How could India win with EVs
as policy gets finally aligned

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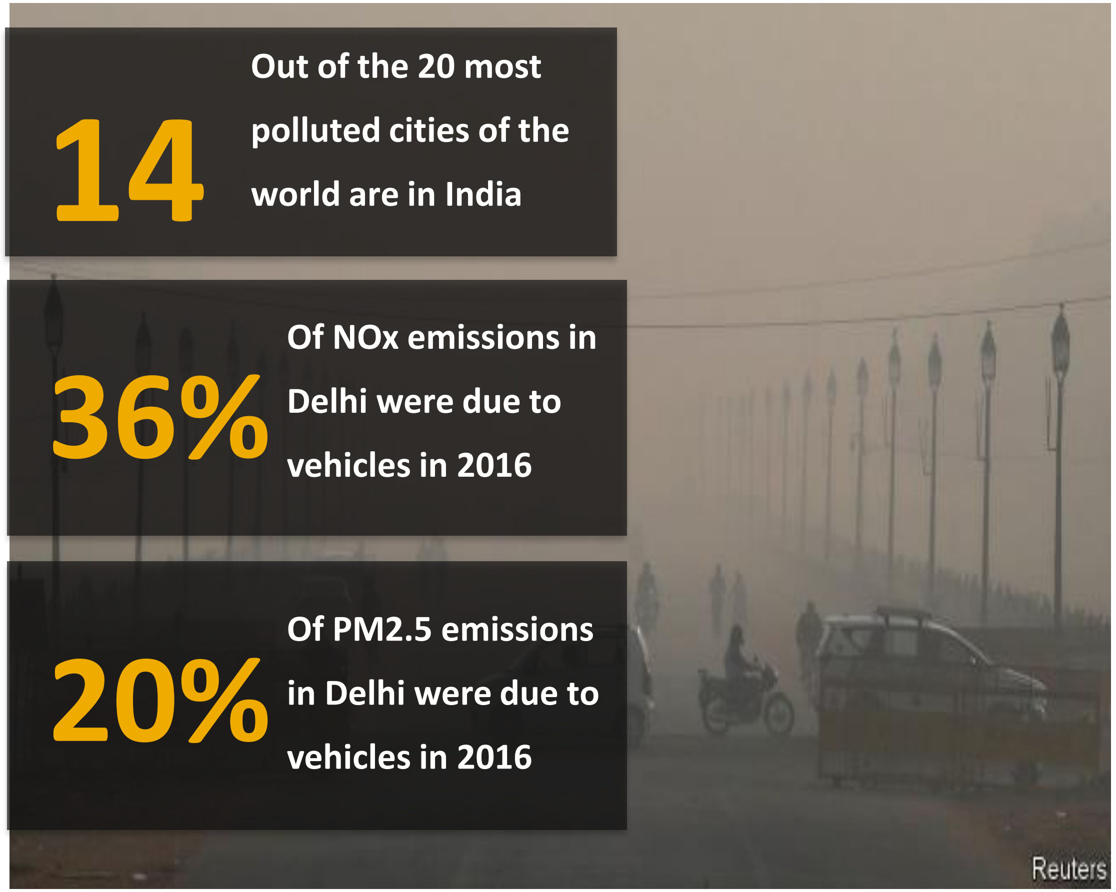
Air quality in Indian cities

