EV ready to accelerate in India

as policy gets finally aligned

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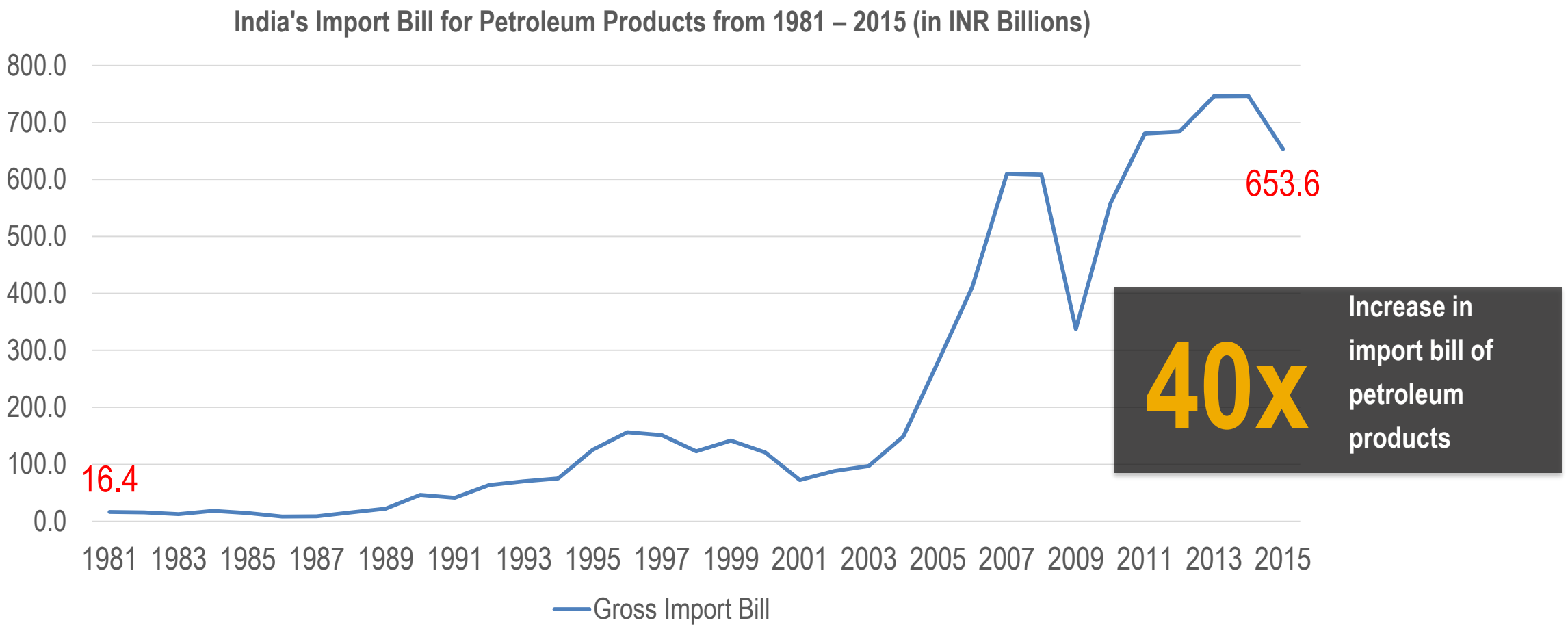
Air quality in Indian cities

The Economist, 2018

DEPENDENCE ON IMPORTED FUEL



Petroleum fuel consumption: 32.5 million tonnes in 1981 184.7 million tonnes in 2015

Indian Petroleum and Natural Gas Statistics

India Recognises

- India imports most of its oil impacting its economy badly
  - It has 14 out of 20 most polluted cities in the world
  - EV is the future: four times higher energy efficiency and 95% less moving parts
    - Less than 30 moving parts in a electric car as opposed to 2000 in IC-engine car

- EV adoption scales as battery price falls
  - Driven by higher energy density (Wh/kg) of batteries
    - 100 Wh/kg → 150 Wh/kg → 200 Wh/kg → 250 Wh/kg → 300 Wh/kg
  - Yet EV with large battery to overcome range anxiety (several hundred kms in a car) is 1.7 to 2 times that of ICE car

