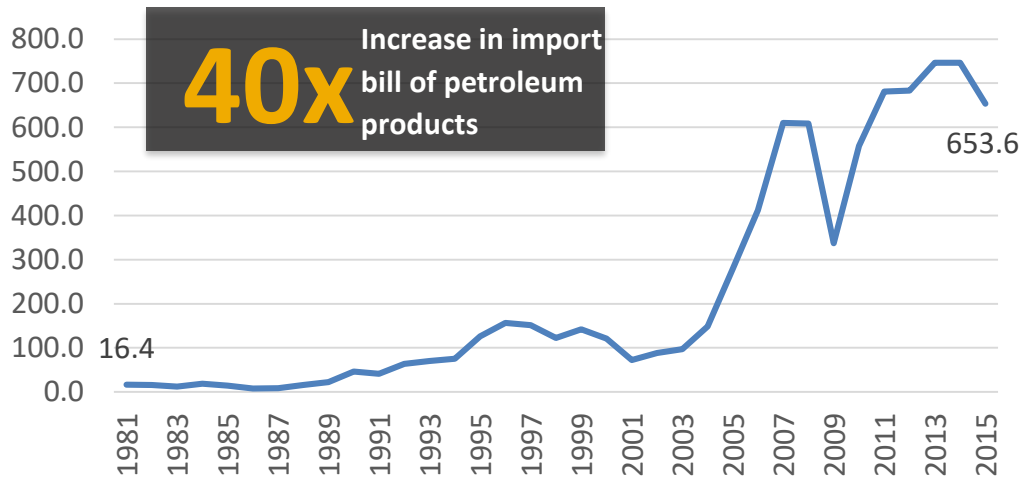


Reuters

Why so much interest in EVs?

- EV is **four-times** as energy efficient as ICE; has **50 times** less moving parts
 - ICE efficiency: 22% to 23% Vs EV motor energy efficiency: 90%

India's Import Bill for Petroleum Products from 1981 – 2015 (in INR Billions)



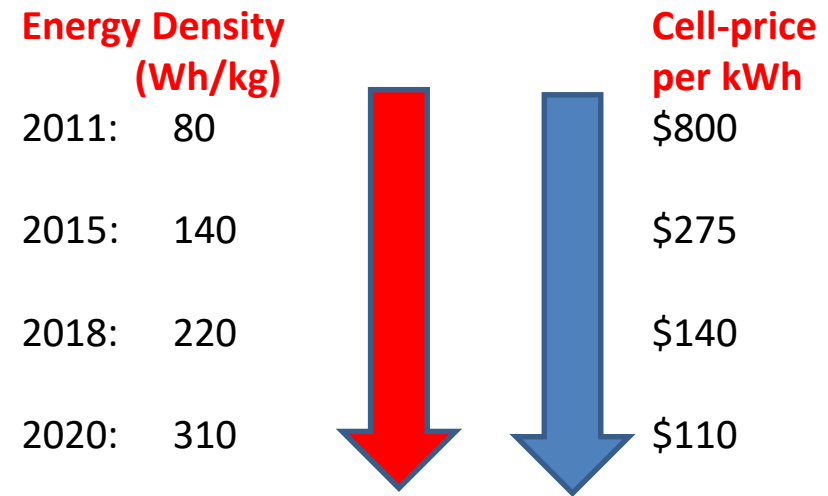
Petroleum consumption up from 32.5 mill tons in 1981 to 184.7 mill tons in 2015

Where is the problem to switch to EVs?

