Scaling Electric Vehicles in India

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Why is Electric Vehicle (EV) the future transport?

Better efficiency with less number of moving parts

Area	Petrol / Diesel	EV
Energy efficiency	17 – 21%	90 – 95%
Moving parts (reliability)	2000+	20+

- In five years, EV capital costs will be less than that of petrol vehicles
  - with acceptable range and operational costs at a fraction of that of petrol vehicles

Falling battery costs

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

But before we begin: Nay-sayers

- But Does India have enough electricity?
- Full conversion of transport to EV will utilise 15% to 20% of total electricity generation
  - No shortage of electricity: thermal plant load factor today is 59.6%
  - Will help power-usage during off-peak hours
  - Alternatively, rooftop solar may provide all required electricity using *0.07% of India's geographical area*

Nay-sayers: Pollution

- But does electricity not cause pollution?
- Zero pollution levels if renewables used
  - Renewable prices have fallen below that of coal-plant: future capacity will mostly come from solar / wind
- If electricity is produced with current thermal plants
  - No tail-pipe emission
  - CO_2 pollution down by 50%

EV is future transport

- Today GDP of auto-sector is 7.1% of GDP + 5% of GDP for transport fuel processing and distribution
  - Large number of jobs

- EV is the future: will make economic sense by itself in 5 years
  - Will displace ICE vehicles in about a decade and half
    - If we wait, India will import most EV sub-systems and batteries instead of oil
      - Catching up with technology would become almost impossible
    - Can potentially impact GDP and jobs, unless we are proactive and innovate so that EV and its accessories contribute equally, if not more, to GDP and jobs
      - A difficult but doable task if we act TODAY

So how do we enable Electric Vehicle today

- EV happens today in USA, Europe, China with 30 to 40% subsidy
  - India can not afford to provide subsidy at scale
  - So how do we do it without subsidy: must make economic sense

- India needs to act to acquire technology leadership in some EV segments and build upon it
  - At the same time scale early
    - as far as possible, Make in India and develop the complete eco-system from end to end

Some Unique aspects impacting EVs in India

- Limited / no subsidy
- Low affordability

- Our driving patterns are different (average vehicle speed in city is 25 kmph as compared to 40 to 60 kmph elsewhere)
  - Will require different motors and controllers

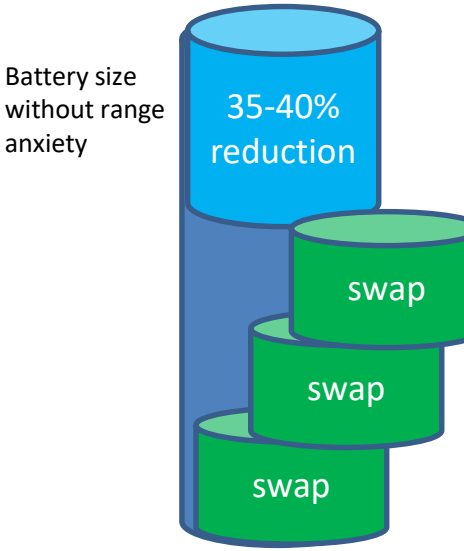
- Our temperature crosses 40 deg C and even 45 deg C quite often
  - FAST Charging of low-cost graphite-NMC batteries (in 30 minutes) would severely impact battery life-time

- Need to evolve new approaches in partnership with industry, R&D community and Government

APPROACH

Approach 1

- Focus on higher efficiency: Wh/km (equivalent to kms/litre of petrol)
  - Lower Wh/km brings down battery size, weight and cost
  - For e-autos in last six months: 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

- Battery-life severely affected by Fast Charging at 45 deg C: one-third as compared to charging in two hours below 25 deg C
  - Low temperature and slower charging Possible with swapping

Approach I (contd)

- Separate vehicle business (without battery) & energy business (battery)
  - Capital cost similar to that for petrol / diesel vehicle
  - Operation cost today same as petrol / diesel vehicle
    - WITH no SUBSIDY; but lower GST for strictly three years

- Drive Volumes using public vehicles
  - Get companies to buy vehicles in bulk (100,000 plus) and lease
  - Get companies to buy batteries in bulk and set up energy business
  - Private vehicles to leverage the eco-system

- No subsidy needed as with these 5 steps, capital cost of vehicle similar to that for petrol vehicles, and ₹/km operation costs same as petrol / diesel / CNG
- Manufacture motors and drives, chargers, batteries, cells and battery-chemicals in India