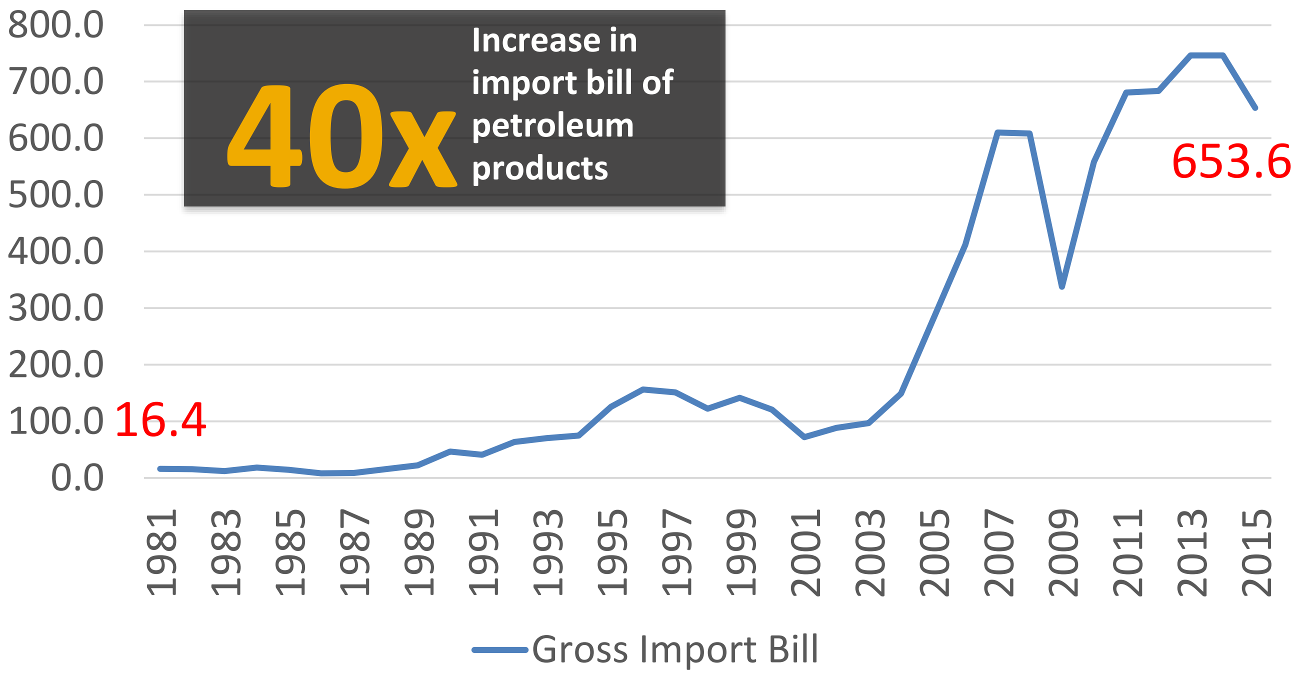


14 Out of the 20 most polluted cities of the world are in India

36% Of NOx emissions in Delhi were due to vehicles in 2016

20% Of PM2.5 emissions in Delhi were due to vehicles in 2016

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



Petroleum fuel consumption
32.5 million tons in 1981
184.7 million tons in 2015

The Economist, 2018

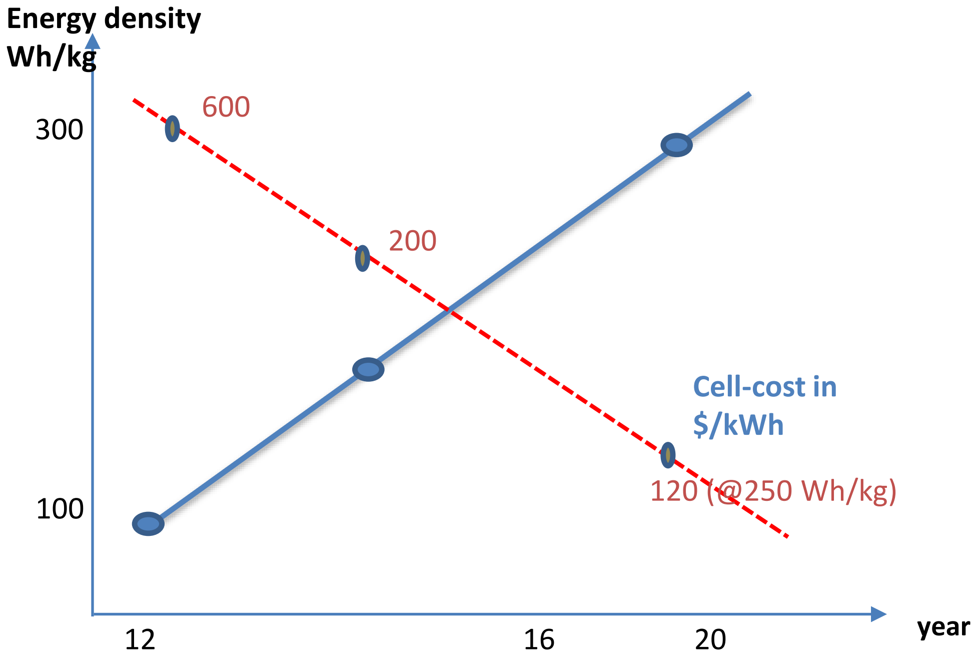
EV is the future: Why and How?

- 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%
- But Energy Density of Li-Ion battery Cells much less than that for petrol
  - Much larger weight / size required for same energy, even with 4 times higher efficiency
  - battery size, range anxiety -- how to overcome it?
  - Cost implications
- India's vehicle composition: low affordability
  - Small and medium sized vehicles dominate
  - We drive smaller distances in a day
  - Way to overcome range limitations may be different

Increasing Energy Density → Affordable Batteries

- Energy density increasing rapidly: main driver for cost reduction
    - Material requirement per kWh goes down
  - Lead Acid Battery: 40 Wh/kg
  - Li Ion Battery: up to 300 Wh/kg available today
    - Towards 400 to 500 Wh/kg in coming years
  - Even then EV with large battery to overcome range anxiety (several hundred kms in a car) is 1.7 to 2 times that of ICE car

- Also, do we have enough Lithium, Cobalt?
  - Primary use of battery, Secondary use, Recycling of batteries for raw materials



Strategy for India

- Onslaught of EV threatens India's GDP (auto-sector 7.1% + 5% transport fuel processing / distribution) and large number of jobs
  - Unless India gets its act together and manufacture not just EV but also every subsystem including battery recycling
- Affordable EVs with Limited subsidy must make business sense
- Today: Indian companies going hammer and tongs on EV, believing that India will charter its own path
  - Government fully behind EVs
    - FAME-II subsidy
    - GST reduced to 5% from 28% and 43% for ICE vehicles
  - Great strides in R&D on EVs

Limited subsidy and Low-affordability imperatives for EVs in India: Copying the EV program of USA, China, Europe will take us nowhere!

Can India Drive its EV program Innovatively and Differently and scale?