Year	Li battery costs per kWh
2012	USD 600
2015	USD 450
2017	USD 250
2020	USD 150
2024	< USD 100

Subsidy, Affordability and Innovation

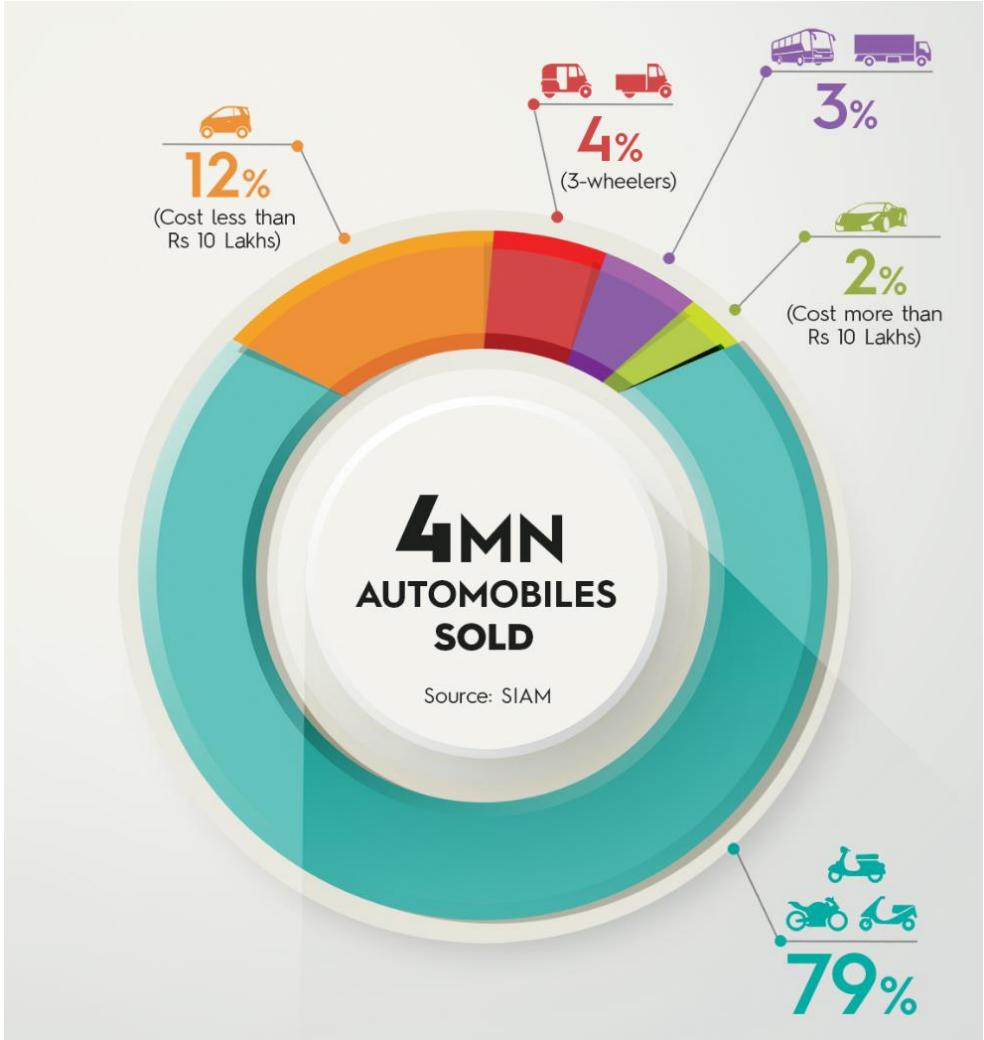
- Worldwide EVs driven by 30% to 40% subsidy
  - India has low affordability and can afford limited subsidy
    - Battery contributes to 50% of costs
      - falling rapidly over last five years but still expensive
  - EV must make business sense: How?