- Batteries: energy-storage
 - **Energy-density** of Li-Ion battery-cells is continuously **increasing** and is in between **250 to 300 Wh/kg** today
 - But much less than that for petrol at 9000 Wh/kg
 - Even taking into account four times higher drive-efficiency
 - **Battery weight per km is 8 to 9 times higher** than that of petrol-tank per km
 - Same with the size
- And Cost of battery is **inversely** related to its energy density
 - Higher energy-density: lower use of materials like Lithium, Cobalt, Nickle
 - Higher energy density will have **higher safety concerns**

Increasing Energy Density → Affordable Batteries

- **Energy density increasing rapidly**: main driver for cost reduction
 - Li Ion Battery: up to 300 Wh/kg available
 - Towards 400 to 500 Wh/kg in coming years
 - NMC with Graphite-Silica anode
 - LFP is limited to 160 Wh/kg
 - Other variants of Li-battery may emerge to drive energy density higher
 - Higher energy-density: higher safety concerns
- EV with large battery to overcome range anxiety (several hundred kms in a car) is still **1.7 to 2 times that of ICE car**

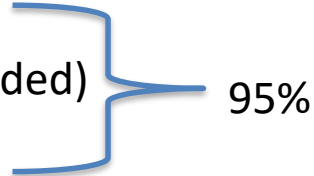


Compute battery pack cost per km, taking into account its life-time, depreciation and interest

Outline

- How do we make EV **affordable in India** with limited subsidy?
 - India's vehicle **composition**
 - **Size** of battery, Range-limitation and **Charging** Strategy?
- How do we make **battery safe** and where will battery **raw materials** come from?
- Will it impact our **GDP**?

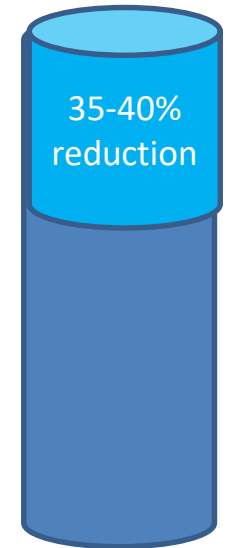
India's Vehicle Composition

- India's auto-segment different from that in most of the world: **small and affordable vehicles**
 - Domination of 2-wheelers: 79%
 - Autos including small goods vehicle: 4% (rickshaw not included)
 - Economy Cars costing below ₹1 million: 12%
 - Premium Cars costing above ₹1 million: **2%**
 - Buses and large goods vehicle (including trucks): 3%

95%
- **98% of public and affordable vehicles:** not the focus of the rest of the world; India would attempt to get leadership here
- **2% vehicles (premium four-wheelers):** similar to that in rest of world; India would learn and adopt; encourage multinationals to manufacture them in India
 - Less than 0.5% costs more than ₹1.5 million
 - Will help us build a stronger ecosystem for components and subsystems

Increase Energy-efficiency of EV

- Battery Dominates the cost of EV
- Focus on higher energy-efficiency: *Kitna deti hai* for EVs (kms/litre of petrol)
 - Lower the energy (Wh/km) used per km, lower is the **battery size and its cost** to drive certain range
 - size and weight of the battery reduces: in fact enhancing efficiency further
 - Efficiency improved by improving Motor and Controller efficiency, better tyres (lower rolling resistance), better vehicle-aerodynamics and lower weight
- Battery size reduced by 35% to 40% over last two years in India
 - For e-autos: from 70 to 80 Wh/km to 45/50 Wh/km
 - E-buses: from 1600 Wh/km to 900 Wh/km

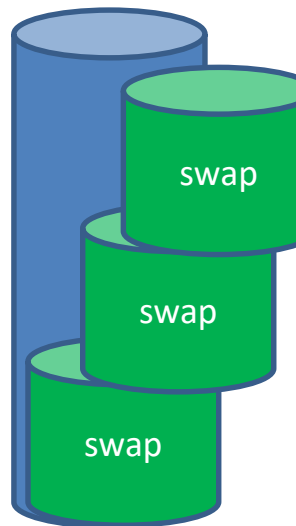


Battery size without range anxiety

Approach I: Business viability for Public Transport

- To make Public Electric Vehicles more affordable
 - **Split battery** into smaller size (one third) and **swap**
 - No waiting time to charge battery: **no public infrastructure** required
 - Smaller Battery size makes EV highly affordable as compared to petrol vehicles
 - no further economic challenge or technical challenge
 - Engineering Challenges for battery-swapping need to be overcome
 - Battery-life severely affected by Fast Charging at **45 deg C**
 - **Swapped battery** can be charged in conditioned environment and in two hours to maximise its life
 - **Separate** vehicle business (without battery) & energy business (Energy Operator)
 - **Capital and operation cost (₹/km)** similar to that for petrol / diesel vehicle
 - WITH limited SUBSIDY, electric autos and buses can compete today with ICE vehicles

