R&D in Electric Vehicles

Towards rapid "Made in India"

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Why Electric Vehicles and Indian Scenario

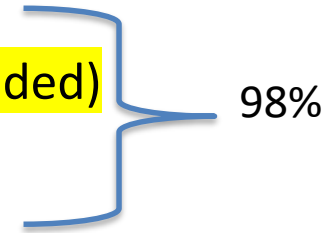
- India imports most of its oil
- India's cities are highly polluted

- EV is the future
  - Energy efficiency of electric motor is 4 times that of IC engines
  - EV is far more reliable: very few moving parts
  - Cost of battery falling rapidly, yet dominates vehicle costs

- World-over EV induction driven by subsidies
  - India's affordability is low and subsidy is limited
  - Sooner we make EVs economically viable, faster it will be able to scale

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

- India's autos 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%



- 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
  - Will help us build a stronger ecosystem for components and subsystems

Auto-industry today has a lot of Made in India

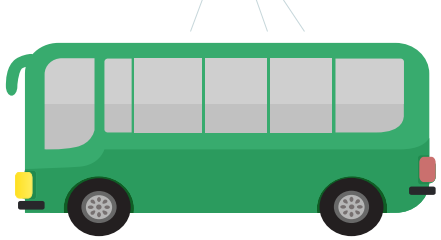
- With switch to EVs
  - Need Subsystems designed and made in India, else import bill will boom
- Energy efficiency of EVs matter more than that of petrol vehicles
  - Higher the efficiency, lower the battery requirement for same range
    - Lower the overall costs, as battery dominates costs of an EV
- R&D required for EV Subsystems which MUST become commercially viable and scale in one to three years
  - Must compete with imported systems in price and performance
- Can we become Leaders in the World at least for small vehicles?

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
- 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

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*

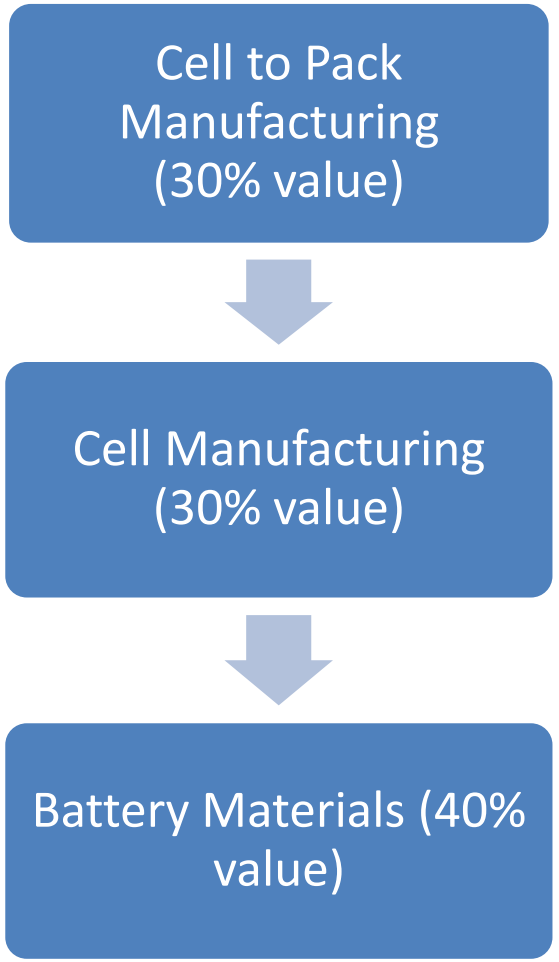
- Bulk-chargers for multiple batteries
  - with built-in cooling of batteries
  - Locked-smart battery protocols to ensure battery is charged only by authorised chargers and discharged in authorised vehicles
- Swapping systems for 2-wheeler, 3-wheeler, 4-wheeler and bus batteries
  - Manual, Semi-automatic 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 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
- A number of established companies and start-ups already manufacturing
  - Costs, life-cycles and temperature remain main concern
- Requires significant life-cycle testing set-ups as per Indian drive conditions
  - Remote Monitoring of each pack and Data-analytics



Li Ion Battery Cells

- Battery Cells today
  - Costs $125 per kWh to $140 per kWh
  - 2500 cycles to 6000 cycles
  - 180 to 230 Wh/kg → moving towards 300 Wh/kg by 2020 and 400 Wh/kg in future
    - Happens as cell chemistry changes (in this case less Cobalt)
  - No commercial cell manufacturing in India today
- Costs likely to go down to $100 per kWh by 2020
  - Work on cell chemistry should target future cell manufacturing
    - Even if we tie up with some international company for manufacturing using today's chemistry, tomorrow's chemistry can come from our R&D
- Also need to come with alternatives to Li-Ion cells, which can compete
  - Li-Sulphur, solid-state batteries and others

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: being scaled today
  - 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?

To Conclude

- Time is of essence: In five years, may be flooded with imported EVs / subsystems
- We have three 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?
  - With whom and how do we work with international R&D organisation?
- More focus on R&D, start-ups and Make in India will help us preserve India's GDP and grow jobs

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