- India needs innovative approach to get its EV to scale today: Not blindly follow the West
  - Failure to do so will imply it gets flooded by imports in four to five years
  - 7.1% (auto-sector) + 5% GDP (fuel-processing) and almost 30 million jobs impacted

India’s Vehicles dominated by two-wheelers

Most Discussions focussed on e-Cars: Premium Segment

For Massive Adoption: Focus has to be on 2W, 3W



India's focus: different from that in the West

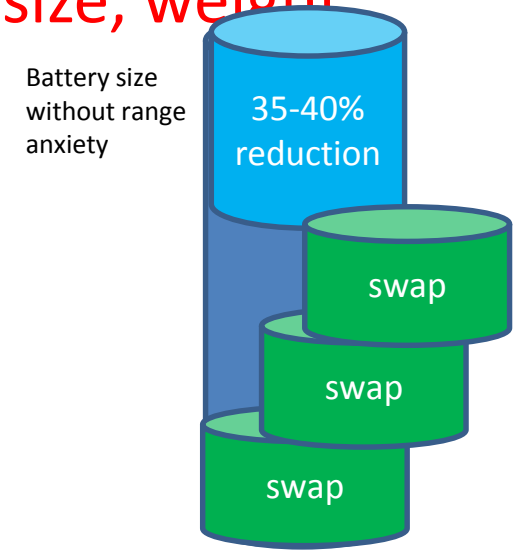
- India's vehicles different from that in most of the world
  - low-cost
  - 98% of public and affordable vehicles: not the focus of the rest of the world; India could attempt to get leadership here
    - Innovative approach needed here
  - For premium cars, it may use the same approach as in the West: large battery, fast-charging assuming medium to large subsidy or premium price

Business needs to depend upon itself

Some help from governments (local manufacturing + promotion)

Innovative Strategy for EVs for Public Transport

- Higher efficiency Wh/km (kms/litre of petrol) reduces battery size, weight and costs
  - For e-autos in last one year: from 70 to 80 Wh/km to 45/50 Wh/km
  - E-buses: from 1600 Wh/km to 900 Wh/km



- Split battery into smaller size (one third) and swap
  - No waiting time to charge battery: no public infrastructure required
  - Customer avoids dead battery-weight improves vehicle energy efficiency

- 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
  - Charge at 0.5 C and at 25deg C, discharge at ambient (Indian temperatures)

Public Charger Infrastructure not required

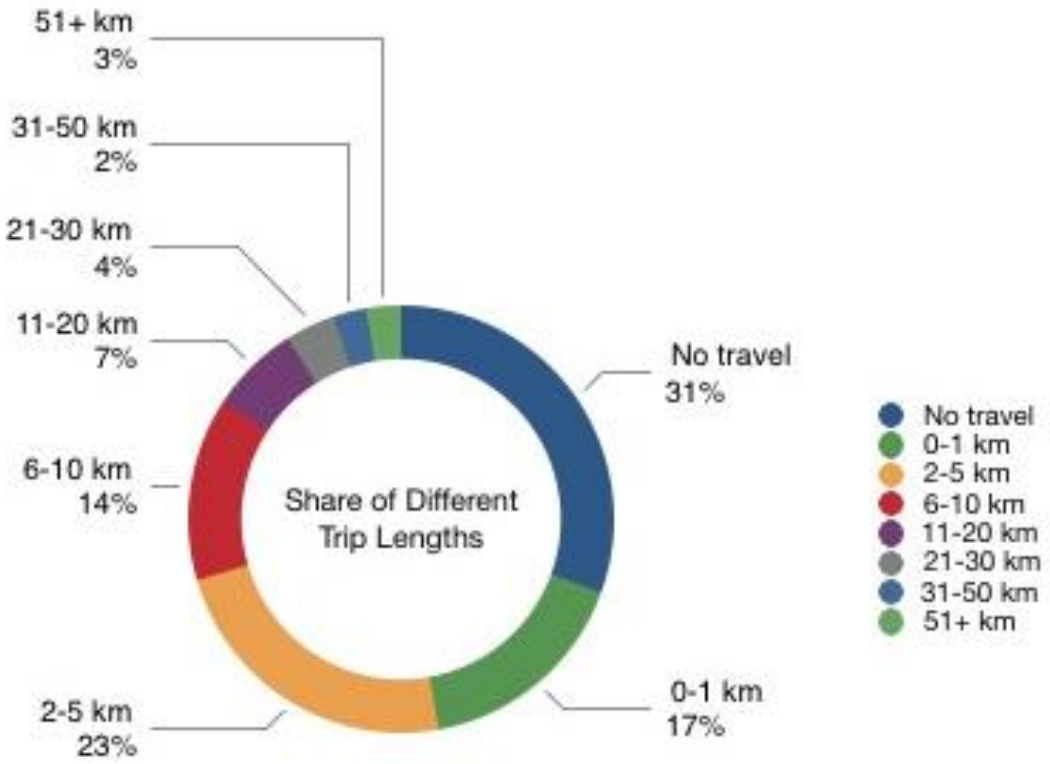
- Instead Swappable battery Infra needed
- Separate vehicle business (without battery) & energy business (battery)
  - Energy Operator to procure bulk batteries and lease charged batteries
    - Capital cost similar to that for petrol / diesel vehicle
    - Operation cost today same as petrol / diesel vehicle
- Drive volumes aided by Public procurement