Battery size
without range
anxiety



Approach II: Private Vehicles (4W/2W)

- Batteries **dominate** the cost of an EV: Tesla uses battery with 540 kms range
 - Increasing the **vehicle weight** (reducing the **energy efficiency or kms/kWh**)
 - On the other hand, Smaller battery creates **range anxiety**
 - Public Fast Charger: **waiting time** + **public charging infrastructure**: takes an hour to charge battery
 - Fast Charge in **15 to 20 minutes**: needs expensive batteries (life impacted as temperature crosses 40°C)
- **Suppose EVs have a small** low-cost battery with limited range built-in: **Affordable**
 - Example: 100/ 50 km range for e-car / e-scooter: **Enough** within cities for **90% of days**
 - Use only night-time **Slow** Charging: **maximising** battery life
- When one needs to drive longer distances (10% of days)
 - use a **RANGE EXTENDER battery** to completely overcome range anxiety
 - **Swap-in** a second (swappable) battery **doubling the range** at a petrol pump (**3 to 5 minutes**)
 - **Swap** the swappable battery again for still longer range (**300 kms or 400 kms**)
 - Swapping carried out by **Energy Operators**

Approach III: Conventional Approach

- Choose **right size** batteries
 - Slow-charge normally
 - Fast Charge when needed: **may impact battery-life**
- Needs chargers to be standardised: **what standardisation?**
 - Connector: plugs and sockets
 - Voltage, current and power (maximum)
 - Communication to vehicle?
 - Communication to charger management: charging operator or utility manager
 - Metering: how does one bill customer
 - protection



Do we have Charging Infrastructure?

Energy Operators could set up Charging /
Swapping Infrastructure

Charging Strategy for **best battery-life**

- Best Charge: SLOW AC at homes in nights (requires on-board chargers)
 - or two to three hours SLOW charging at **office or parking lots**
 - **15 Amp single phase** charging (up to 3 kW) for two-wheelers, three-wheelers or small four-wheelers
 - Three phase charging (6 kW to 20 kW) for larger vehicles with **larger battery**
- Only occasional FAST charging
 - Long-distance trips, vacations, restaurant visits
 - Need to consider that fast charging may impact **battery-life**
 - Especially for low-cost batteries
- Buses and Taxis may need regular FAST charging

Charger for Public places: Where?

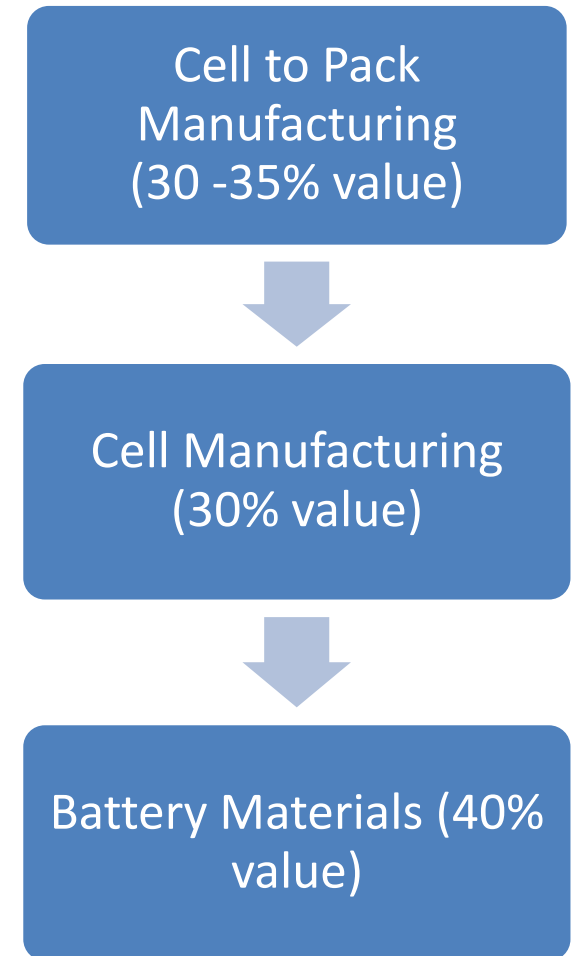
- Petrol pumps: NO SPACE -- pumps designed for servicing a vehicle in **3 to 5 minutes**
 - Vehicles need to keep moving IN and OUT
 - **Swapping** at petrol pumps in three to five minutes is OK
- Office/Street parking, Parking lots, multi-storied buildings: **Yes**
 - Slow Public Chargers: can be same as used in multi-storied building
 - Fast Chargers: how fast? What kind of vehicles and batteries
- DC Fast Charging: industry need to have a common answer to
 - What **voltage and Power**?
 - Connector?
 - Protocols between vehicle - charger and charger - utility back-end
 - Costs about **₹10000 per kW**
 - 50 kW charger will cost ₹500,000: When will there be a business case?

