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
- EV will displace ICE vehicles in about a decade and half

Falling battery costs

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

EV for India

- Today GDP of auto-sector is 7.1% of GDP + 5% of GDP for transport fuel processing and distribution
  - Large number of jobs
- 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
- What does India do?
  - If it waits, India will land up importing 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 proactively innovate so that EV and its accessories contribute equally
  - India needs to act today to acquire technology leadership in some EV segments and build upon it
  - And Scale early with Make in India as far as possible, and develop the complete eco-system from end to end
    - A difficult but doable task if we act TODAY

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, 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 for range-extension
   - Slow-charging, fast charging, battery swapping and petrol-based extender
4. Transition program from ICE to EV and Policies

VEHICLE ENERGY EFFICIENCY

Vehicle Energy Efficiency and Drive-Train

- 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

- Developing new Electrical (power-electronics) industries: to be done over next two years
  - Develop strong R&D to commercialisation in EV areas: slow
  - Distributed Motor architecture for vehicles: Next two years
  - New Motors without or with minimum permanent magnet: Not started
    - China has about 90% of rare-earth magnets

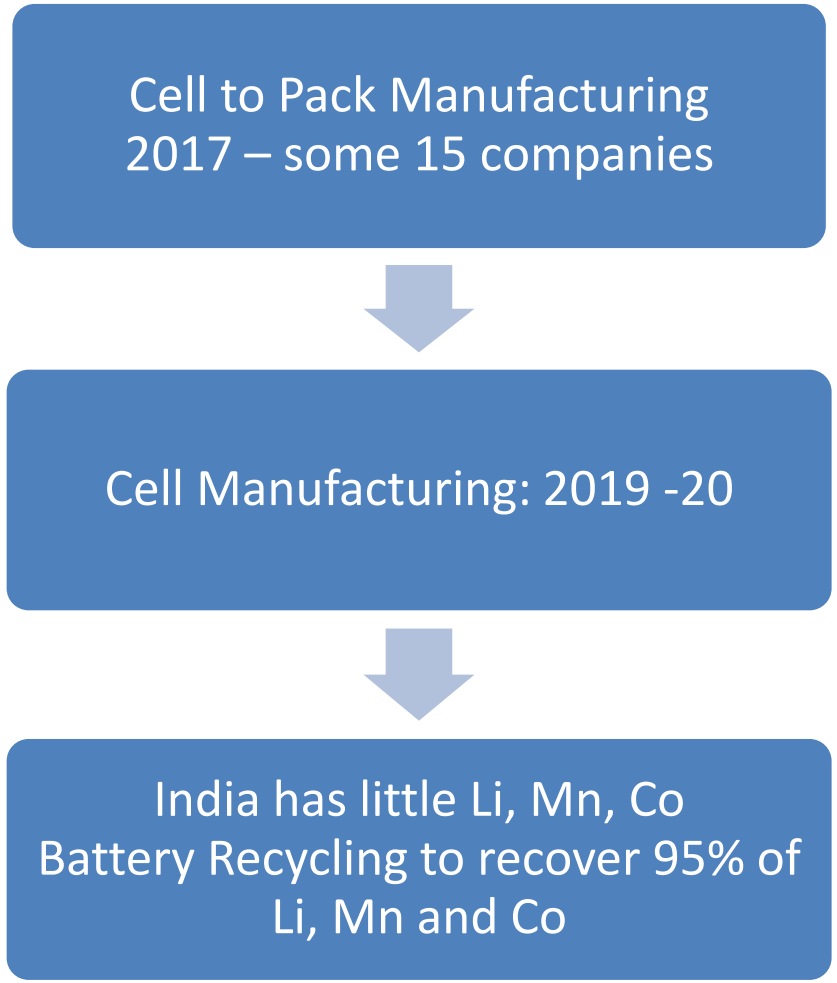
BATTERY ECO-SYSTEM

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)