EV Policy: India’s focus on its 98% vehicles

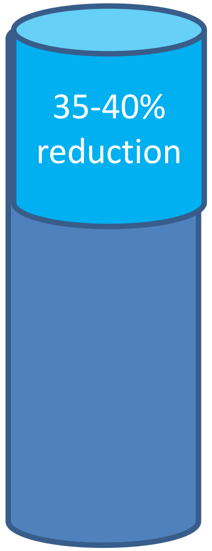
- India’s auto-segment different from that in most of the world: small and affordable vehicles
  - Domination of 2-wheelers: 79%
  - Autos including small goods vehicle: 4% (rickshaw not included)
  - Buses and large goods vehicle (including trucks): 3%
  - Economy Cars costing below ₹1 million: 12%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

86%

- 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

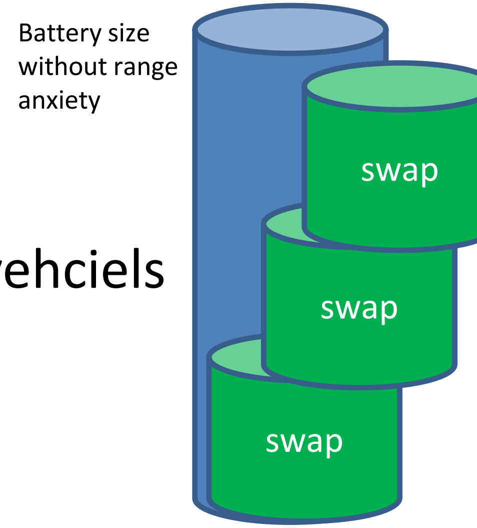
- Battery Dominates the cost of EV
- Focus on higher energy-efficiency: *Kitna deti hai* for EVs (kms/litre of petrol)
  - Lower the energy (Wh/km) used per km, lower is the battery size and its cost to drive certain range
    - size and weight of the battery reduces: in fact enhancing efficiency further
  - 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 vehciels
      - 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



Battery Swapping Advantage

- Separate vehicle business (without battery) & energy business (Energy Operator)
  - Capital cost similar to that for petrol / diesel vehicle
  - Operation cost today same as petrol / diesel vehicle
    - WITH limited SUBSIDY, electric autos and buses can compete today with ICE vehciels

- Volumes for public vehicles would make them highly affordable
  - Get Fleet Operator company to buy vehicles in bulk and lease
  - Get Energy Operators (EOs) to buy batteries in bulk and set up energy business

Capital cost of vehicle similar to that for petrol vehicles, and ₹/km operation costs same as petrol / diesel / CNG

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

- Batteries dominate the cost of an EV
  - Larger battery increase costs (Tesla uses battery for 540 kms)
    - and also vehicle weight (reducing the energy efficiency or kms/kWh)
  - Smaller battery creates range anxiety
    - Use Public Fast Charger: waiting time + public charging infrastructure
    - Fast Charge in 45 to 60 minutes: too long a wait and impacts battery-life
    - Very fast Charge (15 to 20 minutes): possible but significantly impacts battery life or require very expensive battery
      - gets worse as temperature crosses 40°C

Alternatively: Range-extender

- Use Electric vehicles with two small-battery slots
  - One would have fixed low-cost battery: purchased along with vehicle
    - Limited range battery: example 100 km range for e-car or 50 km for e-scooter enough to drive within cities on 95% of the days: may even be solar charged tomorrow
    - Use only night-time Slow Charging: maximising battery life
  - Second would be an empty slot to add a Range-extension Battery
    - Swap-in the second (swappable) battery doubling the range at a petrol pump (3 to 5 minutes)
      - enabling another 100 kms range for a e-car or 50 km for a 2-wheeler
    - Swap the swappable battery again for still longer range (300 kms or 400 kms)
      - No Public charger needed, No need to wait for charging
- Swapping carried out by Energy Operators
  - Who purchases battery and leased charge batteries

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?

What kind of infra do we need?

Charging Strategy for best battery-life

- Best Charge: SLOW at homes in nights
  - or two to three hours SLOW charging at office or parking lots
    - Will use on-board charger: what kind of on-board charger does vehicle have?
    - 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
  - Charging during restaurant visits
- 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: Do not have space for longer-time parking / services
      - Petrol-pumps charging may be OK if FAST charging possible in five minutes
    - Swapping at petrol pumps in three to five minutes is OK
  - Office and Street parking, Parking lots, shopping /food complex parking -- Yes
      - Can not block space for charging -- but charge while being parked
    - What kind of Public chargers?
    - Slow Public Chargers: can be same as used in multi-storied building
    - Fast Chargers: how fast? What kind of vehicles and batteries

What kind of Fast Charging?