Approach II

- Focus on vehicles with larger drive-distance per day
  - Taxis with 200 kms
  - Buses with 200 plus kms

- Possible to work towards solution where total cost of ownership per km comparable to that of petrol vehicles with
  - Some slow (overnight) charging
  - Some fast charging / or top-up charging
    - need to overcome high temperature barrier: may be higher-cost LTO batteries
  - Some combination of slow-charging and swapping

TASKS AND PROGRESS

India's needs to build

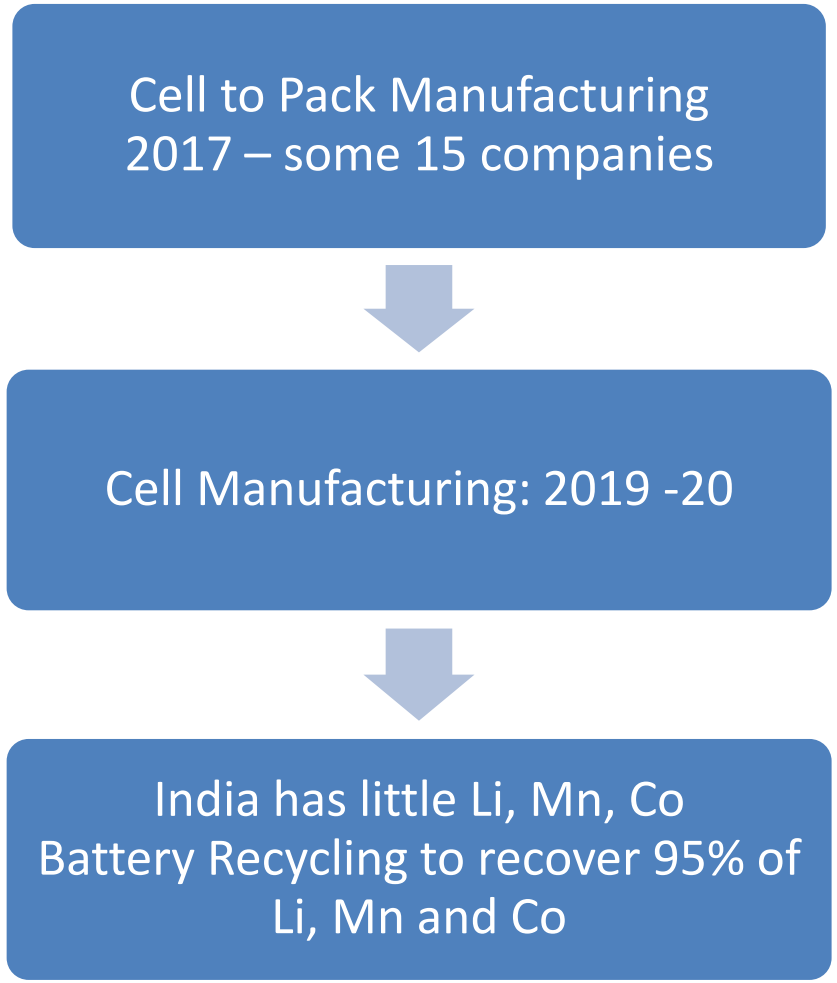
1. Most Energy Efficient Vehicles: low Wh/km will reduce the size of the battery, the most expensive component
   - Better motor and drive (power-train), better tyres, lower weight and better aerodynamics
2. Battery ecosystem: Pack manufacturing (30%), cell-making (30%), materials and chemicals (40%)
3. Charging and swapping Infrastructure
   - Slow-charging, fast charging and battery swapping
4. Transition program from ICT to EV and Policies

Vehicle Energy Efficiency, charging and Swapping

- Build vehicles with higher efficiency (low Wh/km)
  - Some excellent progress by industry; more needed; competition helps
  - much more needed in developing high-efficiency motors and controllers
- Develop Low-cost Swapping infrastructure
  - Ready to launch and scale
- Develop Chargers at affordable costs
  - Overnight chargers: standards defined; product ready and affordable
  - Fast chargers under 100V / 15 kW: standards defined; product ready and affordable
  - Fast Chargers from 100V to 400V: standards to be defined; product to be developed and made affordable over next one year
  - Fast Chargers for buses: standards to be defined; product to be made affordable over next one year
- Develop communication protocols to get highest performance: good progress