How do we make battery safe? Where will we get Lithium for batteries?

*or will we **for-ever import** Lithium, Nickle, Cobalt, Manganese and Graphite!*

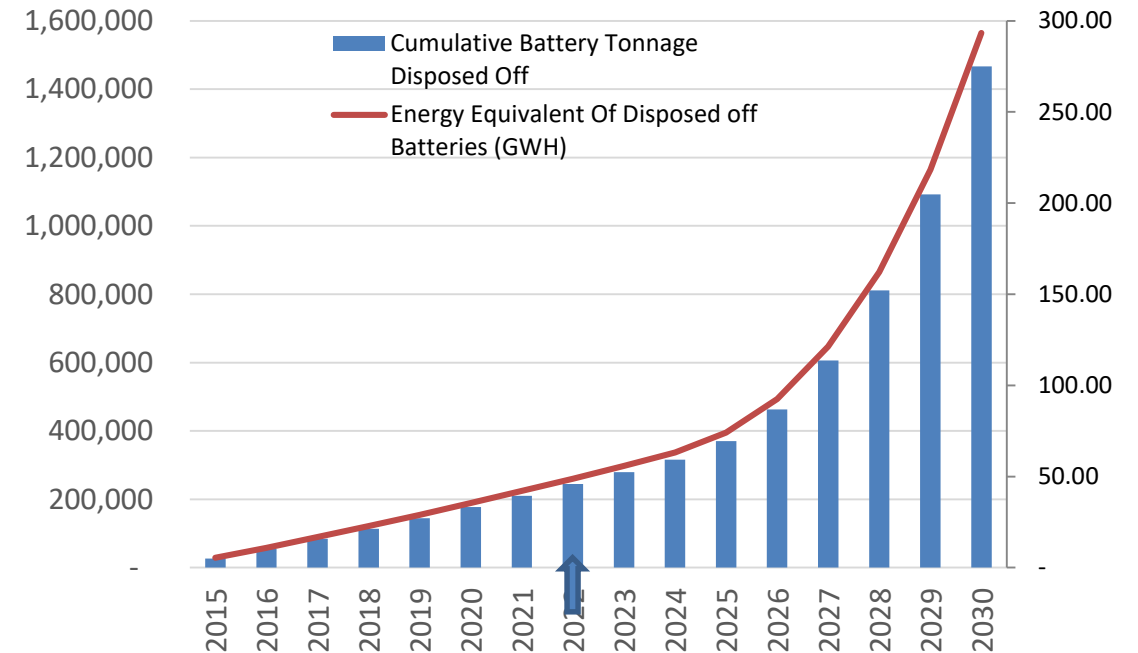
Li Ion Batteries for EV

- **Battery-pack** development involves
 - thermal design as per **Indian** temperature and driving conditions
 - Low-cost Cooling mechanism to withstand 45°C ambient
 - **mechanical design** to ensure cells do not bulge
 - **Battery Management Systems** to get the best out of each cell
 - Safety is a major concern: handled by BMS
 - **established and start-ups making waves in making BMS**
- Cell manufacturing: technology changes every two years
 - Need technology which stays ahead in energy density
 - \$50M per GWh Capital investment: **JV with external tie-ups**