- Need to consider that fast charging may impact battery-life
  - Especially for low-cost batteries

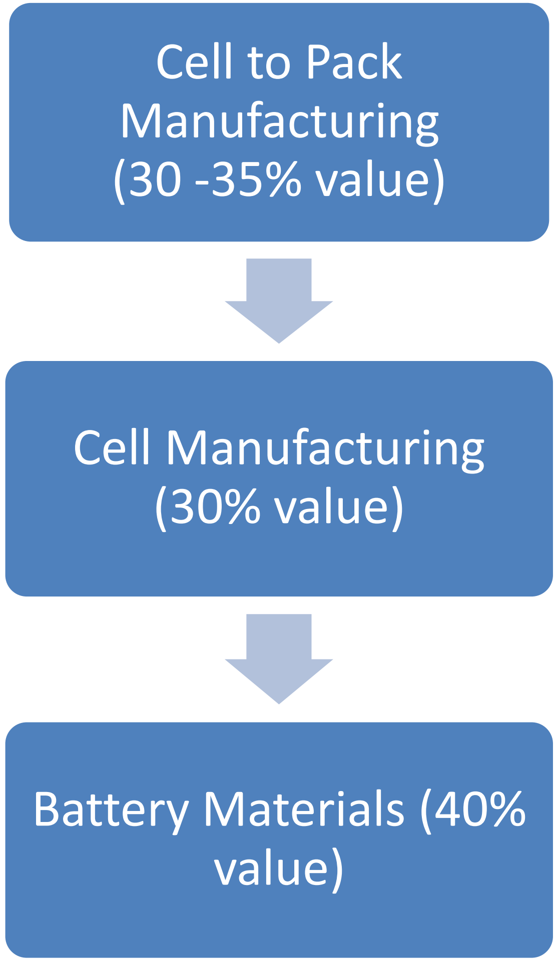
- DC Fast Charging: need to answer
  - What voltage and Power?
    - Connector?
    - Protocols between vehicle - charger and charger - utility back-end
  - Costs under ₹10000 per kW
    - 50 kW charger will cost ₹500,000
    - When will there be a business case?

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 and Battery Management Systems to get the best out of each cell
  - Safety is a major concern
  - established and start-ups making waves
- 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
- Battery Material Development: urban mining
  - Every battery should be regulated for safe disposal



Materials for Batetries

- Li-Ion batteries today use
  - Lithium, Cobalt, Manganese, Nickel and Graphite
  - India does not have much of the mines for any these: 70% cell costs due to material
  - Import bill could sky-rocket if we import all the materials: India may need up to 25 GWh per year by 2025
- While we attempt to secure some mining rights world-wide
  - Focus on recycling of used batteries (urban mining)
  - A start-up is recovering 90% of Li and Co, Ni, Mn and Graphite
  - Need R&D to set-up 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

Will we lose jobs?

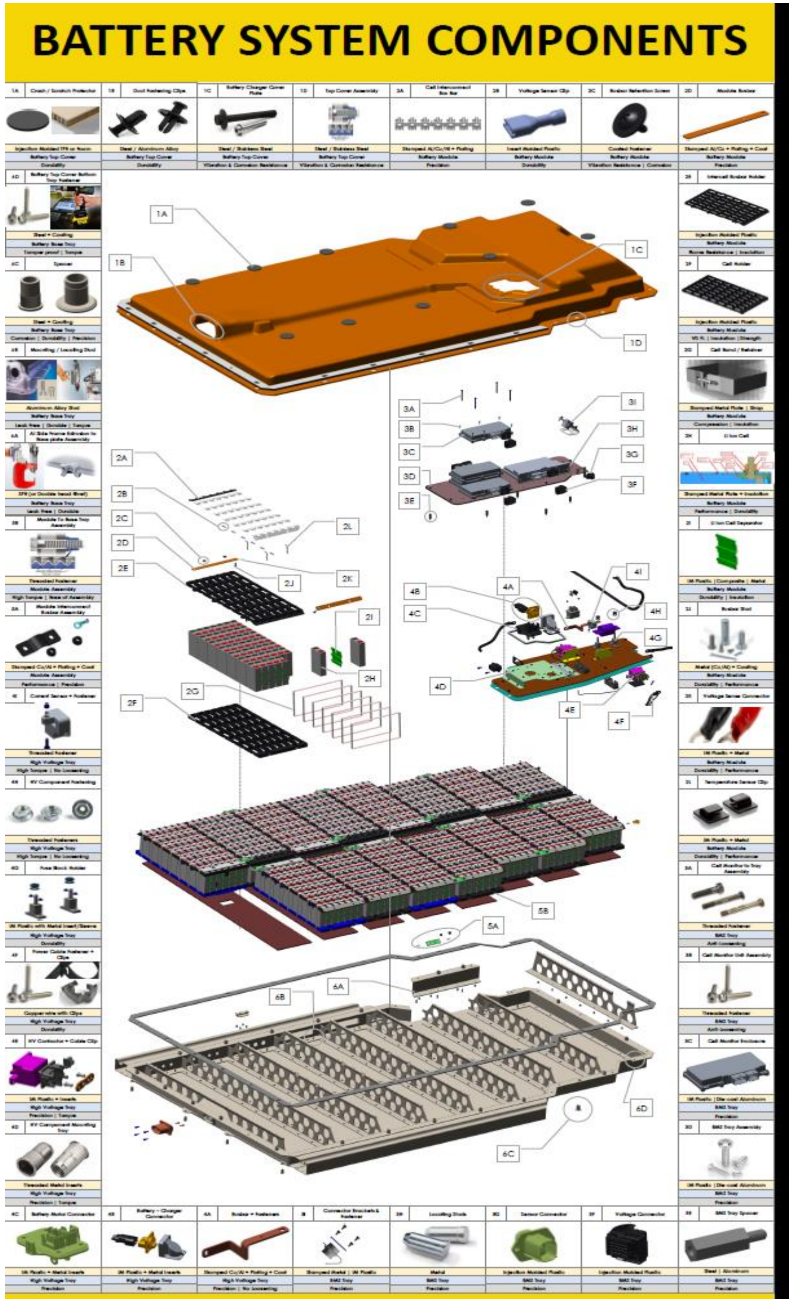
Depends upon whether we design and manufacture sub-systems within India