EV Strategy for Private Transport (2/4-wheelers)

- 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
  - Use 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)

Recognize Indian Trip lengths are smaller



- High urban densities; India lives and moves differently.
- An average vehicle would travel much less in India as compared to the developed world

71% Of the trips are of less than 5 km

16% Of the trips are of length greater than 10 km

Takeaway Short trip lengths mean that several journeys on a single charge possible

Census 2011

Use Small built-in Battery in affordable vehicle

- EVs to have a small low-cost built-in battery with limited range
  - Example: 100 km for a e-car
    - Enough within cities for 90% of days
  - Use only night-time Slow Charging: maximising battery life

50 km range for e-scooter

- When one needs to drive longer distances (10% of days)
  - use a RANGE EXTENDER battery to completely overcome range anxiety
    - Swap-in a second battery doubling range at a petrol pump (3 to 5 minutes)
    - Swap the swappable battery again for still longer range (300 kms or 400 kms)
- Needs a only and slow-AC Charging: 15 A plug-point with meter
  - Would cost ₹5000 and break even in a year: no need for expensive charging infra

Premium vehicles and long-distance buses

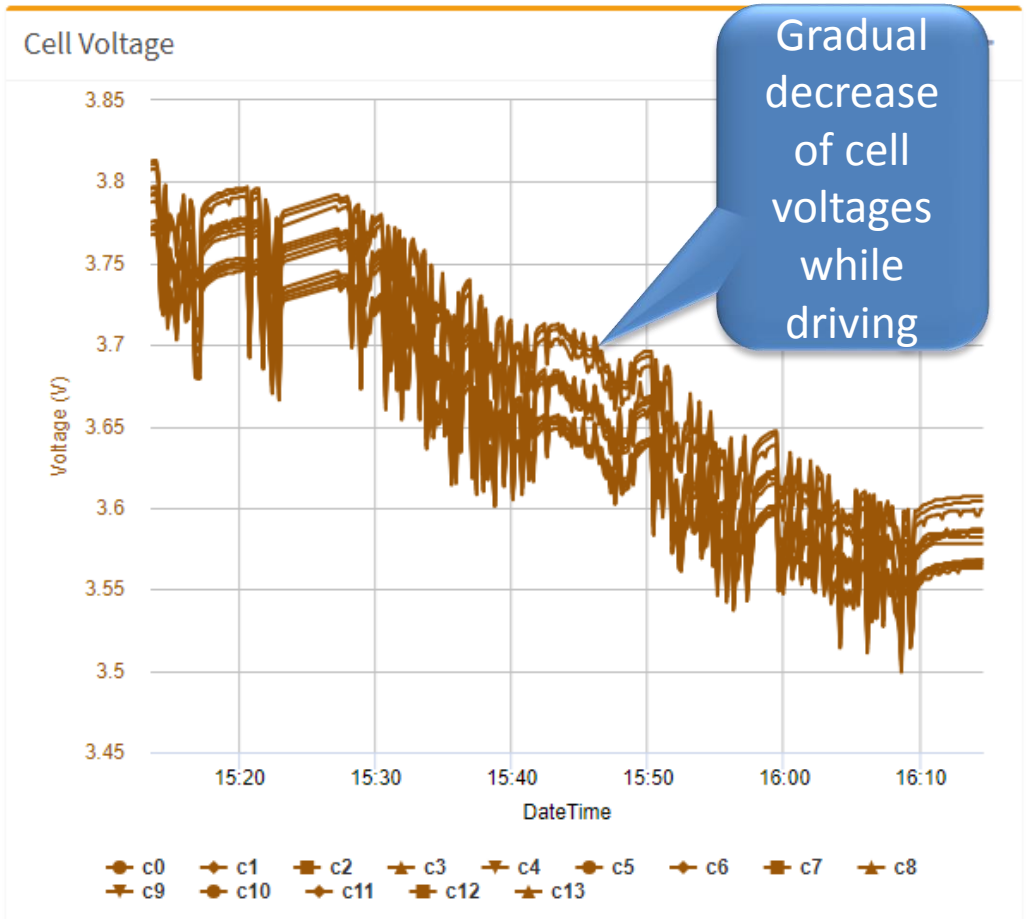
- Use larger battery and fast charging for premium vehicles
  - Similar to what is used in the West
    - Less range anxiety
    - Costs and affordability less of a consideration for premium cars: some subsidy helps
  - Will require fast-charging infrastructure
    - In addition to slow-charging public and home infrastructure
- Long-distance buses: higher usage of battery would justify higher battery size and costs
  - Low-operation costs will make up for larger upfront costs