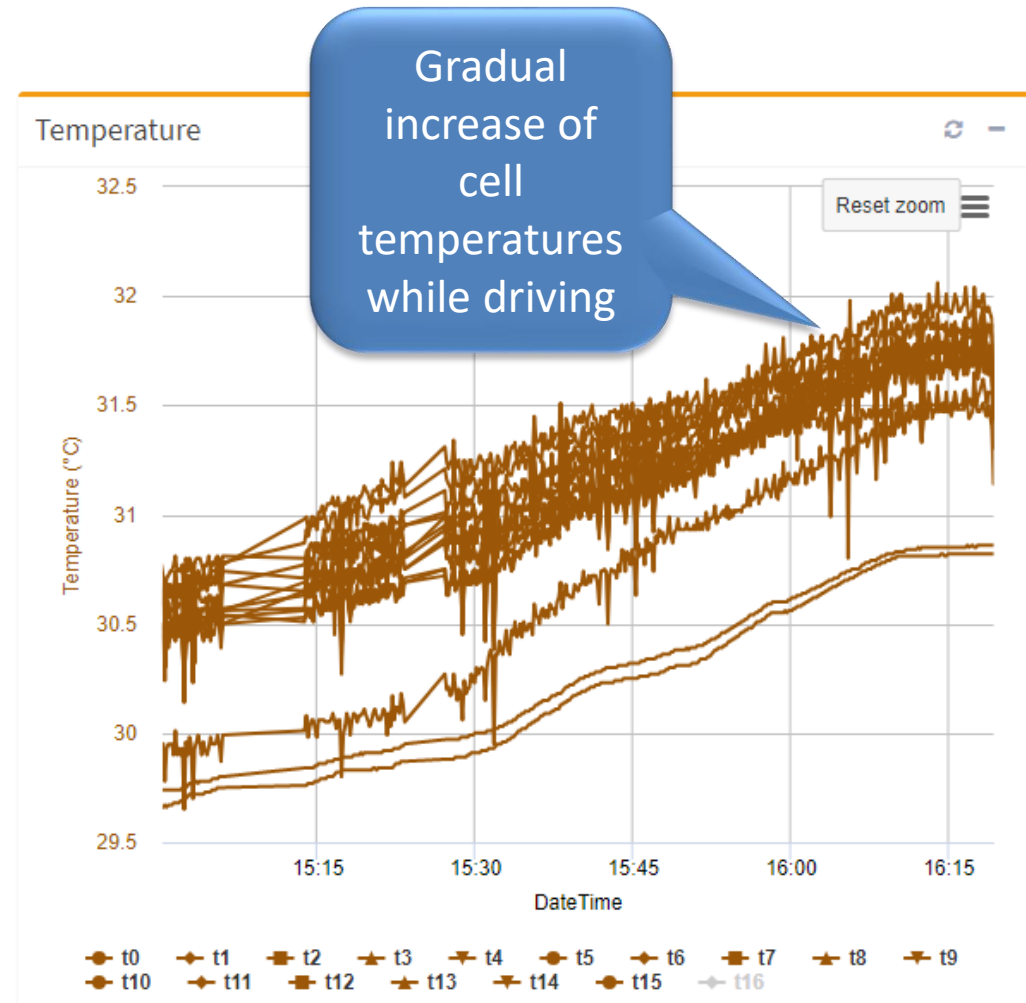