Battery Ecosystem

- Battery pack development: thermal design, mechanical design and Battery Management System to get the best out of low-cost cell: largely ready
  - established and start-ups moving [30% value add]
- Battery Cell Development: strategy needs to be worked out
  - Will need outside help -- evolve as cell demand grows in the country
    - Partnerships over next one year [30% value add]
- Battery Material Development: great progress with battery recycling (urban mining)
  - scaling on way [40% value add]



Battery Types

- Graphite based NMC Battery cells (LiNiMnCoO): Higher than 200Wh/kg and Wh/litre, need to take care of safety
  - Low cost (under USD 140 per kWh for 3000 cycles) and (USD 180 for 6000 cycles) at DOD of 80% at 1C /1C at 25 deg C
  - Life-cycles deteriorate to less than 1000 at 2C charge/disch and 45 deg C
- LFP Cells: Intermediate density, double of NMC cost, more temperature resistant, safer, higher life-cycle
  - China starts replacing LiFePO4 with NMC for EVs last year
- LTO Cells: less than 100 Wh/kg, higher volume, safe
  - Higher costs (USD 500 per kWh), but 10000 plus cycles, can charge-discharge at 4C or more at less impacted by higher temperature (45 deg C)

TRANSITION PROGRAM AND POLICIES

Industry

- Waking up auto industry: done
- Waking up large auto-companies: done
- Waking up large battery industries: done

- Transforming small and medium sub-system and auto-component industries: not begun
- Developing new Electrical (power-electronics) industries: to be done over next two years

Service Industry and Demand Generation

- Creating charger service industry: to be done over next year
- Creating charging and swapping industry: to be done over next year

- Demand generation
  - Volume Buying and leasing 4-wheelers: started
  - Volume Buying and leasing 3-wheelers (e-rick and e-auto): to be started over next three months
  - Volume buying and leasing buses: to be started over next six months
  - Volume buying and leasing of small cargo vehicles: to be started over next nine months
  - 4-wheeler personal vehicle strategy: to be worked out
  - 2-wheeler personal vehicle strategy: to be worked out

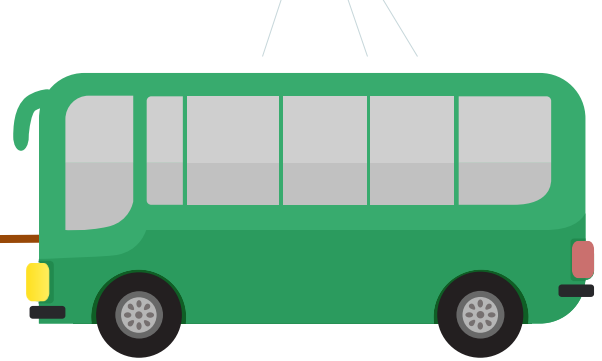
High Quality Three wheelers: e-rickshaw, e-auto

- Use swapping: 50 km range Li-Ion Locked Smart battery
  - swap in 3 minutes at some 200 locations in a city
  - Quality electric vehicles at similar price as petrol/CNG vehicles
  - Charged Li-ion hire price per km less than that petrol/CNG vehicles
- 50 vehicle, battery & subsystem manufacturers, aggregators, energy business enable
  - Common and modular Locked battery pack specs driven with industry
  - Vehicles efficiency (40 Wh/km for e-rick, 50 Wh/km for e-auto), safety and easy battery-swapping
- *Launch in January 2018*
  - 25K early order: can target 1 million 3-wheelers in 18 months

Large e-auto and e-cargo rickshaw and autos to follow

Everything other than battery cells made in India

For City-Buses



- Most city-buses travel less than 30 kms per trip
  - Some 8 to 10 trips per day: Ten minutes break between trips
- Batteries with 50 kms range: Swap batteries (using robots) at trip-terminal point
  - Operation costs per km is no more than for diesel vehicle
- High performance (low Wh/km) buses without battery
  - Capital Costs similar to that of today's buses
- 30 bus, battery and subsystem manufacturers/ swappers define
  - Common Locked battery pack specs
  - Specs for vehicles: efficiency, safety, easy battery-swapping (with robotics)
- Could launch in March 2018: can target 10000 buses in 15 months

Four-wheelers

- Initially focus on taxis and Gov Vehicles, which ply over 200 kms per day
  - Total Cost per Km (capital + operational costs) comparable to today's petrol vehicle costs
  - Government initiated 10,000 vehicle purchase and Chargers
  - May use a combination of fixed plus swappable battery tomorrow
- Will need charging infrastructure
  - Need to be designed to be economically viable
    - AC001 (slow) and DC001 (fast) [less than 100V, 15 kW, approx ₹1.5 lakhs] charger specs defined with this in mind and products made affordable
    - Could be set-up like STD PCOs
  - Working on specifications & financial model for DC002 and AC002 chargers
    - Business case needs to be figured out: current costs ₹10 to 20 lakhs