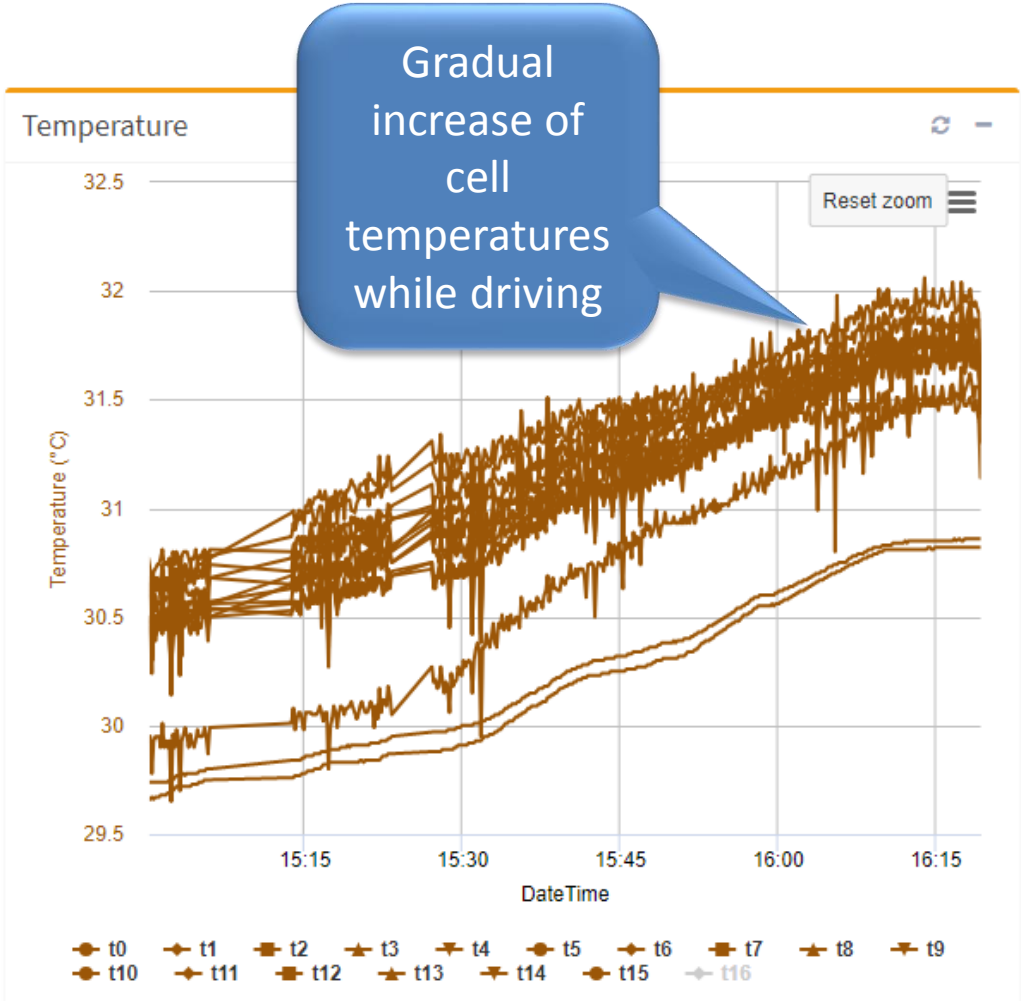
Vehicles on Drive

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 sum up: India's approach

- Focus on Small Vehicles
  - Use smaller battery when possible
  - Use battery swapping, range-extension in addition to slow charging
- For larger battery premium vehicles, use slow and fast-charging
- Some subsidy (lower tax helps)
- Make in India for each sub-system

Technology Tasks

Designed and Made in India to drive costs down

And make EVs affordable in India

India's Technology Tasks

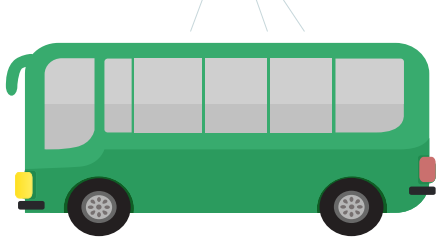
1. Most Energy Efficient Vehicles: low Wh/km will reduce the size of the battery
   - Better motor and drive (power-train), better tyres, lower weight and better aerodynamics
2. Battery ecosystem: Pack manufacturing (30-35%), cell-making (30%), materials and chemicals (40%)
3. Charging and Swapping Infrastructure for range-extension
   - Slow-charging, fast charging and battery swapping

R&D required for EV sub-systems

- Drive train: Motors and Controllers, distributed motors
- DC-DC Converters and Battery-Chargers and Battery Swapping systems
- Electrically driven Power-steering, power-brakes, and air-conditioning
- Battery Packs and Battery Cells
  - Battery Materials: Li, Mn, Co, Ni and Graphite, new Chemistries
- 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 Software, integration
- Future technologies: Hydrogen Fuel Cells, battery chemistry handling 45°C, Grid-integration

Drive-train: Motors and Controllers for EV

- Higher motor + controller efficiency at all velocities (full drive cycle)
  - Not a efficiency figure at a single velocity: India drives at lower velocity
- Motor types: Nb permanent magnets Vs ferrite magnets Vs no magnets
  - Permanent Magnet-synchronous (BLDC or PM-SYN)