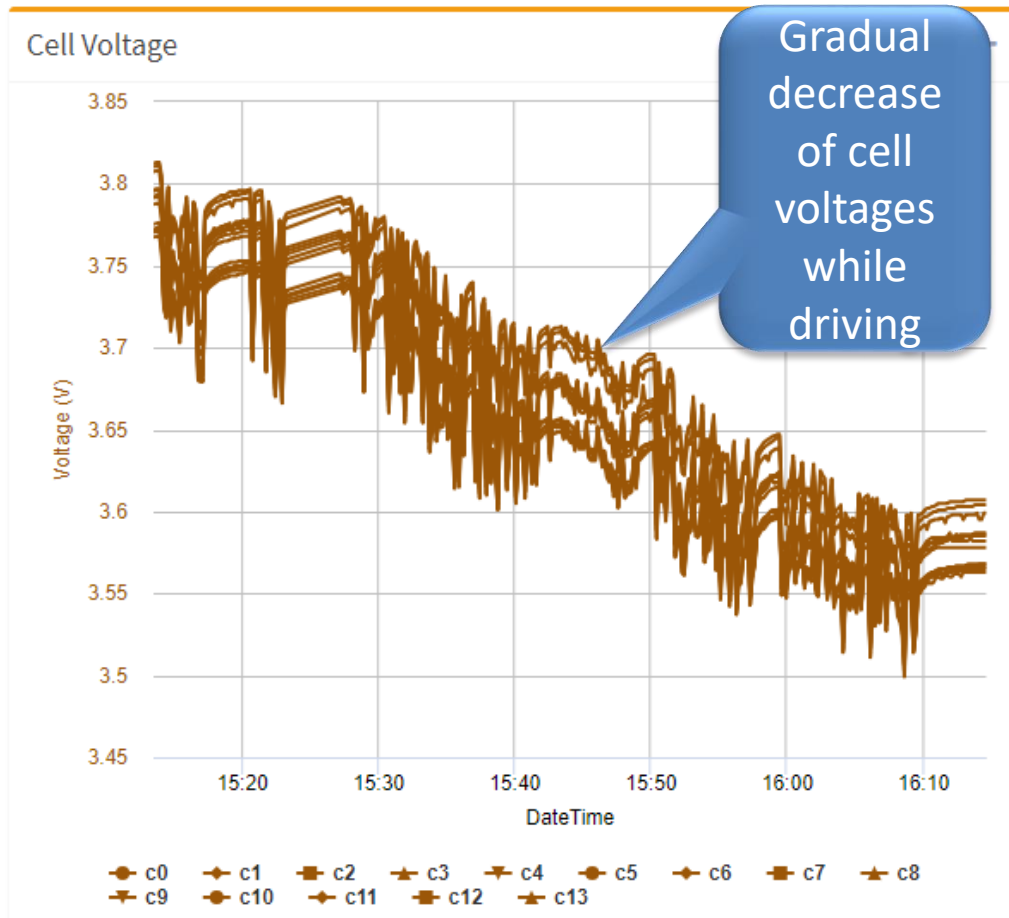
Materials for Batteries