India's 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]



INFRASTRUCTURE AND RANGE-EXTENSION

EV Batteries, costs and range-anxiety

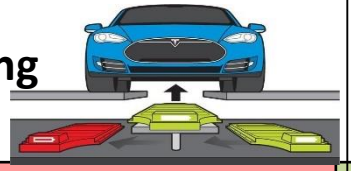
- Batteries dominate the cost of an EV
  - Larger battery will increase costs
    - And also vehicle weight (reducing the energy efficiency or kms/kWh of energy)
  - Smaller battery will create range anxiety (what happens when battery runs-out?)
    - Conventional solution uses Public Fast Charger: waiting time + public charging infrastructure
      - Fast Charger with 1C charge will take a little more than an hour to charge the battery
      - Fast Charger with 4C can charge in 15 to 20 minutes
        - » But fast charge at this rate reduces battery life, specifically the low-cost Graphite-NMC batteries
        - » Problems get worse as temperature crosses 40 degree C, as is common in India
      - Alternatively use LTO batteries which can withstand fast charging as well as higher temperatures
        - » But about three to four times as expensive as low-cost Graphite-NMC batteries

Can Indian EVs do something else?

- Suppose EVs have a small low-cost battery with limited range built-in
  - Enough to drive 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: Two types (overcomes complete range anxiety)
  - First: Swap-in a second (swappable) battery doubling the range at a petrol pump
    - Swap the swappable battery again for still longer range:
  - Second: add a small petrol generator to generate electricity which charges battery along with a fuel tank
    - Strictly not a EV option. Can be misused

Personal Car example: India's options today

- Fixed low-cost built-in battery providing 100 kms range (with AC)
  - Enough for city driving on 90% of days
  - Slow-charged at home in the night
- For 10% of days when one drives longer
  - Option 1: Stop and use a fast charger (1 hour waiting time) giving another 100 kms
    - Another hour wait for a fast charge if one drives longer than 200 kms
  - Option 2: Swap-in a charged swappable battery at a petrol pump (3 to 5 minutes), enabling another 100 kms range
    - swap the swappable second and third time to extend the range to 300 kms or 400 kms
    - Return swappable battery at any petrol station at the end of the trip
  - Option 3: Use petrol-based generator and fill in petrol at a petrol pump (5 minutes) to extend range to 200 kms to 400 kms
    - One may restrict use of generator and petrol within city-limits to avoid tail-pipe emissions
    - Strictly speaking this option is not a FULL EV option and should be avoided. Opened up only if option 1 and 2 does not work

	Public Fast Charging 	Swapping 	Petrol Range Extender
Infrastructure required	Fast Chargers	Swapping stations	Petrol pumps
Electricity Requirement	Reliable and Large	Reliable and very Large to charge used batteries	Reliable but Small
Space Requirement	Very Large	Medium (existing petrol pumps)	Medium (existing petrol pumps)
Vehicle Waiting time	1 hour	3 to 5 minutes	3 to 5 minutes
Emissions	None	None	Petrol emissions during extended range
Battery Costs	High (for fast charging at high temperature)	Small	Small, but requires extra generator costs
Battery Size and weight	High and dead-weight	Small and Light-weight	Small and Light-weight
Battery Life	Medium to Low	High	High
Technology complexity and Practice	Medium and Followed world-over: standards exist	High and New and need to prove reliability	Simple and New but tested
Perception: Is it fully EV?	Yes	yes	No
Extended Range use within city limits	Yes but with wait for charging	Yes	No: GPS to shut down generator in city-limits

Options 1 & 2 needs to be tried. Option 3 is to be intermediate option to be used if option 1 and 2 does not work , as it is likely to be mis-used