  - Switched Reluctance (SR): no permanent magnet
  - Synchronous Reluctance (SYN-Reluctance)
  - PM-assisted SYN-Reluctance or SR: very small permanent magnet
  - Induction: needs VFD; efficiency at smaller velocities an issue (higher power)
- High volume but low cost: must compete with imported motors
  - Design variations consist of Axial flux, Radial flux, Frame and Hub motors
  - Distributed Motors



Motors and Controllers

- Need Motors and Controllers for
  - Two-wheelers, three-wheelers, some small cars
    - 48V / 72V: from 300W to 20 kW
    - Volume (10 years): 150 million
    - Combined efficiency for motor and controller: 82% to 90%
  - medium and large cars
    - 350V: from 15 kW to 75 kW
    - Volume required: 20 million (10 years)
    - Efficiency: 87% to 93%
  - buses and trucks
    - 750V: from 75 kW to 200 kW
    - Volume (10 years): 5 million
    - Efficiency: 90% to 95%
- Power Electronics is key
- Motor Optimization Software
  - Finite element motor-design software: tailor to Indian goals
- Testing facility and 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
      - Each converter adds to costs and contribute to losses
- 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

Battery Swapping Systems: *Battery leasing as a business*

- Bulk-chargers for multiple batteries
  - with built-in cooling of batteries
  - Locked-smart battery protocols to ensure battery is charged only by authorised chargers and discharged in authorised vehicles
- Swapping systems for 2-wheeler, 3-wheeler, 4-wheeler and bus batteries
  - Manual, Semi-automatic or Robotic
- Management Software for batteries, swapping and charging outlets
  - Monitoring of each cell-temperature during charging and usage
  - Monitoring of cell-currents during usage which may impact battery life