- Li-Ion batteries today use
 - Lithium, Cobalt, Manganese, Nickel and Graphite
 - India does not have much of the mines for any these
 - Import bill could **sky-rocket : 25 GWh per year** by 2025
- Recycle used batteries (**urban mining**)
 - **90% of Li and Co**, Ni, Mn and Graphite being recovered
 - Need large number of recycling plants with **ZERO EFFLUENT**
- India could import used batteries and become the **urban-mining capital of the world** for Li-Ion battery-materials



Over 1 Lakh tons of recyclable batteries are currently available in the market

Cell voltage/ temperature monitoring to maximise battery-life



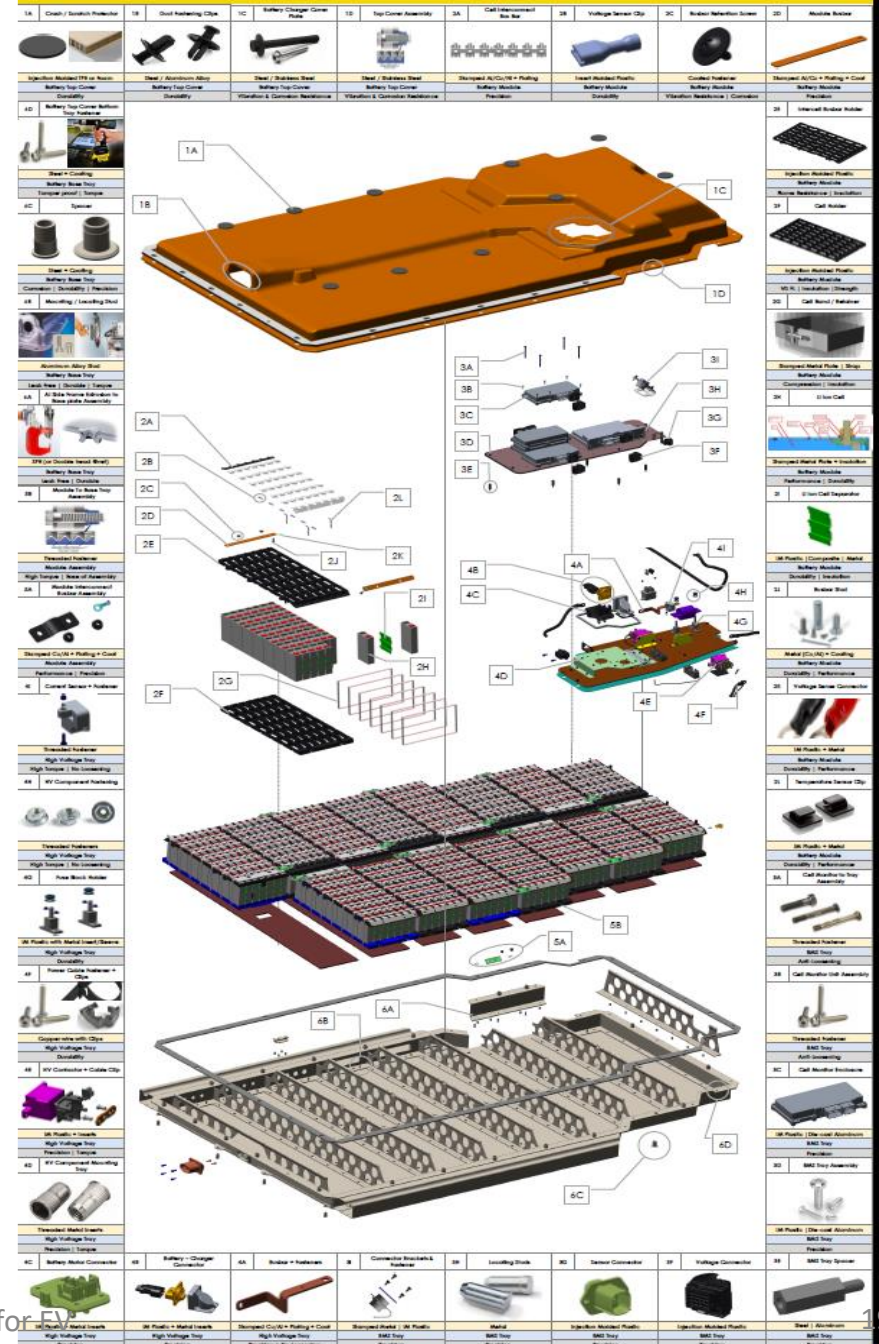
EV threatens India's GDP (auto-sector 7.1% + 5% transport fuel processing / distribution) and large number of jobs

Will we lose jobs and GDP?

Depends upon whether we design and manufacture sub-systems within India

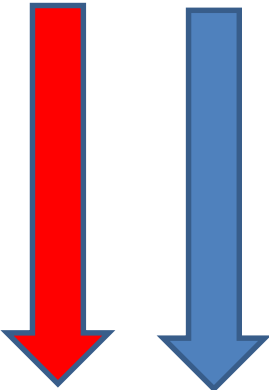
- Battery-pack manufacturing involves large number of components
 - Large number of ancillary industry
 - Large number of jobs
- Battery-packs need to be designed for India's environment conditions
 - Involves quality thermal design
 - Careful mechanical design
 - BMS to ensure cell life maximised and safe operations under all conditions

BATTERY SYSTEM COMPONENTS



Cell-manufacturing: Requires Large plants for

- India needs over 100 GWh of cell manufacturing every year
 - Prismatic, Pouch and Cylindrical
- Battery cell manufacturing like a large process industry
 - High investments
 - Technology changes very rapidly
 - Cost falling rapidly
 - Will require lots of ancillary industries
 - Lots of jobs