Second Swap Battery Concerns and Gains

- Gains
  - No Public Charger Infrastructure required, instead Swappable battery Infra needed
    - Since swap battery is to be used only 10% of days, existing petrol pumps enough
    - Will keep existing petrol pumps alive and employ people even after complete EV transition
  - Customer avoids dead battery-weight on 90% of days, improves vehicle energy efficiency and avoids extra investment on swappable battery, used only once in a while

- Concerns
  - Can this be reliably done?
    - Requires machinery and people for swap
    - Charging cum swapping station must have 24X7 power
  - Investment required for swappable batteries at petrol stations
  - Managing that each swap station has charged battery when a vehicle comes, is complex
    - Too many batteries will imply batteries waiting at swap stations: “dead investments”

Progress in Charging and Swapping

- 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
- Creating charger service industry: to be done over next year
- Locked Smart Battery Definition and implementation: Good progress
- Develop communication protocols to get highest performance: good progress
- Creating charging and swapping industry: to be done over next year

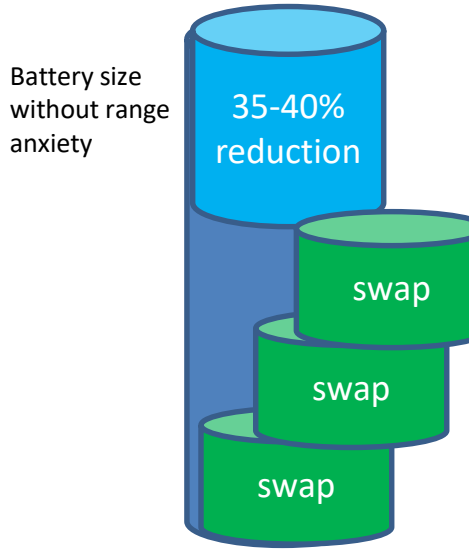
DEMAND GENERATION AND POLICIES

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: range-extension to be worked out
- 2-wheeler personal vehicle strategy: range extension to be worked out

Towards Subsidy-less EVs: One approach

- 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

Towards Subsidy-less EVs (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

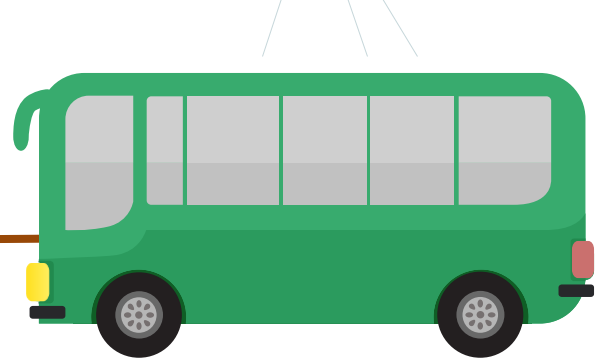
High Quality Three wheelers: e-rickshaw, e-auto

- 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

Policy & Regulatory Issues

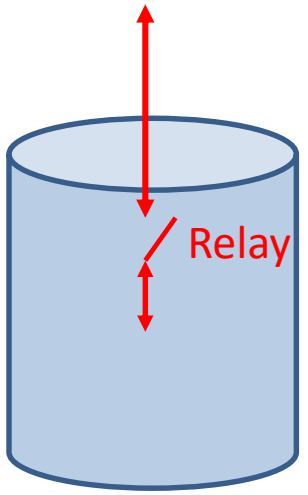
- Develop Comprehensive long-term and stable policy for EVs Including policy to incentivise setting up new technology industry in order to attract investment
  - Have zero import duty and 5% IGST on lithium cells for EVs. Have 5% GST on Locked Smart Batteries, EVs, Charging Equipment for three years
  - 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)

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
- Efficient EVs can be made viable today for city-drive range
- For Range Extension India should explore all options
  - *While Swapping is one option for EVs today without subsidy*
  - *EV with petrol-based range extender could be second*
  - *FAST Charging at 1C could be third*
    - Explore Incremental charging at stops: fast charging at 4C
    - need to overcome impact on battery-life due to fast charging especially 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