EV sub-systems required

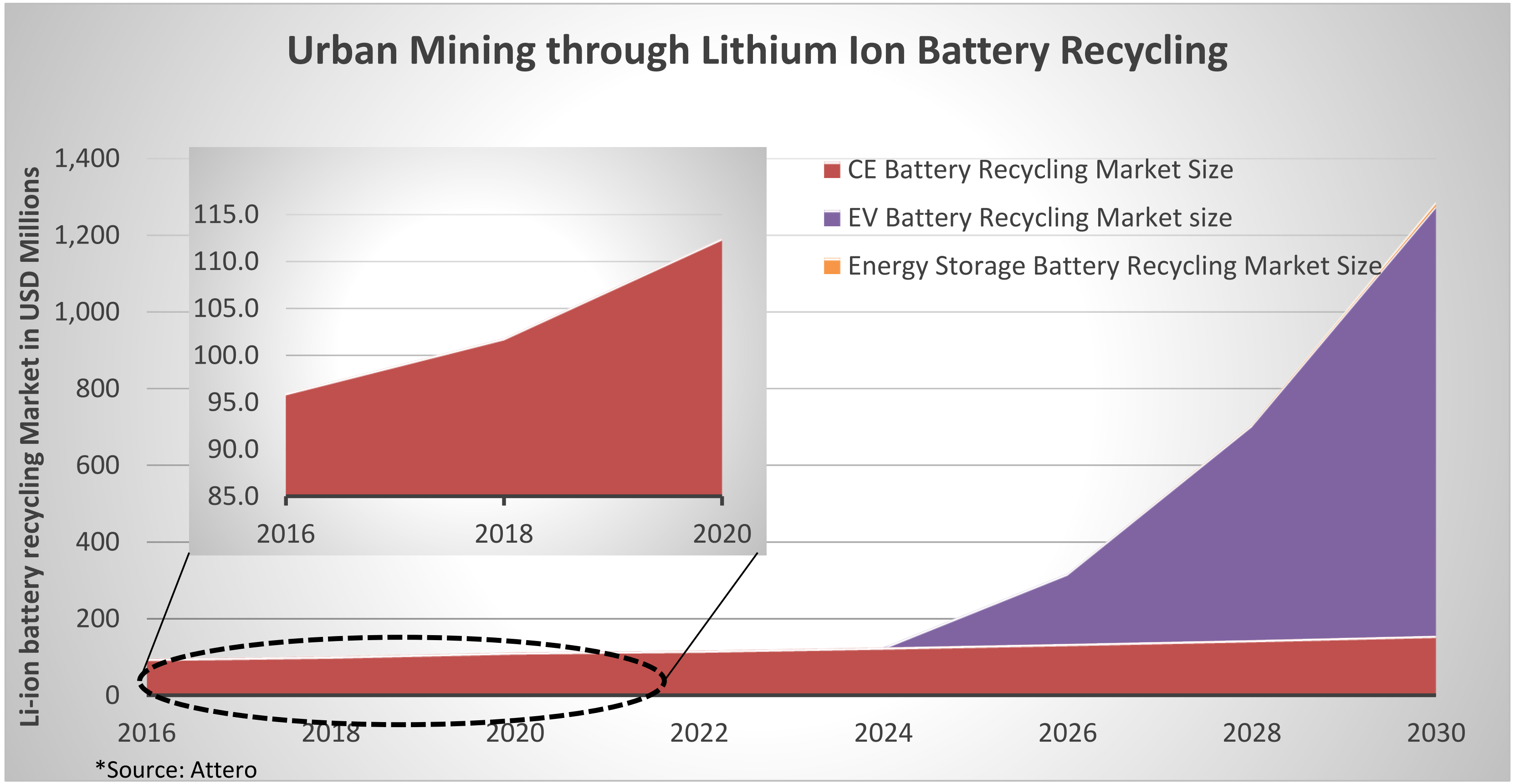
- Battery: Pack, cells and recycling for materials
- Electric Motors and Controllers
- Chargers
- DC-DC converters
- Vehicle Control Unit
- Remote Monitoring
- Software

- FAME-II requires increasing manufacturing and value-add for each sub-system within India
  – Can generate huge number of jobs
  – Large economic activity (in addition to vehicle manufacturing)

- Battery Pack manufacturing involves large number of components
  - Large number of ancillary industry
  - Large number of jobs
- Battery cell manufacturing like a large process industry
  - High investments
  - Technology changes very rapidly



Battery Recycling: Li ion Urban Mining currently a $100M market in India: Will grow to over $1B by 2030