	Energy Density (Wh/kg)		Price per kWh
2011:	80		\$800
2015:	140		\$275
2018:	220		\$140
2020:	310		\$110

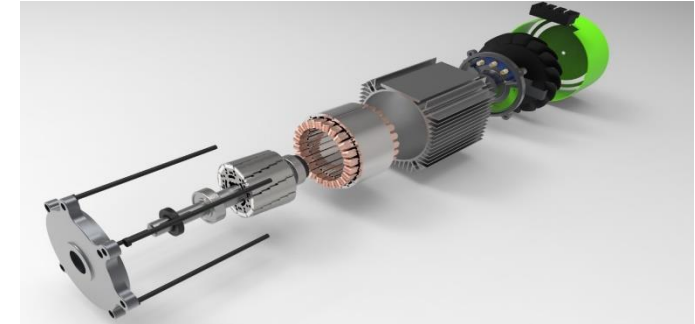


Will we have to import all Battery raw materials?

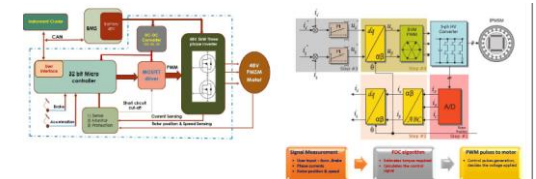
- Not if we recycle all used battery with ZERO effluent
 - Can recover over 90% of Lithium, Manganese, Cobalt, Nickel and Germanium
 - And reuse in new batteries
- Highly manual-intensive work: will create huge number of jobs
 - India could become Urban mining capital of the world
 - Import used battery and recover materials
- Battery Recycling market: \$100M today, over \$1B by 2030
 - 1 lakh ton battery waste available today: 23 GWh of batteries
 - Near Term Driver: Consumer Electronics and laptop battery
 - Long term Driver: Electric Vehicles & Stationary Storage Energy

- Need to recycle each battery
- Ensure that all spent Li Ion batteries are sent for recycling
 - Manufacture's obligation

Motors and Controllers

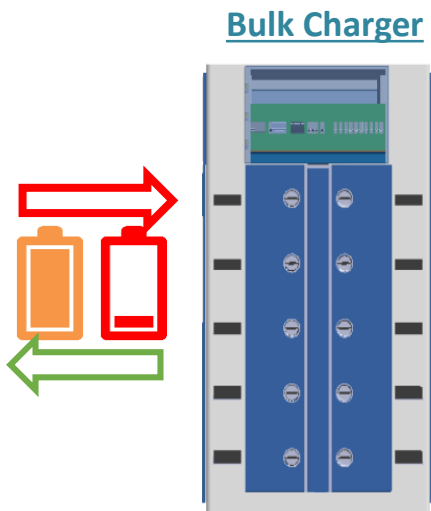


- Need motors and controllers for
 - Two-wheelers
 - Three-wheelers
 - Four-wheelers
 - Buses
 - Trucks
- Hundreds of components



Battery Swapping at street-corners

Battery Swapping



Ideal for Fleet & Delivery Vehicle Use

2W

3W

4W

BUS

- Create a large number of jobs
- Potential for small business

To Conclude

- Possible to make two / three-wheelers EV affordable in India today: 4-wheelers will follow
 - Aided by FAME-II and GST subsidies and smaller swappable battery
 - Charging Infrastructure not a limitation
- Possible to make high energy-density battery affordable and safe
- Possible for India to recover Li, Co, Ni etc from used batteries: urban mining
- Will it impact our **GDP**? No, if we make all subsystems
- Time is of essence: In four years, may be **flooded with imported** EVs / subsystems
- Can we do it by 2030: **Certainly**

EV article in recent IEEE Electrification Magazine: <https://ieeexplore.ieee.org/document/8546812>

For deeper understanding, look at the blog “understanding the EV Elephant”: <https://electric-vehicles-in-india.blogspot.in/2017/12/>