Task III: Immediate Policy & Regulatory support

- Have zero import duty and 5% IGST on lithium cells for EVs. Have 5% GST on Locked Smart Batteries, EVs, Charging Equipment for three years
- Have 5% GST on Integrated Service provided by the Locked Smart Battery Charge and Swap stations
- Allow Aggregators and Businesses to own and operate fleet of electric 3-Wheelers and exempt e-Autos from permit requirement for three years
- Allow Charging and Energy-business (Charge & Swap Stations) to procure power at competitive rates through Open Access (without cross-subsidy)

Future technology tasks

- Examine Hydrogen-fuelled vehicles
- Distributed Motor architecture for vehicles
- New Motors without or with minimum permanent magnet
  - China has about 90% of rare-earth magnets
- Development of low-cost cell chemistry tolerating higher temperatures
- Develop second use of batteries
- Better understand battery behaviour in different use conditions
- Develop heavy duty EV trucks
- Develop Agricultural Machinery using electric power

Other tasks

- Develop Comprehensive long-term and stable policy for EVs
  - Including policy to incentivise setting up new technology industry in order to attract investment
- Develop strong R&D to commercialisation in EV areas
- Encourage electricity production from Renewables
  - Encourage solar-PV modules being manufactured locally
- Watch out for new approaches and technologies

To Conclude

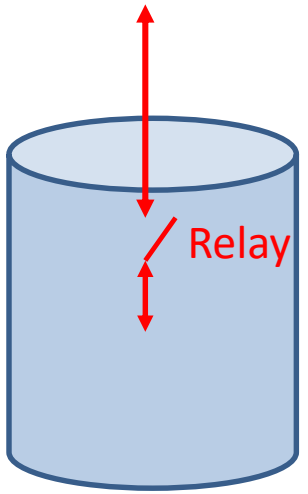
- EVs will give us huge benefit
  - All EV power can be generated by Renewables (sun, wind and water) in due course and give us ZERO pollution
    - Would result into huge boost for auto-components

while Swapping is making EVs possible today without subsidy

- Other financially-viable approaches being explored for tomorrow
    - Incremental charging at stops: fast charging at 4C
    - Fast-charging at 1 to 2C by DC-002
    - Would need to somehow overcome the impact on battery-life due to fast-charging (over 2C) at high temperatures

Extra Slides

What is L-Batt?



- Can not be charged except through authorised Chargers
- Can not feed power except to authorised vehicle
  - Encrypted Key exchange between Charger / vehicle and L-batt
  - Relay turns on only after authentication (each L-batt has an unique ID)
- Important for Energy Business, as they charge by kWh used
    - Charge includes depreciation and interest cost of batteries besides costs of charging and swapping
  - Without Locking, a vehicle owner auto can charge – discharge a battery multiple times and not pay the Energy Business
- At swap-point
  - a mobile phone will read actual kWh used and transmit to CMS for e-payment
  - Program the new battery to be usable to specific vehicle and inform CMS

L-Batt designed

- To contain all data about usage: at what time
  - what speed and acceleration the vehicle had been driven?
  - how much energy of battery was used, L-batt State?
- Data read by authorised chargers and send to CMS where it analyses
  - The efficiency of the vehicle
  - The driver-characteristics (does she speed, how often she applies breaks, etc.)
  - The Battery characteristics: State of Charge, state of cells and unbalanced cells, cell temperature, state of health
  - Determine how to pair multiple modules
- Similarly during charging battery, charger sends all information to the CMS for analysis
  - How to extend life of each battery module
  - Enable second use of battery module (when its capacity deteriorates to below 80% of initial level)

Charging Buildings and Swapping-Outlets

- L-Batt charged in special air-conditioned buildings, which are guaranteed 24 x 7 power and have all safety precautions
  - Large number of swapping outlets in one-two km radius

- Software designed to track each module
  - What are the number of charged and discharged packs at each outlet?
  - How much is the rate of L-batt off-take at each outlet?
  - Coordinate vehicles (e-rickshaws) to transport charged L-batts to outlets and carry back discharged L-batt
  - All payments: from vehicle owners to Energy Business, from Energy business to transport operator and to each outlet
  - Charging uses a combination of kWh used as well as holding-time of a L-batt