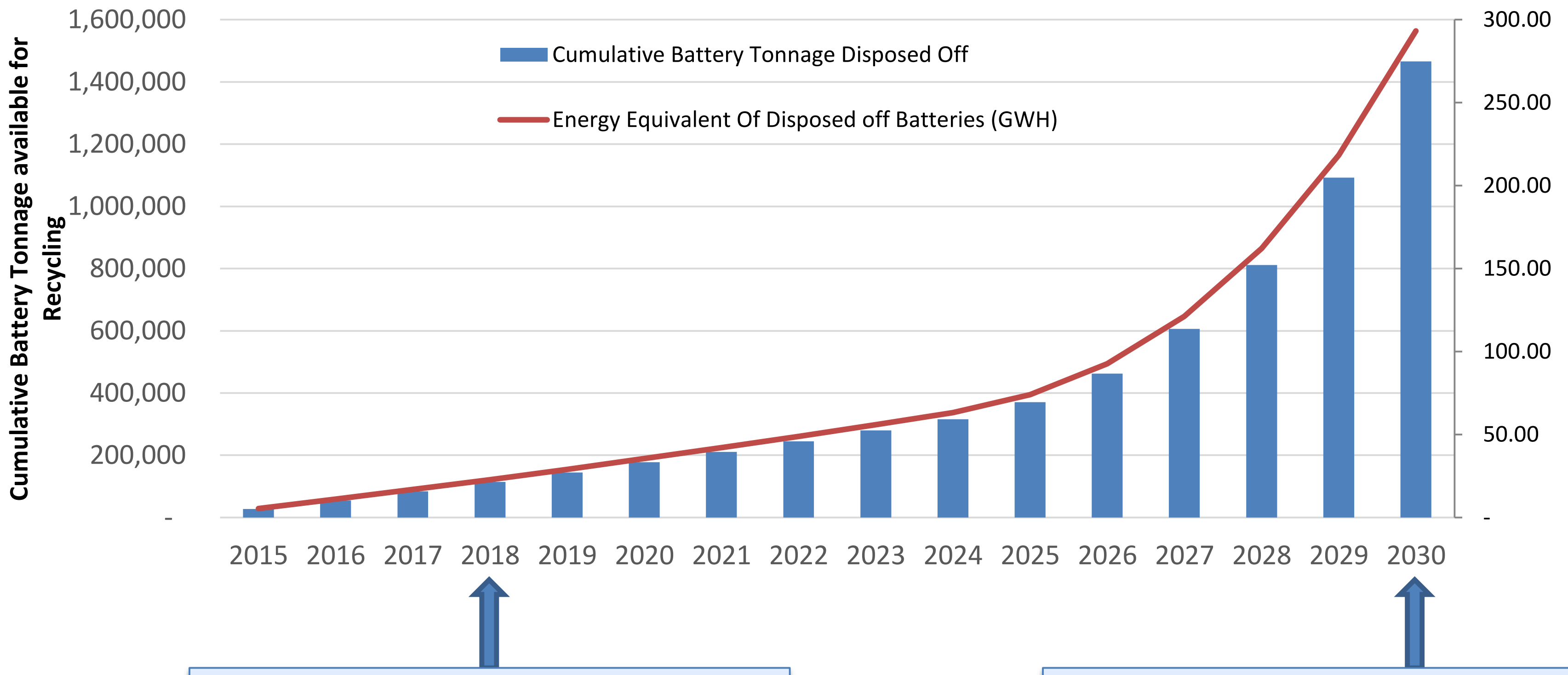


Near Term Driver - Consumer Electronics & Electric Vehicles

Long term Driver - Electric Vehicles & Stationary Storage Energy

India is expected to generate a total of around 14 lac Tons waste Li-ion batteries by 2030

1 Lac Tons of Lithium-ion batteries is equivalent to 23 GWH of Energy



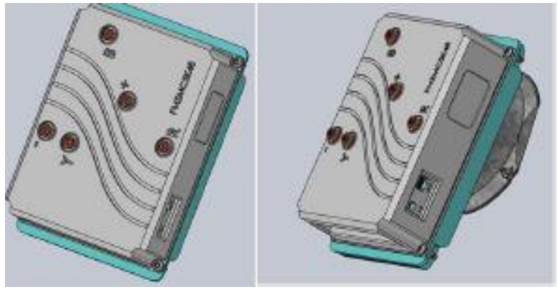
Over 1 Lac tons of recyclable batteries are currently available in the market

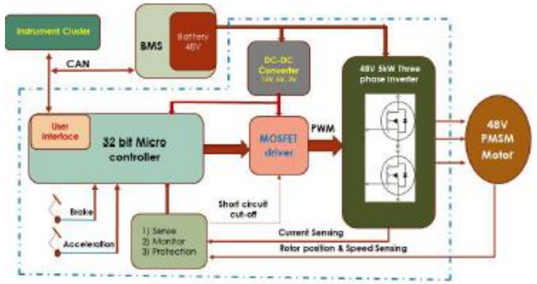
Over 14 Lac tons of recyclable batteries will be available by 2030

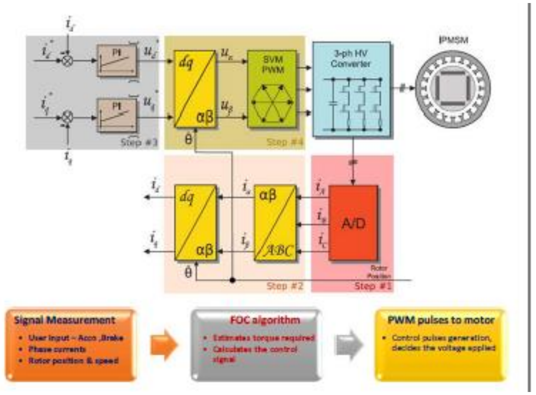
Source: Panasonic, Tesla, Mining.com, IBEF, Gartner, Attero Analytics