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

Li Ion Battery Chemistry Options

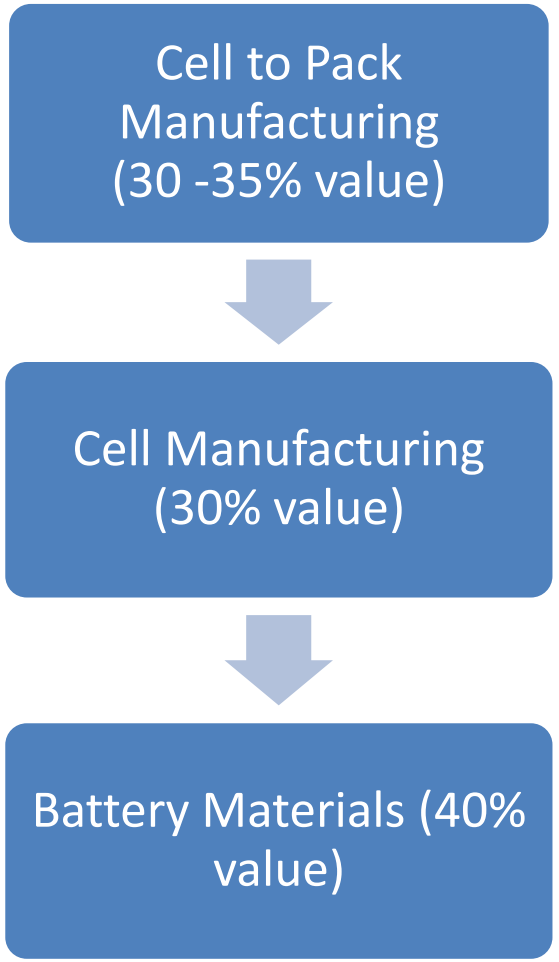
Li-Ion Cell Chemistry	LCO/Graphite or NCA/Graphite	NMC/Graphite	LFP/Graphite	NMC/LTO	LFP/LTO (Nb doped)
Spec. Energy (Wh/kg)	150 -300	150-330 (with Silica in anode)	90-150	60 -100	50 -80
Charge/disc rate	0.5C/1C	1C/1C (2 to 3C discharge possible)	1C/2C (3C disch possible)	4C/4C	5C/10C
Life-cycles	1000	2000 (8000 with Silica)	2500 (4000 with Silica)	10000	20000
Safety*	Cell < 55°C	Cell < 55°C	safer	safest	safest
Cell costs / kWh	$120	$145	$225	$500	High

* Battery-pack has to be designed to be safe irrespective of high-density cell-usage)

China has set a target for all EVs to have 350 Wh/kg by 2020, 400 Wh/kg by 2025 and 500 Wh/kg by 2030
Most of the world uses NMC/ Graphite except some uses NMC/ LTO for buses with top-up charging

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
- A number of established companies and start-ups already manufacturing
  - Costs, life-cycles and temperature remain main concern
  - 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 95% of Li and Co, and 93% of Ni and Mn and 90% 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

Efficient Regeneration

- EVs can recover energy during deceleration, braking and climbing down
  - Motors can act as generator and mechanical energy is converted to electrical energy, which can be driven back to battery
- Needs motor design to recover as much energy as possible
- Need vehicle battery chargers to capture as much recovered energy as possible
- Can regeneration efficiency come close to 90%?
  - Vehicles will then only use energy to overcome rolling-resistance and aerodynamic drag
    - Most acceleration and climbing power can be eventually recovered

Other R&D tasks

- 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 redesign every part of IC engine vehicle as it changes to Electric and gain?

Other tasks

- Develop strong R&D to commercialisation in EV subsystems
- Encourage electricity production from Renewables
  - Encourage solar-PV modules being manufactured locally
- Watch out for new approaches and technologies
  - like fuel-cells, distributed motors, batteries withstanding higher temperatures, motors without permanent magnets, heavy trucks

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?
  - What does industry R&D personnel have to do? How do industry-academia work together?
  - What do we need from the Government?
- More focus on R&D, start-ups and Make in India: helps preserve India's GDP and grow jobs
- 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/