Motors and Controllers

- Need motors an controllers for
  - Two-wheelers
  - Three-wheelers
  - Four-wheelers
  - Buses
  - Trucks
- Design and Development
- Testing facilities
- Skill development







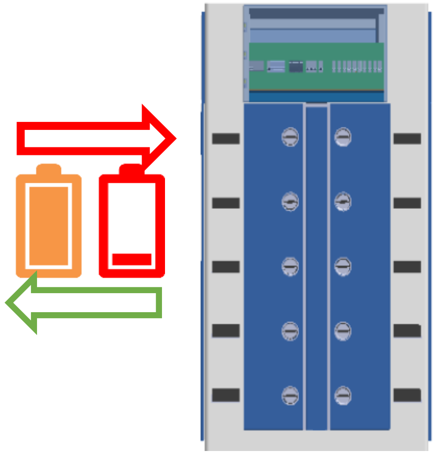
DC-DC converters and Battery Chargers

- DC-DC converters: all sub-systems are not at Battery voltage
  - conversion from battery voltage to voltage of electronic subsystems
    - At power-level required by sub-systems (10W to 5 kW)
    - Example: bus battery at 750 converted to
      - 12V for lights and 48V for motor for power-steering (5 kW) and 5V for electronics
- Chargers: on-board and off-board
  - 1 kW charger to 200 kW chargers
    - Charging protocols and charger Management protocols
  - Costs key to make external charging viable
- Bulk Chargers for swapping Operators

Battery Swapping at street-corners

Battery Swapping

Bulk Charger

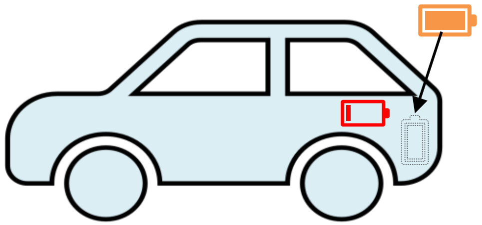


Standardization and Protocol definition – CBEEV defined LS-VBCC

Ideal for Fleet & Delivery Vehicle Use

2W | 3W | 4W | BUS

Range-Extender



Add-on Battery Swapping

RE Battery is designed to have same range as fixed battery

Ideal for Personal Use

2W | 4W

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

Other sub-systems

- In IC engine vehicles
    - Power-steering
    - Power-braking
    - air-conditioners
  - all driven using hydraulic pressure generated by IC engine
- Needs to be redesigned to be electrically driven
  - Ideally using battery voltage
  - Keeping the costs low

Other Technology tasks

- Efficient Regeneration: recovers energy during deceleration, braking, descending
  - mechanical energy converted to electrical energy, to be driven back to battery
- Needs motor design to recover as much energy as possible
- Can regeneration efficiency come close to 90%?
  - Vehicles will then only use energy to overcome rolling-resistance and aerodynamic drag

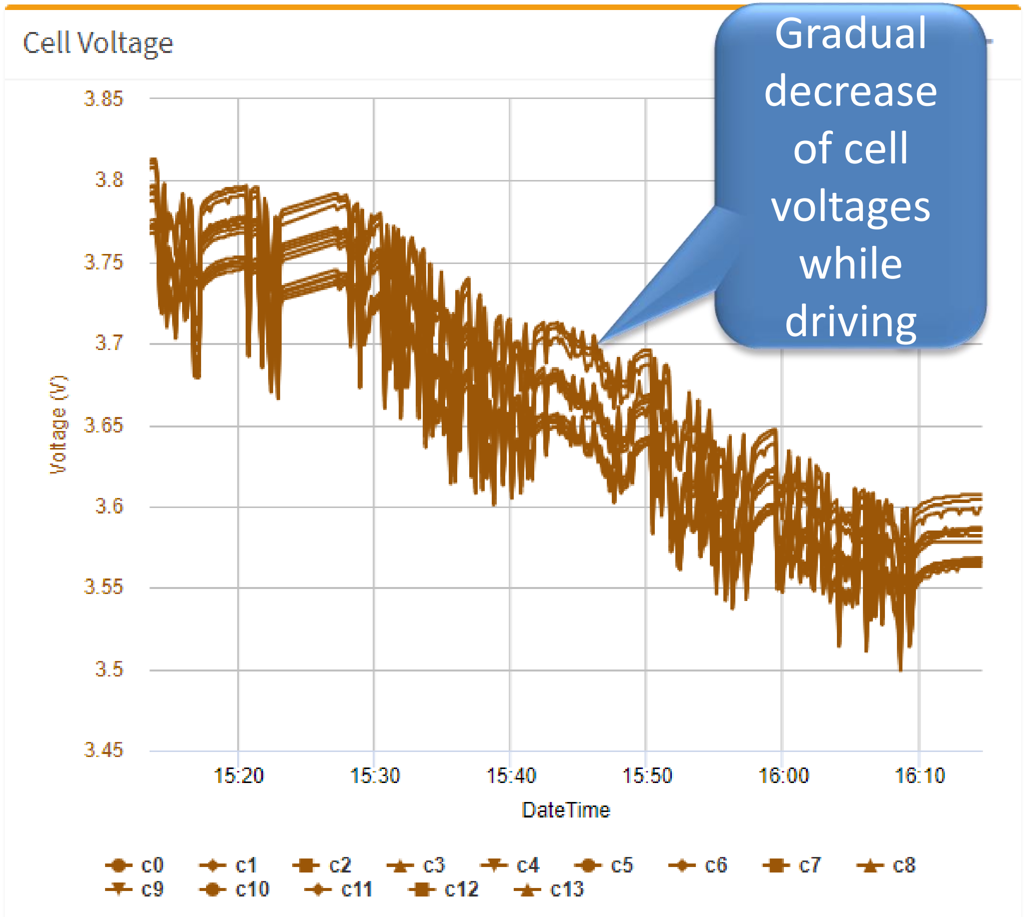
- Materials for light-weighting vehicles
- Materials for better insulation to reduce heat-load
  - air-conditioning competes with drive train for battery-power
- Better tyres and better aerodynamics enhances energy-efficiency of EVs
- Vehicle Controller and Software, Integration and testing
- Can we gainfully redesign every part of IC engine vehicle as it changes to Electric?

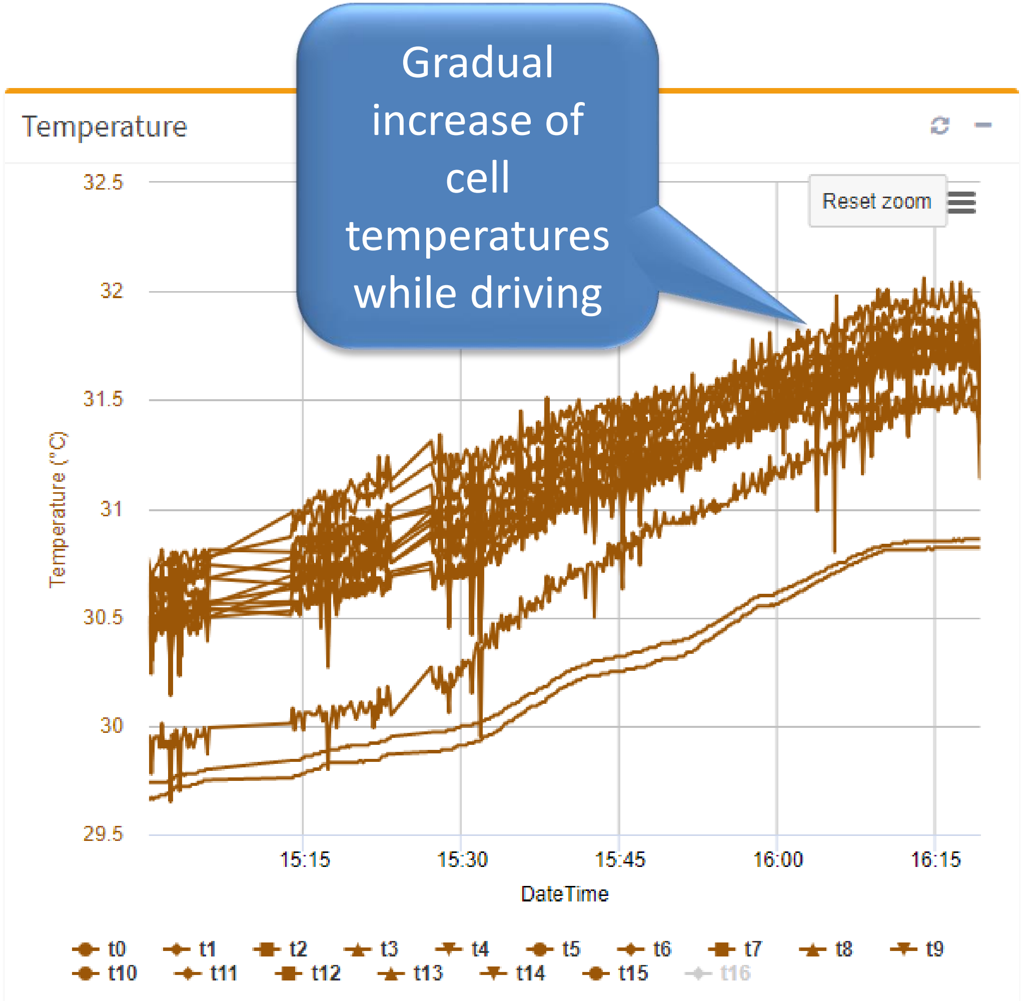
Vehicles on Drive

Pilot with Battery swapping at CBEEV, IITM Campus

Test vehicle with school kids, residents and staff in IITM campus

Cell voltage/ temperature monitoring to maximise battery-life
225 million data points





To Conclude

- Time is of essence: In four years, may be flooded with imported EVs / subsystems
- We have two years time to design and manufacture EV subsystems
  - What can be done in first year, second year and third year?
    - Not JUST development, but commercialise and SCALE
  - What does Start-ups and R&D personnel in educational Institutes/ R&D centers have to do?
  - How do industry-academia work together? What do we need from the Government?
- 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/